EVALUATION OF THE BOZKOV DOLOMITE CAVE GUIDES POTENTIAL DOSE

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Abstract

Caves are one of natural occurring places where higher radon risk should be expected. The aim of this work was to prepare basis for precise dose from radon calculation. Radon and daughters concentration measurement have been carried out together with additional important parameters such as airflows, radon sources, aerosol particle size distribution, etc. estimation. Radon concentration was found to be high with seasonal and daily variations due to changes of airflows. Together with aerosols particle size distribution it should make a base for the dose in lungs model.

Introduction

There are many various airborne pollutants in the human life with possible influence for human health, esp. for respiratory tract. Most of them are man-made, but there are natural-origin matters which are produced without human intervention and which should occur at whatever place on the Earth. Harmfulness of these pollutants should be caused by their chemical toxicity or by their radioactivity. The most important radioactive pollutant is radon which should be found practically everywhere.

Radon is indifferent gas which is produced by radium radioactive decay (i.e. it is one part of the natural radioactive decay-chain). However, in the contrary to the other decay-chain members which are solids, radon is gaseous; therefore it should penetrate through subsoil into outdoor atmosphere. Radon problem is not serious in the case of open atmosphere (concentration is very low, about 10 Bq m^{-3}), but it should cumulate inside closed-atmosphere places (such as buildings, natural closed spaces etc.) where it should reach higher or very high concentration (of course, health risks from radioactivity growth with nuclide activity – for radon case with its volume activity i.e. concentration). As radon originates usually from subsoil only, the most endangered places are cellars, underground tunnels, caves etc. which are in direct contact with subsoil.

Health potential risk comes from the fact, that radon is able to go into the lower part of respiratory tract and to decay here (radon is alpha-particles emitter); inside lungs there is no protective death-cells layer in comparison with epidermis and alpha-particles (which have high linear energy-transfer coefficient) should cause significant cell damage. However, the radon-induced disaster is not so important due to radon long lifetime (about 3.8 day), but in fact radon airborne daughters (short lifetimes in order seconds or minutes) imply the overwhelming majority of possible health damage. Radon daughters are not gaseous, therefore their concentration in atmosphere falls (if we suppose no radon source presence) due to deposition onto aerosols or surfaces (such as walls). So, besides of radon concentration the radon daughters concentration and/or aerosol situation and other factors should be measured. Moreover, radon and other factors described above usually vary in time, i.e. radon health risks vary in time, due to atmospherical conditions changes (the most important fact is pressure difference between outside atmosphere and air inside subsoils) with factor usually 2-10 (it differs from point to point). Thus, continual or sub-continual radon concentration and other factors measurements are appropriate. Based on radon, aerosols concentration, etc. data possible health risk should be calculated, usually in term of effective dose, and based on these values the appropriative recommendations or remedies should be estimated. In fact there are usually limits for effective dose which are based on ICRP recommendations; limits fulfillment is usually required by the national (Czech) law and it is checked by national authorities (Czech State Office for Nuclear Safety – SONS). ICRP based methodology is usually used for radon concentration (or equilibrium equivalent radon concentration – this unit include not radon but radon daughters activity; it is widely used for the radon risk assessment, because possible health damage is caused by radon daughters mainly; on the other hand, radon concentration is much easily measurable in comparison with equilibrium equivalent radon concentration).

There are places with higher radon potential risks both in country and in build-up areas. One of endangered places should be natural underground areas such as caves; risk importance depends on surrounding subsoils composition (uranium or radium content) and internal disposition (i.e. ventilation or air flow abilities). As differences at individual places are significant, the radon concentration measurement should be carried out at each point to evaluate potential risks. One of the most radon-rich caves, where radon problem is very serious, is Bozkov dolomite cave (north from Prague, close to Železný Brod) where annual effective doses are about 4-6 mSv y^{-1} for guides. Bozkov cave is open to public whole year, whole week (except from Mondays); two regular guides and about ten temporary guides work here. It is necessary to notice that radon related problem on this workplace is important for guides only; the time spent in underground by visitors is negligible.

