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Short-Term Measurements of Radon Concentrations in Selected Residential Buildings

Krótkoterminowe pomiary stężenia radonu w wybranych budynkach mieszkalnych

ABSTRACT

Aim: This article presents the results of radon concentration measurements performed in selected residential buildings using PicoRad carbon detectors. In addition, the need to provide information on the risk of exposure to radon radiation and the possible ways to minimise that risk is also emphasized.
Project and methods: Measurements were performed in the rooms which are the most exposed to ionizing radiation from radon: in basements and on ground floors, with PicoRad carbon detectors being used to that end. The detectors were provided to a selected and properly trained group of students who had the task to place them in the studied atmosphere for 48 hours. After the measurements had been taken, the detectors, once hermetically closed and foil-enveloped, had to be sent immediately to the indicated address.
Results: The average concentration of radon in the air in Poland is about 10 Bq/m^3. The results of the research carried out in residential buildings show that the mean radon concentration value in the studied rooms was 30 Bq/m^3. The obtained value, although it was higher than the average concentration, did not exceed the values specified by the applicable radon concentration standards for residential buildings. No significant differences between the basements and the ground floor were noticed.
Conclusions: The measurements revealed that the average concentrations of radon in the studied rooms were relatively low, within the limits of 12–85.5 Bq/m^3. However, it is worth taking into account the fact that, according to the World Health Organization (WHO), the risk of lung cancer development increases proportionally to the increase in exposure to radon. It grows by 16% per a 100 Bq/m^3 increase in the average long-term radon concentration. WHO handbook on indoor radon: A public health perspective recommends to set the national average concentration level of reference to 100 Bq/m^3, but if this level cannot be reached, the reference level should not exceed 300 Bq/m^3. The highest radon concentrations obtained through the measurements were only slightly lower than the average reference level recommended by WHO, reaching 85.5 Bq/m^3. This indicates that such measurements of radon concentrations should be performed in buildings in Poland. Information on the possibility of performing such measurements, on specific countermeasures, and also on the threats posed by high levels of radon should be given to the public in order to raise the general awareness and minimise risks. This appears particularly important from the point of view of strengthening the community's resilience.
Keywords: radon, radiation from natural sources, concentration of radon, social awareness
Type of article: short scientific report

Received: 15.11.2019; Reviewed: 29.11.2019; Accepted: 17.12.2019;
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Please cite as: SFT Vol. 54 Issue 2, 2019, pp. 168–173, https://doi.org/10.12845/sft.54.2.2019.13;

ABSTRAKT

Cel: W artykule przedstawiono wyniki pomiarów stężenia radonu w wybranych budynkach mieszkalnych przy użyciu detektorów węgla PicoRad. Podkreślono potrzebę informowania o zagrożeniu związanym z narażeniem na promieniowanie radonowe, a także na możliwość jego minimalizacji.
Projekt i metody: Pomiary przeprowadzono w pomieszczeniach najbardziej narażonych na promieniowanie jonizujące – w piwnicach i na parterze – za pomocą detektorów węgla PicoRad. Detektory przekazano wybranej, wyszkolonej grupie studentów, której zadaniem było umieszczenie detektora w badanej atmosferze na 48 godzin. Po wykonaniu pomiarów przygotowany detektor musiał zostać natychmiast wysłany na wskazany adres.
Wyniki: Średnie stężenie radonu w powietrzu w Polsce wynosi ok. 10 Bq/m^3. Wyniki badań przeprowadzonych w budynkach pokazują, że średnie stężenie radonu w analizowanych pomieszczeniach wynosi 30 Bq/m^3. Wartości te nie przekraczają norm koncentracji radonu w domach. Nie zauważono istotnych różnic między piwnicami a parterem.
Wnioski: Przeprowadzone pomiary pokazują, że średnie stężenia radonu w badanych pokojach są stosunkowo niskie i mieszczą się w granicach 12–85,5 Bq/m^3. Warto jednak wziąć pod uwagę fakt, że według Światowej Organizacji Zdrowia ryzyko rozwoju raka płuc wzrasta proporcjonalnie do wzrostu narażenia na działanie radonu. Zwiększa się o 16% na 100 Bq/m^3 wzrostu długoterminowego średniego stężenia radonu. W przewodniku WHO

na temat radonu wewnętrznego zaleca się ustalenie średniego krajowego poziomu stężenia odniesienia na 100 Bq/m^3. Jeśli osiągnięcie tych wartości nie jest możliwe, poziom odniesienia nie powinien przekraczać 300 Bq/m^3. Najwyższe zmierzone stężenia radonu były tylko nieznacznie niższe od średniego poziomu odniesienia zalecanego przez WHO. Wskazuje to, że takie pomiary stężeń radonu należy wykonywać w budynkach w Polsce. Informacja o możliwości dokonania takich pomiarów, a także o zagrożeniach i środkach zaradczych, związanych z wysokimi poziomami radonu, powinna zostać podana do wiadomości publicznej. Pozwoli to na zwiększenie świadomości społecznej, minimalizację ryzyka związanego z narażeniem na oddziaływanie radonu oraz wzmocnienie odporności społeczności.

