

16ENV10 MetroRADON

Activity 6.3.4

Guideline on the constituents of the chain “from primary standards to radon maps” (traceability) and the links between them

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# 1. Introduction

The purpose of the MetroRADON project, funded within the European Metrology Programme for Innovation and Research (EMPIR) is to develop reliable techniques and methodologies to enable SI traceable radon activity concentration measurements and calibrations at low radon concentrations. The need for this project has been largely motivated by the requirements of the implementation of the European Council Directive 2013/59/EURATOM (EU BSS) (EC, 2014).

The EU-BSS evokes new challenges for metrology for radon measurements and calibrations in Europe. EU member states are required to set reference levels for radon not higher than 300 Bq/m³. Radon measurements are mandatory in workplaces and the member states need to establish national radon action plans for radon protection measures, as conducting surveys of indoor radon concentrations. This requires reliable calibration and measurement methods for low radon activity concentrations between 100 and 300 Bq/m³. Hence a significant improvement in the metrological infrastructure in Europe in the field of radon calibrations at low activity concentrations is a prerequisite in order to be able to fulfil the EU-BSS requirements.

New procedures and traceable radon reference sources for the traceable calibration of radon measurement instruments at low activity concentrations with adequately low uncertainties therefore need to be developed. Hence, the specific objective of MetroRADON project:

To develop novel procedures for the traceable calibration of radon (222Rn) measurement instruments at low activity concentrations (100 Bq/m3 to 300 Bq/m3) with relative uncertainties ≤ 5 % (k=1). As part of this, to develop new radioactive reference sources with stable and known radon emanation rates.

Thoron and its progeny are known to bias the results of radon activity concentration measurements, however information about this effect is limited. Therefore, better knowledge of this effect is needed together with techniques to reduce the influence of thoron and its progeny on radon end-user measurements and calibrations. Hence, the specific object of MetroRADON project:

To investigate and to reduce the influence of thoron (220Rn) and its progeny on radon end-user measurements and radon calibrations.

Traceability and quality assurance of calibrations of radon monitors and of radon calibration facilities, as well as the development of methods to conduct a large number of traceable and quality assured in-situ and laboratory measurements of radon are required. Therefore, one objective of this project was:

To validate traceability of European radon calibration facilities, and to publish guidelines and recommendations on calibration and measurement procedures for the determination of radon concentration in air.

A significant improvement in the metrological infrastructure in Europe in the field of radon calibrations at low activity concentrations have been achieved within the EMPIR Project 16ENV10 Metrology for radon monitoring (MetroRADON) in order to be able to fulfil the EU-BSS requirements. To achieve this goal, the calibration infrastructure has to be established and suitable procedures have to be developed to calibrate radon measuring devices at activity concentrations of 100 Bq/m3 to 300 Bq/m3 with relative uncertainties ≤ 5 % (k=1).

The experience gained within the EMPIR project for calibrations at low radon activity concentrations is summarized in the following guideline.

This document reports guideline which summarizes the constituents of the chain *“from primary standards to radon maps” (traceability) and the links between them”*. The purpose of this document is to provide to laboratories and end-users guideline on established sound metrology for radon calibrations at low level (< 300 Bq/m3) starting from the developments of radon emanations sources up to the primary and secondary radon calibration facilities in Europe.

This guidelines are based on the work carried out during MetroRADON project. Specifically, it is based on the results reported in three deliverables of the project: D1, D2 and D7, available on MetroRADON website (<http://metroradon.eu/>).

**Deliverable D1**, *Method for the traceable calibration of radon (222Rn) measurement instruments at low activity concentrations (100 Bq/m3 to 300 Bq/m3) with relative uncertainties ≤ 5 % (k = 1)*.

**Deliverable D2**, *Report on the influence of thoron on radon monitors used in Europe including (i) procedures for checking their sensitivity to thoron, (ii) recommendations on the construction of radon monitors that are not sensitive to thoron and (iii) technical approaches aimed at reducing thoron-related bias in the radon signal in existing monitors.*

**Deliverable D7**, *Validation report on the traceability of primary and secondary radon calibration facilities in Europe*.

The guideline reported on this document focuses on the development of 222Rn and 220Rn emanation sources. Then, it considers the procedures for the calibration of radon measurement instruments at low activity concentrations and the influence of thoron on radon monitor. Finally, it analyses the traceability of primary and secondary radon calibration facilities in Europe.

Explanation of terms and definitions can be found in Annex 1.

List of full names of institutions is reported in Annex 2.

**Guidelines**

# 2. Development of 222Rn and 220Rn emanation source

For the traceable calibration of radon (222Rn and 220Rn) measurement instruments at low activity concentrations (100 Bq/m3 to 300 Bq/m3) with relative uncertainties ≤ 5 % (*k* = 1) special 226Ra containing emanation sources are needed. This emanation sources need to have constant, stable measured emanations, which yield after a buildup phase a constant activity concentration in the reference volume. They have to be traceable to primary standards, are based on different technologies and are compared with decaying radon gas standards. The decaying radon gas standards themself are not suitable, because the efficiency of radon measurement instruments is in general not high enough, to produce sufficient statistical uncertainty during the half-life of the radon. To avoid the limitation of the efficiency of the radon measurement instruments a constant activity concentration is preferable for the calibration purpose. The activity range as well as the emanation power of the source have to be chosen according to the volume of the calibration chamber and the scheme used for calibration.

