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CHANGES IN THE CONCENTRATION OF RADON-222 AND ITS DAUGHTER PRODUCTS IN THE AIR OF THE UNDERGROUND TOURIST ROUTE IN WALIM (LOWER SILESIA)

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ZMIANY STĘŻEŃ RADONU-222 I PRODUKTÓW JEGO ROZPADU W POWIETRZU PODZIEMNEJ TRASY TURYSTYCZNEJ W WALIMIU (DOLNY ŚLĄSK)

W pracy przedstawiono wyniki pomiarów średnich miesięcznych stężeń ^{222}Rn oraz chwilowe wartości stężeń produktów jego rozpadu i energii potencjalnej ich promieniowania alfa w powietrzu podziemnej trasy turystycznej w Walimiu. Stwierdzono, że stężenie radonu w powietrzu udostępnionych do zwiedzania sztolni i hal jest niskie i w okresie badań (od października 1995 do stycznia 1997 roku) wyniosło średnio 0,094 kBq/m^3. Stwierdzono brak istotnego przestrzennego zróżnicowania stężeń radonu, a także brak wyraźnych wahań sezonowych. Niemniej jednak stężenia w poszczególnych miesiącach różniły się do 75% od wartości średniej. Ponadto okazało się, że jedynie sporadycznie i tylko w wybranych punktach mogą zaistnieć warunki sprzyjające gromadzeniu się tego gazu. Kumulacji radonu wewnątrz wyrobisk nie sprzyja niezbyt wysokie stężenie nuklidu macierzystego (^{226}Ra) w skałach, które wynosi 43 ± 2 Bq/kg, oraz intensywna, naturalna wentylacja.

Podobnie do radonu zachowują się także produkty jego rozpadu, przy czym ich stężenia w powietrzu podziemnej trasy turystycznej w Walimiu są jeszcze niższe. Oszacowany współczynnik równowagi promieniotwórczej F między radonem a produktami jego rozpadu wynosi 0,1 – 0,2 i jest zbliżony do wartości obserwowanych w podziemnych kopalniach węgla kamiennego w Polsce. Również wartości energii potencjalnej promieniowania alfa od produktów rozpadu radonu są o rząd wielkości niższe niż wartość graniczna przyjęta dla tzw. poziomu inspekcyjnego w kopalniach podziemnych w Polsce.

Uzyskane wyniki badań świadczą o tym, że w podziemnej trasie turystycznej w Walimiu nie można mówić o jakimkolwiek zagrożeniu promieniowaniem zarówno turystów zwiedzających ten obiekt, jak i pracowników oprowadzających wycieczki.

Summary

The paper presents the measurement results of monthly average concentrations of ^{222}Rn and momentary concentration values of its decay products, as well as the potential energy of their alpha radiation in the air of the underground tourist route in Walim. It has been found out that radon concentration in the air of the adits and halls that are open to the public is low and in the measuring period (from October 1995 to January 1997) it averaged 0.094 kBq/m^3. It has been also observed that there was no significant spatial variability of radon concentration, and no distinct seasonal fluctuation has been noticed, either. Nevertheless, the concentrations in particular months varied by up to 75% of the average. Except for this, it has been discovered that only occasionally conditions favourable for radon accumulation can occur in some places. The factors disadvantageous for the accumulation of radon inside the underground workings are rather low concentration of the parent nuclide (^{226}Ra) in the rocks, which amounts to 43 ± 2 Bq/kg, and intensive natural ventilation.

A similar behaviour is characteristic of radon decay products, whose concentrations in the air of the underground tourist route in Walim are even lower. The estimated coefficient F of the radioactive equilibrium between radon and its decay products is of the order of 0.1 – 0.2 and it is close to the values registered in underground coalmines in Poland. Besides, the values of the potential energy of alpha radiation from radon decay products are by an order of magnitude lower than the boundary value accepted for so-called inspection level in underground mines in Poland.

The obtained examination results prove that in the case of the underground tourist route in Walim you cannot speak about any radiation hazards neither for the visitors nor the employees showing them around the object.

