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Evaluation of radon risk for Białystok inhabitants regarding the type of town buildings

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Abstract. Radon and its short-lived disintegration products are the most significant factors of exposure to ionizing radiation from natural sources. Białystok has the population of about 300,000 inhabitants in 100,460 flats in 16,282 houses. They are mostly one-family houses (about 80.7%) and two-family houses (8.2%). It can be estimated that about 2/3 of the Białystok inhabitants live in the so-called "blocks of flats". The study aimed at evaluation of the exposure to radon present in the flats. The integral method of trace detectors was used to measure radon concentration indoors. All values of the radon concentration were the mean annual values as they were obtained on annual exposure or were calculated and corrected to annual exposure based on shorter periods of time. Radon concentration distribution in flats of 3 housing estates in Białystok was analyzed. The effective dose of inhaled radon per a statistical inhabitant of Białystok (about 1.1 mSv) per year was calculated on the basis of mean values of radon concentration. Inhabitants of one-family houses obtained slightly higher annual doses – 1.4 mSv while the inhabitants of block of flats got lower annual doses – 0.8 mSv.

Key words: indoor radon • Białystok • mean annual concentration of radon • type of buildings

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Introduction

According to the estimation of the UNSCEAR (United Nations Scientific Committee on Effects of Atomic Radiation), the mean effective dose per a statistical inhabitant from natural sources of radiation is equal to 2.4 mSv per year. Natural sources of the dose, depending on the localization of a given area, is contained in the range of 1 to 10 mSv per year [17]. Radon inhalation contributes 1.2 mSv per year to the effective dose obtained by a statistical inhabitant of the globe.

Poland is located in the area where the level of natural radiation is not elevated. The mean effective dose per a statistical Polish inhabitant was 3.34 mSv in 2004 [2]. Natural radiation of 2.5 mSv has the highest contribution to this value. Radiation used in medical diagnostics has also a high contribution (0.85 mSv). It is worth noticing that particular components of the effective dose changed in the period of the last twenty years. The contribution of radiation pollution due to the Chernobyl accident decreased from 0.3 mSv in 1986 to 0.006 mSv at present. On the other hand, the contribution of medical diagnostics radiation increased from 0.59 mSv in 1986 to 0.85 mSv in 2004 [2].

Radon and its short-lived disintegration products are the most important factors of exposure from natural sources. Radon is the only gaseous radioactive element and inhalation is the main source of radon exposure. In Poland, the measurements of radon concentrations

Fig. 1. Localization of the investigated city.

Table 1. The values of corrective coefficients for 3 months – f_3 and 6 months – f_6. The month in the table shows the begining of exposition

	f_3	f_6
January	1.08	1.10
February	1.15	1.04
March	1.24	0.99
April	1.11	0.91
May	0.93	0.88
June	0.74	0.87
July	0.70	0.90
August	0.82	0.96
September	1.00	1.01
October	1.10	1.09
November	1.10	1.12
December	1.01	1.08

are conducted in a significantly smaller range than in other countries.

Białystok is the largest city in the Podlasie Province, the north-eastern part of Poland (Fig. 1). There are approximately 294,100 inhabitants that live in 100,460 flats in 16,282 buildings [11]. They are mainly one-family houses (about 80.7%) and two-family buildings (8.2%). Approximately 6% of the buildings are those with 20 flats or more. They comprise about 66% of all flats, which means that most inhabitants live in the blocks of flats [11].

The studies were conducted in 3 housing estates and in a group of one-family houses located in various areas of the town. There is some essential information concerning the examined housing estates:

1. The Zielone Wzgórza housing estate was built in the 1980s and 4 floor buildings of concrete slabs are predominant there.
2. The Piaski housing estate was built in the 1970s with 10 floor concrete slab buildings.
3. The Centrum housing estate was built in the 1950s with 4 floor brick buildings.

A group of one-family houses located in various areas of the city was also included in the study. The age of the houses was different, from very modern, built recently, to those constructed in the 1920s. The aim of the work was the evaluation of radon exposure in the air of flats in Białystok. Special attention was paid to housing estates, built with the use of various technologies and in different periods of time due to the large number of flats in the blocks of flats.