Słowa kluczowe: radon, promieniowanie ze źródeł naturalnych, stężenie radonu, świadomość społeczna

Typ artykułu: doniesienie wstępne

Przyjęty: 15.11.2019; Zrecenzowany: 29.11.2019; Zatwierdzony: 17.12.2019;

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Proszę cytować: SFT Vol. 54 Issue 2, 2019, pp. 168–173, https://doi.org/10.12845/sft.54.2.2019.13;

Introduction

As many as 264 stable atomic nuclei, i.e. those that are not subject to decays, and nearly 2,450 unstable decaying nuclei, called radioactive nuclei, have been identified to date [1]. As revealed by 2018 data, a Polish resident received an average dose of ionizing radiation of approximately 3.74 mSv throughout the calendar year. Most of that dose came from natural sources, accounting for about 2.43 mSv/year, and 32% of that was radon radiation. The dose received by an average Pole from artificial sources was estimated at 1.31 mSv [2]. The total annual dose of ionizing radiation received by an average inhabitant of Poland in recent years has changed slightly; in 2017, it was 3.56 mSv [3], while in 2016, it was 3.55 mSv [4]. Radon is a colourless and odourless gas, heavier than air, and soluble in water. It belongs to radioactive chemical elements from the group of noble gases. The average dose coming from radon has a relatively large range – from 1 mSv/year to even 10 mSv/year [5]. This mainly results from the geological structure of the area. Summing up all the radiation doses, it can be assumed that in recent years an average inhabitant of Poland has received about 3.62 mSv in a calendar year from both natural and artificial sources [2], [3], [6]. According to literature [7–10], the dose received by an average Pole is much lower than in some other regions of the world. In the state of Kerala (India), an average resident receives over 13 mSv/year, in Guarapari (Brazil) about 790 mSv/year, and in Lodève and Lauragais (France) about 870 mSv/year. Nevertheless, it should be remembered that the following statement is one of the most important recommendations of the International Commission on Radiological Protection (ICRP) concerning radiological protection: "No practice involving exposure to radiation should be allowed unless this practice brings sufficient benefits to the exposed people or society, outweighing the detriments caused by radiation in the form of health damage associated with this practice" [11].

Methodology

Radon concentration measurements were performed in selected buildings using PicoRad carbon detectors. These are measuring devices that use the commercially available Accuspec carbon detectors in the form of small cylinders, comprising a transparent gas container with activated carbon and with a mixed vapour sorbent. To measure the frequency of scintillation, the detector is placed in a photomultiplier well. Knowing the date and time of the start and end of exposure, the date and time of flooding with the scintillator, as well as the measurement time in the counter and the temperature during exposure, the concentration of radon is calculated using the TRI CARB 1900 liquid scintillation analyser counter manufactured by Packard-Canberra, with software for converting the measured frequency into radon concentration data. The lower detection threshold of the PicoRad system is approximately 11 Bq/m^3 for a two-day exposure [12].

The detectors were given to a selected group of properly trained postgraduate students of the Main School of Fire Service, specialising in the safety of nuclear energy, who had to place these devices in the studied rooms for 48 hours. Once the measurements had been completed, they had to immediately send the detectors back to the indicated address, i.e. to the Central Laboratory for Radiological Protection (CLOR) in Warsaw. Table 1 features the localities where the students performed the measurements.