Two different schemes are presently in use: open circuit and closed volume.

In the case of an open circuit calibration scheme, the 226Ra activity of the source can be higher, which makes it easier to determine the 226Ra content and the emanation power of the source.

This kind of calibration allows for a fast change of the activity concentration, which makes them more attractive for productive calibration facilities and secondary standards.

On the other hand, a closed volume calibration allowing the activity concentration to get into equilibrium and determining the emanation of the source online, allows to have less free parameters and therefore is more suitable for primary calibration laboratories or key comparisons.

Different kinds of sources have been produced and characterized by the MetroRADON consortium. They are available for the preparation of the desired constant radon activity concentrations in a variety of different calibration facilities. The flow through sources prepared by CMI are available through Eurostandard (https://www.eurostandard.cz/products.html#rf) . The active radon emanation sources developed by PTB are up to now distributed to partners of MetroRADON but a production for other NMI/DI can be arranged bilateraly.

The sources developed by the JRC are based on drop deposition and chemical adsorption as well as precipitation. The main advantage of the drop deposition is that the sources are easy to produce but could not be fully characterized due to a lack of available defines solid angle alpha particle spectrometry. The chemical adsorption as production process proved to be not very efficient, which allows to produce accurate low activity emanation sources with relatively low emanation power (between 18 % and 25 %, for details see Table 1 in A.1.1.1 of D1). JRC concludes that these sources might need further method refinement and additional long-term stability testing, due to degradation of the base source materials. The advantage of this source is the good quality and homogeneity of even larger surface emanation sources.

PTB decided to produce emanation sources via electro-deposition, also known as “molecular plating” for 226Ra. The advantage of this method is, that the same setup can be used as for the production of 228Th sources, which deploy the setup for electrolytical deposition (for the schematics of the experimental setup, for details see Table 1 in A.1.1.1 of D1).

The advantage of these sources itself, is the defined geometry, the homogeneity, the in general high emanation power and the possibility to characterize the source for its 226Ra/228Th content through primary defined solid angle alpha spectrometry, as well as to follow its emanation power online, with the help of a primary loss measurement applying -spectrometry using e.g. portable scintillation detectors (LaBr3, CeBr3, SrI2). These sources have been characterized very carefully directly traceable to national standards and therefore the dependence of the emanation power to humidity is known accurately. The sources are meant to be used in National Metrology Institutes (NMI) or designated Institutes (DI). Therefore, online measurement systems and procedures have been developed (for details of the active, online emanation measurement to derive the radon activity concentration, see section 4 in A1.1.1of D1). In addition, a small number of sources are produced for special scientific purpose, applying mass separated ion implantation of laser ionized 226Ra. To further improve the quality (alpha energy distribution, content of impurity (Ba), environmental parameter dependence) of the emanation sources, a dedicated setup for physical vapor deposition of 226Ra on target materials or even detectors is planned.

The CEA-LNHB produced sources forming a radium barium stearate co-precipitate placed between cellulose/glass fiber filters, to emanate the radon. The 226Ra activity is determined via HPGe--spectrometry according to ISO17025 rules. These sources are placed in a gas flow and the emanation of 222Rn is determined using the method of direct and traceable measurement of the activity concentration in the air flow developed by CEA with support of METAS. The advantage of these sources is the possibility to use them in noble gas tight loop systems like at CEA-LNHB. In addition, it is possible, to mix in one loop, sources with 226Ra and 228Th. Therefore, mixed atmospheres consisting of 222Rn and 220Rn are produced with one source. Within the loop system of CEA the dependence of the emanation power from environmental parameters (relative humidity, pressure, temperature) is measured.

At CMI with support from SUJCHBO, a 222Rn emanation source is developed based on an emulsion of salts of fatty acids in silicone rubber that are allowed to polymerize to a thin foil. The process is controlled by weighing and -spectrometry. The emanation coefficient of the source was determined by measuring the activity of the 222Rn daughter products (214Pb/214Bi) and the activity of 226Ra and was almost equal 1. The detection efficiency of the gamma photons was calculated by the MCNP code. The activity of 226Ra within one stainless steel container in the order of 5 kBq. Together with an aged air pressure vessel and a calibrated mass flow controller of type Bronkhorst EL-Flow[[1]](#footnote-1), these sources are used, to dilute the radon flux of 0.010 Bq/s, to achieve the desired activity concentration range. Due to the regulation of the dilution with the help of the mass flow controller, the activity concentration can be changed in short time. With this scheme there is no need to wait for radioactive equilibrium.

The different types of radon activity standards have been compared during several intercomparison exercises.