Materials and Methods

Measurements have been carried out in one of the Czech public-open cave with the high radon concentration (from 700 Bq m^{-3} to 30 kBq m^{-3}). The measurement duration has been from February 2002 to March 2003 and now the measurement continues with continual radon monitors, track detectors and some mine personal dosimeters (which are under testing). The "operation day" for one-shoot-measurement at nine places inside the cave was Monday once a month (whole year), when the cave was closed for public. The continual measurement has been carried out with the short pauses caused by loss of power or technical trouble through the whole year and it is continuing up now. Besides from our measurement the standard SONS alpha-track detector monitoring was coincided for "official" dose calculation. One part of the dose calculation detailing was radon sources tracking. For that reason radium concentration in dolomite, cave sediments and water have been determined, airflow was measured and emanation model have been calculated.

These equipments had been used:

For continual radon monitoring

- the essential equipment for continual radon measurement the RADIM3 has been placed into an untight (the air should flow through a leak between upper and lower parts) plastic toolbox, together with a small amount of desiccant ($CaCl_2$), which was chosen because it has no radon absorption.
- the ionization-chamber-based continual radon monitor (RADONIC) with the active volume amount of ~8 l and with the forced airflow has been tested.

For one-shoot radon and radon daughters measurement

- the set for radon daughters measurement (air pump+2×PSDA reader) has been used.
- the radon-in-soil test set (incl. reader ERM 2) with the ionization chambers IK 250 has been used for one-shoot and radon in sub-soils measurements.

For gamma dose rate measurement

- monitors TEMA (RM 552 GS) and Eberline (FH 40F2).

For airflow and temperature measurement

- TESTO apparatus has been used for airflow velocity measurements and smoking tubes for flow direction.

For laboratory gamma activity measurement

- gamma spectrometer which consists of HPGe detector with built-in pre-amplifier (mfg. by EG&G Ortec), amplifiers 2022 Canberra, Source VN31060 Canberra, ADC built-in analyzer, analyzer model 4202 Canberra and a PC

Place	^{226}Ra	^{232}Th	^{40}K	A (equiv.)
Vánoční	18	10	114	40
Peklo	51	15	468	110
Loupežnická	30	18	268	76
Křižovatka	29	20	378	87
Jezero	31	13	363	79

Tab. 1 Results of the laboratory gamma spectrometry in cave's sediments (Bq kg^{-1}).

For five-day aerosol particle size distribution measurement

- TSI instruments based on diffusion battery or electrostatic classifier.

The radon concentration in the cave's water was evaluated in the laboratory of National Radiation Protection Institute.

The annual effective dose calculation (SONS's methodology) from passive alpha track detectors results is based on equation

$$E = j \cdot h_p \cdot a_{Rn} \cdot T \text{ (mSv)}, \quad (1)$$

where h_p=3.1 nSv (Bq h m^{-3})$^{-1}$ is the radon-to dose conversion factor based on ICRP 65 recommendation, a_{Rn} (Bq m^{-3}) is the average seasonal (summer or winter) equivalent equilibrium radon concentration estimated by passive alpha-track detectors, T (h y^{-1}) is the time spend in underground and j=1.5 is the "cave factor" estimated from some measurement of unattached and attached fraction in dwellings and caves. From these measurement results that ratio Rn:RaA:RaB:RaC is 1.56:1:0.56:0.39 because the cave air is cleaner (lower aerosol particles concentration) in comparison with air in dwellings.

Place	A
Jezerní dóm-jezero	<15
2. labutí jezírko	<15
1. labutí jezírko	<14
Kramářova vyvěr.*	18

Tab. 2 Results of the radon activity (Bq l^{-1}) in cave's water (*out of the cave).

