Executive Summary

The 3-year Research Project MetroRADON (Metrology for Radon Monitoring) started in June 2017 and is funded within the European Metrology Programme for Innovation and Research (EMPIR). The purpose of the project is to develop reliable techniques and methodologies to enable SI traceable radon activity concentration measurements. More information about the tasks of the project can be found in the 1st newsletter and on the MetroRADON website. First results were discussed already in the previous status reports and highlight newsletters, which can be found on the MetroRADON website.

Due to the relevance and topicality of the subject, the consortium of 17 partners from national metrology institutes and research institutes was expanded with currently 8 official collaborating institutions and an Industry Interest Group of 29 companies was initiated. In addition, co-operations with existing networks (e.g. EURADOS) and research programmes were established. The high interest in collaboration and in the topics of MetroRADON confirms the importance of the project for a variety of European stakeholders in the field of radon.

This status report describes the status and work done in the first half of the project, focused on the latest results structured by work packages. In addition some of the dissemination activities at conferences and first reports are listed and linked. The highlights are summarized also in the 4th Newsletter. All the mentioned material is available on the MetroRADON website and directly linked in this status report.

If you are interested in collaborating with MetroRADON or want to join the Industry Interest Group, please contact us!

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Save the date! Workshops and Training course to present and discuss the MetroRADON results

To present the results of MetroRADON, two workshops and a training course will take place in spring 2020. We invite all our stakeholders from national authorities, industry, scientific sector, end users and all other interested parties to participate. Please, save the date, more information will follow in autumn!


This workshop will be combined with a European Commission JRC workshop about “Challenges in the implementation of EU-BSS” (27-28 February 2020, Vienna) and the European Radon Association (ERA)-workshop about “Radon Research” (24 February 2020, Vienna)

12 May 2020, Berlin: Workshop “New procedures for radon monitoring” (results of WP1/WP2/WP5)

13 May 2020, Berlin: Training seminar for radon instrument calibration and measurements (WP2/WP5)
Development of novel procedures for the traceable calibration of radon measurement instruments at low activity concentrations (WP1)

The aim of work package 1 (WP1) is (i) to develop radon gas activity standards for the realization of reference fields for radon activity concentration in air, (ii) to undertake two CCRI(II) comparisons of existing radon gas primary standards at different European NMIs/DIs for $^{222}$Rn and $^{220}$Rn in the range of a few kBq and (iii) to develop novel procedures in order to calibrate radon measurement instruments traceable to primary standards in a range of activity concentrations (100 Bq/m$^3$ to 300 Bq/m$^3$) with relative uncertainties ≤ 5 % ($k = 1$). This activity range is relevant for regulations defined by the European Council Directive 2013/59/EURATOM for indoor radon concentrations at workplaces (article 54) and dwellings (article 74).

A main part of WP1 is the development of emanation sources with constant, stable emanations and activity measurements of the emanated radon traceable to primary standards. PTB has produced new emanation sources based on electrodeposition and ion implantation of $^{226}$Ra. The characterization of the long-term stability and the dependency on environmental parameters of the emanation coefficient of the new emanation sources manufactured at PTB is ongoing. CEA has prepared emanation sources of $^{222}$Rn and $^{226}$Rn with a relative standard uncertainty of 2 %. $^{226}$Ra and $^{228}$Th liquid sources were respectively used to prepare these sources by precipitation techniques. The powder of the precipitation is safely placed between 2 filters and composes the emanation source. The influence of the humidity, temperature, and air pressure on the emanation rate was evaluated.

CEA has also developed and tested a method for the direct and traceable measurement of the activity concentration of $^{222}$Rn and $^{220}$Rn in an air flow. The device is composed by a loop inside in which the gas circulates. The device is already in use for measurements.

CMI with the help of SÚJCHBO have developed and tested a long-term stable radon low activity emanation flow-through source based on mass flow controller. Radon is released from the solid phase with high emanation power (0,998(10)). The radon source (emanator) is in the form of polymer foil on a stainless-steel plate and is enclosed in an aluminium alloy cylindrical case equipped with two ball valves at each end and placed in the middle of the case. Several of the new produced sources are currently on measurement at CEA.