Radon concentration measurements with PicoRad detectors were performed in accordance with the following procedure [13]:

1. Close hermetically the room in which the measurement is taken at least the day before the measurement starts (close the doors and windows).
2. Place the detector in the basement not closer than 1 m from the walls (if there is no basement in the building, the detector should be placed on the ground floor).
3. Open the detector (remove the cap) and place it in the

studied atmosphere for 48 hours. Write down the date and time of the measurement start.
4. During the measurement, close the room and, if possible, do not get in the room.
5. After the exposure, screw the cap hermetically and write down the date and time of the end of exposure, as well as the average ambient temperature during exposure.
6. Send the detector back, hermetically closed and foil-enveloped, together with the following information:
   - the date and time of the measurement start,
   - the date and time of the measurement end,
   - the average temperature of the room during the measurement,
   - the place in which the measurement was performed (type of the building – a free-standing house or a block of flats, the basement or the ground floor),
   - the detector number (as per the sticker on the detector),
   - the name and surname of the person who performed the measurement,
   - the locality in which the measurement was taken,
7. Immediately after the study, send the detector back to the indicated address.

Reading was done by the Central Laboratory for Radiological Protection (CLOR) in Warsaw.

Table 1. Localities where the students performed radon concentration measurements

Locality	Voivodeship
Ludźmierz near Nowy Targ	Małopolskie
Jastrzębie Zdrój	Śląskie
Piła	Wielkopolskie
Nowy Sącz	Małopolskie
Kraków	Małopolskie
Sośnicowice	Śląskie
Zakrzew	Mazowieckie
Szerzyny	Małopolskie
Katowice	Śląskie
Kędzierzyn-Koźle	Opolskie
Leszno	Wielkopolskie
Sanok	Podkarpackie
Opole	Opolskie
Kielanówka	Podkarpackie
Oświęcim	Małopolskie
Białystok	Podlaskie
Stryszawa	Małopolskie
Wrocław	Dolnośląskie

Source: Own elaboration based on the research results.

Results

The results of radon concentration measurements are presented in Table 2. All the studies were conducted either in the basements or on ground floors of buildings where people live or work. The exposure time was two days (48 hours).

In the PicoRad method, errors in measuring radon concentrations are likely to result from errors in measuring the average number of pulse counts per minute. These measurements were performed with an error of 2δ, not exceeding 10% for low radon concentrations and 5% for concentrations greater than 20 Bq/m^3.

Research analysis

In Poland, the average radon concentration in the open air reaches around 10 Bq/m^3 [5]. An increased value of radon activity can be observed in south-western Poland (Świeradów 24 Bq/m^3, Kowary 30 Bq/m^3) due to the geological structure of this region and soil type (the presence of areas with exposed magma rocks – the Sudetes) [5]. Furthermore, the atmospheric conditions impact on the amount of radon exhalation from the ground. Another important source of radon presence in buildings are building materials since natural minerals are used in their production. In addition, due to the solubility of radon in water, another source of its presence comes from ground waters and secondary rivers in which mine water is spilled. However, this is not a phenomenon occurring along the entire course of the river, but only near the estuary of these water sources [14].

The results of the research carried out in residential buildings indicate that the 2-day average value of radon concentrations in the studied rooms was 30 Bq/m^3. The lowest radon concentration was measured in single-family house basements in Ludźmierz near Nowy Targ, with a value of 12 Bq/m^3, and the highest concentration reached 85.5 Bq/m^3 in the basement of a one-storey house in Zakrzew. The most important factor influencing the radon concentration in apartments is their ventilation. The way apartments are ventilated depends on the external temperature and inhabitants' habits. Other factors influencing the radon concentration can also be the technical changes introduced in buildings, such as window replacements, building insulation or ventilation improvements.

In the measurements carried out, the average radon concentration on the ground floor was 31 Bq/m^3, while on the first floor it was 29 Bq/m^3.

Social aspects of radon testing

Let us remind you that radon (Rn-222) is a colourless and odourless, natural radioactive noble gas that is formed from the decay of radioactive uranium-238, a mineral found in the earth's crust. Emissions in areas rich in uranium give rise to the presence of a certain level of radon in the facilities located in these areas, including residential buildings. Due to its natural presence, forced human contact with radiation is noted.

Table 2. Measurement start and end dates, locality, place of exposure and radon concentrations in the studied rooms

