THE EMPIR RADON INTERCOMPARISON

- EMPIR Project *Metrology for Radon* -

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EMPIR EURAMET
The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States

Metro RADON

EMPIR Project *Metrology for Radon*

Radon Intercomparison & Validation of Traceability

- Selection of a suitable reference instrument for the use as transfer standard and its preparation for the intercomparison (good linearity and repeatability of the measurements, a high measurement range, mechanical robustness, ease of use).
- Developing of a protocol for the comparison, including a form for the participants to document their calibration procedures and measures for quality assurance.
- Excecution of the comparison.

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Radon Intercomparison & Validation of Traceability

- Assessment of the results of the intercomparison regarding their closeness of agreement (precision). Conclusions shall be drawn for the realization of radon activity concentration in air at the European radon calibration facilities in the range from 300 Bq/m^3 to 10 000 Bq/m^3.

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Radon Intercomparison

The comparison was carried out according to the EURAMET Guide on Comparison and taking into account the CCQM Guidance note on the estimation of a consensus reference value.

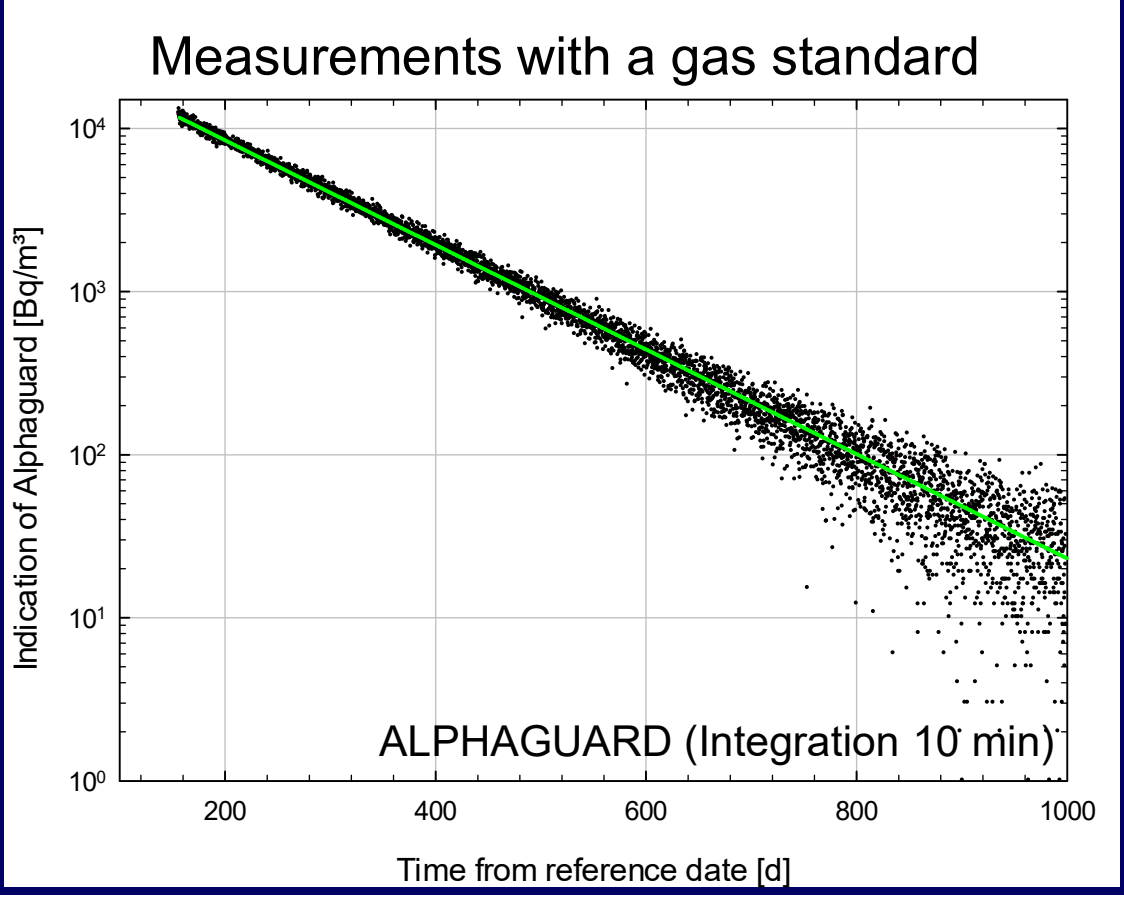
EMPIR Radon Intercomparison

Transfer comparison device: AlphaGUARD PQ 2000 PRO TTL

Transfer Comparison Device

Procedure for checking linearity and precision

Slope
(estimated from regression)
$\lambda = 0{,}007502 \pm 0{,}000025\ h^{-1}$



Transfer Comparison Device

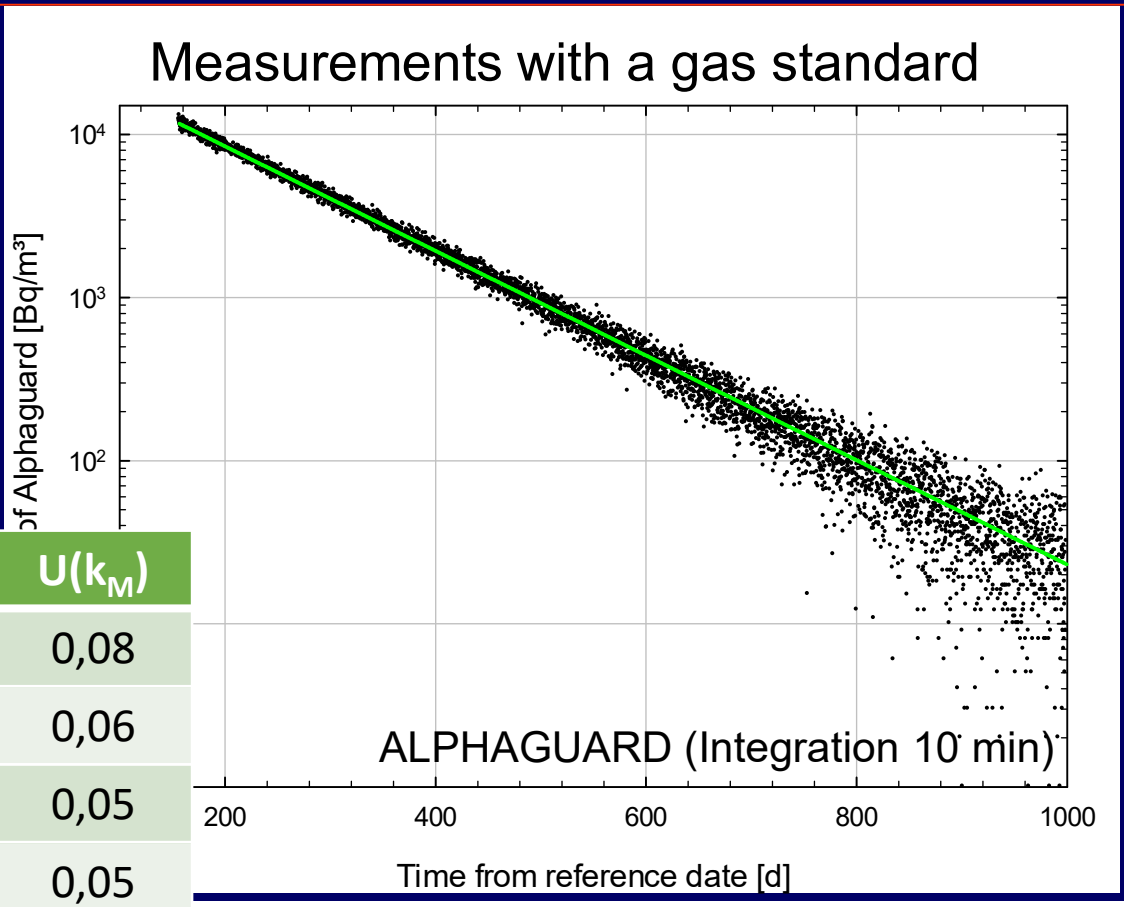
Procedure for checking linearity and precision

Slope
(estimated from regression)
$\lambda = 0{,}007502 \pm 0{,}000025\ h^{-1}$

Calibration factor k_M at fixed levels

No.	C_{ref} [Bq/m³]	k_M	$U(k_M)$
1	330	0,98	0,08
2	1480	0,97	0,06
3	5750	0,97	0,05
4	11800	0,98	0,05

U includes a coverage factor of 2

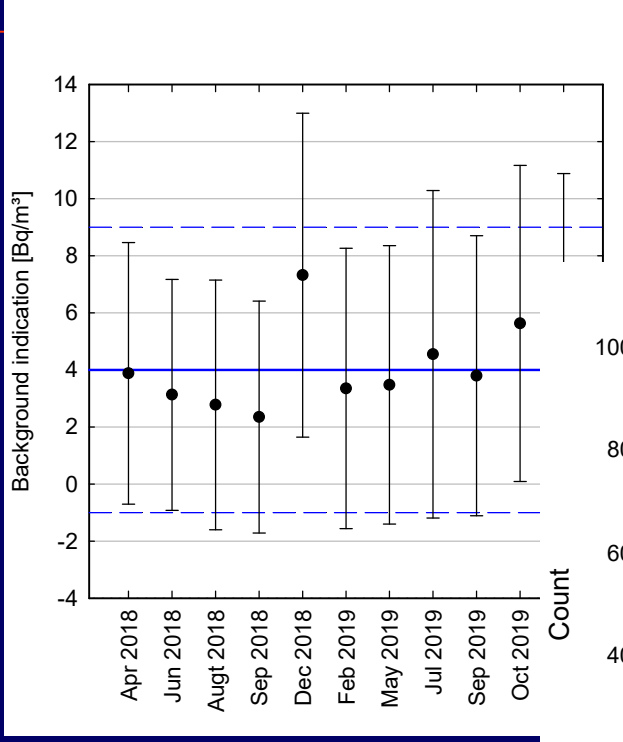


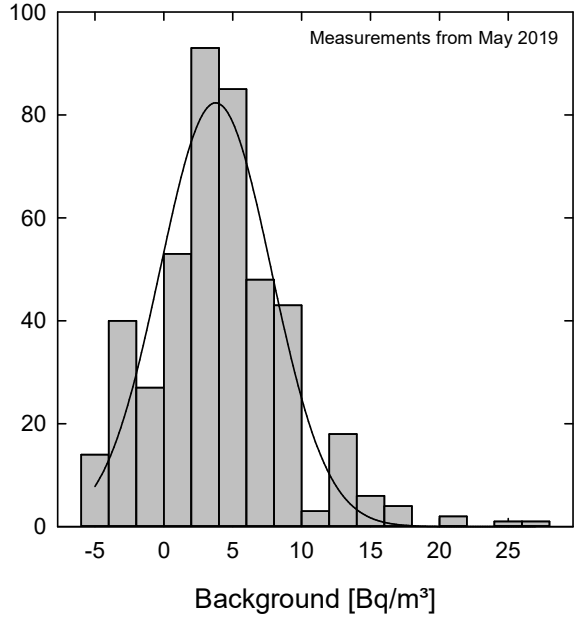
Bundesamt für Strahlenschutz

Transfer Comparison Device

Regular checks of background and instrument settings

Nominal correction for background: 4 Bq/m³





Bundesamt für Strahlenschutz

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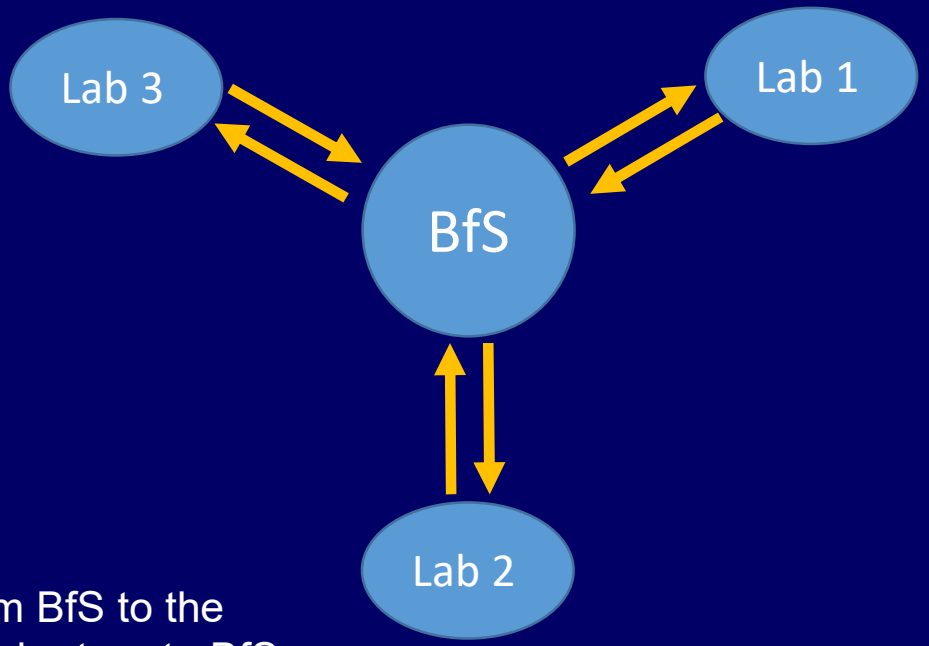
Procedure:

Comparison device calibrated with a primary radon gas standard was shipped to European radon calibration facilities for a comparison with their existing secondary standards.



Shipment from BfS to the participant and return to BfS

EMPIR Radon Intercomparison

Protocols, Information and Documentation

Information about

- Instrument used as transfer comparison device
- Course of the comparison
- Shipment and transport
- Concentration levels

Provision of forms

- for recording calibration procedures and
- for reporting results

Basis for compiling the data and calculating the results

EMPIR Radon Intercomparison

Participants

15 Laboratories
(12 EU countries + Montenegro)

NMI & DI: 7
National Authorities: 5
Universities/Research: 3

MNE	Montenegro
BEV-PTP	Austria
IRSN	France
STUK	Finland
SUJCHBO	Czech Rep.
BFKH	Hungary
CLOR	Poland
SSM	Sweden
UNICAN	Spain
SMU	Slovakia
UBB	Romania
IFIN-HH	Romania
UPC	Spain
BfS	Germany ← Coordinator
ENEA	Italy

Radon Intercomparison

Laboratory Reference (Status 2018/2019)

No. of Participants	Laboratory Reference
13	AlphaGUARD (various models), 3 participants use additional instruments like scintillation cells (2 participants) or Atmos (1 participant) as working standards or for other verification purposes.
1	Atmos
1	Radon Scout

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Radon levels

	Nominal value	Accepted deviation
1	400 $Bq \cdot m^{-3}$	350 $Bq \cdot m^{-3}$ – 450 $Bq \cdot m^{-3}$
2	1000 $Bq \cdot m^{-3}$	900 $Bq \cdot m^{-3}$ – 1100 $Bq \cdot m^{-3}$
3	6000 $Bq \cdot m^{-3}$	5500 $Bq \cdot m^{-3}$ – 6500 $Bq \cdot m^{-3}$

Data Assessment

Quantity of Comparison, R_i

Ratio of radon activity concentrations determined by participant and by transfer device:

$$R_i = \frac{\bar{C}_{Participant,i}}{\bar{C}_{transfer,i}}$$

Relative standard deviation of R_i:

$$u_{rel,i}^2 = \left(\frac{\Delta R_i}{R_i}\right)^2 = \left(\frac{\Delta \bar{C}_{Participant,i}}{\bar{C}_{participant,i}}\right)^2 + \left(\frac{\Delta \bar{C}_{transfer,i}}{\bar{C}_{transfer,i}}\right)^2$$

Only statistical uncertainties, no calibration uncertainties

Data Assessment

Uncertainty-weighted mean $\bar{R}$ of all participants

$$\bar{R} = \frac{R_1/u_1^2 + \cdots + R_n/u_n^2}{1/u_1^2 + \cdots + 1/u_n^2} = \sum_{i=1}^{n} w_i R_i$$

Normalized weights: $$w_i = \frac{1/u_i^2}{\sum_{i=1}^{n} 1/u_i^2}$$

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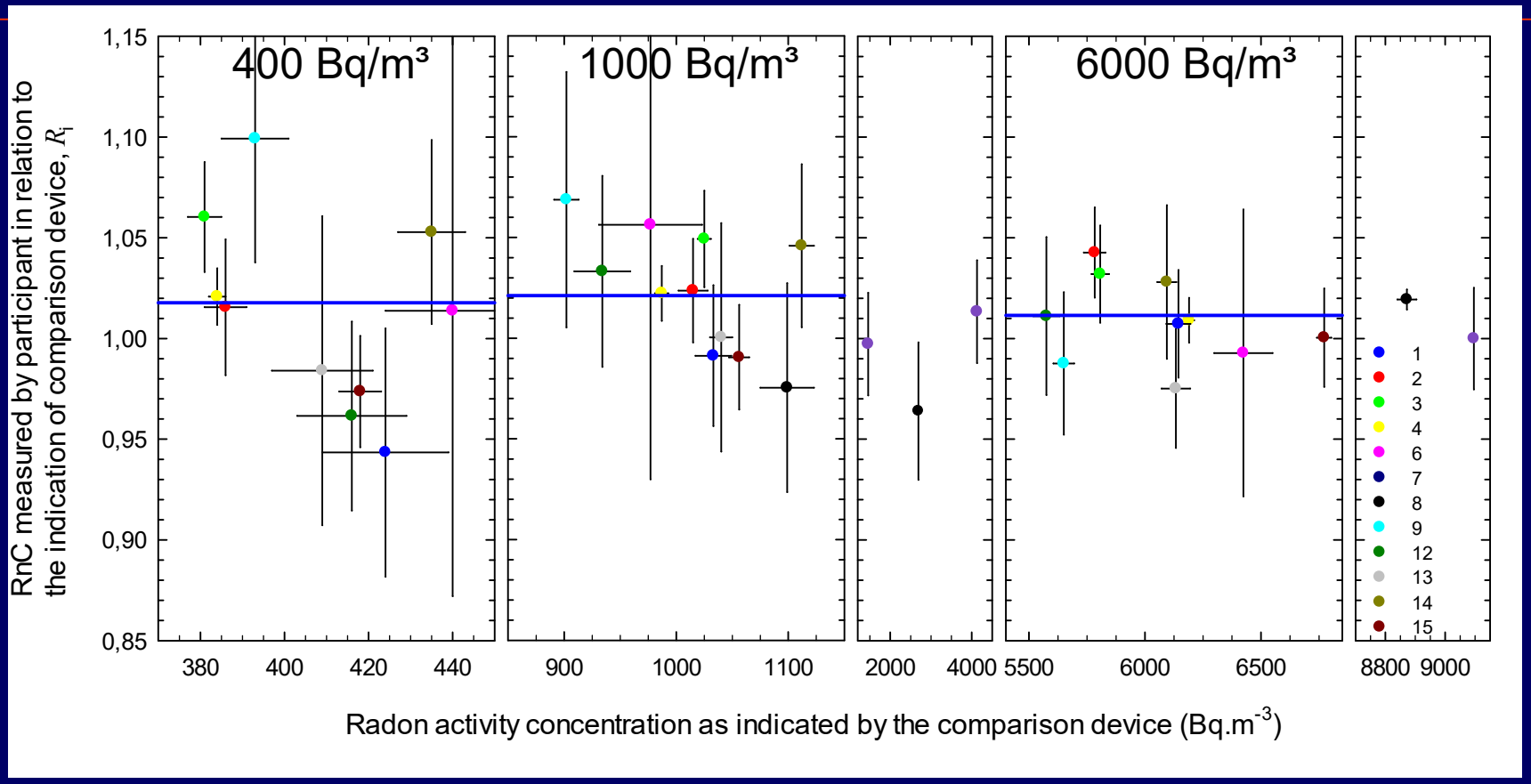
Results related to comparison device



