CALIBRATION CERTIFICATE

Certificate N°: CC-0337-2022

This calibration certificate documents the traceability to national standards, which realize the physical units of measurements according to the International System of Units (SI).

Date of issue: 06.12.2022 **Number of pages: 7**

Calibration object: Continuous radon measuring instrument

Type/Model:	**Corentium Pro**	Manufacturer:	Airthings A.S. - Norway
Serial N°:	**2700015378**	Firmware updated for calibration:	No
Former firmware version:	0x 138A	New firmware version:	0x 138A
Operation mode:	Diffusion mode	Integration interval:	60 minutes
Last calibrated:	not specified	Preset Calibration Factor Multiplier:	1,049

Reference instrument / Working standard: Continuous radon measuring instrument

Type/Model:	AlphaGUARD® PQ2000 PRO	Manufacturer:	Genitron GmbH - Germany
Serial N°:	EF1256	Calibration date:	March 2021
Calibrated by:	BfS - Berlin, Germany	Calibration certificate:	1478 D-K-15063-01-00
Data-readout software:	DataView Pro	Software version:	v.15.03.00 b.2011 13023
Operation mode:	Diffusion mode	Integration interval:	60 minutes

Software version for data-readout and calibration of the calibration object:

Designation: Corentium Pro Calibration Software Software version: v.1.6.1 / 2021-01-08

General condition of the calibration object at receipt and preparative setups:

The calibration object is new, as supplied by the manufacturer. The radon detector has successfully performed the self-test and its time was synchronized with the time server of PTB-Braunschweig (ptbtime1.ptb.de). No indications of error codes or deviating parameters were detected during the performed calibration measurements. The current consumption is normal at 150 µA.

Method of calibration and evaluation of conformity:

Determination of the calibration object's arithmetic mean background concentration value **(C_0)** followed by a two-point calibration. Calibration measurements are conducted in a calibration chamber by exposing the calibration object and the reference instrument to two constant radon activity concentrations (reference atmospheres) for specified sampling times **(t_1, t_2)**. The calibration correction factor **(F_{CCal})** is obtained for each exposure (calibration point) as the ratio of the mean activity concentration determined with the reference instrument **(C_{Ref})** to the background-corrected mean activity concentration measured with the calibration object **(C_M)**, where $C_M = C_G - C_0$ and C_G is the gross measurement result. The weighted mean calibration correction factor **(F^*_{CCal})** is calculated from the radon exposures in the unit [kBq.h/m³] of both calibration points. The preset calibration factor multiplier **(CFM_{old})** of the calibration object is adjusted by multiplication with **(F^*_{CCal})**. According to GT-Analytic's quality standards the applied compatibility test has to meet the requirement **$|E_n|<0,5$** and coefficients of variation must be **<5%** for all results calculated with the adjusted calibration factor multiplier **(CFM_{new})**.

signed:

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Measurement uncertainties:

All measurement uncertainties **(U)** in this document are extended uncertainties that result from standard measurement uncertainties **(u)** multiplied with a coverage factor k=2. Therefore, the conventional true values of the measurement quantities lie in the range of values with 95% probability. The measurement uncertainties are determined in accordance with '*JCGM 100:2008. Evaluation of measurement data – Guide to the expression of uncertainty in measurement, Joint Committee for Guides in Metrology*' .

$U(C_{Ref})$: The combined measurement uncertainty of the reference value **(C_{Ref})** is obtained by quadratic addition of the extended statistical measurement uncertainty of the reference value to the combined extended uncertainty of the calibration factor of the reference instrument, determined via the last calibration at Bundesamt für Strahlenschutz (BfS) - Berlin, Germany.

$U(C_M)$: The uncertainty of the calibration object's background-corrected measuring value **(C_M)** is calculated as: $U(C_M) = U(C_G - C_0) = 2 \times \frac{s_M}{\sqrt{n_M}}$ in which (s_M) is the standard deviation of the background corrected measurement results and (n_M) is the number of integration intervals.

$U(\mu_0)$: The measurement uncertainty of the calibration object's average background signals per hour is calculated as: $U(\mu_0) = 2 \times \sqrt{\mu_0}$

$U(C_0)$: The signals of the exposure to radon-free atmosphere follow a Poisson distribution, thus the associated measurement uncertainty for the entire background measurement can be calculated as: $U(C_0) = 2 \times \frac{s_0}{\sqrt{n_0}}$ in which (s_0) is the standard deviation of the background measurement results and (n_0) is the number of the respective integration intervals.

