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ORIGINAL PAPER

Environmental and radon measurements in the underground workplaces in the Czech Republic

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Abstract. Most of radon and other environmental measurements were carried out in connection with research focused on improvement of radon dose assessment in the underground workplaces in the Czech Republic. The following methods are very useful for the detection of radon sources: air flow measurement; continual and short volume activity of radon and its progeny measurement; volume activity of thoron measurement; mapping of radon level in all workplace areas including horizontal and vertical gradient; radon in water measurement; integral radon monitor RAMARN testing, etc. In conjunction with equilibrium radon concentration (ERC) monitoring studies were conducted of radiogenic characteristics of caves clastogene and carbonate sediments, and other rock formations present in the Czech Massif and Western Carpathian. Over 150 samples of cave sediments were collected, in which the mass activities of present radionuclides were determined. Spectrometric analysis of the sediments enabled monitoring of disturbance in secular radioactive equilibrium in the given geochemical systems, through evaluation of $^{238}U/^{226}Ra$ or $^{228}Th/^{224}Ra$ proportion. Ratio of $^{208}Tl/^{226}Ra$ was monitored for the rock groups from the origin point of view assessment. Typical values for such ratio for carbonate rocks (including amphibolite and erlan) varied between 0.2–0.5, while for clastogene sediments and crystalline limestone the typical values were in the range 1.4–1.6. Conclusions from measurements were implemented in the new methodology for radon dose assessment.

Key words: underground workplaces • radon • effective dose • spectrometric analysis

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Introduction

The area of the Czech Republic is formed by two basic geological units, forming inseparable component of larger geological structure, being the base of the geological constitution of Europe. Diverse geological substructure led to the formation of two larger karstic units and a number of karstic "islands". These karstic systems have developed in bodies of limestone, lime dolomites, mostly from the Devon period, less frequently from the Silurian period in the framework of Czech Massif and from the Jurassic period in the area belonging to the regional area of West Carpathian Mountains.

The karstic areas are characterized by chemical dissolution of the carbonate basement and by creation of the typical karstic phenomena. Their total surface is about 230 km^2 (from the total area of 78 866 km^2).

There are 1771 karstic and 456 pseudokarstic caves and abysses in the Czech Republic. From those, 14 are open-to-public. The show caves in Czech Republic can be classified according to their genesis as corrosive, (i.e. formed through dissolution along cracks and surfaces with lesser resistivity), abrasive (i.e. where the major carving factor was an active water flow), in areas with combination of both the above activities and even in a special case as hydrothermal caves (caves created through flow of warm mineral waters through the massif). Some caves still have an active underground stream [1, 3, 4, 6].

The radon concentration in the Czech Republic shows caves is quite high, up to tens of thousands Bq/m^3 in summer season [7]. There are two known sources of radon in the caves. The first one is a geological material of the caves (limestone or other cave rocks, in substance cave clastogene sediments, chemical sediments) and the second one are underlying rocks. The actual radon concentration level is influenced by cave air flow, mainly depending on the outside temperature changes and inside/outside temperatures ratio [5]. For the time integral of radon volume activity measurement, (for dose assessment in agreement with recommendation ICRP65 [2]), the RAMARN system is used. The exposure period, selected according to seasonal radon variation, is half a year.

Studies of radiogenic characteristics of caves clastogene sediments (speleogene, allogene and fluvial), carbonate sediments (limestone, dolomite) and other rock formations present in the Czech Massif (Devon period) and Western Carpathian Mountains (Jura period) were conducted in conjunction with ERC monitoring in caves. As compared to the clastogene cave sediments, the radioactivity of carbonate sediments is very low. The relation between ERC and the radioactivity of clastogene sediments was studied in individual caves (*in situ* surface exhalation of radon including).

Materials and methods

Most of radon concentration measurement and other environmental measurements were carried out in connection with research focused on improvement of radon dose assessment in the underground workplaces in the Czech Republic. For the detection of radon sources, the following methods were found very useful: air flow measurement; continual and grab sampling volume activity of radon and its progeny measurement; volume activity of thoron measurement; mapping of radon level in all workplace areas including horizontal and vertical gradient; radon in water measurement; integral radon monitor RAMARN (based on bare Kodak LR115 solid-state nuclear track detectors (SSNTDs) inside a plastic diffusion chamber) testing, etc. The measurements were realized in public open caves, wine cellars, tunnels and speleotherapy areas.