All uncertainties are given with the extension k=1.

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Consistency check of results

Hypothesis H_0: Results belong to the same basic population
Hypothesis H_1: Results do not belong to the same basic population

Test statistic $$\chi^2 = \sum_{i=1}^{n} \frac{(R_i - \bar{R}_i)^2}{u_i^2}$$

n: Number of participants

Hypothesis H_0 has to be rejected, if $\chi^2 \geq \chi^2_{n-1;1-\alpha}$

$\chi^2_{n-1;1-\alpha}$: Quantile of the χ^2 distribution for the significance level $1 - \alpha$

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Consistency check of results, Error probability 5% (α=0,05)

Radon Level	n	χ^2		$\chi^2_{n-1;1-\alpha}$
400 Bq/m³	10	10,5	<	16,9
1000 Bq/m³	11	5,5	<	18,3
6000 Bq/m³	10	5,2	<	16,9
All	36	25,2	<	49,8

Hypothesis H_0 cannot be rejected: The results are samples of the same population.

The results are mutually consistent. Participants share a common mean value. Deviations from the mean value are normally distributed.

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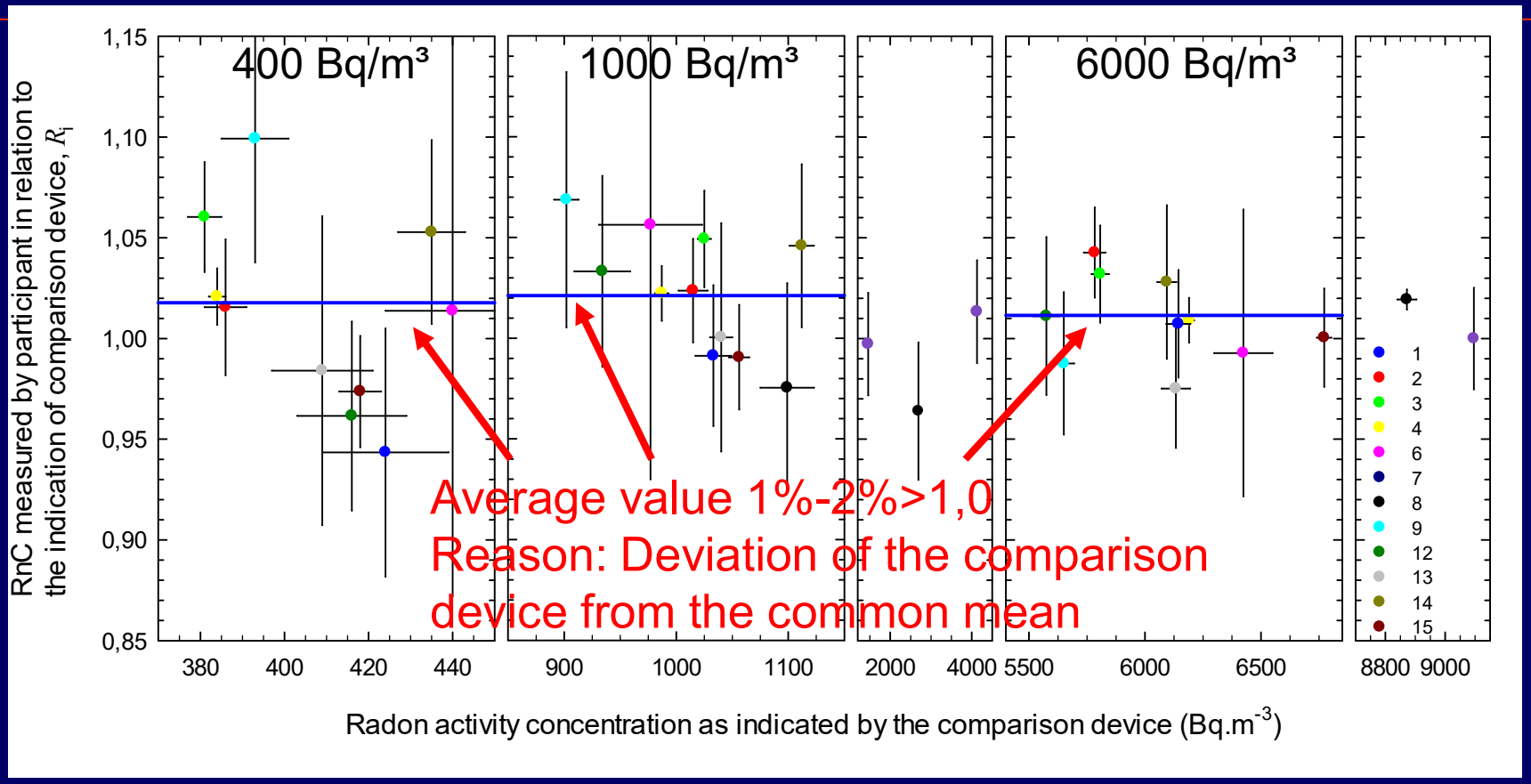
Results related to comparison device



All uncertainties are given with the extension k=1.