The agreement of the results was within the assigned uncertainty. Still some discrepancies could be observed between the open circuit scheme and the closed volume measurements. Due to traveling restrictions, these inconsistencies could not be resolved by now and need further investigation, including the in-air flow measurement system developed at CEA.

The method for generating a reference atmosphere for 220Rn characterized in terms of activity per unit volume requires a rapid activity transfer. This is achieved by rapidly transferring the 220Rn gas emanated from an open thin source of 228Th (prepared by electrolysis) into the reference volume

(Röttger et. al.,2010).

# 3. Procedures for the calibration of radon measurement instruments at low activity concentrations

## 3.1 Technical equipment and accessories

* Calibrations of instruments shall be carried out in a radon chamber. The volume of the chamber should be large enough to enable calibrations of several instruments at once. Calibration objects are brought into the volume through an opening of sufficient size.
* The radon chamber must have a feedthrough for the radon supply and a gas outlet. Each feedthrough must be equipped with a valve to control the connection to the environment or external components.
* The radon chamber should be equipped with sufficient electrical feedthroughs to supply electrical power to calibration objects or electrical equipment within the chamber.
* Chamber walls and equipment must be electrically grounded to ensure protection against electric shock and to avoid electrostatic potential differences inside the chamber.
* The tightness of the radon chamber must be sufficient for the calibration method used. Leakages must not significantly affect the stability of the radon atmosphere.
* Thermal insulation of the radon chamber is recommended to minimize the influence of environmental conditions on the measurements. The radon chamber should not be directly exposed to solar radiation during the measurements.
* The radon chamber shall be equipped with sensors to monitor temperature and air pressure. An additional sensor to monitor the air humidity is recommended.
* It must be ensured that the radon introduced is evenly distributed in the air volume of the chamber. Calibration objects and equipment shall not cause a significant disturbance of the homogeneous distribution of radon. Make sure that the equipment inside the radon chamber is made of stainless steel. If other materials are used inside the radon chamber, it must be demonstrated that these materials do not absorb radon or have no effect on the distribution of radon in the volume of the chamber. The installation of fans can help to homogenize the distribution of radon. Where fans are used, the turbulence generated by them shall be moderate and shall not create local pressure differences that could affect the measurements.

**3.2 Sources and supply of radon**

* Radon sources must be able to create a radon atmosphere with an activity concentration in the range of 100 Bq/m³ to 300 Bq/m³ and to maintain this concentration constantly over a long period of time.
* Radon emanation sources containing 226Ra salt bound in a solid matrix are recommended. The radon emanated in the source can be released directly into the free air volume of the radon chamber or transferred by an air stream.
* The source shall provide with a certificate issued by an approved body indicating at least the 226Ra activity and the radon emanation rate. In addition, the certificate shall specify the ranges of temperature, pressure and humidity within which the stability of the radon emission rate is ensured and at which characteristics of the source do not change with repeated use.
* If the emanation source is operated inside the radon chamber or in a closed loop with the radon chamber, the build-up and the final level of the radon activity concentration, $C\_{Rn}$, is calculated by

$$C\_{Rn}\left(t\right)=\frac{ε}{λ\_{Rn}V}\left(1-e^{-λ\_{Rn}t}\right),$$

where $ε$ is the radon emanation rate, $λ\_{Rn}$ is the decay constant of radon given by $λ\_{Rn}=ln\left(2\right)/T\_{1/2}$, $V$ is the effective air volume of the radon chamber, $t$ represents the time that has elapsed since the beginning of the radon supply.

* If the emanation source is operated in an open circuit in which air flows through the source and the exhaust air is discarded without being returned to the source, aged air is used to purge the source and transfer the emanated radon to the chamber. This minimizes background.
* If the emanation source is operated in an open circuit, the build-up and final value of the radon activity concentration, $C\_{Rn}$, is calculated by

$$C\_{Rn}\left(t\right)=\frac{ε}{λ\_{Rn}V+ϕ}\left(1-e^{-\left(λ\_{Rn}+\frac{ϕ}{V}\right)t}\right).$$

In addition to the previously used parameters, the volume flow rate, $ϕ$, has to be taken into account.

* If the emanation source is operated in an open circuit, a flow controller shall be used to control the air flow rate. The flow controller shall be calibrated at an approved calibration body to prove the traceability of the flow rate. A certificate issued by the calibration body shall document the calibration. The flow rate controller shall be calibrated for the flow of air or nitrogen. Calibration shall be performed for flow rates corresponding to the operating ranges of the flow controller for the production of the respective radon atmospheres. The calibration certificate of the air flow controller shall specify the temperature, air pressure and other relevant information (gas components, humidity) to enable the correction of the indicated gas flow to the actual gas flow for the conditions prevailing during operation.