In the caves studied over 150 samples of cave sediments were collected. The mass activity of the present radionuclides was determined in each of the samples using the laboratory gamma spectrometric analysis. The gamma laboratory measuring equipment consists of a coaxial semiconductor detector HPGe (35% efficiency) with built-in preamplifier (mfg. by EG&G Ortec), amplifiers 2022 Canberra, Source VN31060 Canberra, an ADC built-in an analyser, analyser model 4202 Canberra and a PC, Marinelli geometry 0.5 l. For the spectrum analysis in the energy range up to 3 MeV, the software Genie was selected. Spectrometric analysis of the sediments enabled monitoring of disturbance in secular radioactive equilibrium in the given geochemical systems, using a study of $^{238}U/^{226}Ra$ or $^{228}Th/^{224}Ra$ ratio.

Measurements of the radon exhalation rate from subsoil were performed in several caves. The difficulty

Table 1. Results of the laboratory gamma spectrometry measurements

Cave		^{226}Ra (Bq/kg)			^{208}Tl (Bq/kg)			^{40}K (Bq/kg)			Th/Ra			ERC (Bq/m^3)		Ratio
		Min	Max	Av	Min	Max	Av	Min	Max	Av	Allogene sediments	Autogene sediments	Karst rocks	Summer	Winter	S/W
The Mladec caves	D	15	183	53	16	56	39	178	580	448	1.4	0.4	0.4	1738	2378	0.73
The Sloup-Sosuvka cave	D	14	33	28	33	57	44	447	674	598	1.6		0.2	1234	662	1.86
The Balcarka cave	D	16	33	25	23	48	38	443	667	565	1.4		0.4	900	583	1.54
The Katerina's cave	D	26	30	18	14	43	27	239	495	390	1.5	0.7	0.8	863	526	1.64
The Javoricko caves	D	18	52	29	16	56	29	217	804	431	1.5	0.7	0.3	1518	309	4.91
The Zbrasov ar. caves	D	35	52	47	31	65	47	614	959	805	1.5	0.7	0.3	1980	2137	0.93
The Koneprusy caves	D	10	44	26	9	72	41	96	410	190	1.6	0.7	0.5	861	799	1.08
The Na Pomezi caves	D	14	51	30	15	63	42	227	661	498	1.4		0.3	600	718	0.84
The Na Spicaku caves	D	15	29	22	36	41	38	232	442	337	1.7		0.4	411	172	2.39
The Chynov caves	S	11	73	19	3	120	25	376	669	504	1.6	0.3	0.4	481	90	5.34
The Bozkov dol. caves	S	18	51	32	10	20	15	114	468	318		0.5		2190	1410	1.55
The Na Turoldu caves	J			19			19			226	1.0		0.3	137		

S – Silurian; D – Devonian; J – Jura; Av – average.

arises from the fact that the radon from the cave air can penetrate into the diffusion chamber through leaks and can distort the measured results. A special construction of the diffusion chamber was used to suppress the penetration of the high concentration of radon from the cave environment.

Results

The knowledge of mass activities for ^{226}Ra, ^{40}K and ^{232}Th (mainly ratio of $^{208}Tl/^{226}Ra$) in the individual collected samples could be one of the important indicators for judging or categorizing the above-mentioned samples to the appropriate rock groups from the origin point of view. These results are presented in Table 1.

Typical values of the $^{208}Tl/^{226}Ra$ ratio for carbonate rocks (including amphibolite and erlan) varied between 0.2–0.5, while for clastogene sediments and crystalline limestone the typical values of this ratio were in the range 1.4–1.6. The ratio of $^{208}Tl/^{226}Ra$ enabled the assessment of the clastogene sediments origin. In the case of speleogene sediments or allogene and fluvial sediments, the ratio varies around 0.5 or 1.5. The isotope ^{137}Cs was identified in three samples. Samples with cesium content were located near surface and represent clastogene sediments flushed into the cave, or they might be transported artificially during the cave arrangement.