Data Assessment

Revised Quantity of Comparison, R_i^*

Quantity for Comparison $$R_i^* = \frac{R_i}{\bar{R}_i}$$

Expectation value equal to 1

$$E(R_i^*) = 1$$

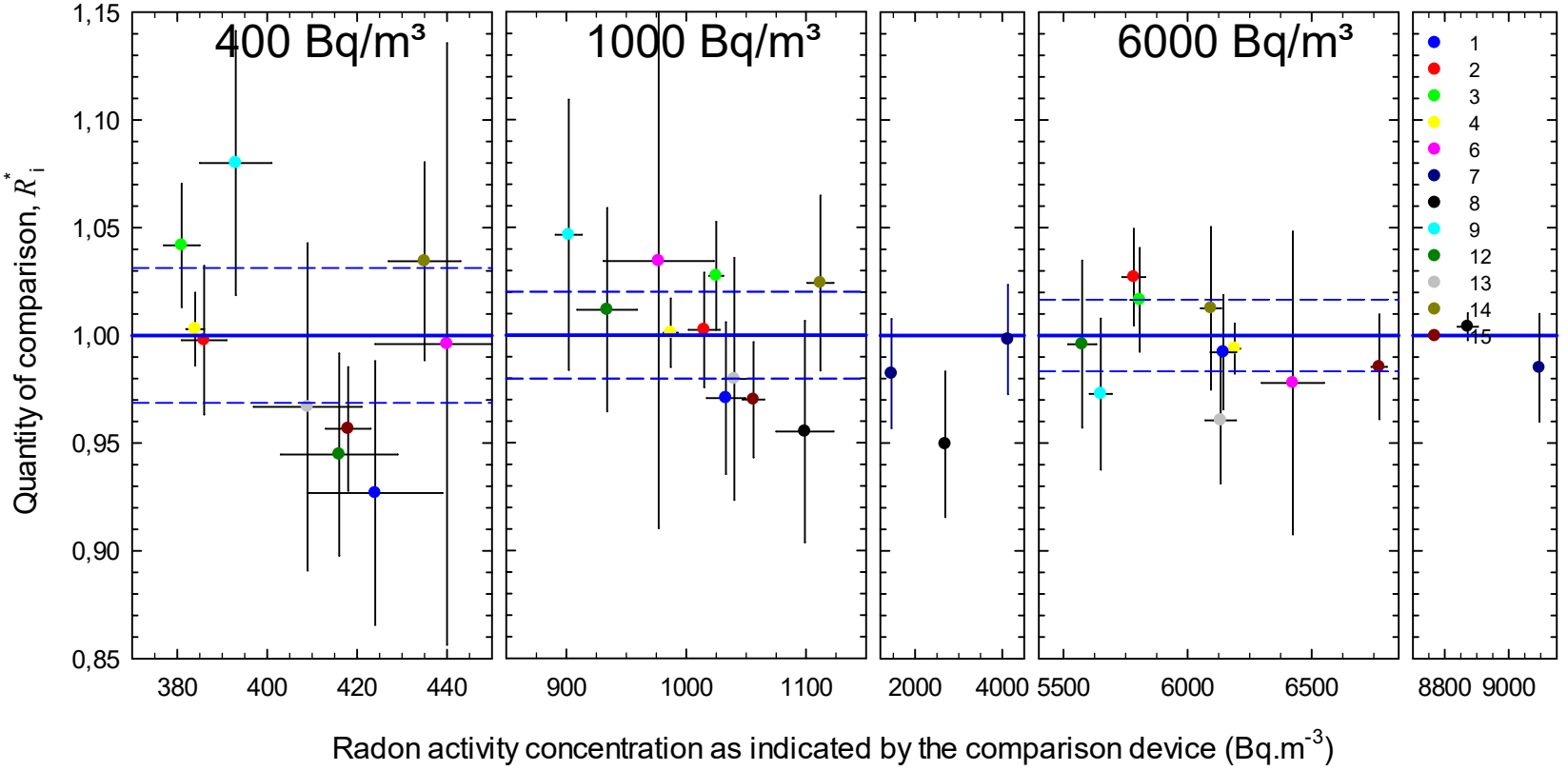
Mean value over all participants

Weighting: calculated from reciprocal squared uncertainties

Variance of R_i^* $$\sigma^2(R_i^*) = \sum_{i=1}^{n} w_i (R_i^* - 1)^2$$

EMPIR Radon Intercomparison

Results indicating the deviations from the common mean



All uncertainties are given with the extension k=1.

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Variance of R_i^* for quantifying the closeness of agreement

Radon Level [Bq/m³]	Variance extended by a factor of 2 (k=2)*
400	6,3
1000	4,0
6000	3,4
All levels including the singular exposures	3,4

* Confidence interval for a coverage of 95%

The radon activity concentrations realized by the European calibration facilities fluctuate around a common mean value.
The range of variation is about 4 % for above 1000 Bq/m³ and about 6 % for a level of 400 Bq/m³.

EMPIR Radon Intercomparison

Comparison with the results of the EUROMET Project 657

(final report 2005)

Radon Level [Bq/m³]	Confidence Interval at 95% (k=2)	
	This work (all participants)	Project 657
400	0,063	--
1000	0,040	0,057
3000	--	0,075
6000	0,034	--
10000	--	0,081

