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Short Communication

Radon dosimetry - comparison of selected measurement methods

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Abstract

Introduction: Recently, the measurement of radon concentration has become one of the necessary procedures for implementation and execution in dosimetry. The aim of this study was to compare effectiveness, accuracy and ease of use of three selected radon measurement methods: one active and two passive.
Material and Methods: Lucas chambers (scintillation method), thermoluminescent detectors (TLD) and track detectors (CR-39) were used. Air measurements were performed for two different locations: Czeladz (C) and Krakow (K). The measuring devices were placed in the basements for a specified time (30 days) and, in case of active detectors, additional measurements were performed in the exposure-reading mode.
Results: For the Lucas chamber, single-day and seasonal measurements were done. For all detectors, results from the winter session (C: 657 ± 16 Bq/m^3, K: 825 ± 17 Bq/m^3), CR-39 (C: 138 ± 47 Bq/m^3, K: 72 ± 35 Bq/m^3) and TLD (C: 0.82 ± 0.04 mGy, K: 0.82 ± 0.08 mGy), autumn (C: Lucas chamber 1458 ± 19 Bg/m^3, CR-39 430 ± 92 Bq/m^3, TLD 0.21 ± 0.01 mGy) and spring (most readings at background level) were compared. Additionally, an attempt was made to convert the obtained radon concentrations into doses.
Conclusion: Lucas chambers, designed for measurements in the exposure-reading mode, can also be used in long-term measurements. Both track and thermoluminescent detectors can be used for long-term measurements. More than one method may be required to obtain accurate measurement information. The results of measurements conducted in the seasonal mode indicate that the implementation of protective procedures, such as systematic ventilation, can contribute to a significant reduction in high radon concentrations.

Keywords: radon dosimetry, Lucas chamber, TLD, track detectors.

Introduction

Radon is a colorless, odorless, and radioactive noble gas that is a product of the decay of uranium and thorium in the Earth's crust. Its chemical symbol is Rn, and its atomic number is 86. It occurs naturally in soil, rocks, and groundwater and can penetrate residential buildings, where it accumulates in closed rooms.[1]

Due to its radioactive properties, Rn can have a significant impact on human health. Radon decay products such as polonium, bismuth, and lead combine with aerosols in the air and enter the respiratory system. Particles with a diameter of less than 0.1 µm enter the lung alveoli and emit alpha radiation there. It has poor penetration and strong ionizing properties, therefore it can damage genetic material, which in turn can lead to cancer of the respiratory system: lungs, larynx, oral cavity and trachea. The risk of cancer increases for people who smoke tobacco products. The probability of developing cancer in such a case is greater than the sum of probabilities of both factors separately. Therefore, it is important to avoid excessive exposure to radon, especially in residential buildings. Radon is considered the second most important cause of lung cancer after smoking.[1,2]

Radon concentrations are monitored and controlled in many countries to minimize health risks associated with radiological exposure.[3,4,5] In Europe, maps of areas classified in terms of radon emanation are created, e.g. the European Indoor Radon Map[6]. In Poland, there is still no clear identification of areas with increased exposure to radon. The National Atomic Energy Agency provides annual dose levels from both natural and artificial sources. However, these are average values for the entire area of Poland. In 2023, the annual total effective dose of ionizing radiation received by a statistical resident of Poland was 4.36 mSv. Exposure from natural sources accounts for 58.53% of this value, i.e. 2.55 mSv. The dose from exposure to radon was estimated at 1.22 mSv, which is 27.53% of the total dose.[7]

Authors' contribution: A – Research concept and design, B – Collection and/or assembly of data, C – Data analysis and interpretation, D – Writing the article, E – Critical revision of the article, F – Final approval of the article.

Legal regulations related to broadly understood radon dosimetry are included, among others, in Council Directive 2013/59/Euratom, the Atomic Law, the Labor Code and the Construction Law. These documents specify, among others, reference levels for the average annual concentration of radon in the air in workplaces. Measurement of radon concentration has become one of the necessary procedures in dosimetry to implement and perform.[8]

In Poland, the regulation of the Marshal of the Sejm of the Republic of Poland of September 16, 2021 is in force, which sets the limit for radon concentration in the air at 300 Bq/m³. This regulation also imposes an obligation on employers to supervise radon concentration, which is intended to protect the health of employees in the workplace. In residential buildings, determining the level of radon concentration is made at the request of the buyer or tenant.

There are various methods of protection against radon. The first step is always to find the main source of exposure, where the concentration is the highest. Then, it is crucial to implement the least invasive preventive measures, such as ventilating the rooms[9] and sealing cracks and gaps in the floor and pipes to prevent the gas from entering. Another fairly common method of protection is to install an external system to reduce the pressure under the building. Regardless of the method selected, regular monitoring of radon concentrations inside buildings, especially residential buildings, is crucial to protect against excessive exposure to this gas.[10] In order to carry out a reliable measurement of radon concentration, it is crucial to choose a measuring device that is appropriate for the place and conditions of measurement.