**3.3 Calibration object**

* Each calibration object shall have a free space to the walls of the volume, equipment or other calibration objects of at least 10 cm. Suitable stands, holders and other equipment should be used to place the calibration objects.
* Care must be taken to ensure that the sensitive measuring unit of the calibration object is not placed in the vicinity of gas ducts, fans or other devices that could impair the measurements. Ideally, the sensitive measuring unit should be placed free in the volume, away from other installations or walls.
* By introducing a calibration object into the radon chamber, a corresponding part of the air volume is replaced. Especially in radon chambers with small volumes, this could influence the calibration result. It may therefore be necessary to re-determine the effective air volume taking into account the calibration object.
* Calibration objects with electronic components could be heat sources, which can influence the calibration atmosphere especially in small radon chambers. Measures must be taken to minimize or correct the effects.

**3.4 Calibration methods and traceability**

* The measurand radon activity concentration is a combined quantity consisting of the primary quantities activity and volume. The quantities must be traced back to approved primary standards through an unbroken chain of calibrations.
* The measurand radon activity concentration can be realized by a radon chamber of known volume into which a certain amount of radon activity is fed. Both the chamber volume and the radon activity must be separately traced back to primary standards. This method is used by secondary reference laboratories. It places high demands on the stability and precision of established radon atmospheres. The determination of the effective air volume in the radon chamber, which includes all installations and the calibration objects, should be considered. The uncertainty of the calibration result is composed of the uncertainties of the free air volume in the radon chamber and the radon activity, and additionally the uncertainty caused by the calibration object.
* The measurand radon activity concentration can also be determined with a reference instrument, which directly measures the measurand in the atmosphere of the radon chamber. The reference instrument is traced back to a secondary reference laboratory. The uncertainty of the calibration result is composed of the uncertainties of the calibration factor of the reference instrument and the fluctuation of its indication, and additionally the uncertainty caused by the calibration object.

**3.5 Specific requirements on the calibration procedure**

* The calibration shall include the determination of the measurement background of the calibration object. It is determined after replacing the chamber air with aged air. The time period for background measurements must be sufficiently long to minimize the background uncertainty. It is not uncommon for the duration of background measurements to be much longer than that of calibration exposures.
* The calibration determines the relationship between the instrument display and a reference activity concentration of radon under specified conditions. This relationship can be expressed as a factor or function and is the calibration result.
* The calibration service must ensure that calibrations are performed within the limits of the standard test conditions given in Table 1. The conditions for the calibrations may differ from the ranges given in Table 1 by agreement between the calibration service and the customer.

**Table 1 – Reference conditions and standard test conditions**

| **Quantity** | **Reference conditions** | **Standard test conditions** |
| --- | --- | --- |
| Activity concentration of 220Rn | Negligible | Negligible |
| Ambient temperature | 20 °C | 18 °C to 22 °C |
| Relative humidity | 65 % | 50 % to 75 % |
| Atmospheric pressure | 1013 hPa | 980 hPa to 1030 hPa |
| Ambient dose equivalent rate | Laboratory background | Laboratory background,0,20 Sv⋅h–1 |
| Electromagnetic field of external origin | Negligible | Negligible |
| Magnetic induction of external origin | Negligible | Negligible |
| Radio frequency | Negligible | Less than the lowest value that causes interference |

* The uncertainty of the calibration factor or function has a significant influence on the uncertainty of the radon measurements performed by customers on site. It results from the uncertainty of the reference radon atmosphere provided by the calibration service and the fluctuations of the instrument's indication due to the statistical nature of the radiation detection.
* The calibration service should take measures to limit the fluctuations of the instrument's indication. For this purpose, the following should be considered:
1. The relative uncertainty of the calibration factor is proportional to $\~^{1}/\_{\sqrt{t\_{exp}}}$.

The greater the time interval of exposure, $t\_{exp}$, the smaller the uncertainty. An extension of the exposure time has a greater influence on the uncertainty for short periods. The longer the exposure time is already, the smaller is the influence of a further extension.

1. Calibrations shall be performed at sufficiently high radon activity concentrations to minimize the influence of the background.
2. The relative uncertainty of the calibration factor is proportional to $\~^{1}/\_{\sqrt{C\_{ref}}}$.

It follows that the greater the reference activity concentration, $C\_{ref}$, the smaller the uncertainty. The influence on the uncertainty by further increase is the smaller, the higher the activity concentration is.

* The final uncertainty of the calibration result must be acceptable to the customer. The calibration service and the customer should agree on the uncertainty to be aimed for and the measures to be taken to limit the fluctuations in the instrument's readings before performing the calibration.
* Statistical fluctuations of the measurements contribute to the uncertainty especially at low activity concentrations. Since the extension of the exposure time interval is limited for practical reasons and because of the ever decreasing influence on the uncertainty, calibrations in radon atmospheres with higher activity concentrations should be considered. To confirm the validity of the calibration in such a case even at low radon concentrations, the calibration object must show a linear response over the measurement range. The linearity of the measurement range shall be specified by the manufacturer or preferably determined by a type test performed by an approved laboratory.