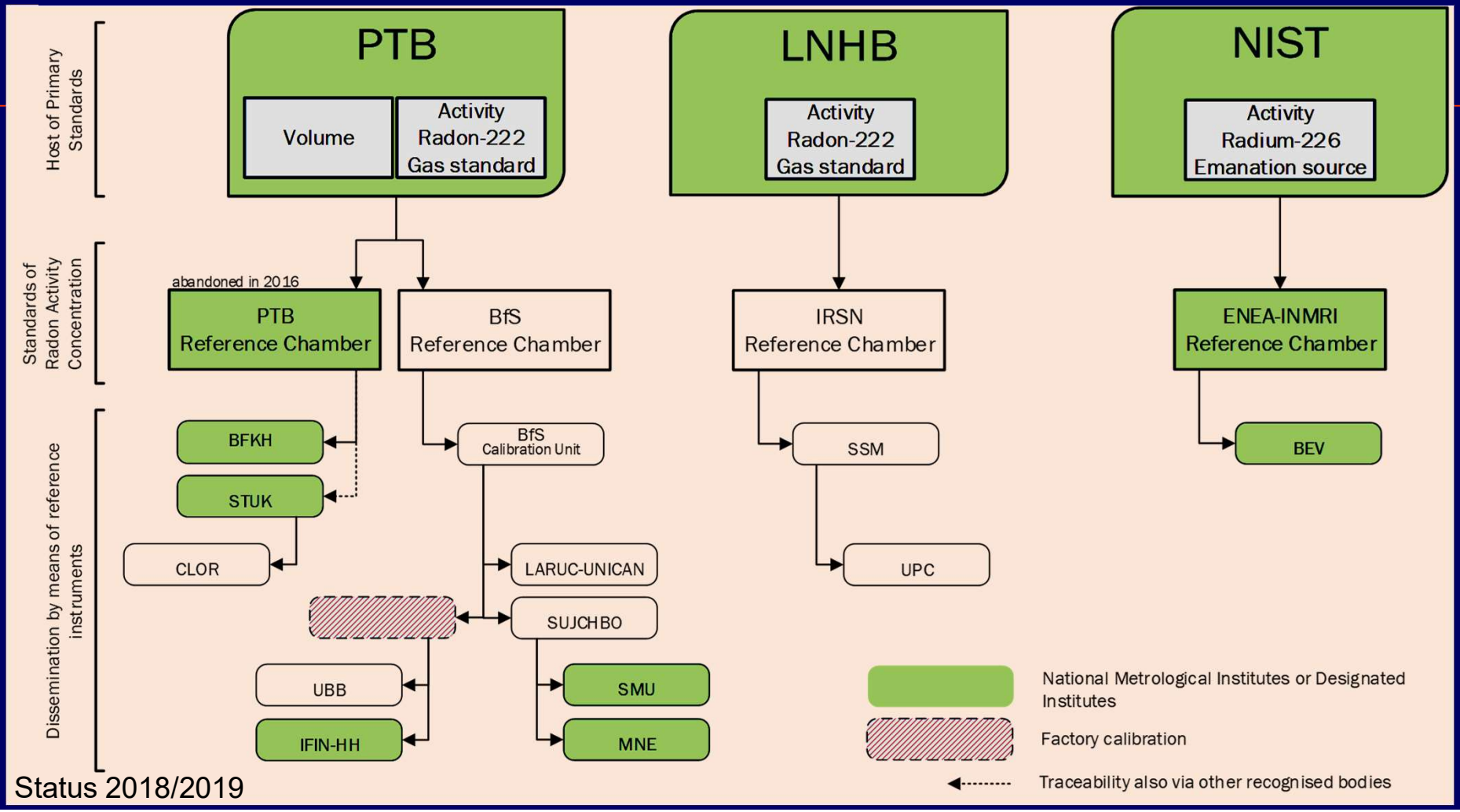
As lower the concentration as higher the deviations
Little improvement comparted to the former comparison

EMPIR Radon Intercomparison

Summary

- 15 laboratories (12 EU countries + Montenegro; NMI & DI, National Authorities, Universities/Research) participated in the intercomparison. 13 laboratories were included in the assessment.
- The current status of the realization of radon activity concentration in air at European radon calibration facilities was validated.
- AlphaGUARD instruments are often used as reference standards. In some cases other types of instruments are also used.
- The results are mutually consistent. Not outlier was observed.
- European calibration services realize the quantity radon activity concentration within a range of 4 % to 6 % (k=2) around the common mean value.

Chart of traceability of European calibration services for radon



Status 2018/2019

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Additional observations

EMPIR Radon Intercomparison

Additional observations

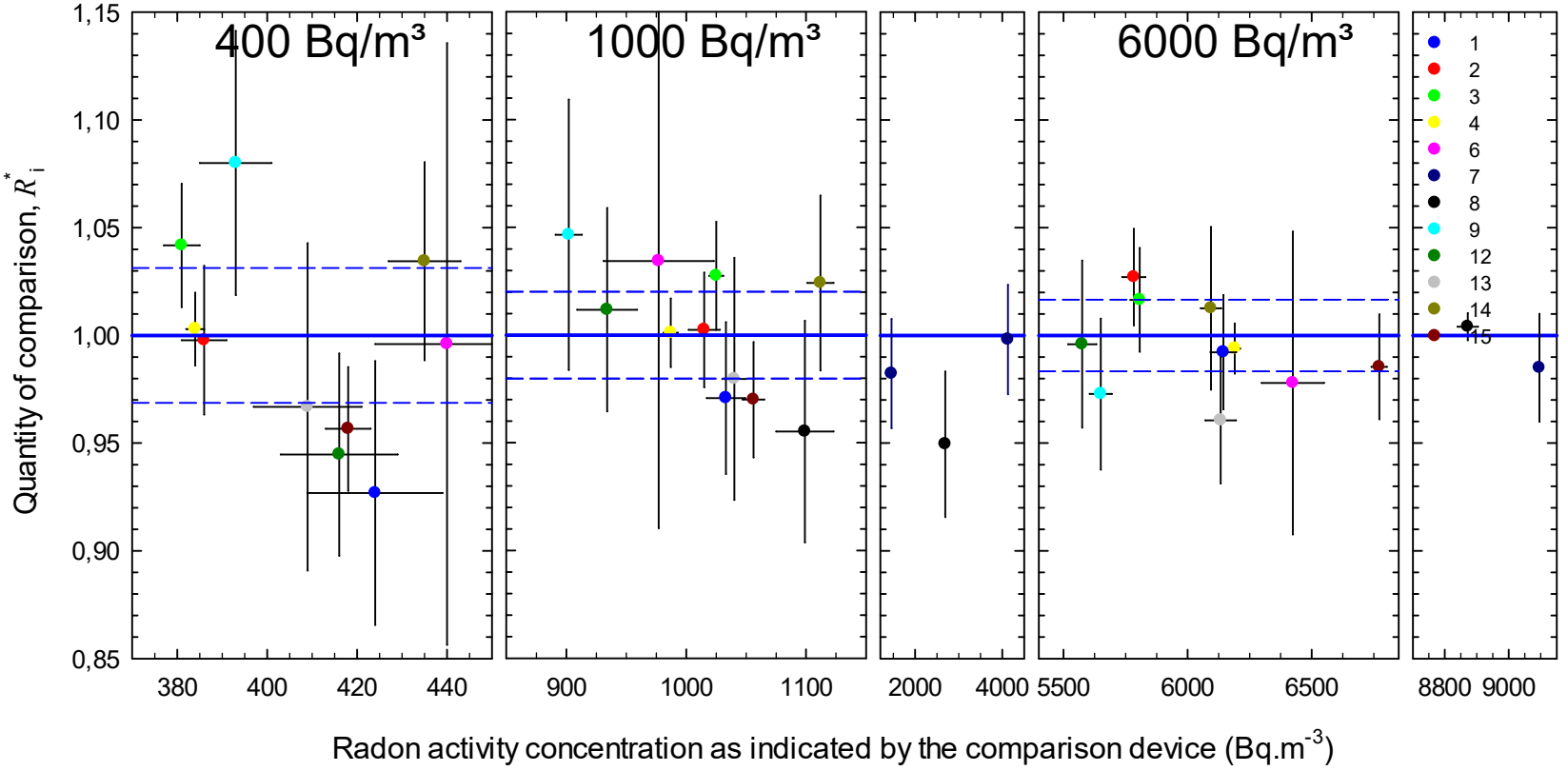
1. Measurement uncertainties and weightings