Material and methods

Measurements of radon concentrations were performed in a series in 2007–2009. All in all, there were 490 measurements conducted in this period. An integral method of trace detectors was used to measure radon concentrations in the air of flats. CR-39 detectors in chambers of type NRPB and diffusive chambers of Karlsruhe type were used in the study. Foil CR-39 calibration was performed in a radon chamber at the Institute of Nuclear Physics, Polish Academy of Sciences in Kraków, and the Radon Standard Station at the Central Laboratory for Radiological Protection in Warsaw. After exposure, the CR-39 detectors underwent etching in 10 a N NaOH solution at 70°C for 8 h. Surface density of traces was calculated on the basis of the registered traces with the use of an automatic computerized reader. The accuracy of measurement is approximately 10% [10]. The time of detectors exposure was from 3 months to 1 year. Due to the seasonal changes of radon concentration, its values obtained during the shorter than annual exposure were divided by corrective coefficients to determine mean annual concentration. Values of the corrective coefficients f_3 and f_6, assigned for north-eastern Poland are presented in Table 1 [13]. All the values of radon concentrations analyzed in this study are the mean annual values as they were obtained during a one-year exposure or were calculated and corrected to annual exposure based on shorter times. 63 measurements of radon concentrations in soil air using the method of trace detectors were also conducted in the city. The detectors CR-39 (RSFV) were placed in a drilled hole at a depth of 1 m. Exposition time was 6 months.

As radon concentration distribution is close to the log-normal one (Fig. 2), Kruskal-Wallis non-parametrical tests were used to compare the selected groups. Differences between the examined group were considered statistically significant at $p < 0.05$. The

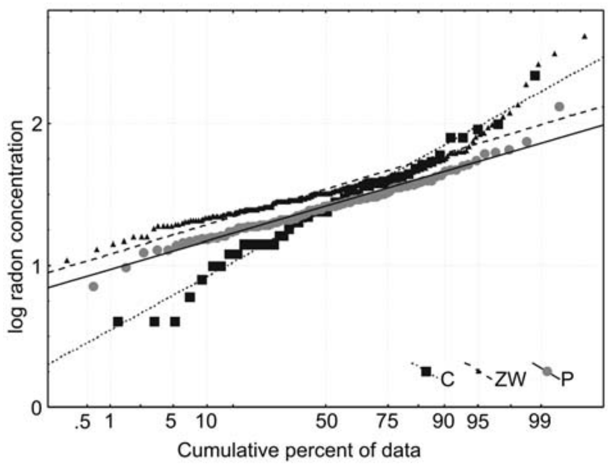

Fig. 2. The diagrams of cumulated frequency of radon concentration in dwelling places of Centrum (C), Zielone Wzgórza (ZW), and Piaski (P) housing estates. The symbols have the same meaning in Figs. 2, 3 and 4.

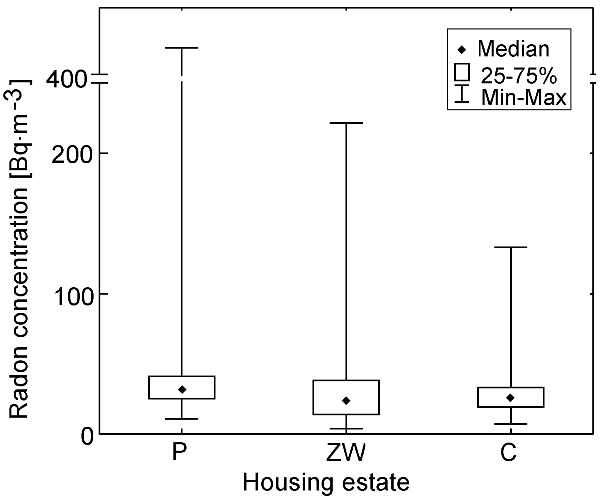

Fig. 3. Distribution of radon concentration in basements of the examined blocks of flats.

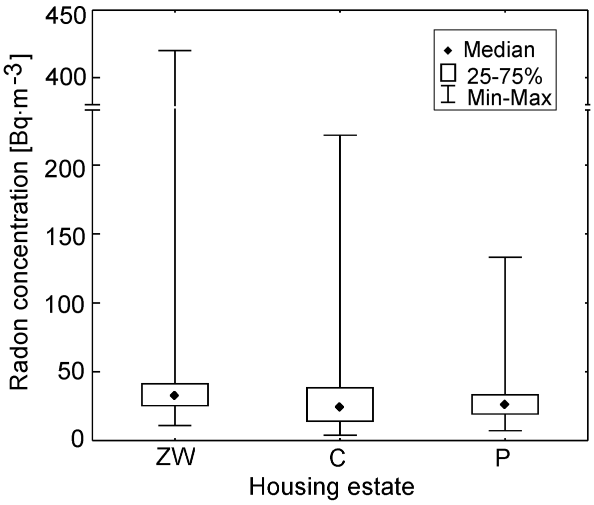

Fig. 4. Radon concentrations distribution in the whole blocks of flats in 3 housing estates.

Spearman non-parametrical correlation coefficient was used to evaluate the correlation of the investigated parameters between the compared groups.