Another main aim of WP1 is to conduct comparisons of existing radon gas primary standards at European NMIs/DIs in the few kBq range according to CCRI(II) rules. Comparisons of existing radon gas primary standards at European NMIs/DIs in the few kBq range have been performed. The $^{222}$Rn comparison is registered at EURAMET under the number 1475. The evaluation of the comparison is ongoing.

A third big aim of WP1 is the development of traceable procedures for the calibration of radon measurement instruments at low activity concentrations. Parallel to the source developments, the work is under way at the calibration chambers to ensure that the new emanation sources can be included into radon tight gas circuits at the different calibration chambers.

SÚJCHBO tested the new $^{222}$Rn flow-through source produced by the Czech Metrology Institute (CMI). The new $^{222}$Rn source has activity of $^{226}$Ra 4,955 (50) kBq and the radon output 0,0104 (1) Bq/s. The new
source was tested in the SÚJCHBO Low-Level Radon Chamber (Figure 1). The SÚJCHBO Alphaguard DF2000 was calibrated in the BFS laboratories. This Alphaguard will be used for the intercomparison measurements which will be realized in WP5. To determine the most accurate radon activity concentration, the mass flow meter was calibrated by the CMI by the Department of primary metrology of pressure, vacuum and low mass flow in the range from 0 l/min to 20 l/min.

![Figure 1](image1.png)

**Figure 1:** The system for generating the $^{222}$Rn time stable atmosphere in the range of radon concentration from 100 Bq·m$^{-3}$ to 300 Bq·m$^{-3}$.

The radon reference facility was established at the German Federal Office for Radiation Protection (BfS). The facility enables the creation of stable and traceable radon reference atmospheres for calibration purposes. Long-term stable activity concentrations are achieved by using an emanation source with a constant emanation rate.

Figure 2 shows the time course of the calibration of a customer instrument (Alphaguard). Starting from an atmosphere without radon (measurement of the instrument background), the instrument then passes through various radon activity levels (1-4). In addition to the approximation to the set radon values, the figure also shows the decrease in the radon activity concentration due to radioactive decay (5). The time course is interrupted between about 500 and 800 hours to reset the display of the device by exposure in a zero radon atmosphere. Exposures resumed for periods longer than 800 hours are used to verify measurements and to test the repeatability of exposures. Each of the set radon values was kept constant for about 4 days. The data provided by the customer instrument are on average about 5% below the calculated radon activity concentrations.

The results will be used for the development of calibration procedures in the activity concentration range from 100 Bq/m$^3$ to 300 Bq/m$^3$. 
**Figure 2:** Example for the time course of four different calibration exposures imposed on a customer instrument (Alphaguard) in the range between 100 Bq/m$^3$ to 300 Bq/m$^3$; Dots indicate the readings of the instruments, and lines the results of calculation.

Calibration procedures in radon chambers – especially at low-level radon concentration in air (100 Bq/m$^3$ to 300 Bq/m$^3$) – involve several specific metrological aspects that are under study at IFIN-HH: the activity uncertainty of the used radon source, study of the radon volume distribution (homogeneity) in the radon chamber, radon activity decay in a long time period, validation of the new software (automated functioning of the radon chamber), the volume calibration of the radon chamber and the calibration of the temperature and pressure sensors. New stainless steel recipients for radon extraction, storage and transfer into the radon chamber were purchased and will be tested and connected to the radon system.

**Figure 3:** Stainless steel recipients for radon extraction, storage and transfer into the radon chamber.
Influence of thoron and its progeny on radon end-user measurements and radon calibrations (WP2)

The aim of WP2 is to investigate and reduce the influence of thoron ($^{220}$Rn) and its progeny on radon ($^{222}$Rn) end-user measurements and radon calibrations.