$$\bar{R} = \frac{R_1/u_1^2 + \cdots + R_n/u_n^2}{1/u_1^2 + \cdots + 1/u_n^2} = \sum_{i=1}^{n} w_i R_i$$

Normalized weights: $w_i = \frac{1/u_i^2}{\sum_{i=1}^{n} 1/u_i^2}$

EMPIR Radon Intercomparison

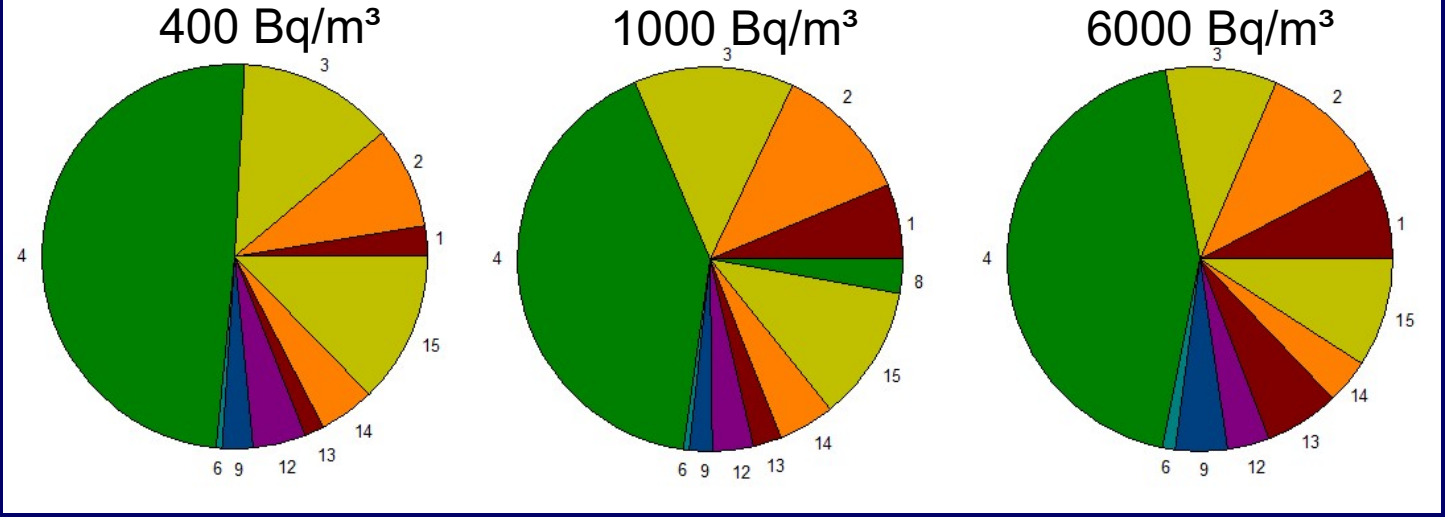
Results indicating the deviations from the common mean



All uncertainties are given with the extension k=1.

EMPIR Radon Intercomparison

Measurement uncertainties and weightings



Weights of the different participants calculated according to their reported uncertainties

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Additional observations

2. Influence of climatic conditions on the calibrations

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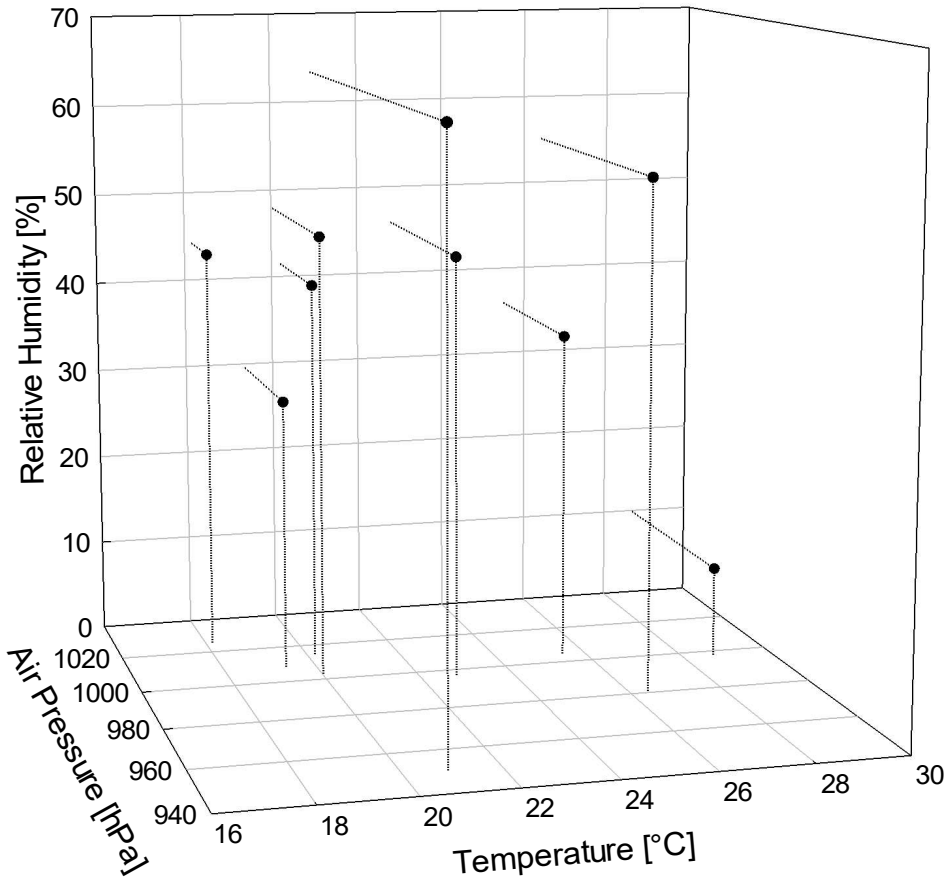
Climatic conditions during the calibrations at the participants



