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FIRST NATIONAL COMPARISON ON RADON ACTIVE MONITORS AT ENEA-INMRI

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Abstract. *This is the first Italian interlaboratory comparison (ILC) on active radon monitoring organized by the National Institute of Ionizing Radiation Metrology of ENEA (ENEA-INMRI). The ILC was financed by the Ministry of Economic Development (MiSE). The objective is to investigate the quality of radon measurements carried out by operators in the sector and improve their performance. Participants were asked to determine radon exposure in air over a time interval in which the radon concentration was varied over a wide range from approximately 500 to 5500 Bq/m3. The results were analyzed using the relative percentage difference D (%) and the normalized error En. Over 65% of the results fall within the range of En < 1. Most of the deviations were detected when the instruments were not calibrated correctly.*

Keywords: *Radon concentration in air, Active radon monitors, Interlaboratory Comparison (ILC)*

1. INTRODUCTION

National legislation, aligned with European directives, establishes limits for radon activity concentrations in dwellings and workplaces, mandating their monitoring; therefore, many laboratories have been engaged in radon measurements. The Italian National Institute of Ionizing Radiation Metrology (INMRI), belonging to ENEA, has organized a national quality assurance program for reliability of ionizing radiation measurements, based on Interlaboratory Comparison (ILC) [1]. The program was funded by the Italian Ministry of Economic Development (MiSE) as part of the initiatives and studies aimed at promoting the quality of measurements, particularly in contexts relevant to consumers with implications for health and safety. This exercise is designed to enhance the reliability of these measurements by providing operators in the sector with the opportunity to carry out radon measurements in controlled conditions, to verify their operation, and to validate the calibration.

Several national and international intercomparison exercises on passive radon detector took place in Italy [4, 5, 6]. This is the first Italian intercomparison exercise on active radon monitors, and it is particularly important because the results that will come out of it will provide information on the quality of the measurements carried out in the country.

The need is particularly urgent for new monitors of small dimensions and contained costs, which are not always adequately calibrated.

This intercomparison for radon measurements in air has been open to all Italian national operators, both public and private, active in the field of radon measurements.

2. MATERIALS AND METHODS

The exercise concerned only active radon monitors, electronic devices that provide a time series of radon concentration measurements in which radon detection is based on detection of alpha radiation (by ionization chamber, gross alpha counting or alpha spectrometry). Integration devices, such as solid state nuclear track SSNTD and electret, were excluded. The exercise occurred in the ENEA-INMRI ‘walk-in radon chamber’ (WRC) [7], a spacious room with a volume of about 150 m3. Radon gas is generated in the room’s basement which, during construction, was filled with volcanic lapillus naturally enriched in 226Ra. The diffusion of radon from the basement to the WRC’s volume is facilitated by room’s slight depression relative to the external environment. The radon concentration inside the room can be controlled by opening and closing the appropriate shutters in the room’s ventilation system. However, the radon concentration remains partly influenced by external climatic conditions and it is not always constant over time, even if the position of the ventilation system gate valves is fixed. These circumstances are not a disadvantage, as they make the test more similar to what actually happens in real scenarios, such as workplaces and dwellings, where sudden changes in radon concentration can occur following the opening of doors or windows or changes in external weather conditions. Furthermore, before the beginning of the intercomparison exercise, a preliminary study about the spatial homogeneity of the radon activity concentration distribution in the WRC was carried out. This study highlighted the possibility of differences in activity concentration of up 10% could arise between different points in the chamber rather close to each other, about 2 m. To avoid this problem, two fans were positioned in appropriate manner so as

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to obtain a difference in activity concentration not exceeding 2%.

As mentioned previously, radon activity concentration is not constant over time, even if the position of the ventilation system gate valve is fixed. To minimize the effect of fluctuations, the data were acquired over a sufficiently long time interval, and in this way, an average value of the radon concentration activity in the fixed time interval was obtained.

The instruments of the participants were placed on a large shelf of about 330 cm x 120 cm. At the two ends of shelf there were two ENEA-INMRI reference monitor instruments, as shown in Figure 1.

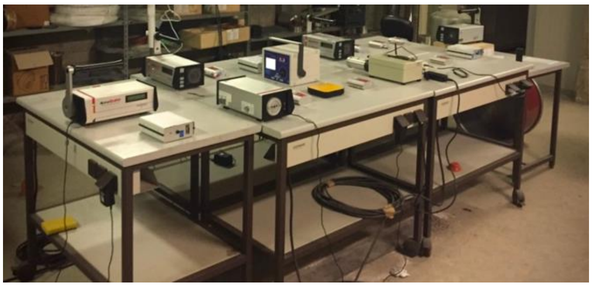

Figure 1. Radon monitors in WRC of ENEA-INMRI during the ILC.