$U(F_{CCal})$: Combined uncertainty of the calibration correction factor, calculated by quadratic addition of the relative uncertainties **$u(C_M)$** and **$u(C_{Ref})$** and multiplication of the obtained value with the calibration correction factor **(F_{CCal})** according to: $U(F_{CCal}) = 2 \times (F_{CCal}) \times \sqrt{u(C_M)^2 + u(C_{Ref})^2}$

Reproducibility of measurement results:

The coefficients of variation **(CV_{stat} , CV_{intr} , CV_{comb})** indicated in ***Table 2*** and ***Table 4*** are calculated from the detection efficiency **(ε)** of the calibration object and the statistical distribution of its measurement results. Conformity with the requirements of GT-Analytic quality standards is met if the coefficients of variation for the results given in ***Table 4*** do not exceed 5%.

CV_{stat}: Coefficient of variation referring to counting statistics, standardized to a radon concentration of 300 Bq/m³ and an exposure period of 40 hours.

CV_{intr}: Intrinsic coefficient of variation of the measuring instrument determined from the calibration exposures, referring to a stadardized exposure period of 40 hours.

CV_{comb}: Combined coefficient of variation, standardized to a radon concentration of 300 Bq/m³ and an exposure period of 40 hours.

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Operating conditions:

The volume of the reference atmosphere is 0,046 m³, relative humidity is adjusted to a level of 40 ±2 % by means of $MgCl_2$ slurry. The values of temperature **(T)**, barometric pressure **(P)** and relative humidity **(RH)** of the reference atmosphere indicated in ***Table 1*** and ***Table 3*** don't contribute to the measurement results of the radon-222 activity concentration.

Determination of the calibration object's background signals:

Due to previous radon exposures, long-lived radon decay products may have accumulated inside the calibration object's probes, generating background signals ('blank counts') that are not caused by current radon decay. By exposure of the calibration object to nearly radon-free atmosphere for a period of 100 h, the relative distribution of blanc counts, the average number of background signals per hour **(μ_0)** and the mean value of the calibration object's total background, expressed as radon-222 activity concentration **(C_0)**, can be determined. Background signals are quantified as counts per hour (cph).

Average number of background signals per hour: μ_0 = **0,20 ±0,89 cph**

Arithmetic mean of total background concentration value: C_0= **0,4 ±0,2 Bq/m³**

Detection efficiency (ε) and minimum detectable radon concentration (MDC):

Assuming Poisson distribution of the blank counts **(μ_0)** and based on the calibration object's detection efficiency **(ε)**, the smallest detectable net signal from radon decay as well as minimum detectable radon concentrations **(MDC)** for periods related to common working-times (8 h and 40 h) can be estimated by Stapleton approximation. The value of the typical detection efficiency is provided by the manufacturer.

Detection efficiency (ε) of the calibration object: ε = **0,1 cph/(Bq/m³)**

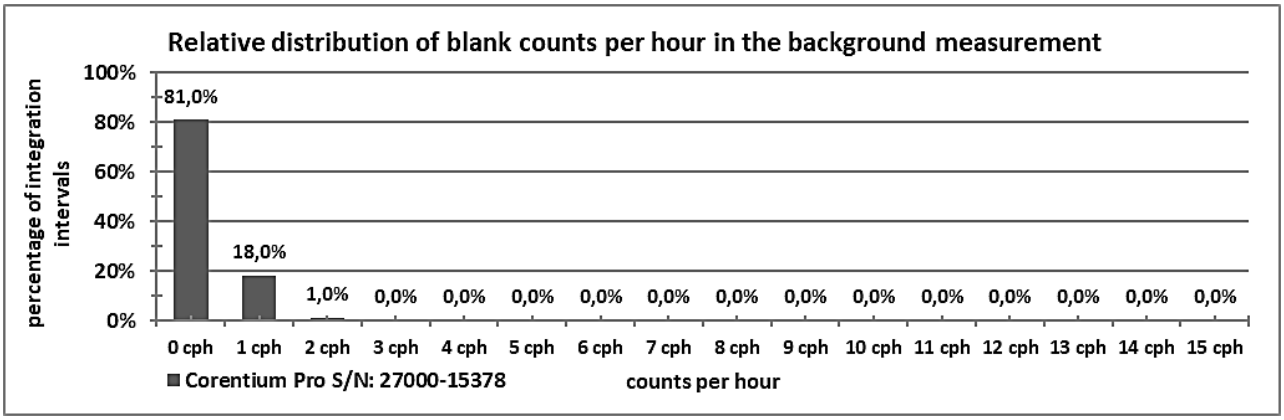
Minimum detectable radon concentrations (MDC):