The aim of the study was to compare the effectiveness, accuracy, and ease of performing three selected radon measurement methods: one active and two passive. The study included radon concentration measurements in two different locations: in the basement of a residential building in Czeladz (a multi-family housing estate) and in the basement of the building of the Faculty of Physics and Applied Computer Science of the AGH University of Science and Technology in Krakow.

Materials and Methods

In this study, Lucas chambers (scintillation method), thermoluminescent detectors (TLD) type MCP-N (thermoluminescence method) and CR-39 foil track detector (track method) were used. The choice of measurement methods was based on the following assumptions: the selected method should be described in the literature as used in radon measurements, represent an active or passive method and be available in the in-house laboratory.

The scintillation method is an active method, while the other two are passive methods of measuring radon concentration. Radon concentration in the air was measured for two different locations: Czeladz (C) and Krakow (K). The measuring devices were placed in the basements of buildings. The measurements were seasonal (autumn, winter, spring). The detectors were placed in the measurement locations for a specified period (30 days). In the case of active detectors, measurements were additionally performed in a one-day mode (exposure-reading).

Lucas chamber

Lucas chamber KS-11 (**Figure 1a**) produced by POLON was used. Calibration was performed in the laboratory gas installation using a radium chloride ($RaCl_2$) calibration source with an activity of 421.5 Bq to determine the calibration coefficient. Then, the chamber was placed in the measurement location, where an air sample was manually introduced into the chamber's active volume. Once radioactive equilibrium was achieved, the chamber was ready for reading. In the case of the KS-11 chamber, reading required placing it on the GF-11 head connected to the counting system

Track detectors

Track detectors equipped with CR-39 foil (**Figure 1b**) produced by RadoSys were used to assess the average radon concentration at both locations. This foil is sensitive to alpha radiation, therefore structural defects were formed in it during the exposure. When exposition was completed, the foil was etched in sodium hydroxide solution for 8-10 hours at 90°C in the RB4 etchant. After etching, the foil was analyzed using a RADOMETR optical microscope (RS01/3104) connected to a computer. Taking into account the exposure time (30 days) and the previously determined calibration factor, the radon concentration was estimated using the RadoMeter 1.4 program based on the density of tracks present in the etched foil.

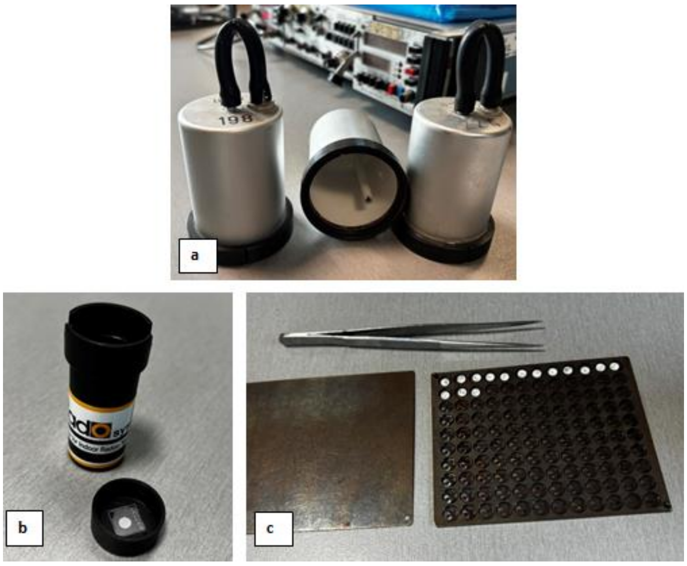

Figure 1. Measurement detectors: a) Lucas chamber (KS-11), b) CR-39, c) TLD.

Termoluminescent detectors

Fifteen thermoluminescent detectors (TLDs) LiF:Mg,Cu,P (MCP-N type) (**Figure 1c**) produced by IFJ PAN Krakow were used to measure the average absorbed dose. Before starting the main measurements, individual sensitivity coefficients for each detector were determined and a calibration curve was prepared to convert the obtained number of counts into a dose. The TLDs were placed at the measurement location for 30 days. Then, a dedicated reader RA'04 produced by MicroLab was used to obtain the number of counts in a three-stage READER heating mode (150°C – 10 seconds, 245°C – 15 seconds and 245°C – 10 seconds).

Location

The concentration of radon in the air was measured in two different locations: Czeladz (C) and Krakow (K). The measuring devices were placed in the basements of the buildings.