INTRODUCTION

In Poland, like in many other European countries, most of the radiation exposure of the population comes from natural sources and it constitutes ca 2/3 of the total exposure. In our country the radiation exposure from natural sources amounts to ca 2.4 mSv a year, which is over twice as much as the limit established at 1 mSv. The biggest contribution to this exposure is that of radon and its decay products, which are the source of the estimated annual effective dose equivalent of ca 1.3 mSv. It constitutes ca 40% of the mean annual effective dose equivalent received by the average Polish citizen in 1998 from all sources of ionising radiation [31]. Therefore, the recent literature often draws attention to the necessity of complex investigations into the processes leading to high radon concentrations, defining the areas of their potential occurrence, as well as monitoring and the application of methods preventing people's presence in such places. The enhanced concentrations of this radioactive noble gas might be the reason for a greater risk of tumours, especially of the respiratory tract. On the other hand, some researchers adopt the theory of radiation hormesis, which says that the receiving of small radiation doses is not only harmless, but even beneficial for the organism. From this notion follows the use of radon in balneological therapy. The problem of enhanced radon concentration is concerned chiefly with residential buildings situated in specific geological conditions or built of materials containing parent isotopes of radon. To a lesser extent the problem also affects the employees of underground mines and other underground structures (tunnels, caves, underground tourist routes).

In the world there is now rich literature concerning the threat of high radon concentration in mines and methods of reducing the related hazards [1, 2, 5, 9, 16, 26, 28, 39]. In Poland numerous specialists in the Central Mining Institute, the Institute of Occupational Medicine and other research institutions have been occupied with these issues [3, 6, 7, 23–25, 41, 42]. A lot of attention has been recently devoted to problems related to radon accumulated in underground tourist structures such as caves, adits, underground passages etc. [8, 10, 11, 15, 17–21, 40, 44–47]. In Poland there are only a few literature data on this subject. The most important task in the studies of radon presence in such structures is to determine the natural conditions of its occurrence (its genesis), changes in its concentration in time, and possible dependence of these concentrations on various parameters (e.g. ventilation). So far such studies have been conducted only in a few places in Poland, e.g. in Niedźwiedzia and Radochowska caves [37, 38], in the "Kopalnia Złota" (gold mine) adits in Złoty Stok [34] and along the Millennium of the Polish State Underground Tourist Route in Kłodzko [36]. The next step, if necessary, should be to determine the radiation exposure of the employees in such structures.

LOCATION, DESCRIPTION AND GEOLOGY

The adits in Walim are actually situated ca 200 m south of the village, beside the road to Rzeczka. They are located on the left bank of the river Walimka, on the eastern side of Ostra hill (654 m a.s.l.). It is a complex of 3 horizontal adits leading toward two connected spacious "halls". The adits run parallel to each other for ca 60–80 m. The halls are perpendicular to the adits. They are ca 30 meters long, with the width and height of several metres (5–8). The workings are accompanied by small chambers of unexplained function, known as guardrooms (Fig. 1).

The Walim adits were excavated during the Second World War, in 1943–1945, by Todt organisation, which used the slave labour of prisoners-of-war and the prisoners of Groß Rosen and Auschwitz concentration camps. There is still little agreement about what function the structures of this kind were supposed to perform. Owing to the air of mystery, they have been attracting visitors for many years, although they were not open to the public until 1995. There are many more similar underground complexes in the Góry Sowie mountains, since the Walim adits were only a part of the wide-ranging "Riese" plan [43]. A similar complex of workings has been opened to visitors in Głuszyca (inside Osówka hill).

The Walim adits were hewn in the Góry Sowie gneisses with a distinct schistose texture. These are migmatised biotite gneisses. In the west and north they are surrounded by Lower-Carboniferous gneiss conglomerates. Nearby there also appear veins of Permian-Carboniferous effusive rocks – quartz porphyries (ryolites), felsite porphyries and kersantites, as well as mylonites of the Precambrian/Older Palaeozoic age. The river valleys are filled with Quaternary sediments (Fig. 2) [13].