STUK has started validating the cross-interference testing of radon instruments in the thoron chamber. This includes:

- ensuring the repeatability of exposure concentration and cross-interference signal of an instrument
- ensuring the stability of thoron concentration during the exposures
- investigating homogeneity of thoron inside the chamber first by assessing temporal variations of thoron concentrations during exposures and later by aerogel traps
- stabilization of humidity in the chamber using salt slurry humidifier
- fitting the cross-interference signals into in-growth function of $^{212}$Pb and considering uncertainty calculations relating to the results.

A discussion between STUK and SUBG about standardized testing protocol is in progress. SUBG has instructed STUK on homogeneity testing with aerogel traps and will provide material for this purpose.

SUBG has completed the investigation of solubility and diffusion coefficient of radon in different polymer foils at different temperatures using LSC technique. A manuscript with the results is under preparation for journal submission. SUBG has carried out theoretical and/or experimental research on radon and thoron penetration in closed volumes by diffusion through polymer membranes or pin-holes. It was found (in accordance with observations of other authors) that the radon permeability of the membranes and penetration in the volume are highly dependent on the temperature. It was shown that membranes that are efficient barriers against thoron introduce a substantial temperature bias in the radon response. There is no substantial temperature dependence of radon transmission through pin-holes, however the performance of such chambers at high humidity can be problematic. A dedicated workshop on “Transport of Radon and Thoron in Polymers” was organized in Sofia in 21-22 March 2019. The outcomes and achievements of different groups/researchers engaged in research in this field were reported on the workshop. More information and the presentations are available at the Documents Section on the MetroRADON website.

The creation of an anti-thoron and anti-humidity barrier that does not introduce a substantial temperature bias in radon response was identified as a technical challenge. A concept beyond state-of-the-art was proposed to overcome it and a patent application was submitted for the invention entitled: “Compensating module for sensors for measuring of radioactive Noble Gases” (Bulg. Pat. Appl. Reg. Nr. 12897, priority 19.03.2019, inventor: D. Pressyanov, assignee: SUBG). Pilot results will be reported at the International Radon Symposium AARST 2019, Denver, Colorado, 9-11 September 2019.

Outcomes of WP2 were presented at two international conferences in May 2019:

Two posters were presented at the 22th International Conference on Radionuclide Metrology and its Applications (ICRM), Salamanca, 27-31 May 2019:
“Methods for experimental study of homogeneity in $^{220}$Rn calibrations” (authors: K. Mitev, P. Cassette, D. Pressyanov, S. Georgiev, Ch. Dutso, N. Michielsen, B. Sabot); submitted for publication to Applied Radiation and Isotopes.

“Testing and calibration of CDs as radon detectors at highly variable radon concentrations and temperature” (authors: D. Pressyanov, L.S. Quindos Poncela, S. Georgiev, I. Dimitrova, K. Mitev, C. Sainz, I. Fuente, D. Rabago)

An oral presentation was presented on the International Symposium on Natural Radiation Sources – Challenges, Approaches and Opportunities, Bucharest, 21-24 May 2019:

“The problem of the temperature dependence of radon diffusion chambers with anti-thoron barrier” (authors: D. Pressyanov, D. Dimitrov) and a manuscript is prepared for submission to a peer-reviewed journal.

All contributions are available at the Documents Section at the MetroRADON website.

Comparison and harmonization of radon measurement methodologies in Europe (WP3)

The aims of WP3 are (i) to collect and analyse meta-information on radon surveys performed and existing radon databases in European countries, (ii) to evaluate if the data and methodologies are comparable and (iii) how they could be harmonized in case of methodical inconsistency.

Intercomparison of indoor radon and geogenic radon measurements under field conditions: main results

The intercomparison was held from 5-8 November 2018 in the Laboratory of Natural Radiation (LNR) located at the facilities of the former uranium mine of Saelices el Chico (Salamanca, Spain). 20 participants from 13 countries took part in radon in air intercomparison, three in radon exhalation from soil and five in radon in soil exercise.