**3.6 Calibration result and certificate**

* The calibration result consists of
1. the calibration factor or function describing the relationship between the instrument display and a reference activity concentration of radon established in the radon chamber during the exposure period of the calibration object, and
2. the attributed measurement uncertainty.
* Unless otherwise agreed between the calibration service and the customer, the calibration result for the reference conditions shall be given according to Table 1.
* The calibration result is performed in a calibration certificate. The calibration certificate must meet the requirements of ISO/IEC 17025.

# 4. Influence of thoron on radon monitors

The influence of thoron (220Rn) on the radon activity concentration measurements has been observed in some radon monitors and detectors. This influence, if not properly corrected, can introduce bias in the radon risk estimates or can generate false alarms if the detectors are used to identify dwellings with radon concentrations that exceed reference/action levels. Both thoron and its progeny (216Po, 212Pb, 212Bi+212Po/208Tl) need to be taken into account in testing for thoron interference of radon monitors/detectors and analysis of the results. The following basic guidelines can be recommended to follow for assessment and reduction of thoron interference on radon monitors and detectors:

* The testing of radon monitors for thoron sensitivity should include reference (secondary) thoron monitor that is calibrated with, or traceable to a primary thoron measuring system. We recommend a stable reference thoron atmosphere to be created in an exposure chamber by flushing air with constant flow-rate consecutively through the thoron source and the exposure chamber. To ensure thoron homogeneity fan(s) should operate in the exposure chamber during exposure. We recommend the reference instrument to be placed inside the exposure chamber throughout the exposure.
* Thoron homogeneity in the chamber should be checked during exposure or in another experiment under the same exposure conditions. The air pressure, temperature, humidity and air velocities (if applicable) during the tests should be recorded;
* The manufacturers of radon monitors/detectors should perform testing for thoron cross-interference of their radon instruments and should include this information in the specifications of the instrument.
* The cross-interference tests should be planned taking into account the possible contribution from thoron progeny (216Po, 212Pb, 212Bi+212Po/208Tl). After the end of thoron exposure the integrated passive detectors should be left for at least three days at low thoron/radon levels before analysis. This is needed to leave thoron progeny deposited in their volume to decay.
* A minimum of three days test with a high thoron activity concentration (around 10 kBq/m3 or more) is recommended to determine an accurate final CI of the active monitors, instead of the 4 hours at 1000 Bq/m3 required in the IEC 61577-2 standard.
* For instruments for which fast reaction to rapidly changing concentrations is required a spectrometric discrimination between radon and thoron is probably the best option. For active monitors with active sampling, counting in two different time intervals can also be used. With a proper data processing such instruments can measure radon and thoron separately still keeping capacity for fast reaction to rapidly changing concentrations.
* If spectral discrimination is not used but the instruments are expected to have a fast reaction, a proper approach is to incorporate a delay line either within the instrument design or as supplementary module. The parameters of such delay line (buffer volume and flow-rate) should correspond to the instrument’s technical characteristics.
* For continuous radon monitors which do not perform spectral discrimination, but record the temperature and for which a fast reaction is not necessarily required, the thoron interference may be reduced by packing the monitors (or their sensitive volume) in polyethylene foils. The temperature induced bias in the radon readings can be corrected from the temperature record and using the known dependence of the radon permeability of the foil on the temperature, as described in Deliverable 2.
* For instruments for which fast reaction to rapidly changing concentrations is not required, and which work in a diffusion mode, additional diffusion barrier can be used.
* For passive detectors diffusion barriers might be considered in the design and tested in the prototypes. If instruments are scheduled to work at high humidity we recommend diffusion barriers based on polyethylene foils of low density polyethylene.
* For detectors in which the usage of polyethylene packing is planned to reduce the thoron interference, it is recommended to calibrate the packed detectors and to perform the calibration at temperature which is close to the expected mean temperature during the measurement. This is to comply with the general principle that the conditions during the calibration and the measurement should be as close as possible.
* For detectors in which the usage of polyethylene packing is planned to reduce the thoron interference, a possible temperature bias may be introduced. Methods for handling and taking account of this bias are proposed in Deliverable 2 (http://metroradon.eu/). In particular, for detectors that have response decreasing with the increase of the temperature, also the temperature bias can be compensated if the anti-thoron polymer packing is designed as a compensation module, as described in Deliverable 2. Such compensation module can reduce/compensate the temperature dependence of the detectors’ response + thoron interference + humidity influence.

# 6. Traceability of primary and secondary radon calibration facilities in Europe

The traceability is a basic requirement in quality assurance of measurements.

As an output of the two intercomparison exercises performed within the MetroRADON project the following documents were created, available on MetroRADON website (http://metroradon.eu/):

* Deliverable D7 :Validation report on the traceability of primary and secondary radon calibration facilities in Europe,
* Deiverable D8: Guideline and recommendations on calibration and measurement procedures for the determination of radon concentration in air.

The document “Validation report on the traceability of primary and secondary radon calibration facilities in Europe” provides results from the validation of the traceability of European radon calibration facilities at stable radon atmosphere in the range from 100 Bq/m3 to 300 Bq/m3 (first intercomparison) and in the range from 300 Bq/m3 to 10000 Bq/m3 (second intercomparison) conducted in the framework of the MetroRADON project.