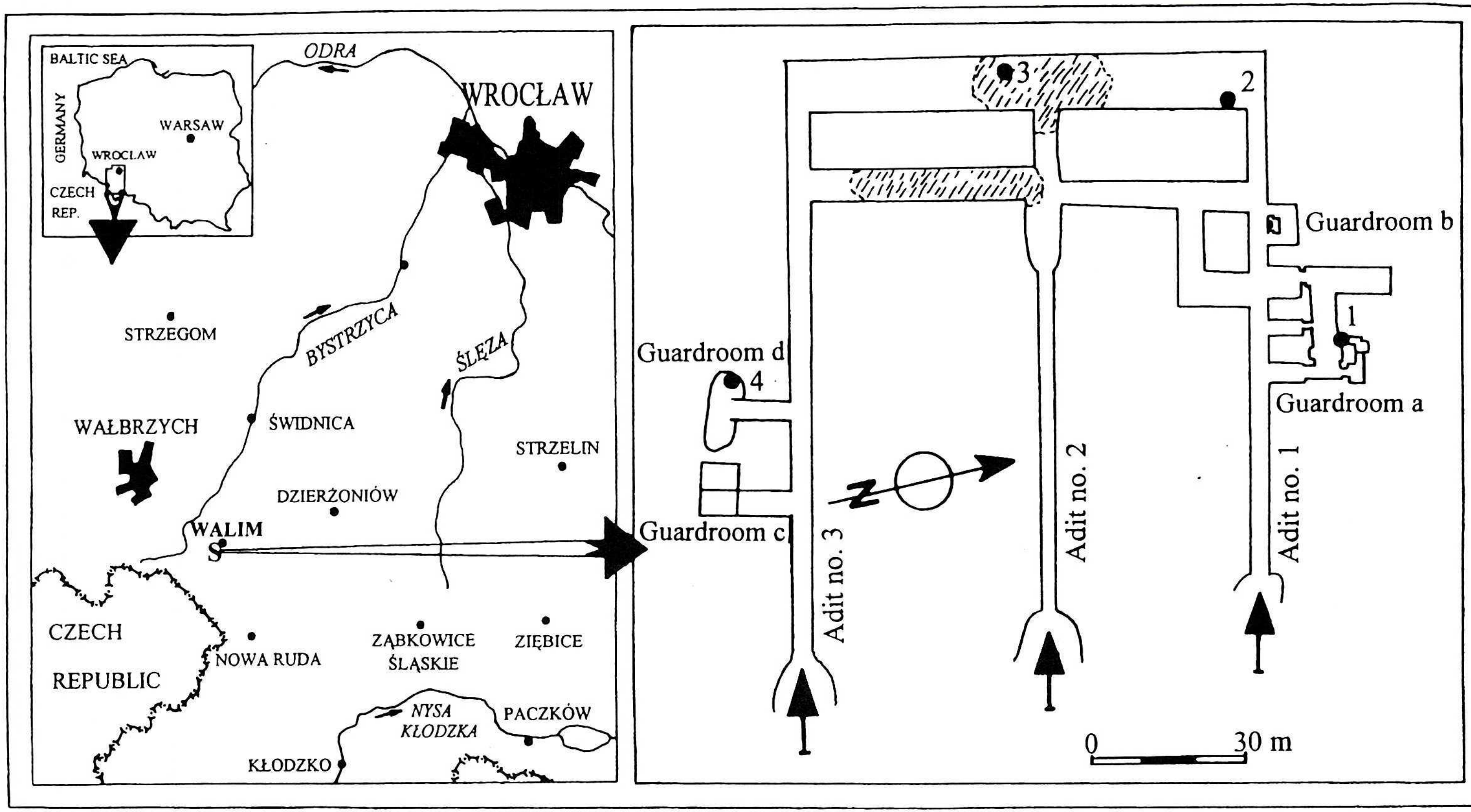

Fig. 1. The location and a schematic plan of the workings in Walim (after [33])

A dot with a number marks a measurement points for measuring the mean monthly values of radon concentrations and momentary concentrations of the potential energy of alpha radiation resulting from their decay. The striped parts denote refilled or partly refilled areas

The Góry Sowie gneisses make the old crystalline structure of the western Sudetes called the Góry Sowie plate. Most of this unit is built of quartz--plagioclase-biotite gneisses and, more rarely, of other kinds of gneiss. They are accompanied by migmatites, granulites, amphibolites and other rocks. The Sudetic marginal fault divides the plate of the Góry Sowie into the raised part in the Sudetes and the lowered, within the Sudetic Foreland [13, 22, 48]. The adits in Walim lie to the southwest of the Sudetic marginal fault, i.e. in the Sudetes, in the Góry Sowie range. Micropaleonthogical studies resulted in defining the age of this complex as Late Proterozoic [14]. The rocks inside the workings are strongly weathered, particularly along the planes corresponding to the schistosity. In the area near measurement point 3 the fault zone appears, within which rocks slide down from the roof, resulting in forming a gravity cone on the floor of the "hall".