The reference monitor instruments were two calibrated [2, 8] ALPHAGUARD PQ 2000 PRO by Saphymo Gmbh (pulse ionization chamber) [9]. The position of each monitor on the shelf have been recorded. Two measurements cycles were carried out: the first cycle was in June, and the second one in July 2022. Each measurement cycle lasted approximately 12 days. All participant monitors were turned on at the beginning of the exposure and turned off at the end.

2.1. Participants

The participation in the ILC was free, and each laboratory could register and participate with more than one instrument. The only condition was that the participating instrument was of active type. The number of participant laboratories was 11 for a total of 29 detectors. The registered laboratories were both private and public institutions from different regions of Italy. The participant's detectors were based on different detection principles, such as pulse ionization chamber, semiconductor detector, and scintillation cell.

2.2. Data Analysis

The performance of the participant laboratories was assessed according to the method described in the ENEA-INMRI ILC protocol [1] and in ISO-13528:2015 standard [3]. The parameters used for evaluation were the relative percentage deviation D(%) and the normalized error En:

$$D(\%) = 100\frac{E_i - E_{ref}}{E_{ref}} \tag{1}$$

$$E_n = \frac{E_i - E_{ref}}{\sqrt{\left(u_{E_i}\right)^2 + \left(u_{E_{ref}}\right)^2}} \tag{2}$$

where: Eref is the reference value of radon exposure measured by ENEA-INMRI in Bq/m3 determined by the average of the values measured by the two reference monitors, Ei is the value measured by each participant's monitor, uEref and uEi are the uncertainties of reference value and participant value respectively, expressed with a coverage factor k=2; uEref was obtained by combining the uncertainties relating to the values measured by the two reference monitors.

The limit for D was chosen at 10%. According to ISO-13528:2015 standard, the conventional interpretation of En numbers is: |En| ≤ 1.0 indicates ”satisfactory” performance, |En| > 1.0 indicates ”unsatisfactory” performance (action signal).

3. RESULTS AND DISCUSSION

Figure 2 shows the reference radon activity concentration measured at ENEA-INMRI WRC in the first and the second exposure. The time “zero” in the graphs is June 7, 2022 at 00:00 and July 6, 2022 at 00:00 respectively. The vertical lines on the graphs highlight the three intervals of interest for the ILC.

Measurement results are presented in Table 1. The table also shows the duration of each interval. Temperature, pressure and relative humidity were also monitored inside the WRC by the ENEA-INMRI's ALPHAGURD monitors. The values reported are the average of the two instruments.

3.1. Laboratory performances

Participants provided the activity concentration values with their uncertainties, measured by each monitor in the three intervals indicated. Subsequently, it was possible to calculate the value of their D(%) and En according to equations (1) and (2).

The monitor code is a random number assigned to each monitor in order to maintain the anonymity of the participants.

Table 1. Average value of activity concentration measured in the WRC during the two exposures. The uncertainties U are expressed with a coverage factor k=1

Exposure	Interval	Duration (h)	Concentration (Bq/m^3)	U (Bq/m^3)
1	1	92	1208	30
1	2	65	4524	82
1	3	92	2337	46
2	1	101	1039	25
2	2	83	5239	93
2	3	97	3276	62

Figure 3 shows the |D(%)| values obtained for the 29 monitors; the red line on the graph is the limit fixed at 10%. It can be observed that 31%, 38% and 35% of monitors exceed the limit in the first, second and third interval respectively.

Figure 4 shows the |En| values obtained for the 29 monitors, the red line on the graph is the limit fixed at 1. It can be observed that 21%, 31% and 17% of monitors exceed the limit in the first, second and third interval respectively.

