THE PERFORMANCE OF EUROPEAN CALIBRATION SERVICES REGARDING RADON IN AIR

- EMPIR Project *Metrology for Radon* –

Preliminary Results

T. R. Beck

German Federal Office for Radiation Protection (BfS)
EMPIR Project *Metrology for Radon*

Work Package 5.2 (extract): Radon Intercomparison

— **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.

— **Execution** of the comparison.
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$^3$. 
EMPIR Radon Intercomparison

Transfer comparison device: AlphaGUARD PQ 2000 PRO TTL

- Diffusion mode
- Integration time 10 min
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)
\[ \lambda = 0.007502 \pm 0.000025 \text{ h}^{-1} \]

Calibration factor \( k_M \) at fixed levels

<table>
<thead>
<tr>
<th>No.</th>
<th>( C_{\text{ref}} ) [Bq/m(^3)]</th>
<th>( k_M )</th>
<th>( U(k_M) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>330</td>
<td>0.98</td>
<td>0.08</td>
</tr>
<tr>
<td>2</td>
<td>1480</td>
<td>0.97</td>
<td>0.06</td>
</tr>
<tr>
<td>3</td>
<td>5750</td>
<td>0.97</td>
<td>0.05</td>
</tr>
<tr>
<td>4</td>
<td>11800</td>
<td>0.98</td>
<td>0.05</td>
</tr>
</tbody>
</table>

\( U \) includes a coverage factor of 2
Transfer Comparison Device

Regular checks of background and instrument settings

Nominal correction for background: 4 Bq/m³

Measurements from May 2019

Nominal correction for background: 4 Bq/m³
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
<table>
<thead>
<tr>
<th>Nominal value</th>
<th>Accepted deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>400 Bq·m⁻³</td>
<td>350 Bq·m⁻³ – 450 Bq·m⁻³</td>
</tr>
<tr>
<td>1000 Bq·m⁻³</td>
<td>900 Bq·m⁻³ – 1100 Bq·m⁻³</td>
</tr>
<tr>
<td>6000 Bq·m⁻³</td>
<td>5500 Bq·m⁻³ – 6500 Bq·m⁻³</td>
</tr>
</tbody>
</table>
EMPIR Radon Intercomparison

Execution

Lab 3 - BfS - Lab 1

Lab 2

Shipment from BfS to the participant and return to BfS
# EMPIR Radon Intercomparison

## Participants

<table>
<thead>
<tr>
<th>Laboratory</th>
<th>Country</th>
<th>Contact Person</th>
</tr>
</thead>
<tbody>
<tr>
<td>NMI</td>
<td>Montenegro</td>
<td>Goran Vukoslavovic</td>
</tr>
<tr>
<td>BEV-PTP</td>
<td>Austria</td>
<td>Franz Josef Maringer</td>
</tr>
<tr>
<td>IRSN</td>
<td>France</td>
<td>Sylvain Bondiguel</td>
</tr>
<tr>
<td>STUK</td>
<td>Finland</td>
<td>Tuukka Turtiainen</td>
</tr>
<tr>
<td>SUJCHBO</td>
<td>Czech Rep.</td>
<td>Josef Vošahlik</td>
</tr>
<tr>
<td>BFKH</td>
<td>Hungary</td>
<td>Norbert Szabó</td>
</tr>
<tr>
<td>CLOR</td>
<td>Poland</td>
<td>Katarzyna Wołoszczuk</td>
</tr>
<tr>
<td>SSI</td>
<td>Sweden</td>
<td>Jens Jensen</td>
</tr>
<tr>
<td>UNICAN</td>
<td>Spain</td>
<td>Carlos F. Sainz</td>
</tr>
<tr>
<td>SMU</td>
<td>Slovakia</td>
<td>Matej Krivošík</td>
</tr>
<tr>
<td>UBB</td>
<td>Romania</td>
<td>Kinga Szacs vai</td>
</tr>
<tr>
<td>IFIN-HH</td>
<td>Romania</td>
<td></td>
</tr>
<tr>
<td>UPC</td>
<td>Spain</td>
<td></td>
</tr>
<tr>
<td>BfS</td>
<td>Germany</td>
<td></td>
</tr>
<tr>
<td>ENEA</td>
<td>Italy</td>
<td></td>
</tr>
</tbody>
</table>

**15 Laboratories** (12 EU countries + Montenegro)
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

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

Normalized weights:

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

Variance associated with $\bar{R}$:

$$\frac{1}{u^2(\bar{R})} = \frac{1}{u_1^2} + \cdots + \frac{1}{u_n^2}$$
Radon Intercomparison
Provisional results

Radon Activity Concentration as indicated by the comparison device [Bq.m\(^{-3}\)]

- Mean 1,018 ± 0,007 for 400 Bq/m\(^3\)
- Mean 1,021 ± 0,007 for 1000 Bq/m\(^3\)
- Mean 1,013 ± 0,003 for 6000 Bq/m\(^3\)

All uncertainties are given with the extension k=1.
Radon Intercomparison

Problems with the common variance (and accordingly standard derivation)

\[
\frac{1}{u^2(R)} = \frac{1}{u_1^2} + \ldots + \frac{1}{u_n^2}
\]

Variance associated with \( R \):

Literature:
... the reciprocal square-root ... becomes too small as the number of participants increases and many labs fall outside the uncertainty interval.
[Rukhin, Metrologica 46 (2009)]

The widely used traditional variance estimator ... underestimates the variance ... and the intervals formed by this estimator have poor coverage probability .... [Zhang, Metrologica 43 (2006)]

The variance estimator seems to be not suitable for quantifying the closeness of agreement (precision) between the participants.
Radon Intercomparison

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

\[
\chi^2 = \sum_{i=1}^{n} \frac{(R_i - \bar{R}_i)^2}{\sigma_i^2}
\]

\( n \): 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 \( \chi^2 \) distribution for the significance level \( 1 - \alpha \)
Radon Intercomparison

Consistency check of results, Error probability 5% \((\alpha=0.05)\)

<table>
<thead>
<tr>
<th>Radon Level</th>
<th>(n)</th>
<th>(\chi^2)</th>
<th>(\chi^2_{n-1;1-\alpha})</th>
</tr>
</thead>
<tbody>
<tr>
<td>400 Bq/m³</td>
<td>9</td>
<td>9.94</td>
<td>(&lt;) 15.5</td>
</tr>
<tr>
<td>1000 Bq/m³</td>
<td>10</td>
<td>5.12</td>
<td>(&lt;) 16.9</td>
</tr>
<tr>
<td>6000 Bq/m³</td>
<td>11</td>
<td>9.44</td>
<td>(&lt;) 18.3</td>
</tr>
<tr>
<td>All</td>
<td>30</td>
<td>24.40</td>
<td>(&lt;) 42.6</td>
</tr>
</tbody>
</table>

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.
Radon Intercomparison

Preliminary Summary

— The comparison is carried out according to relevant guidelines: EURAMET Guide on Comparison; BIPM/CCQM Guidance note on the estimation of a consensus reference value.

— The results are mutually consistent. No outlier was observed.

— The majority of the calibration facilities shows a closeness of agreement within an interval of ±5% around the common mean values.

— A statistically meaningful quantification of the closeness of agreement is still in progress.
Thank you for your attention!