The first location – C – was an example of a multi-family housing. It was selected due to the structural features of the building and environmental factors. The materials used to build the block of flats may contain uranium microparticles, which may lead to the emission of radioactive radiation. In addition, the building is located above the Saturn coal mine, which may additionally increase radiological exposure. There was a window in the basement of the building.

The second location – K – was an example of a public utility building (university). It was selected due to the structural features of the building and ease of access, especially in the context of a one-day measurement. There were no windows in the basement.

After the autumn measurements were completed, due to exceeding the permissible radon concentrations, preventive measures were taken in the form of airing the basement and sealing the pipes at point C. For the same reason, after the winter measurement, the floor at location K was painted.

Results

The calibration of Lucas chambers is always performed in the same way and under the same conditions. A dedicated laboratory gas installation for preparing radon concentration standards in air was used for calibration. This installation was equipped with a source in the form of an aqueous solution of $RaCl_2$ with an activity of 421.5 Bq and a glass container with a volume of 10 liters, to which the calibration sample was collected.

After calibration, one-day measurements were performed in the exposure-reading mode in location K. The obtained results together with the uncertainties determined based on the uncertainty propagation law are presented in **Table 1**.

Table 1. One-day measurement results for Lucas chamber.

Lucas Chamber	Measurement day	Rn concentration [Bq/m^3]
KS-11 nr 224	26.10.2023	751 ± 30
KS-11 nr 224	23.11.2023	895 ± 29

Table 2. Seasonal measurement results.

	Lucas chamber [Bq/m^3]	CR-39 [Bq/m^3]	TLD [mSv/month]
Location C			
Autumn	1458 ± 19	430 ± 92	0.21 ± 0.01
Winter	657 ± 16	138 ± 47	0.82 ± 0.04
Spring	1218 ± 19	background	0.04 ± 0.01
Location K			
Winter	825 ± 17	72 ± 35	0.82 ± 0.08
Spring	74 ± 19	background	0.04 ± 0.01

Table 3. Seasonal measurement results – doses.

	Lucas Chamber [mSv/1month]	CR-39 [mSv/month]	TLD [mSv/month]
Location C			
Autumn	3.02 ± 0.04	2.71 ± 0.91	0.21 ± 0.01
Winter	1.37 ± 0.12	0.29 ± 0.01	0.82 ± 0.04
Spring	2.53 ± 0.02	background	0.04 ± 0.01
Location K			
Winter	1.71 ± 0.15	0.15 ± 0.01	0.82 ± 0.08
Spring	0.15 ± 0.01	background	0.04 ± 0.01

In **Table 2** the results obtained during seasonal measurements performed using all detector types together with the uncertainties determined based on the uncertainty propagation law are presented.

In order to compare the results obtained with different methods, an attempt was made to convert the radon concentrations into doses. For this purpose, the estimation method proposed in the ICRP reports was used (**Equation 1**).[11,12]

$$40\,\frac{Bq}{m^3} = 1\,\frac{mSv}{year} \qquad \text{Eq.1}$$

The results together with the uncertainties determined based on the uncertainty propagation law are presented in **Table 3**.

Discussion

Radon is a naturally occurring radioactive gas that can pose a health risk due to its ability to accumulate in enclosed spaces. It is odorless, colorless, and tasteless, making it difficult to detect without specialized equipment. Long-term exposure to the high levels of radon is the second leading cause of lung cancer after smoking. Therefore, it is crucial to monitor and control radon concentration in residential and occupational environments.

Three different measurement methods were used in this study to estimate radon concentrations. They can be characterized by a similar degree of ease of use. All three methods require calibration before starting the main measurements, using dedicated reading equipment, and recalculating the obtained results. The choice of method in this context depends largely on the availability of the necessary equipment in the measurement laboratory. To assess the effectiveness and accuracy of these methods, the results obtained during the measurements were analyzed.

The first pilot seasonal measurements were carried out at location C (**Table 2**). Due to the location above the coal mine and the selection of materials for the construction of the block, it was predicted that radon concentrations could exceed acceptable levels. An almost five-fold exceedance was shown in measurements using the scintillation method (Lucas chamber). In the case of the track method (CR-39), the exceedance was about 43%. The permissible dose level for the general population, which is 1 mSv/year (which gives a value of 0.083 mSv/month), was also exceeded in the case of measurements conducted using thermoluminescent detectors (measured value 0.21 ± 0.01 mSv/month). Due to the obtained results, an analysis was carried out, which indicated the potential causes of the exceedance, i.e. lack of ventilation of the room despite the presence of a window and lack of sealing of the floor at the point of the sewage pipe inlet. A decision was made to systematically ventilate the room and seal the floor discontinuities. Measurements were continued in the following season (winter). Implementation of preventive methods led to a decrease in the concentration recorded using the Lucas chamber from 1458 ± 19 Bq/m^3 to 657 ± 16 Bq/m^3. In the case of measurements using track detectors, an indication was recorded that did not exceed the permissible limit value, i.e. 138 ± 47 Bq/m^3. In the case of TLD measurements, an increase in the dose to the level of 0.82 mSv/month was observed. Measurements in the spring season indicated a renewed increase in the concentration recorded by the Lucas chamber while reaching the background level in the case of CR-39 detectors and doses recorded by TLD detectors. The reason for such a large discrepancy may be the fact that during this measurement series the Lucas chamber and TLD were placed closer to the sewage pipe at the place where the floor was sealed. After the reading, a decision was made to re-seal the area around the pipe.