Results and discussion

There were carried out 63 measurements of radon concentrations in soil air in the city and the obtained values were from 3.2 kBq·m^{-3} to 39 kBq·m^{-3} with the arithmetic mean AM = 12.5 kBq·m^{-3}. Taking into consideration G. Akerblom's classification as the basis of division into the low radon risk areas (from 10 kBq·m^{-3}), the medium radon risk (from 10 to 50 kBq·m^{-3}), and the high radon risk areas (higher than 50 kBq·m^{-3}). Białystok fulfils criteria for the areas of radon medium risk [1]. The Piaski housing estate showed definitely the lowest range of values, from 3 kBq·m^{-3} to 8.9 kBq·m^{-3}, and the lowest radon concentrations in the soil air with AM = 5.4 kBq·m^{-3}. There were statistically significant differences in radon concentrations in the soil air between the Piaski housing estate and two others housing estates (Zielone Wzgórza and Centrum) ($p < 0.05$).

In typical conditions, that is excluding some special architectonic construction or using very special materials, the soil air is the source of approximately 80% radon in the house.

Studies of other authors' concerning predictions of radon concentrations in buildings on the basis of radon concentration in the soil air, did not give satisfactory results [8, 18]. It is well known that in the case of high radon potentials, elevated radon concentration in the houses would occur in about half of the buildings [18]. Radon penetration into the buildings depends on the soil conditions (permeability, porosity, size of soil grains) as well as building parameters (type of basement, construction tightness, ventilation rate). Even if we know what is the value of radon concentration in soil gas, its concentration in the building is not determined although influenced by the value. The measurements of radon inflow velocity from the soil show a high changeability which is the result of radon concentration changes in the soil. ^{222}Rn concentration in the soil air may change even between close points and may show significant changes in time. Radon concentrations were close to the log-normal distribution in all housing estates, which is presented in Fig. 2.

Some of the measurements (50) were performed in the basements to examine the amount of radon that inflows the building. Statistic parameters characterizing radon concentration in basements of the examined blocks of flats is presented in Fig. 3. Differences between the radon concentrations in the basements of the examined buildings were statistically significant ($p < 0.05$).

Radon distribution in flats of the examined housing estates was analyzed. In this type of buildings small values of radon concentrations are usually observed. Out of 490 measurements of radon concentrations in the air of buildings, 437 were conducted in the blocks of flats. The statistic parameters characterizing radon concentration in the whole buildings are presented in Fig. 4 and Table 2.

Radon concentrations values in the dwelling parts of the blocks of flats were compared and the results are shown in Table 3 and Fig. 5.

The distribution of radon concentration values in the air of the dwelling part of buildings are compared. There were statistically significant differences between radon concentration in the whole block (with cellar) at

Table 2. Statistic parameters characterizing radon concentrations (Bq·m^{-3}) in 3 housing estates (whole buildings). AM – arithmeric mean; GM – geometric mean; M – median; GSD – geometric standard deviation; *N* – number of measurements; MAX – maximum value; MIN – minimum value

Housing estate	*N*	AM	M	GM	MIN	MAX	GSD
Piaski	107	29	26	26	7	133	1.6
Zielone Wzgórza	279	40	35	34	17	136	1.7
Centrum	51	42	27	29	18	220	1.9

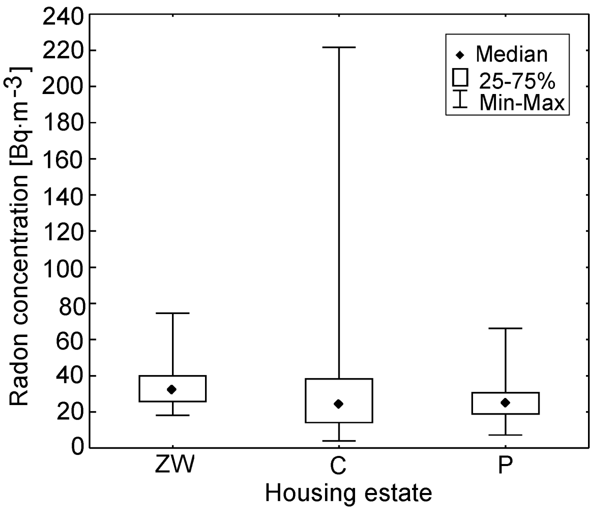

Fig. 5. Radon concentrations distribution in dwelling parts of the blocks of flats.

Zielone Wzgórza and Piaski as well as Zielone Wzgórza and Centrum ($p < 0.05$). Statistically, significant differences between the radon concentrations are observed also in the dwelling parts of the buildings $p < 0.05$.

In the whole group of buildings, the relation between radon concentration and construction material of the building was analyzed. Radon concentrations observed in brick houses were higher than those measured in the concrete slabs. Radon concentrations in the dwelling parts of brick houses were approximately 25% higher than that in the concrete slabs ones. The highest differences occurred between the determined arithmetic means of radon concentrations in basements and on the ground floors of particular types of the buildings. However, together with height the differences disappeared. Similar observations were found while analyzing radon concentrations in the blocks of flats in the Zielone Wzgórza housing estate [14].