The relationship between the mass activity of ^{226}Ra (Bq/kg) in clastogene sediments and averages of radon concentration from integral measurements using

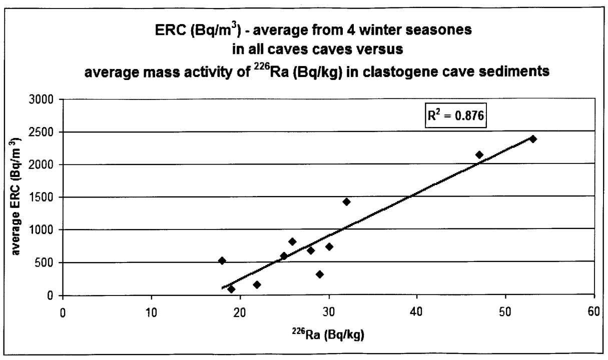

Fig. 1. ERC (Bq/m^3) – average from 4 winter seasons – in all caves vs. average mass activity of ^{226}Ra (Bq/kg) in clastogene cave sediments.

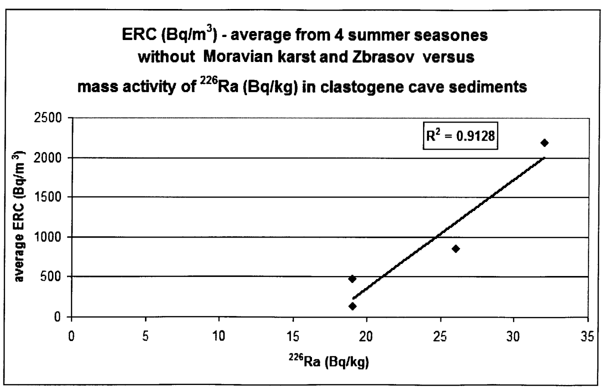

Fig. 2. ERC (Bq/m^3) – average from 4 summer seasons – without Moravian karst and Zbrasov vs. mass activity of ^{226}Ra (Bq/kg) in clastogene cave sediments.

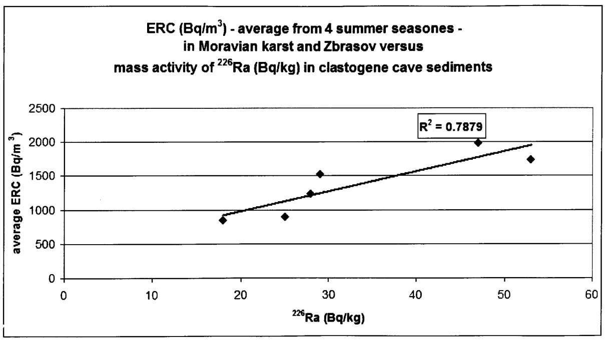

Fig. 3. ERC (Bq/m^3) – average from 4 summer seasons – in Moravian karst and Zbrasov vs. mass activity of ^{226}Ra (Bq/kg) in clastogene cave sediments.

RAMARN detectors in each cave is shown in Fig. 1 (winter season), Figs. 2 and 3 (summer season). The conclusion from Figs. 2 and 3 is a presumption that the Moravian karst caves and Zbrasov aragonite cave are part of the same geological unit from the genesis point of view.

The surface radon exhalation rate measured on the speleogene sediments in Bozkov dolomite caves or Zbrasov aragonite caves was 45 or 60 mBq/m^2/s.

From the measurements performed and from the careful analysis of the data obtained, the thoron contribution in all caves has not reached 10% of radon concentration.

The study of the isotope ratio (e.g. $^{234}Th/^{226}Ra$, $^{234}Th/^{214}Bi$, $^{228}Ac/^{208}Tl$) has proven disturbance of the permanent equilibrium in most of the samples for the reason of chemogene processes. The higher disturbance was present in the thorium decay chain.

Conclusions from the measurements results were implemented in the new methodology for radon dose assessment.

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