Results and discussion

Sediments and rocks analysis

Based on evaluation of results from gamma spectrometry cave's sediments and dolomite rock, radon activity measurement in water, airflow measurement and emanation calculation it should be concluded that it is a very low probability of the radon source presence out of the caves surroundings

Place	a_{Ra-226} (Bq kg^{-1})	a_{stat} (Bq m^{-3}) [p=0.2,f=0.2,K=0.1]		a_{stat} (Bq m^{-3}) [p=0.3,f=0.1,K=0.2]	
		air	rock	air	rock
Peklo	18	2994	39600	499	13200
Vánoční	51	8482	112200	1414	37400
Loupežnická	30	4990	66000	832	22000
Křižovatka	29	4823	63800	804	21267
Jezero	31	5156	68200	859	22733

Tab. 3 Stationary radon activities calculated from emanation model for two sets of parameters (p is porosity factor, f is emanation factor, K is ventilation factor – these parameters were guesses for dolomite; ventillation coeficient have been estimated based on radon growt-curve analysis). For both sets of parameters it should be concluded, that surrounding rocks should be sufficient radon source for the cave.

(See Tab1-3). Besides of rock analyses, radon concentration in subsoils above cave network (outside cave) has been measured by standard techniques routinely used in the Czech Republic. Cave's plot has been classified to be middle-radon-risk area (radon concentration in subsoils is 10-20 kBq m^{-3}).

Airflow measurements

Regular one-shoot month-by-month airflow measurements (as airflow is the most important factor for radon distribution through cave network as well as for radon concentration values) at eighteen selected places inside underground network were carrying out during whole year. There were two points at each place – at height 30 cm and 200 cm above ground. In general, airflow velocities found to be low inside whole cave (i.e. internal atmosphere is very conservative). Seasonal variations of airflow

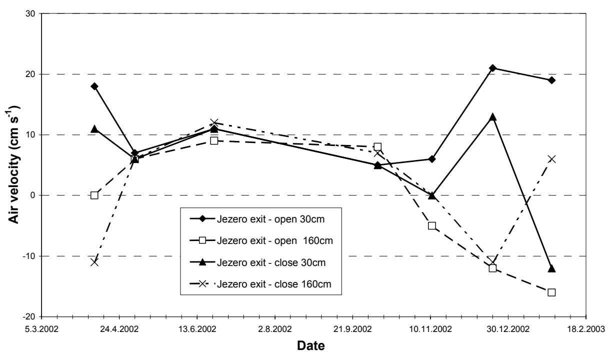

Fig. 1 Influence of seasonal temperature changes and double-door installation for airflow velocity (connecting line is drawn for the better visibility only).

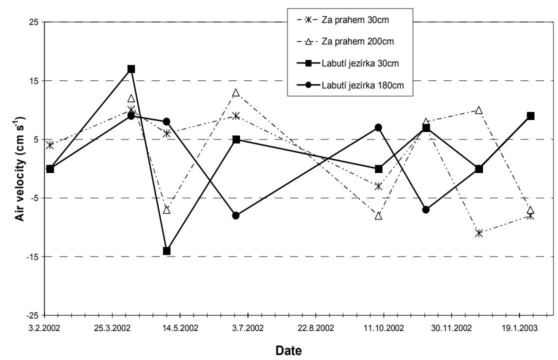

Fig. 2 Comparison of airflow velocities and direction at two selected places inside underground network (connecting line is drawn for the better visibility only).

velocities close to cave exit is shown on Fig. 1 (double door was installed and two measurements have been carried out – with open and closed double door). It is clear, that during summer practically no air goes from inside to outside even if the exit door is open. This fact is very important – due to warmer air outside colder air stay in underground and it has significant influence for radon concentration. Radon concentration inside cave is 2-10 times higher during summer in comparison with winter (this effect should be found on many other underground places with natural ventilation). Airflows direction differs place-to-place (see Fig. 2); moreover, if it is compared at different heights directions of airflow should be opposite (Labutí jezírka) or identical (Za prahem). As airflow intensity growth during winter, the values dispersion is higher during this season. SONS's dose estimation based on alpha-track detector methodology is suitable, because two sets of detectors are used (winter and summer) – few years ago one set was used only for annual measurement and the information about seasonal variations were lost.