The document “Guideline and recommendations on calibration and measurement procedures for the determination of radon concentration in air” summarizes recommendations on calibrations in the determination of radon concentration in air based on the intercomparisons of the selected European radon calibration facilities in the ranges between 100 Bq/m3  - 300 Bq/m3 and 300 Bq/m3  – 10 000 Bq/m3. Two approaches of evaluation of the results in the two different validations of radon monitors are described. This document provides recommendation on how to evaluate secondary standards at participant’s laboratory or directly at the reference laboratory. The first approach is suitable for cases when the secondary standard is calibrated in the range between 300 Bq/m³ and 10 000 Bq/m³. For lower radon concentrations, calibration in a stable radon atmosphere at the reference laboratory is recommended. It means that the comparison device is sent to each participant or each participant is requested to send their secondary standard to reference laboratory. The parameter allowing to a ssess the performance of the participant is the ratio of the radon activity concentration measured by the secondary standard for the relevant reference period to the mean of the values measured by the comparison device over the same period. The interlaboratory comparison of European radon calibration facilities is a powerful tool to detect discrepancies in traceability and to ensure the quality of radon measurements in Europe. It is strongly recommended to carry out the interlaboratory comparison regularly.

The traceability of calibrations for radon activity concentration in air measurement to European radon calibration facilities (national or international standards) has been established by using the new radon activity standards developed within the MetroRADON project, and two different approaches were used. The first way was to calibrate the secondary standard devices used by European radon calibration facilities in the same place with traceability to the new radon gas standards. The other way of validation was for one reference device calibrated with a primary radon gas standard to be shipped to European radon calibration facilities for a comparison with their existing secondary standards.

The comparison at three different levels of radon activity concentration (400 Bq/m³, 1 000 Bq/m³ and 6 000 Bq/m³) was conducted by the German Federal Office for Radiation Protection (BfS). The results of the interlaboratory comparison show that, taking into account the statistical uncertainties, the ratios of radon activity concentrations are identical for all exposure values and for the summary of all values.

The intercomparison performed by the staff of SUJCHBO was realised at two levels of radon activity concentrations, at 200 Bq/m3 and at 300 Bq/m3. The analysis of individual parameters of the participant’s performance shows that the results of the secondary standards of the European calibration laboratories are at a very good level.

The detailed results of these two performed validations and results from the questionnaire are given in the “Validation report on the traceability of primary and secondary radon calibration facilities in Europe”.

The electronic instruments of the type AlphaGUARD were selected as comparison devices due to their commonness. The devices were compared to each participant’s secondary standard, which are used for the calibration of the end-user devices.

In total 15 calibration facilities from 12 different countries of the European Union and one from Montenegro participated in the validation of the traceability in the range from 300 Bq/m3 to 10 000 Bq/m3. The comparison device of type AlphaGUARD was sent to each participant by BfS. The participants were to expose the comparison device at three different levels of radon activity concentration: 400 Bq/m³, 1 000 Bq/m³ and 6 000 Bq/m³. It can be assumed that radon activity concentration realized by the European calibration facilities fluctuate around a common mean value. For exposures above 1 000 Bq/m³ the range of variation of the common mean value was about 4 % with a coverage interval of 95 %. For the exposure level of 400 Bq/m³, the 95 % coverage interval increased to about 6 %. The participants performed their measurements under different climatic conditions. The statistical analysis revealed a correlation between the results of the intercomparison and the air pressure at an exposure level of 6 000 Bq/m³. The European radon calibration facilities trace back their primary quantities to the national metrological institutes PTB (Germany), LNHB (France) and NIST (USA). The statistical analysis did not show any evidence that the different traceability chains influence the result of the intercomparison or the performance of the calibration facilities in Europe.

Eight European laboratories participated in the intercomparison in the range from 300 Bq/m3 to 10 000 Bq/m3. The calibration was performed by the SUJCHBO using the unique equipment developed in MetroRADON for testing of measuring devices at low-level radon activity concentrations. The intercomparison was realised at two levels of radon activity concentrations, at 200 Bq/m3 and at 300 Bq/m3. The analysis of individual parameters of the participant’s performance shows that the results of the secondary standards of the European calibration laboratories are at a very good level.

The considerable number of participants from various European countries with different positions in the metrological hierarchy and thus different positions in the traceability chain of the considered quantity allowed a representative validation of the performance and quality in the calibration of radon measuring devices.



Figure 2: Map of states involved in interlaboratory comparisons (violet background – country participating only in comparison performed by BfS, orange background – country participating in comparisons at BfS and SUJCHBO).

The interlaboratory comparison of secondary standards of European radon calibration facilities for radon calibration is a powerful tool to detect discrepancies in traceability and to ensure the quality of radon measurements in Europe. Traceability of European radon calibration facilities was found to be good overall.

The main approach of the validation was that the devices have been calibrated in the stable radon atmosphere which allowed calibration at lower levels of radon concentrations in air and also not such significant uncertainties as in the case of decreasing radon atmosphere.