At location K, regular measurements began in the winter season, after a series of one-day measurements (examples of the lowest and highest values are given in **Table 1**). The average concentration of 820 Bq/m^3 was 273% of the permissible limit. A series of 30-day measurements was performed using three types of detectors. The readings showed an increase in the concentration measured with the Lucas chamber and no exceedance in the case of measurements using CR-39 and TLD. To assess the reliability of the Lucas chamber for long-term measurements, an additional one-day measurement was taken at the end of the cycle. The results were consistent with the one-day measurements. Despite the exceedance of permissible levels in only one of the methods (scintillation), a preventive measure was implemented by painting the floor. The spring measurements, conducted with all three methods, showed that the preventive actions had successfully reduced radon levels, as no exceedances were recorded.

To facilitate comparison, the radon concentrations measured by the Lucas chamber and CR-39 detectors were converted to doses (**Table 3**). The results from both the winter and spring seasons at location K show a similar trend (increase in winter, decrease in spring), which was also observed at location C.

The results suggest that Lucas chambers can be used for both short-term (one-day) and long-term radon measurements. The results from one-day measurements at location K (26.10.2024 and 23.11.2023) were consistent with the seasonal measurements taken during the same period. In subsequent measurement cycles, the obtained long-term results were also verified by performing one-day measurements. The obtained values were always comparable. It can therefore be stated that leaving the chambers for a longer period of time at the measurement site is possible and the obtained results are correct.

The results obtained by the track method exceeded the permissible limit of 300 Bq/m^3 only in one case (location C, autumn). Although the results obtained using Lukas chamber and track detectors in autumn and winter did not agree within the uncertainty limits, the ratio of the measurements results were comparable.

Many publications show the benefits of using TLD for radon measurement.[13-15] Our studies may support this possibility. However, due to low dose readings, thermoluminescent detectors should be used in pair with alternative measurement method. Taking into account the high sensitivity of TLDs to gamma radiation, perhaps their use in combination with the activated carbon measurement method[16] would give satisfactory results.

Results of seasonal measurements indicate that the use of preventive measures in the form of ventilating the basement, sealing the pipes in location C and painting the floors in location K effectively reduced radon concentrations. However, the increase in radon levels during the spring at location C requires further verification.

Conclusions

Measuring the concentration of radon in air is a complex task. Even using the same measurement method, different results can be obtained. These differences can be influenced by several factors, such as the location of the detector and the use of preventive measures, such as ventilation of the room or painting of the floors. The choice of measurement method also depends on factors such as the availability of the method, the cost of measurement, and the duration of exposure.

The results obtained with the three different measurement methods in this study showed a large variability. Therefore, it is important to standardize the protocols for measuring radon concentration in air, including the selection of appropriate measurement methods.

Considering the current state of knowledge on measuring radon concentration in the air, recommendations from authorities such as Polish CLOR or Finish STUK and the obtained results, it should be recognized that the use of track detectors is the most popular method of measuring radon in the air. Lucas chambers, designed for measurements in an exposure reading mode, can also be used for long-term measurements. Thermoluminescent detectors can also be used as a measurement method. The results of measurements carried out in the seasonal mode indicate that the implementation of protective procedures, such as systematic ventilation, can contribute to a significant reduction in high radon concentrations.

Using a single measurement method is risky. It would be best to use at least two of them. Active methods (real-time measurement) will work well for intervention measurements, while passive detectors (e.g. CR-39) can be used for long-term measurements. The results obtained with different methods may be different, but the trend is consistent in most cases. Exceedances or their absence are obvious.

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Editor's comment

The abstract of the work was submitted to the 18th Congress of the Polish Society of Medical Physics (held in Poznań, Poland, 19-21 September 2024). The authors of the work were invited by the Scientific Committee of the Congress and the Editor-in-Chief of the Polish Journal of Medical Physics and Engineering to present their work in the form of a Short Communication in the Journal.

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