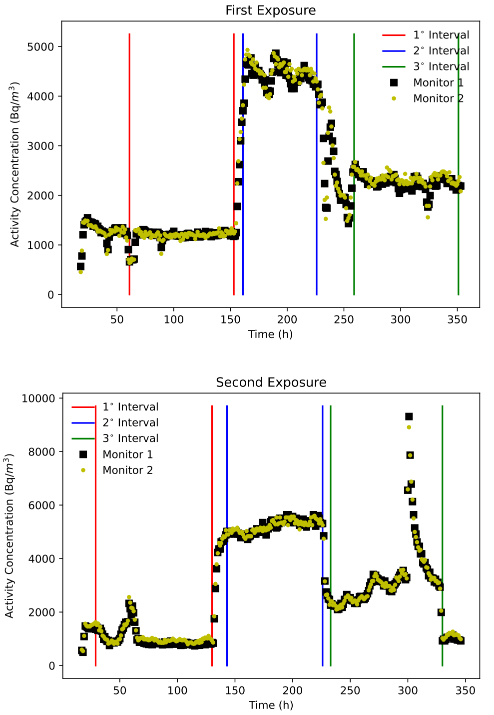

Figure 2. The time course of radon activity concentration in WRC for the first exposure and the second exposure. Data are displayed every hour. During the second exposure a black out of a couple of hour occurred. The ventilation system did not work and the radon activity concentration rose to 9500 Bq/m^3.

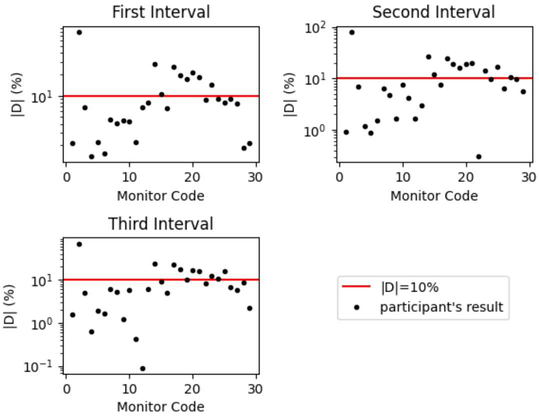

Figure 3. Absolute value of relative percentage difference, |D(%)|, of participant's results.

In general, it is observed that the percentages of monitors that exceed the established limits are smaller for |En| than for |D(%)| criteria. Therefore, it is interesting to draw a graph of |D(%)| as a function of |En| for each monitor, as shown in Figure 5. The points in the upper right region of the graph, about 25%, are the monitors that exceed both |D(%)| and |En| and these instruments need to be calibrated. Just one point falls in the lower right region in the second interval's graph, this instrument has a good value of |D| and a bad value of |En| which could indicates an underestimation of the measurement uncertainty. On the contrary, the points in the upper left region (about 10% of total monitors) have a bad value of |D| and a good value of |En| which could indicate an overestimation of the measurement uncertainty. This is due to a strong dependence of En-test value on uncertainty of the results. The En-test value may satisfy the criterion even for a big spread of results, if uncertainties are high enough.

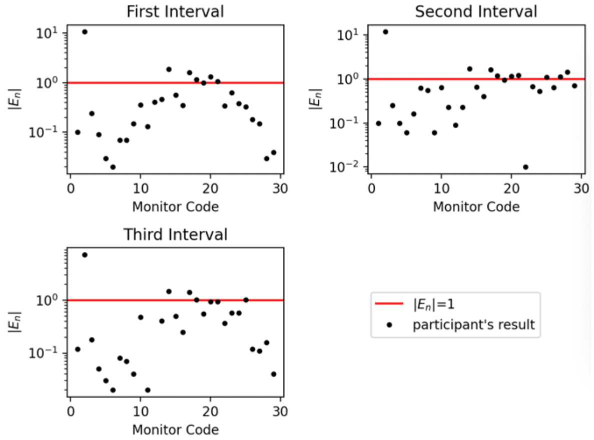

Figure 4. Absolute value, |E$_n$|, of normalized error of participant's results.

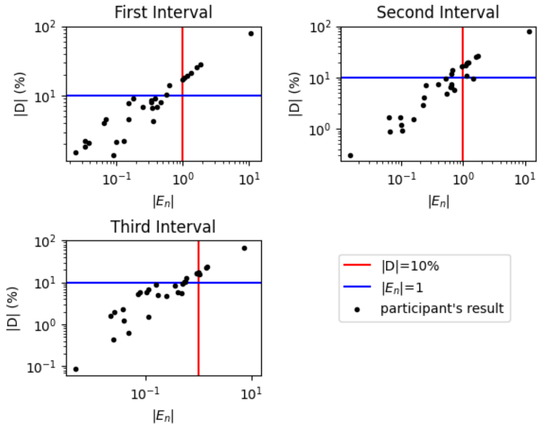

Figure 5. Absolute relative percentage difference |D(%)| as a function of the absolute value of normalized error |E$_n$|.

It is also noted that the higher the radon concentration, the higher the percentage of monitors that exceed the limit values.