The traceability and quality assurance of radon calibration facilities as well as the development of methods have been concerned within the MetroRADON project. The electronic instruments of the type AlphaGUARD were selected as comparison devices due to their commonness. The devices were compared to each participant’s secondary standard, which are used for the calibration of the end-user devices.

In total 15 calibration facilities from 12 different countries of the European Union and one from Montenegro participated in the validation of the traceability in the range from 300 Bq/m3to 10 000 Bq/m3. The comparison device of type AlphaGUARD was sent to each participant by German Federal Office for Radiation Protection (BfS). The participants were to expose the comparison device at three different levels of radon activity concentration: 400 Bq/m³, 1 000 Bq/m³ and 6 000 Bq/m³. It can be assumed that radon activity concentration realized by the European calibration facilities fluctuate around a common mean value. For exposures above 1 000 Bq/m³ the range of variation of the common mean value was about 4 % with a coverage interval of 95 %. For the exposure level of 400 Bq/m³, the 95 % coverage interval increased to about 6 %. The participants performed their measurements under different climatic conditions. The statistical analysis revealed a correlation between the results of the intercomparison and the air pressure at an exposure level of 6 000 Bq m-³. The European radon calibration facilities trace back their primary quantities to the national metrological institutes PTB (Germany), LNHB (France) and NIST (USA). The statistical analysis did not show any evidence that the different traceability chains influence the result of the intercomparison or the performance of the calibration facilities in Europe.

Eight European laboratories participated in the intercomparison in the range from 100 Bq/m3 to 300 Bq/m3. The calibration was performed by the SUJCHBO using the unique equipment developed in MetroRADON for testing of measuring devices at low-level radon activity concentrations. The intercomparison was realised at two levels of radon activity concentrations, at 200 Bq/m3 and at 300 Bq/m3. The analysis of individual parameters of the participant’s performance shows that the results of the secondary standards of the European calibration laboratories are at a very good level.

The interlaboratory comparison of secondary standards of European radon calibration facilities for radon calibration is a powerful tool to detect discrepancies in traceability and to ensure the quality of radon measurements in Europe. Traceability of European radon calibration facilities was found to be good overall.

**Recommendations:**

Validation of the radon measurement instruments in range from 100 Bq/m3 to 300 Bq/m3

* Participants of the intercomparison should arrange a transport company for the shipment of their secondary standard to SUJCHBO and back and will also cover all transfer fees.
* The Participant´s standard, together with necessary accessories should be safely packed and transported in a shipping box.
* Upon delivering the Participant´s device, SUJCHBO will check the integrity of the shipping package and its secondary standards.

The shipping address is: MSc. Josef Vosahlik

SUJCHBO, v.v.i

Kamenna 71, Milin 262 31

Czech Republic

* The Participant guarantees a sufficient memory capacity of the device for about ten days. The Participant should also note the possibility of operating the device via batteries or only with an external power source. The device time-unit will be set to Central European Time. The sampling interval will be set to 60 minutes.
* The time required for the intercomparison measurement of each secondary standard is estimated for approximately two weeks.
* Together with the Participant`s device, the AlphaGuard DF 2000 (owned by the SUJCHBO) will be placed into the Low-Level Radon Chamber. This reference measuring device has been calibrated in the BfS Berlin (Calibration Certificate No R-19-1).
* The Participant will receive the List of technical records together with the returned instrument. In the List, there will be noted the time of exposure and a climatic condition monitored during the calibration.

Validation of the radon measurement instruments in range from 300 Bq/m3 to 10 000 Bq/m3

* An electronic radon instrument ALPHAGUARD (Type PQ 2000 PRO TTL, SN 1336) will be provided as transfer comparison device for the intercomparison. The device is owned by BfS, and will be made available to the laboratory for a predefined time duration, in order to perform the exposures. After performing the exposures, the device has to be sent back to BfS.
* A parcel service for shipment of the transfer comparison device from BfS to the participating laboratory and back to BfS should be ordered.
* The device and accessories should be packed safely and shipped in a transport box. A list of every item shipped should be included. During transport, the device shall be turned off.
* After receipt of the transfer comparison device, the participating laboratory should check it for intactness. The device will be delivered with fully charged battery. The data memory will be empty.
* The device is capable for operation without external power supply over several days. In order to recharge the battery or to operate under continuous external power, a power supply will be provided.
* The participating laboratory should not change any of the settings. Even the background of the device will be already determined by BfS. Although ALPHAGUARD provides measurements of the temperature, the humidity and the air pressure, these measurements are not evaluated and discarded. Climatic parameter should be monitored by the laboratory with its own equipment.
* When turning on the transfer comparison device, an initializing phase starts, which lasts about 10 minutes. After this, the device is in the operation mode, taking measurements of the radon activity concentration. The device indicates 90% of the radon activity concentration after 30 minutes. The laboratory should check the indication of date and time. If necessary, the laboratory should record the time indicated by the device and the local time, as well.
* The transfer comparison device should to be placed in the corresponding radon atmosphere to perform exposures in agreement with the procedures of the laboratory. The device has to be exposed in three radon atmospheres each with different radon activity concentration.
* The records on the intercomparison should be delivered to BfS.
* The laboratory will issue a report on the intercomparison. The report shall contain the following information at least:
	+ - name and address of the laboratory
		- name and e-mail of the person(s) in charge
		- a short description of the procedures of the laboratory, information about the local reference instrument for the radon activity concentration, information about traceability to primary standards
		- operating conditions during the exposures: average values of temperature, rel. humidity and air pressure
		- measurement results specified for each exposure:
			* The mean value of radon activity concentration measured by the transfer comparison device. This value is determined from the collocated list of single measurement data provided by BfS after reading out the data from the device. The single measurement data are provided with a correction for background and the application of the calibration factor of BfS.
			* The measurement uncertainty of the value given under item.
			* The mean value of the radon activity concentration established in the radon atmosphere of the laboratory. This value is determined with the equipment of the laboratory.
			* The measurement uncertainty of the value given under item.
* The measurement uncertainties shall be given as expanded uncertainties resulting from the standard uncertainties of measurement multiplied by a coverage factor k=2.
* The report of results shall be delivered to BfS via e-mail: tbeck@bfs.de