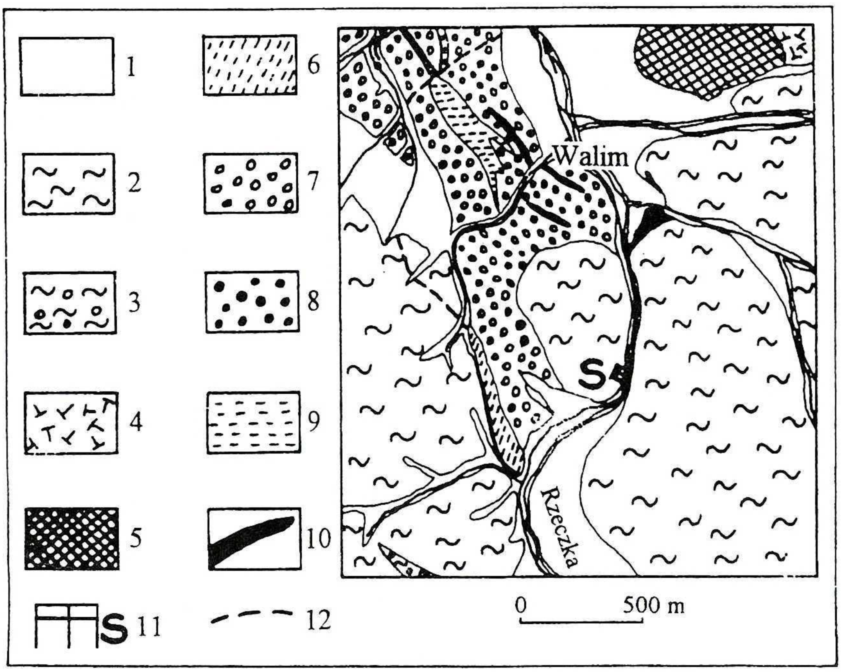

Fig. 2. A simplified geological sketch of the Walim area (after [13])

1 – Quaternary, 2 – biotite migmatised gneisses, 3 – granite-gneisses with the domination of (augen gneisses), 4 – biotite and migmatic gneisses, 5 – biotite-plagioclase gneisses, 6 – gneiss mylonites, 7 – gneiss conglomerates, 8 – gabbro conglomerates, 9 – kersantites, 10 – quartz porphyries, 11 – adits in Walim, 12 – faults

METHODS OF INVESTIGATION

In order to obtain the possibly fullest description of radon occurrence, its decay products and radioactivity itself, mean monthly concentrations of this radioactive gas, momentary concentration values of its short-lived decay products and the concentrations of the potential energy of their alpha radiation were measured in the air of the underground tourist route in Walim. The values of mean monthly radon concentrations were measured at four points along the tourist route (cf. Fig. 1) from October 1995 to January 1997. The momentary concentration values of the short-lived products of radon decay and the concentrations of the potential energy of alpha radiation caused by their decay were measured from March 1996 to January 1997 at the same points. In order to determine the content of ^{226}Ra, the parent isotope of ^{222}Rn in the rocks, a sample of ca 3 dm^3 of migmatised biotite gneiss with schistose texture was taken from the area near detector 3. This sample is representative of all the area encompassing the workings. Next, the sample was crushed to fraction smaller than 0.1 mm. After such preparation, an analysis of the content of ^{226}Ra nuclide in this sample was carried out in the laboratory of the Central Mining Institute in Katowice, which holds ISO 9001 certificate. The measurement was conducted by the method of gamma radiation spectrometry, with the use of a semi-conductor detector, in compliance with Polish Norm PN-89/Z-70073, according to procedure BR-3/2-004.

In order to measure the mean monthly radon concentrations in the air of the underground tourist route in Walim, the author used trace detectors LR-115 type II. They were placed in plastic containers with a paper filter preventing pollution and radon decay products, which also emit alpha particles, from getting close to the detector. The detectors were hung ca 2 metres above the floor of the workings. They were replaced once a month and sent for chemical processing and result reading to the laboratory of the Department of Radioactive Contamination in the Institute of Occupational Medicine in Łódź.

The momentary concentrations of short-lived radon decay products and the concentration of the potential energy of alpha radiation originating in their decay were measured by a mining radiometer RGR-40. The measurement principle of this device is based on pumping a 10-litre air sample through a glass-cloth filter, on which dusts and aerosols are deposited, including those to which ions of radon decay products cling. The filter is placed a small distance from the window of a silicon detector (operation with the efficiency up to 25%), where the emitted alpha particles are converted to electric impulses. The counting of these impulses is carried out with Markov method (a 15-minute measuring cycle: 5 minutes of air pumping, 1-minute pause, 3 minutes of impulse counting (N_1), 3-minute pause, 3 minutes of impulse counting (N_2)). The N_1 and N_2 values obtained thereby are then converted to the potential energy of alpha radiation (E) and the concentration of radon decay products RaA (^{218}Po) (A), RaB (^{214}Pb) (B) as well as RaC (^{214}Bi) and RaC′ (^{214}Po) (C) according to the following dependencies:

$$E = 3.2 \cdot 10^{-3} \cdot N_2 \cdot K \qquad [\mu J/m^3], \qquad (1)$$

$$A = 2.19 \cdot (N_1 - N_2) \cdot K \qquad [Bq/m^3], \qquad (2)$$

$$B = 0.55 \cdot N_2 \cdot K \qquad [Bq/m^3], \qquad (3)$$

$$C = (1.1 \cdot N_2 - 0{,}45 \cdot N_1) \cdot K \qquad [Bq/m^3], \qquad (4)$$

where K is the calibration coefficient. The apparatus is equipped with a processor that enables the storing of 99 results and the direct connection with a PC computer and/or a printer. The detection limit for the concentration of potential energy of alpha radiation is ca $20.67 \cdot 10^{-3} \mu J/m^3$ [12, 27].

RESULTS AND DISCUSION

The analysed sample of the biotite migmatised Góry Sowie gneiss was discovered to contain 43 ± 2 Bq/kg of ^{226}Ra nuclide (Tab. 1). This value does not differ from the typical values registered in the upper part of the earth's crust, which amount to 10–100 Bq/kg, on average 30 Bq/kg [4, 30, 32]. This value is slightly higher than that recorded for similar Góry Sowie gneisses in the area of Szczawno Zdrój (cf. Tab. 1) [35]. Therefore it should be stated that the rocks from the sides, roof and floor of the adits are not the source of enhanced radon emission. Consequently, the only cause of potential enhanced radon concentrations inside the tourist route would be the cracks and the fault zone found in the area around measurement point 3. In this case good ventilation should prevent radon from accumulating.

Table 1. The content of ^{226}Ra nuclide in the Góry Sowie gneisses for the samples taken in Szczawno Zdrój in 1996 (after [35]) and in Walim in 1997

Góry Sowie gneiss	^{226}Ra content [Bq/kg]
Szczawno Zdrój	34 ± 2
Walim	43 ± 2

During the 15 months of measurements it was found out that the mean monthly ^{222}Rn concentrations usually did not exceed 0.16 kBq/m^3. Only exceptionally in the period between December 1996 and January 1997, the concentration of 0.33 kBq/m^3 was registered by the detector placed at point 4. The fluctuations of mean monthly ^{222}Rn concentrations were considerable – of the order of $\pm 75\%$ of the mean values at particular measurement points (Fig. 3). However, the registered concentration values were lower in comparison to the values registered in similar structures, even lower than the values acceptable for residential buildings. This dependency is reflected by the mean ^{222}Rn concentration of 0.094 kBq/m^3 for the whole tourist route during the whole research period (Tab. 2 and 3). Besides, the extreme values at all the measuring points were similar, both in particular months and in the whole research period (cf. Tab. 3). Such results prove the uniform distribution of ^{222}Rn concentrations in all the structure. This means that there are no local sources (e.g. a fault or uranium mineralisation) that could supply larger amounts of radon. Besides, there are no areas where this radioactive gas would accumulate. This fact proves the presence of good ventilation, which causes the