3.2. Instruments performance

The performance does not only depend on the users but on the quality of the instrument itself. This work investigates the performance of the most common used commercial continuous radon monitors and some new low cost devices whose characteristics have yet to be studied.

Participating instruments types were ionization chamber, Lucas scintillation cell and semiconductor detector. More information on such kind of instruments are reported in Table 2.

Five ionizing chamber, operating in diffusion mode, participated in the ILC; these instruments were ALPHAGUARD (Saphymo Gmbh, Germany) [9]. All of these devices passed the intercomparison, providing radon activity concentration measured values very close to the references, with the |D(%)| and |En| values are below the fixed limit threshold.

Table 2. List of instrument type participating the ILC.

Type	Operating mode	Number
ionizing chamber	diffusion	5
Lucas cell	diffusion	4
semiconductor detector	diffusion	19
semiconductor detector	flow mode	1

A total four Lucas scintillation cell operating in diffusion mode participated in the ILC-3. Two were MR1 PLUS (Tesys, Italy) [10], one was Radon Mapper (Mi.am Srl, Italy) [11] and one Radon Scout Professional (Sarad GmbH, Germany) [14]. In this case as well, 100% of these devices passed the intercomparison, providing |D(%)| and |En| values below the fixed limit threshold.

This demonstrates that both ionization chamber and Lucas cell operate very well in the radon activity concentration range used in this exercise. They were not affected by large variations in radon activity concentrations, showing their ability to work properly within this range.

One monitor Alpharad Plus (SPC Doza, Russia) [12] based on electrostatic deposition with a semiconductor detector operating in flow mode also participated in the ILC-3. This monitor did not pass the intercomparison; it underestimates radon activity concentration providing very high values for |D(%)| and |En| parameters. This necessitates further studies. It should consider the temporal trend of the measured activity concentration and check if the trend of these points follows that of the reference. If so, a calibration of the instrument is necessary; otherwise, it can conclude that the monitor is not working well.

Radon Scout Plus (Sarad GmbH, Germany) [13], based on high voltage chamber for electrostatic collection and silicon detector operating in diffusion mode, joined the ILC. A total of 3 of these monitors joined, and 100% passed the intercomparison.

In addition to these devices that have been on the market for a long time, new radon monitors based on semiconductor detectors have recently become widespread. The main characteristics of these detectors are their small size and low purchase cost. This exercise provided a good opportunity to test their performances and compare them with those of well-known and studied instruments.

Corentium Pro (Airthings, Norway) contains four high-precision radon chambers operating in parallel. Instrument samples air through a passive diffusion chamber, using alpha spectrometry to calculate the radon level. Radon is detected using silicon photodiodes to both count and measure the energy of alpha particles resulting from the decay chain of radon gas [15].

AER Plus (ALGADE, France), ambient air penetrates inside the device by diffusion and a photodiode detects particle emitted by disintegration [16].

Five Corentium Pro and eleven AER Plus were studied.

In the first and third measurement interval, 100% of Corentium Pro devices passed the intercomparison. In the second interval, 80% and 60% obtained a satisfactory values for |D(%)| and |En|, respectively. The second measurement interval, where the highest activity concentration occurs, reveals, on the basis of the achieved results, that these devices have difficulty measuring high radon activity concentration.

AER Plus results are collected in Table 3.

Table 3. Succes rate of AER Plus.

Parameter	Success rate (%)		
	1° interval	2° interval	3° interval
|D(%)|	27.3	18.2	18.2
$\|E_n\|$	54.5	45.5	63.6

Judging by the results in Table 3, the monitors are not working well. Further studies are needed, and, in this case as well, it should consider the temporal trend of the measured activity concentration and check if the trend of these points follows that of the reference

4. CONCLUSION

During the ILC exercise of the active radon monitors (organized in the frame of MiSE-ILC 2022) radon exposure measurements were performed in the ENEA-INMRI WRC at three exposure levels: low, medium and high. In total 11 Italian institutions participated for a total of 29 monitors.

The index used to analyze the participants results were the relative percentage difference D(%) and the normalized error E_n.

Regarding the participants' laboratory performance, most E_n results are satisfactory, with about 70% of results having a value of lower than 1 for all three intervals. The second interval, with the highest radon activity concentration, shows the highest percentage of monitors exceeding the limit value. In terms of the relative percentage difference, about 65% of results are satisfactory, with the largest percentage of monitors exceeding the limit value also in the second interval.