As it is widely known, the level of radon in a dwelling house is influenced by the intensity of air exchange between the inside and outside of the building. The efficiency of ventilation system, tightness of connections of constructing elements (walls and windows), habits of inhabitants concerning ventilation of flats are all responsible for the speed of air exchange in the flat [7, 9, 10, 12]. The influence of building tightness on the increase in registered radon concentration values was observed in the late 1970s [7, 15]. In Białystok, similarly to the rest part of Poland, the number of houses with tight double glazed windows begins to be more and more popular. Last years revealed exchanged windows in a vast majority of houses and it can be expected that this trend will continue due to financial reasons. Double glazed windows, as more tight than the traditional ones, diminish air exchange between inside and outside of the buildings. It was noticed that radon concentration values are higher in houses with double glazed windows. Radon concentration in the group of flats with double glazed windows appear to be higher by about 18% and the difference is statistically significant ($p < 0.05$).

There was a weak correlation between the age of buildings and radon concentrations. The Spearman's coefficient is 0.3 ($p < 0.05$). The low quality of buildings construction and ageing of construction materials probably result in higher radon concentrations in older buildings. Measurements of radon concentrations in the air were also performed in one-family houses and the results are presented in Table 4.

As it is shown in Table 4, radon concentrations in the air of one-family houses were higher. The arithmetic mean of radon concentration is almost 2 fold higher than in flats in the blocks of flats in all housing estates and the differences are statistically significant ($p < 0.05$). The weighted average of radon concentration was determined on the basis of radon values measured in the dwelling parts of different type of buildings (blocks of flats and one-family house) and it is equal approximately to 43 $Bq \cdot m^{-3}$.

The effective dose due to inhaled radon on a statistical inhabitant of Białystok was also determined and it was about 1.1 mSv. The calculations were made assuming an inhabitation time coefficient of 0.8, an equilibrium coefficient for closed room of 0.4, and a dose conversion factor of 9 $nSv \cdot h^{-1}/Bq \cdot m^{-3}$ [17]. It is obvious that those who live in one-family houses obtain slightly higher doses, i.e. about 1.4 mSv per year while those living in the blocks of flats obtain lower doses of about 0.8 mSv per year.

Radon has been regarded as a carcinogenic factor since the 1980s. The results of studies concerning the relation between lung cancer and radon inhalation in buildings are inconclusive. Some authors questioned this connection [3–5, 16], while others confirmed it. The collective analysis from 13 European studies concerning the relation between radon inhaled in the buildings and lung cancer pointed to the fact that radon is responsible for 2% of deaths due to cancer and approximately 9% of deaths due to lung cancer. The increase in risk of lung cancer was estimated to be 8.4% at a concentration increase by each 100 $Bq \cdot m^{-3}$ [6]. While referring our

Table 3. Radon concentrations ($Bq \cdot m^{-3}$) distribution in dwelling parts of buildings of 3 examined housing estates, abbreviation like in Table 2

Housing estate	*N*	AM	M	GM	MIN	MAX	GSD
Piaski	96	28	26	26	10	133	1.47
Zielone Wzgórza	246	35	32	33.6	18	75	1.3
Centrum	40	36	25	26	4	135	2.2

Table 4. Radon concentration ($Bq \cdot m^{-3}$) distribution in one-family houses, abbreviation like in Table 2

	N	AM	M	GM	MIN	MAX	GSD
Whole building	53	60	31	36	15	950	1.7
Dwelling part	46	57	39	36	15	720	1.8

results to the mean value in Poland, it can be said that the mean radon concentration in the flats in Białystok is slightly lower than that in Poland which is 49.1 $Bq\cdot m^{-3}$ [2]. In accordance with the linear dose-effect theory, it might be expected that any concentration of Rn increases the risk of neoplastic diseases and particularly of lung neoplasm. In the light of measurements mentioned above it should be assumed that it is probable that initiation of a neoplasm is least risky in flats constructed from concrete slabs on higher floors.

Conclusion

From our investigation, it is possible to make the statement that inhabitants of the blocks of flats constructed from concrete slabs obtain smaller exposition by about 25% than the inhabitants of brick houses.

Smaller radon concentrations in flats with double glazed windows were also noticed. Radon concentration indoor one-family houses was almost 2 fold higher than in the flats in blocks. Our results also show that the mean radon concentration in flats in Białystok is slightly smaller (43 $Bq\cdot m^{-3}$) than in the rest of Poland (49.1 $Bq\cdot m^{-3}$).

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