Regarding to radon in air measurements, a total of 23 groups of passive detectors and 22 active monitors were exposed in Room1 of the LNR with variation of radon concentration from approximately 0.5 to 30 kBq/m$^3$. Two exposures were performed with reference values of $E_1 = 356 \pm 8$ kBq m$^{-3}$ h and $E_2 = 1014 \pm 13$ kBq m$^{-3}$ h obtained from participant results according to ISO 13528:2015.
Figure 4: Boxplot diagram of the participant’s results for exposures E1 and E2.

Over 80% of the results for radon in air exposure are within the interval defined by the reference value and the standard deviation, established as 20% and 10% for the first and the second exposure respectively. The exercise was successful, taking into account the large number of different devices used, especially in passive detectors where holder materials, diffusion chamber volume, detectors area or detection principle were diverse.

Radon exhalation and radon in soil measurements were carried outside the LNR in “Green Ballesteros”. The participants did not perform the exhalation measurements during the same time and weather conditions due to the different methodologies involved, which could explain the widespread of results. Radon in soil results, between 550 and 900 kBq m⁻³, are acceptable taking into account the arithmetic mean value and its standard deviation.

The full report of the comparison exercise is downloadable here and at Document Section of the MetroRADON website.

Qualitative overview of indoor radon surveys in Europe

A paper based on the research and results of MetroRADON WP3 task “Qualitative overview of indoor radon surveys in europe” is published in the Journal of Environmental Radioactivity with open access!

Abstract: The revised European Directive from 2013 regarding basic safety standard oblige EU Member States to establish a national action plan regarding the exposure to radon. At the same time, International Atomic Energy Agency started technical projects in order to assist countries to establish and implement national radon action. As a consequence, in recent years, in numerous countries national radon surveys were conducted and action plans established, which were not performed before. In this paper, a qualitative overview of radon surveys performed in Europe is given with a special attention to the qualitative and conceptual description of surveys, representativeness and QA/QC (quality assurance/quality control).

First results on the analysis of MetroRADON questionnaire data on indoor radon surveys

To answer the question, if existing indoor radon measurements procedures (including rationale, design, measurement methods and data analysis) from different indoor radon surveys are comparable in Europe, a questionnaire was developed in the framework of the MetroRADON project. The questionnaire was addressed to all European institutions working in this field (not only national authorities but also regional administrations, universities, research centres). They were invited to complete a separate questionnaire for each survey. Between December 2017 and July 2018, a total of 56 questionnaire forms on national and regional indoor radon surveys were completed and returned by universities, research institutions and competent authorities from 24 European countries (see Figure 5).

The first results were presented at the III International Conference Radon in the Environment (27-31 May 2019, Krakow, Poland) and are available [here](#) and in the Documents section of the MetroRADON website. The work on a document reporting a detailed analysis of all the replies is in progress and will be shared, when finished.

Figure 5: Participating countries to the survey and number of questionnaires completed
Radon priority areas and the development of the concept of a geogenic radon hazard index (WP4)

The aim of this work package is to analyse and develop methodologies for the identification of radon priority areas, to investigate the relationships between indoor Rn concentrations and quantities related to geogenic Rn, including soil exhalation and to develop the concept of a “geogenic radon hazard index” (GRHI) as a tool to help identify radon priority areas.

Retrospective radon measurement by CD/DVD method

Within this work package SUBG continued the research on the design and study of the performance of CD/DVD-based detectors of enhanced sensitivity. The sensitivity is improved by using radon absorption/adsorption foils coupled with a CD/DVD. Dedicated efforts were focused on compensation of the temperature dependence and the thoron interference of such detectors.

A new concept that can overcome these problems was proposed and a patent application was submitted by SUBG; see WP2.

The Geogenic Radon Hazard Index (GRHI)

One central topic of Metro Radon WP4 is development of the Geogenic Radon Hazard Index (GRHI). The GRHI can be conceptualized in different ways:

- A universally applicable tool to quantify the susceptibility of an area to geogenic Rn;
- The GRHI shall be a quantity which measures the contribution of geogenic factors to the potential risk that exposure to indoor Rn causes;
- A quantity which measures the availability of geogenic Rn at surface level;
- Measure of "Rn proneness" or “Rn priorityness” of an area due to geogenic factors.