Well-known devices (ALPHAGUARD, MR1 Plus, Radon Mapper, Radon Scout Plus and Radon Scout Professional) passed the intercomparison excellently. Alpharad Plus did not pass and further studies are needed. New radon monitors based on semiconductor detectors have recently become widespread on the market, and this exercise was a good opportunity to test their performances. Corentium Pro device passed the intercomparison but revealed some measurement difficulties on high radon activity concentration. A small percentage of AER Plus passed, presenting difficulties of measurements on all intervals. Further studies are needed, and it should consider the temporal trend of the measured activity concentration, check if the trend of these points follows that of the reference, and use a calibration coefficient.

In general, the highest percentage of monitors who fail the test occurs, for both exposures, in the second measurement interval where the activity concentration is highest.

The results of this intercomparison reveal detector calibration problems for the participants' laboratory when both |D(%)| and $|E_n|$ exceed the limit values. In the cases where the |D(%)| value is poor but $|E_n|$ value is good, the laboratory does not adequately evaluate the uncertainty of their measurements, providing a large value, which results in a small value of $|E_n|$. Indeed, the E_n-test value may satisfy the criterion even for a big spread of results if uncertainties are high enough.

Therefore, most deviations were detected when the instruments were not calibrated properly. Indeed, these monitors have never been calibrated by accredited institutes or need to be re-calibrated. This result highlights the need and the importance of periodic calibration.

For these reasons further investigation and periodical intercomparison are needed to improve the quality of data.

The exercise was successful, considering the large number of laboratories participating for the first time for all over the country and the significant variety of monitors used.

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REFERENCES

1. https://www.inmri.enea.it/attivita-di-ricerca/confronti- interlaboratorio.html
2. S. Pierre, et al., ”International comparison of activity measurements of radon 222 EURAMET Project n 1475-EURAMET. RI (II)-S8. Rn222”.
3. ISO 13528:2015 (010248); Statistical Methods for Use in Proficiency Testing by Interlaboratory Comparison. ISO: Geneve, Switzerland, 2015.
4. F. Campi et al. “Radon data from different laboratories: an Italian intercomparison”, *Recent Advances in Multidisciplinary Applied Physics*, Elsevier Science Ltd, 879-885, 2005.
5. F. Cardellini et al., ”Main results of the international intercomparison of passive radon detectors under field conditions in Marie Curie's tunnel in Lurisia (Italy)”, *Nukleonika*, **61**(3), 251-256, 2016. https://doi.org/10.1515/nuka-2016-0042
6. F. Berlier et al., “Main results of the second AIRP international radon-in-field intercomparison for passive measurement devices”, *Radiat. Meas*, **128**, 106177, 2019. https://doi.org/10.1016/j.radmeas.2019.106177
7. R. Trevisi et al., “A comparison of radon and its decay products' behaviour in indoor air”, *Radiation Protection Dosimetry*, **162**(1-2), 171-175, 2014. https://doi.org/10.1093/rpd/ncu253
8. P. De Felice et al., “The 222Rn reference measurement system developed at ENEA”, *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, **369**(2-3), 445-451, 1996. https://doi.org/10.1016/S0168-9002(96)80028-3
9. AlphaGUARD PQ2000 PRO Portable Radon Monitor User Manual 08/2012, Saphymo GmbH, Frankfurt, Germany, 2012.
10. Tesys MR1 plus. User Manual available online: http://www2.lnl.infn/.it/~canella/RADON/ManualeMR1-MIAM.pdf
11. Mi.am Srl. Radon Mapper. Available online: https://miam.it/en/radon-mapper/
12. Doza Alpharad Plus website: https://www.doza.ru/catalog/radiometry-radona-torona-i-ego-dpr/Alpharad-plus/
13. Sarad Radon Scout Plus datasheet: https://www.sarad.de/cms/media/docs/datenblatt/ds-radon_scout-en.pdf
14. Sarad Radon Scout Professional datasheet: https://www.sarad.de/cms/media/docs/datenblatt/ds-radon_scout_professional-en.pdf
15. Airthings Corentium Pro website: https://www.airthings.com/en/professionals/pro
16. ALGADE AER Plus. User Manual available online: https://algade.com/wp-content/uploads/2023/04/Manuel-AER-basique-C-EN.pdf
17. D. Zoul, P. Zháňal, L. Viererbl, A. Kolros, M. Zuna, V. Havlová, “3D reconstruction of inner structure of radioactive samples utilizing gamma tomography”, *Radiation Protection Dosimetry*, **186**(2-3), 239-243, 2019. https://doi.org/10.1093/rpd/ncz211