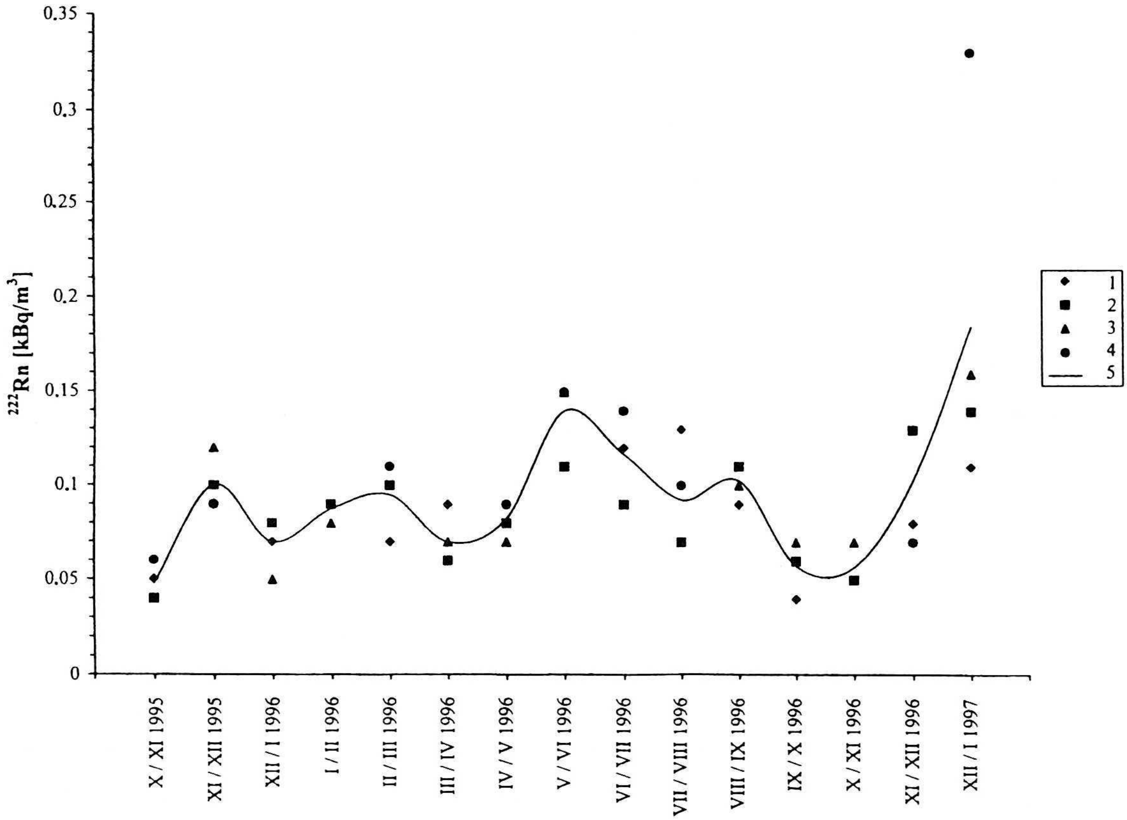

Fig. 3. Changes in the mean monthly ^{222}Rn concentrations in the Walim adits between October 1995 and January 1997

1—4 — measurement points numbers, 5 — line representing the average of mean ^{222}Rn concentrations in all measuring points in a particular month

uniformisation of radon concentrations in the air of the tourist route. The presence of efficient natural (unforced) ventilation is also confirmed by fluctuations in the temperatures registered inside the structure, which reach several degrees Celsius (4—6°C) in comparison to ca 0.5°C in the air of the Niedzwiedzia cave in Kletno [37]. The efficient ventilation results in the levelling of the effect of seasonal variations in ^{222}Rn concentration, which is characteristic of e.g. Niedźwiedzia cave in Kletno [37, 38], or Nerja Cave in Spain [8], as well as of other underground structures. Slightly higher mean monthly values of radon concentrations along the tourist route registered in the period from May to September 1996 could be a manifestation of the incompletely blurred seasonal character of the oscillations in radon concentration in the air of the underground structures. The value of 0.33 kBq/m^3 registered by the detector placed at point 4 proves that at times this radioactive gas can accumulate locally (cf. Tab. 3 and Fig. 3).

The momentary concentrations of radon decay products turned out to be, in many cases, lower than the detection level of the radiometer. On average, the concentrations oscillated from several to over 20 Bq/m^3, occasionally

Table 2. Mean ^{222}Rn concentrations recorded in the air of selected underground structures in the world (after [8, 10, 11, 18, 20, 21, 35 – 37, 44, 46]) compared with the value obtained in the air of the tourist route in Walim and with the upper boundary of the mean annual concentration in residential buildings (after [29])

Object	^{222}Rn concentration [kBq/m^3]
Walim Underground Tourist Route (Poland)	0.09
Kłodzko Underground Tourist Route (Poland)	0.3
Niedźwiedzia Cave (Poland)	1.3
Radochowska Cave (Poland)	0.4
Mamoth Cave (USA)	3.1
Altamira Cave (Spain)	3.2
Nerja Cave (Spain)	0.1
Moestroff Cave (Luxemburg)	4.3
Postojna Cave (Slovenia)	1.5
Planina Cave (Slovenia)	0.2
Tabor Cave (Slovenia)	3.5
Gorjanska Cave (Slovenia)	2.0
Szemlö Hill Cave (Hungary)	5.3
Pál Valley Cave (Hungary)	3.3
Gyokusen-do Cave (Japan)	1.5
Upper bound of yearly mean in buildings:	
in Poland	0.2
CEC*	0.2
WHO**	0.1

* – Commission of European Community;
** – World Health Organization.

exceeding the boundary of 20 Bq/m^3 (Tab. 4, 5, 6). This corroborates the conclusions drawn on the basis of the measurements of mean monthly radon concentrations, in particular the good ventilation of the tourist route, as well as the absence of concentrated sources of radon supply, or places of its accumulation. Considering the absolute values of the registered concentrations of radon daughters, one can estimate that the coefficient F of the radioactive equilibrium between radon and its decay products is of the order of 0.1 – 0.2. It is closer to the values registered in mines, where it oscillates within a wide range (0.1 – 0.9, with the commonest values at 0.1 – 0.2), than to the conditions in residential buildings, where it usually reaches ca 0.5 [23].