The GRHI should be independent of regionally available datasets, albeit if possible taking advantage of the information contained in them; it should be applicable irrespective borders. Most importantly, it should be an optimal predictor for the geogenic contribution to indoor radon. The GRHI is conceptually similar to the geogenic radon potential (GRP), but rescaled to an index quantity, such as ranging from 0 to 1 or 0 to 100 %. The idea has first been conceived around 2008 during the work on the European Map of Geogenic Radon (part of the European Atlas of Natural Radiation, https://remon.jrc.ec.europa.eu/About/Atlas-of-Natural-Radiation), when it was realized, that due to lack of GRP data in most of Europe, construction of a Europe covering GRP map was out of reach in the near future. It still is today, as GRP surveys are resource consuming and no priority in most countries.

The next conceptual step thus was to estimate the GRP from available geogenic predictor or proxy data (uranium concentration, ambient dose rate, geology etc.); later generalized to the index concept in the early 2010s. The GRHI shall serve as quantity to compare the geogenic radon hazard at different locations. In consequence, a European GRHI map can be generated which may serve to delineate radon priority areas on European scale. There are two approaches: "Bottom-up", use input data from Europe-wide harmonized databases; "top-down", construct GRHIs from regionally available databases in a way that the resulting GRHIs are consistent between databases from which they have been calculated.
The first attempts focused on the top-down approach, but with increasing availability of Europe-wide geogenic databases, the bottom-up approach seems more promising at current. While it does not have the consistency problem by definition, it may be regionally less precise, because regionally dense data are not included. Two test maps based on the bottom-up approach have first been proposed at the III International Conference Radon in the Environment (27-31 May 2019, Krakow, Poland) and are shown in Figure 6. Methodically, the left map use a machine learning algorithm (specifically, MARS) including predictors as petrography, hydrogeological classes, soil types, silt and clay content, available water capacity, coarse fraction and bulk density, as well as the (x,y) coordinates. The right map uses a general linear model, with predictors simplified geology, fine fraction, pH, bulk density, K$_2$O concentration and ln (U concentration). As one can see, the patterns coincide approximately. The methodology is currently being developed further. The presentation given at the III International Conference Radon in the Environment (27-31 May 2019, Krakow, Poland) is available here and at the Documents section of the MetroRADON website.

![Figure 6: Test maps for GRHI based on machine learning algorithm (left) and general linear model (right) with different input variables](image)

Validation of traceability of European radon calibration facilities (WP5)

Many existing laboratories still look for uniform traceability to a validated radon standard. The aim of WP5 is to validate the traceability of existing European radon calibration facilities over the ranges from 100 Bq/m$^3$ to 300 Bq/m$^3$ and 300 Bq/m$^3$ to 10 000 Bq/m$^3$. In WP5 international comparisons will be performed that will fulfill the need to provide confidence in the capability of European radon calibration facilities in the field of radon activity concentration measurements in air.
Validation of traceability, performance and precision of European radon calibration facilities in the range from 300 Bq/m³ to 10 000 Bq/m³

In order to validate the traceability of European radon calibration facilities, a measurement intercomparison is being conducted. The intercomparison for the validation of European radon calibration facilities in the range from 300 Bq/m³ to 10 000 Bq/m³ started in March 2018. BfS provides an electronic radon instrument ALPHAGUARD as transfer comparison device. The AlphaGUARD has been selected as a reference instrument because it is commonly used. For the purpose of the comparison, the device should be exposed in three radon atmospheres at levels of 400 Bq/m³, 1000 Bq/m³ and 6000 Bq/m³. As a result of the intercomparison, the precision and performance of European radon calibration facilities as well as differences in the traceability will be identified. Because of the large number of laboratories that request participation and the short time scheduled, the intercomparison is carrying out in two stages. In the first stage, the national metrological institutes are involved. The second stage involves other laboratories. The intercomparison is still ongoing due to the high interest and large number of participants and will be finished in autumn. Then BfS will compile all the results. BfS has developed the protocol for the comparison exercise to validate the traceability, performance and precision of European radon calibration facilities in the range of 300 Bq/m³ to 10 000 Bq/m³ and selected three calibration points. The results and findings from the intercomparison exercise will be a part of the guideline and recommendations on calibration and measurement procedures for the determination of radon concentration in air.