# Reference laboratories and contacts

## BfS

BfS is a higher federal authority in the portfolio of the German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB). BfS has the aim to pool competences in the fields of radiation protection, nuclear safety, transport and storage of nuclear fuels, and radioactive waste disposal. BfS is involved in the implementation of the Council Directive 2013/59/Euratom into national legislation and is developing methods to identify radon priority areas. BfS maintains a calibration service laboratory accredited for the measuring quantities "activity concentration of 222Rn in air" and "potential alpha energy concentration” (PAEC) of the short-lived 222Rn progenies.

BfS (reference laboratory for the comparison in the ranges from 300 Bq/m3 to 10 000 Bq/m3) selected an electronic instrument of the type AlphaGUARD as a comparison device for the verification. The device was sent to each participant. The participants had to expose the comparison device at three different levels of radon activity concentration: 400 Bq/m3, 1 000 Bq/m3 and 6 000 Bq/m3.

*Contacts:* e-mail: tbeck@bfs.de

www.bfs.de

## SUJCHBO

SÚJCHBO is the Czech National Institute for Nuclear, Chemical, and Biological Protection with responsibility for the development and research in the field of chemical, biological and radioactive agents. One of laboratories is engaged in the measurement and the evaluation of natural radioactivity with a special concern for the measurement of radon and its decay products. Such laboratories had a long tradition, starting in 1954. The Authorized Metrological Centre (AMS) is the only laboratory in the Czech Republic for calibration and testing of the instruments that measure the radon air concentration and the energy equivalent radon concentration connected with the radon decay products. Radon Measurement Laboratory is a division of the Nuclear Protection Department.

To verify the secondary standards of European calibration laboratories, which are used for the calibration of end-user devices, SUJCHBO was selected as reference laboratory. As part of the WP1 task, SUJCHBO in cooperation with the Czech Metrology Institute, Prague (CMI) have developed a device for the calibration of measuring devices at low-level radon activity concentrations (Low-Level Radon Chamber, LLRCH). The equipment consists of a radon chamber LLRCH (Low-Level Radon Chamber) with a volume of 324 liters, a flow-through source of radon with an activity of 4 955 Bq, a calibrated mass flow controller type Bronkhorst EL-Flow and a humidifier. The equipment meets the condition of relative uncertainty less than 5 % (k = 1) for calibration of measuring instruments at low-level radon activity concentrations (100 Bq.m-3to 300 Bq/3).

*Contacts:* e-mail: otahal@sujchbo.cz e-mail: vosahlik@sujchbo.cz

www.sujchbo.cz

# References

Röttger A. , Honig A., Dersch R., Ott O., Arnold D., 2010. A primary standard for activity concentration of 220Rn (thoron) in air, Applied Radiation and Isotopes 68 (2010) 1292–1296, <https://doi.org/10.1016/j.apradiso.2010.01.004>

ISO/IEC 17025 General requirements for the competence of testing and calibration laboratories. https://www.iso.org/standard/66912.html

IEC 61577-2:2014, INTERNATIONAL ELECTROTECHNICAL COMMISSION, Radiation protection instrumentation - Radon and radon decay product measuring instruments - Part 2: Specific requirements for 222Rn and 220Rn measuring instruments. ISBN 978-2-8322-1675-0

1. Bronkhorst® model F201CV (Bethlehem ‐ PA, USA) mass flow controllers (MFCs) are suitable for the accurate measurement and control of flow ranges at operating pressures between a vacuum and 64 bar. The MFC consists of a thermal mass flow sensor, a precise control valve and a microprocessor‐based PC‐board with signal and fieldbus conversion. The MFC is equipped with a digital high accuracy PC‐board with a fast response. [↑](#footnote-ref-1)