The low registered concentrations of radon decay products also result in the low values of momentary concentrations of potential energy of alpha radiation originating from their nuclear transformations (Tab. 7). The highest registered value is 0.11 μJ/m^3 and the average of all the measurements is 0.048 μJ/m^3 (Tab. 7). These values prove that we cannot speak of any radiation hazards. The values of the potential energy of alpha radiation are lower by an order of magnitude than the boundary value accepted for so-called inspection level in underground mines – 0.8 μJ/m^3 [23]. At the same time it should be

Table 3. Recorded values of mean monthly ^{222}Rn concentrations in the air of the underground tourist route in Walim between October 1995 and January 1997

Period of measurement	Point no. 1	Point no. 2	Point no. 3	Point no. 4	Mean
	[kBq/m³]				
X/XI 1995	0.05	0.04	0.04	0.06	0.0475
XI/XII 1995	0.09	0.10	0.12	0.09	0.10
XII/I 1996	0.07	0.08	0.05	0.08	0.07
I/II 1996	0.09	0.09	0.08	0.09	0.0875
II/III 1996	0.07	0.10	0.10	0.11	0.095
III/IV 1996	0.09	0.06	0.07	0.06	0.07
IV/V 1996	0.09	0.08	0.07	0.09	0.0825
V/VI 1996	0.15	0.11	0.15	0.15	0.14
VI/VII 1996	0.12	0.09	–	0.14	0.117
VII/VIII 1996	0.13	0.07	0.07	0.10	0.0925
VIII/IX 1996	0.09	0.11	0.10	0.11	0.1025
IX/X 1996	0.04	0.06	0.07	0.06	0.0575
X/XI 1996	–	0.05	0.07	0.05	0.057
XI/XII 1996	0.08	0.13	0.13	0.07	0.1025
XII/I 1997	0.11	0.14	0.16	0.33	0.185
Mean	0.091	0.087	0.091	0.106	**0.094**
Min	0.04	0.04	0.04	0.05	
Max	0.15	0.14	0.16	0.33	

Table 4. Momentary ^{218}Po (RaA) concentrations recorded between 15.03.1996 and 14.01.1997 in the air of the underground tourist route in Walim

Date of measurement	Point no. 1	Point no. 2	Point no. 3	Point no. 4	Mean
	[Bq/m³]				
1996.03.15	< LLD*	1.94	16.75	22.1	13.60
1996.04.17	< LLD*	< LLD*	1.94	< LLD*	1.94
1996.05.16	5.34	11.65	11.65	< LLD*	9.55
1996.06.18	< LLD*	6.31	13.84	< LLD*	10.075
1996.07.16	10.68	< LLD*	< LLD*	< LLD*	10.68
1996.08.17	17.97	< LLD*	< LLD*	< LLD*	17.97
1996.10.15	< LLD*	20.15	< LLD*	24.52	22.335
1996.11.15	8.5	3.16	5.1	23.31	10.0175
1996.12.13	13.84	5.34	23.31	13.6	14.0225
1997.01.14	< LLD*	3.16	< LLD*	< LLD*	3.16
Mean	11.266	7.387	12.098	20.8825	**11.33**
Min.	5.34	1.94	1.94	13.6	
Max.	17.97	20.15	23.31	24.52	

* Below the detection limit.

Table 5. Momentary ^{214}Pb (RaB) concentrations recorded between 15.03.1996 and 14.01.1997 in the air of the underground tourist route in Walim

Date of measurement	Point no. 1	Point no. 2	Point no. 3	Point no. 4	Mean
	[Bq/m³]				
1996.03.15	< LLD*	21.27	10.63	< LLD*	17.72
1996.04.17	< LLD*	85.08	21.27	10.63	38.99
1996.05.16	< LLD*	< LLD*	< LLD*	< LLD*	–
1996.06.18	< LLD*	< LLD*	< LLD*	< LLD*	–
1996.07.16	< LLD*	< LLD*	< LLD*	< LLD*	–
1996.08.17	< LLD*	< LLD*	< LLD*	10.63	10.63
1996.10.15	< LLD*	< LLD*	21.27	< LLD*	21.27
1996.11.15	< LLD*	< LLD*	21.27	< LLD*	21.27
1996.12.13	< LLD*	< LLD*	< LLD*	10.63	10.63
1997.01.14	10.63	< LLD*	< LLD*	< LLD*	10.63
Mean	15.95	53.175	18.61	10.63	**18.73**
Min.	10.63	21.27	10.63	10.63	
Max.	21.27	85.08	21.27	10.63	

* Below the detection limit.