Validation of the traceability of European radon calibration facilities at stable radon atmospheres in the range from 100 Bq/m³ to 300 Bq/m³

The first step was to calibrate radon measuring device to be used as reference device in this intercomparison. The radon reference facility was established at the German Federal Office for Radiation Protection (BfS) – see WP1. The facility enables the creation of stable and traceable radon reference atmospheres for calibration purposes. Long-term stable activity concentrations are achieved by using an emanation source with a constant emanation rate (see WP1, Figure 2). The results will be used for the development of calibration procedures in the activity concentration range from 100 Bq/m³ to 300 Bq/m³.

The National Institute for Nuclear, Biological, and Chemical protection is interested in being a reference laboratory. They will compare reference device calibrated at BfS with costumer devices. SUJCHBO has developed a unique equipment for testing of devices at low-level radon activity concentration as part of the project. The equipment consists of an airtight Low-Level Radon Chamber (LLRCH) with an inner volume of 324 liters; a flow-through source of 222Rn type RF 5 with activity 4.955 kBq of 226Ra which was also developed within the project by Czech Metrological Institute; and the air pressure bottle as the source of radon-free air. The mass flow controller of type Bronkhorst EL-Flow is part of the apparatus and ensures the requested air flow through the radon source to the chamber. The homogeneity of the inner atmosphere in the chamber is ensured by the help of an continuously regulated fan which allows setting up the air flow in the range from 0,1 m/s to 3,5 m/s. One component of the chamber is a measuring device of climatic conditions for measuring temperature, air pressure, and relative humidity. The construction of the equipment allows the maintaining of a time stable radon activity concentration on a precise level for several days. It is possible to arbitrarily and continuously set up values of radon concentration in the range from 100 Bq.m-3 to 300 Bq.m-3.
MetroRADON at conferences and publications

MetroRADON results were presented at several conferences, e.g. at III International Conference Radon in the Environment, 27-31 May 2019, Krakow, Poland; ICRM 2019 - 22th International Conference on Radionuclide Metrology and its Applications, 27-31 May 2019, Salamanca, Spain

A paper was published within MetroRADON framework:

Presentations, posters and reports can be found in the Documents Section on the MetroRADON website.

MetroRADON – upcoming events

MetroRADON workshops and training course:

Workshop “Harmonisation of radon measurement methodologies and radon priority areas”, Vienna, 25-26 February 2020

Workshop “New procedures for radon monitoring”, Berlin, 12 May 2020

Training seminar for radon instrument calibration and measurements (WP2/WP5), Berlin, 13 May 2020

Relevant upcoming conferences with MetroRADON contribution:

Asia Oceania Geosciences Society (AOGS) 16th Annual Meeting, Singapore, 28 July - 2 August 2019:
Presentation: Radon Regulation and Research in Europe: Is It Relevant for the Asian-Pacific Region? (Authors: Bossew, Janik, Cinelli, Tollefsen, De Cort)

International Radon Symposium AARST 2019, Denver, Colorado, 9-11 September 2019:
Presentation: Highly sensitive passive detectors for short-term pre- and post-mitigation measurements (Author: Pressyanov)

International Conference on Radiation Applications (RAP 2019), Beograd, 16-19 September 2019;
Presentation: The Metro Radon project as support for the implementation of the Basic Safety Standards (Author: Bossew).

More details can be found in the Upcoming Activities Section on the MetroRADON website.

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