Measurement start	Measurement end	Locality	Place of exposure	T [°C]	Crn [Bq/m³]
20.02.2017	22.02.2017	Ludźmierz near Nowy Targ	basement in a single-family house	6	12
01.02.2017	03.02.2017	Jastrzębie Zdrój	room in the basement of the municipal headquarters of the State Fire Service	28	16
27.03.2017	29.03.2017	Piła	basement in a block of flats	18	14.5
23.01.2017	25.01.2017	Nowy Sącz	ground floor in the municipal headquarters of the State Fire Service	19	31.3
21.01.2017	23.01.2017	Kraków	basement in a block of flats	16	34.2
23.01.2017	25.01.2017	Śośnicowice	basement in a single-family house	18	47.2
24.02.2017	24.02.2017	Zakrzew	basement in a one-storey house	4.5	85.5
24.02.2017	24.02.2017	Zakrzew	basement under stairs in a one-storey house	22	17.7
04.02.2017	06.02.2017	Szerzyny	basement in a single-family house	10	17.6
31.01.2017	02.02.2017	Katowice	basement in a block of flats	10	16.4
31.07.2017	02.08.2017	Kędzierzyn-Koźle	ground floor in a house	22	17.6
30.01.2017	01.02.2017	Leszno	basement in a brick building	18	35.9
22.01.2017	24.01.2017	Sanok	basement in a single-family house	12	11.3
21.01.2017	23.01.2017	Lwow	ground floor in a single-family house	21	21.7
03.02.2017	05.02.2017	Opole	high ground floor in a free-standing house	20	15.2
05.02.2017	07.02.2017	Kielanówka	basement in a single-family house	15	14.7
27.01.2017	29.01.2017	Oświęcim	basement in a single-family house	10	39.6
30.01.2017	01.02.2017	Białystok	ground floor in a free-standing house	20	68.3
22.01.2017	24.01.2017	Stryszawa	basement in a brick house	5	54.2
26.01.2017	28.01.2017	Wrocław	basement in a housing unit	11	24.2

Source: Own elaboration based on the research results.

Many people underestimate the seriousness and long-term health effects of radon exposure, and despite having the knowledge and awareness of its level in their homes, as well as preventive measures, they do not take action to minimise the risk of specific activities [15–17].

Important, from the point of view of the resilience of inhabitants of the areas exposed to radiation, is their own ability to monitor and minimise the risks associated with the level of radon. Resilience is understood as flexibility of a given community in the context of the internal adaptation capacity before, during and after certain events that interfere with its multidimensional functioning, connected with the sense of trust and security. However, in order for such activities to take place, it is necessary to inform people on these possibilities and to shape their attitudes, mainly in the cognitive sphere. This task rests with decision-makers whose role is to send the right message.

The social message, as an aid in undertaking appropriate preventive actions, is formulated in the following five steps:

- testing to determine to what extent radon is present,
- deciding whether the level is a threat,
- choosing the right recovery strategy,
- implementing the corrective strategy, and
- re-checking to ensure that the corrective action has been successfully completed [18].

It is important to create guidelines for this type of a message and investigate the social perception of such risks. Identifying the variables that affect risk perception, the standards recognized by a given group, and the level of trust in the sources of information about it come to the fore. Risk perception can be defined as "people's beliefs, attitudes, judgments and feelings, as well as the broader social and cultural values, and the disposition that people adopt regarding risks and their benefits" [19]. On the one hand, from the psychological point of view, this definition particularly includes two components of attitude, i.e. cognitive and emotional, which together determine the third behavioural component. On the other hand, sociologically speaking, risk perception is strongly embedded in the social context, a joint definition and actions taken. Therefore, it is important for the successful testing of radon levels and the implementation of appropriate practices, a holistic approach to the community at risk of radiation, consisting in strengthening both individual and collective behaviours related to monitoring, reacting, learning and predicting possible events [20] with their consequences. All these variables are the germ of the methodology of studying social resilience in relation to the features of the social system.

Conclusions

The measurements carried out show that the average concentrations of radon in the studied rooms are relatively low, within the limits of 12–85.5 Bq/m^3. However, it is worth taking into account the fact that, according to the World Health Organization (WHO), the risk of lung cancer development increases proportionally to the increase in exposure to radon. It grows by 16% per a 100 Bq/m^3 increase in the average long-term radon concentration [21]. "WHO handbook on indoor radon: A public health perspective" recommends setting the national annual average concentration level of reference to 100 Bq/m^3, but if this level cannot be reached, the reference level should not exceed 300 Bq/m^3 [21]. In Poland, also in the Atomic Law, the reference level was established for the average annual radioactive concentration of radon in the air, for both indoor workplaces and rooms intended for people, as not exceeding 300 Bq/m^3 [6].

The highest radon concentrations measured were only slightly lower than the average reference level recommended by WHO, reaching 85.5 Bq/m^3. This indicates that such measurements of radon concentrations should be performed in buildings in Poland. Information on the possibility of performing such measurements, on specific countermeasures, and also on the threats posed by high levels of radon should be given to the public in order to raise the general awareness and minimise risks.

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