MDC for a measurement period of **1 hour**: **47 Bq/m³**

MDC for a measurement period of **8 hours**: **9 Bq/m³**

MDC for a measurement period of **40 hours**: **4 Bq/m³**

Graphic presentation of background measurement results:



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Calibration Measurement

Type of calibration: ☑ **Initial calibration** ☐ **Recalibration**

Automatic background correction set to calibration object prior to calibration measurement:

☐ **Yes** ☑ **No**

If "**Yes**", the value determined in the preceding background measurement for C_0 has been programmed to the calibration object and will be automatically subtracted for correct measurand outputs. In this case, it can be considered for subsequent measuring results that $C_0 = 0$ **Bq/m³**, thus $C_M = C_G$.
If "**No**", C_0 must be subtracted according to: $C_M = C_G - C_0$ to obtain valid subsequent measurement results.

Exposure period (t_1) selected for calibration point 1: 29.11.2022 06:00 - 03.12.2022 10:00 (CET)
Exposure period (t_2) selected for calibration point 2: 04.12.2022 02:00 - 06.12.2022 04:00 (CET)

Filename of the reference instrument's measurement data: AG1256_CALREF_061222.upf2
Filename of the calibration object's measurement data: CoPro15378_GTCAL_061222.cor

Table 1: Measurement results for the measurand *'radon-222 activity concentration in air'* :

Expos. N°	C_{Ref} [Bq/m³]	$U(C_{Ref})$ [Bq/m³]	C_M [Bq/m³]	$U(C_M)$ [Bq/m³]	Error [%]	F_{CCal}	$U(F_{CCal})$	t [h]	T [°C]	RH [%]	P [hPa]
1	354	± 46	397	± 14	**12,1%**	**0,89**	**± 0,11**	100	19	40	991
2	2267	± 113	2583	± 39	**14,0%**	**0,88**	**± 0,04**	50	18	40	991

Symbols and explanations see chapters: 'Method of calibration', 'Operating conditions' and 'Measurement uncertainties'

Graphic presentation of calibration measurement readings:

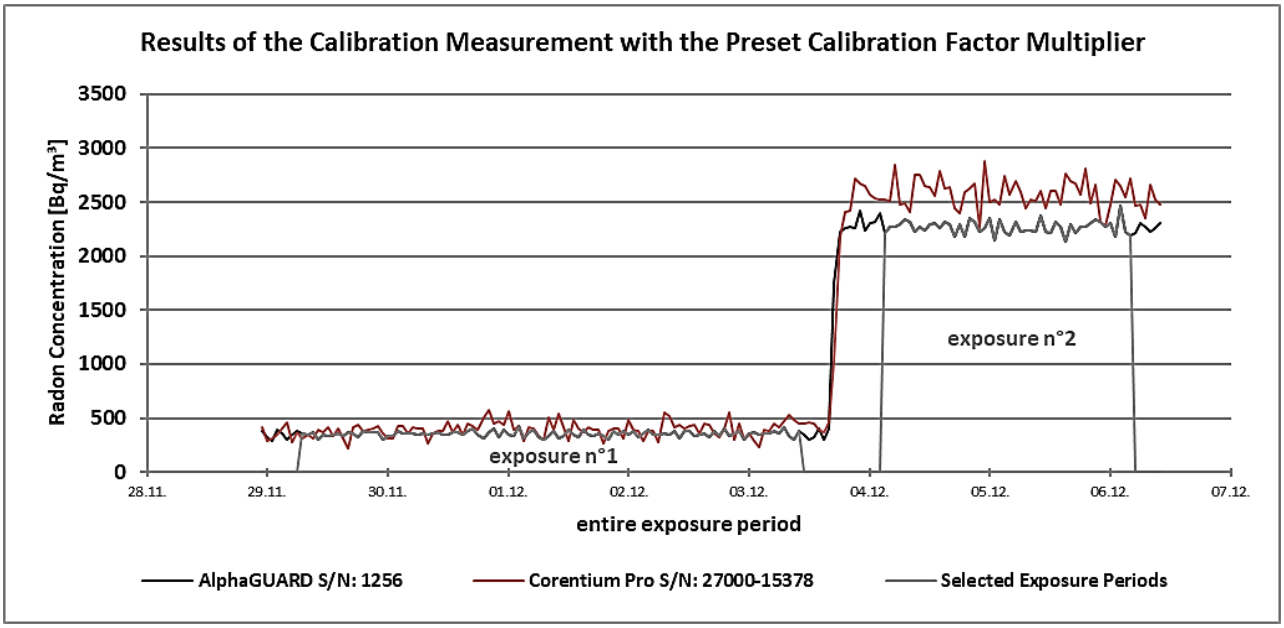

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Table 2: Coefficients of variation and compatibility test:

Exposure N°	CV_{stat} [%]	CV_{intr} [%]	CV_{comb} [%]	Compatibility $\lvert E_n \rvert$
1	**1,4%**	**2,9%**	**3,2%**	**0,88**
2	**1,4%**	**0,8%**	**1,6%**	**2,64**

Compatibility test applied:

$$E_n = \frac{C_{Ref} - C_M}{\sqrt{U(C_{Ref})^2 + U(C_M)^2}}$$

Summary and evaluation of results:

The background concentration value determined for the calibration object is: **0,4 ±0,2 Bq/m³**

Calibration point n°1:

Radon reference exposure of calibration point n°1: **35,4 kBq.h/m³**

Radon exposure measured by the calibration object: **39,7 kBq.h/m³**

Deviation of the calibration object in exposure n°1: **12,1%** Calibration correction factor: **0,892**

Calibration point n°2:

Radon reference exposure of calibration point n°2: **113,3 kBq.h/m³**

Radon exposure measured by the calibration object: **129,2 kBq.h/m³**

Deviation of the calibration object in exposure n°2: **14,0%** Calibration correction factor: **0,877**

The weighted mean calibration correction factor **(F^*_{CCal})** from both exposures is: **0,881**

The value of the calibration object's preset calibration factor multiplier **(CFM_{old})** is: **1,049**

The value of the adjusted calibration factor multiplier **(CFM_{new})** is: **0,924**

Evaluation of Results with Adjusted Calibration Factor Multiplier

This section states the resulting theoretical data that would have been obtained if the calibration object had been subjected to the calibration measurement with the adjusted calibration factor multiplier.

Exposure period **(t_1)** selected for calibration point 1: 29.11.2022 06:00 - 03.12.2022 10:00 (CET)

Exposure period **(t_2)** selected for calibration point 2: 04.12.2022 02:00 - 06.12.2022 04:00 (CET)

Filename of the reference instrument's measurement data: AG1256_CALREF_061222.upf2

Filename of the calibration object's measurement data: CoPro15378_GTCAL_061222.cor

Table 3: Measurement results for the measurand *'radon-222 activity concentration in air'* :

Expos. N°	C_{Ref} [Bq/m³]	$U(C_{Ref})$ [Bq/m³]	C_M [Bq/m³]	$U(C_M)$ [Bq/m³]	Error [%]	F_{CCal}	$U(F_{CCal})$	t [h]	T [°C]	RH [%]	P [hPa]
1	354	± 46	349	± 13	**-1,3%**	**1,01**	**± 0,14**	100	19	40	991
2	2267	± 113	2273	± 34	**0,3%**	**1,00**	**± 0,05**	50	18	40	991

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Graphic presentation of calibration measurement readings:

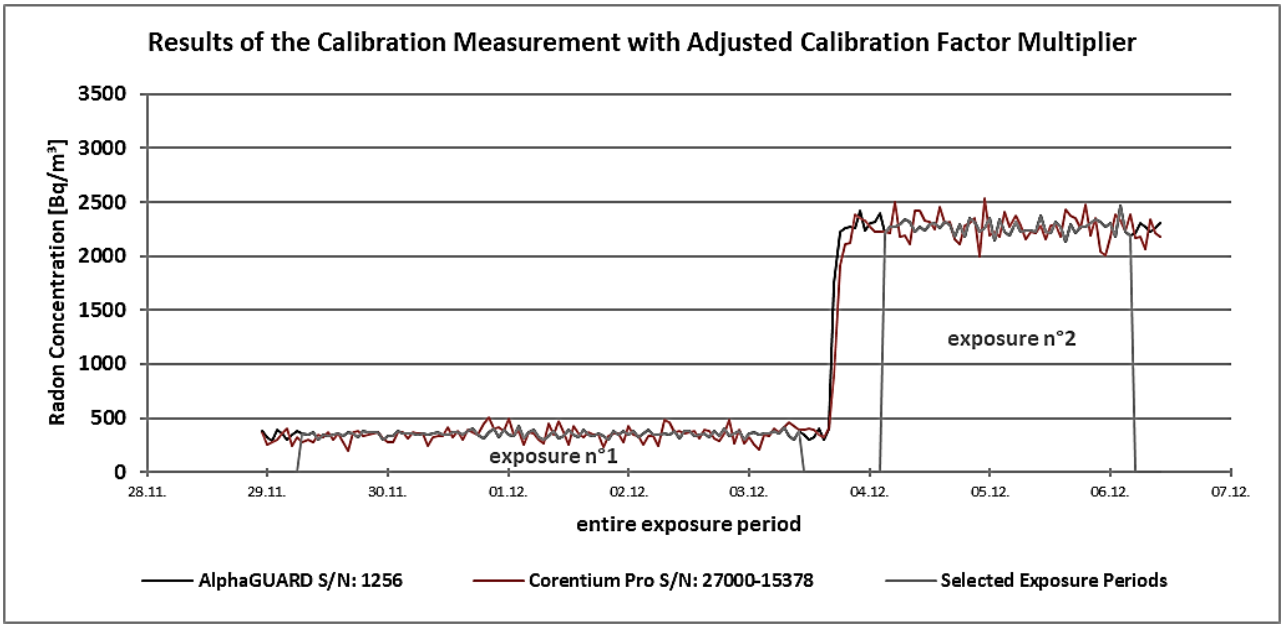

Table 4: Coefficients of variation and compatibility test:

Exposure N°	CV_{stat} [%]	CV_{intr} [%]	CV_{comb} [%]	Compatibility $\lvert E_n \rvert$
1	**1,4%**	**2,9%**	**3,2%**	**0,10**
2	**1,4%**	**0,8%**	**1,6%**	**0,05**

Compatibility test applied:

$$E_n = \frac{C_{Ref} - C_M}{\sqrt{U(C_{Ref})^2 + U(C_M)^2}}$$

Summary and evaluation of results:

The background concentration value determined for the calibration object is: **0,4 ±0,2 Bq/m³**

Deviation of the calibration object in exposure n°1: **-1,3%** Calibration correction factor: **1,013**

Deviation of the calibration object in exposure n°2: **0,3%** Calibration correction factor: **0,997**

The weighted mean calibration correction factor **(F^*_{CCal})** from both exposures is: **1,001**

The results of the compatibility test and the coefficients of variation determined from the exposures of the calibration measurement with the adjusted calibration factor multiplier comply with GT-Analytic's requirements and quality standards, that is: **$\lvert E_n \rvert$<0,5** and **CV_{stat} , CV_{intr} , CV_{comb}** each **<5 %**

The value of the new calibration factor multiplier **(CFM_{new})** set for the calibration object is: **0,924**

The calibration object was calibrated in compliance with the specified requirements.

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It is the responsibility of the user to have the calibration object recalibrated at appropriate intervals and to comply with respective guidelines, norms, directives or other legal regulations applicable to the use of the calibration object. Calibration certificates in general don't have an expiry date, however, the current calibration software requires setting a calibration validity date to the calibration object. The validity assigned to the calibration object by default is 2 years from the date of calibration.
TO NOTE: This does not guarantee the performance of the calibration object under the present calibration results until the expiration of the validity date.

Normative references:

This document is in accordance with ISO/IEC 17025:2017 "*General requirements for the competence of testing and calibration laboratories* " and the examinations stated therein were done in consideration of ISO 11665-5:2020 "*Measurement of radioactivity in the environment - Air: radon-222 - Part 5: Continuous measurement methods of the activity concentration* " and IEC 61577-4:2009 *"Radiation protection instrumentation – Radon and radon decay product measuring instruments – Part 4: Equipment for the production of reference atmospheres containing radon isotopes and their decay products (STAR)"*

Responsible for the calibration and certified by:

Jochen Gschnaller
GT • Analytic

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