Table 6. Momentary ^{214}Bi (RaC) and ^{214}Po (RaC′) concentrations recorded between 15.03.1996 and 14.01.1997 in the air of the underground tourist route in Walim

Date of measurement	Point no. 1	Point no. 2	Point no. 3	Point no. 4	Mean
	[Bq/m³]				
1996.03.15	< LLD*	5.34	16.03	18.7	13.357
1996.04.17	< LLD*	2.67	5.34	< LLD*	4.005
1996.05.16	2.67	8.01	8.01	< LLD*	6.23
1996.06.18	< LLD*	< LLD*	5.34	8.01	6.675
1996.07.16	5.34	< LLD*	< LLD*	< LLD*	5.34
1996.08.17	13.35	< LLD*	< LLD*	< LLD*	13.35
1996.10.15	< LLD*	13.35	2.67	13.35	9.79
1996.11.15	5.34	2.67	8.01	16.03	8.0125
1996.12.13	8.01	2.67	16.03	13.35	10.015
1997.01.14	< LLD*	2.67	< LLD*	< LLD*	2.67
Mean	6.942	5.34	8.775714	13.888	**7.94**
Min.	2.67	2.67	2.67	8.01	
Max.	13.35	13.35	16.03	18.7	

* Below the detection limit.

Table 7. Momentary concentrations of potential energy of alpha radiation resulting from nuclear transformations of short-lived ^{222}Rn decay products registered between 15.03.1996 and 14.01.1997 in the air of the underground tourist route in Walim

Date of measurement	Point no. 1	Point no. 2	Point no. 3	Point no. 4	Mean
	[μJ/m³]				
1996.03.15	< LLD*	0.03	0.09	0.11	0.077
1996.04.17	< LLD*	0.02	0.03	< LLD*	0.025
1996.05.16	< LLD*	0.02	0.05	0.05	0.04
1996.06.18	< LLD*	< LLD*	0.03	0.05	0.04
1996.07.16	0.03	< LLD*	< LLD*	< LLD*	0.03
1996.08.17	0.08	< LLD*	< LLD*	< LLD*	0.08
1996.10.15	< LLD*	0.08	0.02	0.08	0.06
1996.11.15	0.03	0.02	0.05	0.09	0.0475
1996.12.13	0.05	0.02	0.09	0.08	0.06
1997.01.14	< LLD*	0.02	< LLD*	< LLD*	0.02
Mean	0.0475	0.03	0.051	0.077	**0.048**
Min.	0.03	0.02	0.02	0.05	
Max.	0.08	0.08	0.09	0.11	

* Below the detection limit.

emphasised that the value of the inspection level has been defined for the 8-hour working day (2000 hours a year), while the employees guiding visitors along the underground tourist route in Walim stay there much shorter. Certainly, the problem of radiation exposure by no means affects tourists visiting the Walim adits.

CONCLUSIONS

The concentration of radon in the air of the tourist route in Walim is low (on average 0.094 kBq/m^3) and does not exhibit distinct seasonal variability. No spatial variation of concentrations can be discerned, either. This results from the average content of the parent nuclide ^{226}Ra (43 ± 2 Bq/kg) in the rocks, as well as from the intensive natural ventilation of the structure. Nevertheless, during the 15 months of measurements, deviations of up to 75% of the average value were noticed. It was also observed that occasionally in some parts of the route there might occur conditions favourable for the accumulation of this gas.

The behaviour of radon decay products is similar, but their concentrations in the air of the underground tourist route in Walim are even lower. Therefore the estimated coefficient F of the radioactive equilibrium between radon and its decay products is of the order of 0.1 – 0.2 and it approaches the values recorded in underground coalmines in Poland. The values of the potential energy of alpha radiation from radon decay products are by an order of magnitude lower than the boundary value accepted for so-called inspection level in the underground mines in Poland.

The obtained research results prove that we cannot speak of any radiation hazards along the tourist route in Walim; neither to the tourists visiting the structure nor the employees showing them around.

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