Ranges:

Temperature	18°C – 29°C
Air pressure	950 hPa – 1025 hPa
Rel. Humidity	<10% – 63%

Do the different climatic conditions affect the results?

Test for Influence of Climatic Conditions

Multiple Correlation, Coefficient of Determination

$$r^2_{R,(T,p,rH)} = \begin{pmatrix} r_{R,T} \\ r_{R,p} \\ r_{R,rH} \end{pmatrix}^T \begin{pmatrix} 1 & r_{T,p} & r_{T,rH} \\ r_{T,p} & 1 & r_{p,rH} \\ r_{T,rH} & r_{p,rH} & 1 \end{pmatrix}^{-1} \begin{pmatrix} r_{R,T} \\ r_{R,p} \\ r_{R,rH} \end{pmatrix}$$

$r_{x,y}$: Pearson correlation coefficient

Test statistic $$F = \frac{r^2_{R,(T,p,rH)}(n-1-q)}{q\left(1-r^2_{R,(T,p,rH)}\right)}$$

n: Number of participants

q: Number of characteristics ($q = 3$)

Correlation between x and y has to be rejected, if $F > F_{q,n-1-q;1-\alpha}$

$F_{q,n-1-q;1-\alpha}$: Quantile of the F distribution for the significance level $1-\alpha$

Test for Influence of Climatic Conditions

Multiple Correlation

	Test Statistic				$F_{3,5;1-\alpha}$ $\alpha = 0{,}05$
	Rn ActCon [Bq/m³]	400	1000	6000	
Coefficient of determination	$r^2_{R,T}$	0,052	0,048	0,003	
	$r^2_{R,p}$	0,021	0,001	0,746	
	$r^2_{R,rH}$	0,042	0,072	0,123	
	$r^2_{T,p}$	0,039	0,099	0,079	
	$r^2_{T,rH}$	0,122	0,221	0,131	
	$r^2_{p,rH}$	0,270	0,148	0,251	
	$r^2_{R,(T,p,rH)}$	0,157	0,391	0,857	
	F-value	**0,311**	**1,068**	**9,990**	**5,409**

Correlation between RnC and air pressure at 6000 Bq/m³ !

Correlation of at least one pair of parameter!

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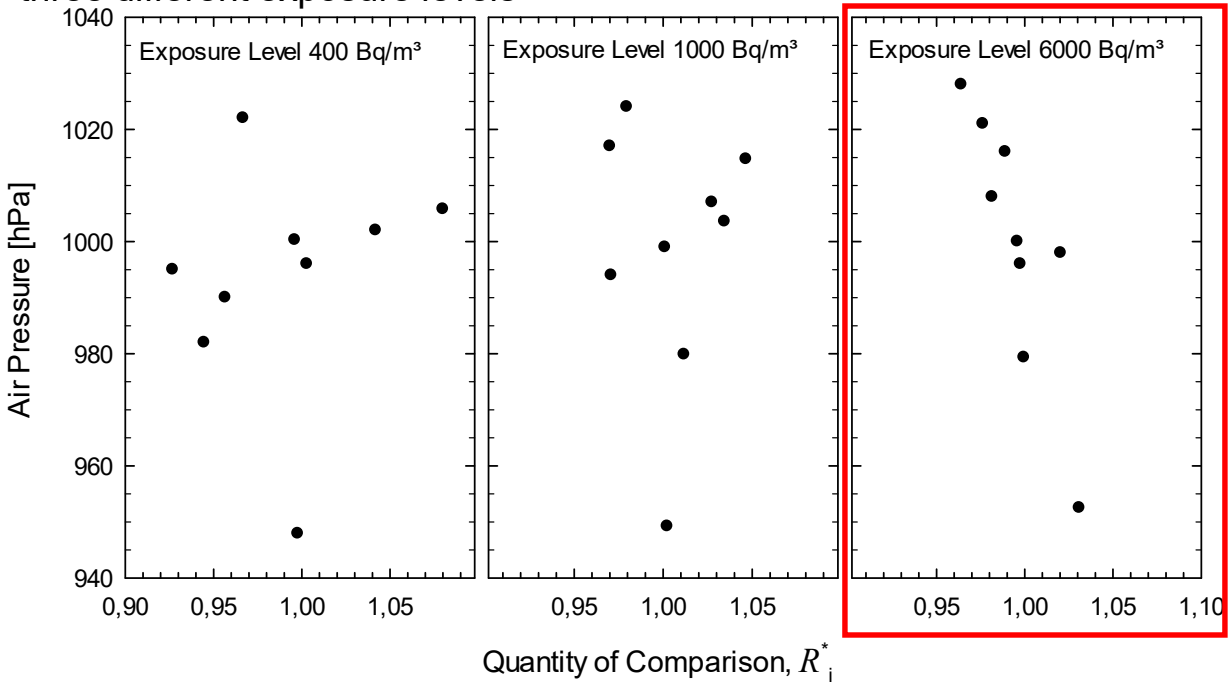
Influence of climatic conditions on the calibrations

Dependency between ratio R_i^* and air pressure for the three different exposure levels



The correlation between the quantity of comparison and air pressure at an exposure level of 6000 Bq/m³ is statistically significant.

Is it a random artifact or is there a real reason behind it?