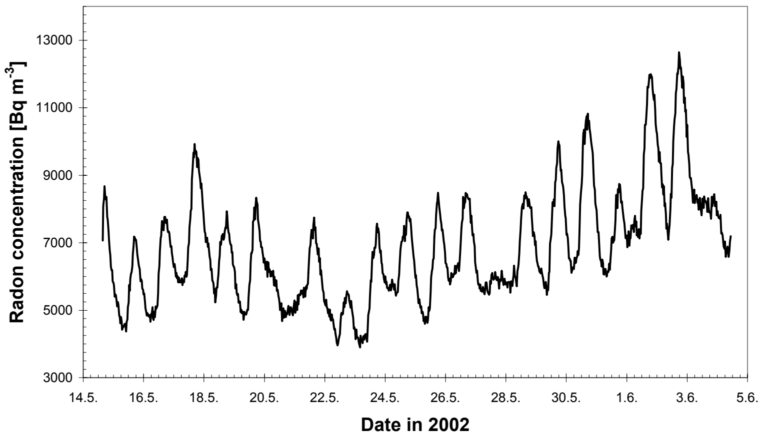

Fig. 3 Radon concentration from continual measurement.

Radon and daughters concentration measurements

Radon concentration as the aim of all measurements has been measured both by continual monitors and one-shoot measurements. Based on continual measurements (see Fig. 3) the time radon profile should be reconstructed to compare real guides' presence inside cave and radon concentration at given time. This comparison should precise the dose calculation, but it is hard to do and cannot be routinely used. Fig. 3 shows typical radon concentration curve during spring to summer period (in total, radon concentration inside cave growth due to airflows direction changes – see above); drops during working hours are visible which are triggered by the visitors movement. From one-shoot radon measurements it is possible to calculate radon equilibrium factor (and/or ventilation factor) – see Fig. 4. Moreover, radon to daughters ratio have been calculated to be 1.36:1:0.56:0.39 (compare with "official" value in Material and Methods chapter – se above). The double-doors installation influence is shown in Tab. 4 (alpha-track detectors measurement). These doors have been mounted to keep stable atmosphere inside the cave; unfortunately, the air exchange between outside and inside became significantly lower and as a result radon concentration growth (approx. two times) has appeared.

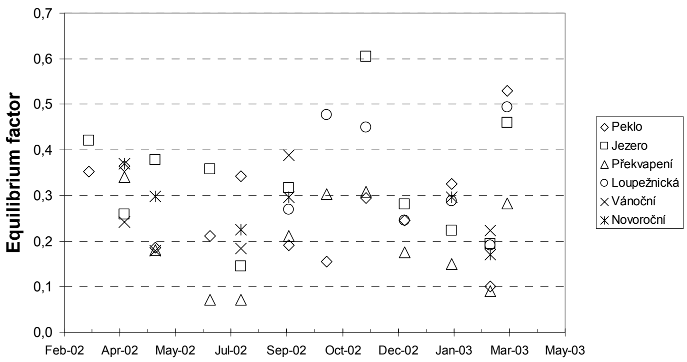

Fig. 4 Equilibrium factor seasonal variations.

Place	Sum. '01	Wint. '02	Sum. '02
Peklo	3857	1282	5192
Jezero	1524	1001	2152
Překvapení	764	-	1311
Kaple	1109	802	1907
Blátivá	2391	-	3460
Křižovatka	1332	787	1936
Půlnoční	1289	-	6919

Tab. 4 Variations of EERC during 2001-02 (in Bq m^{-3}). The double-door has been installed at July '02.

Aerosols particle size distribution

This distribution is one of the most important fact for dose calculation (un-/attached fraction estimation). But, it is very difficult to measure it due to extreme conditions inside cave (first of all practically absolute humidity); it is impossible to measure aerosols distribution continuously. Few-days aerosols

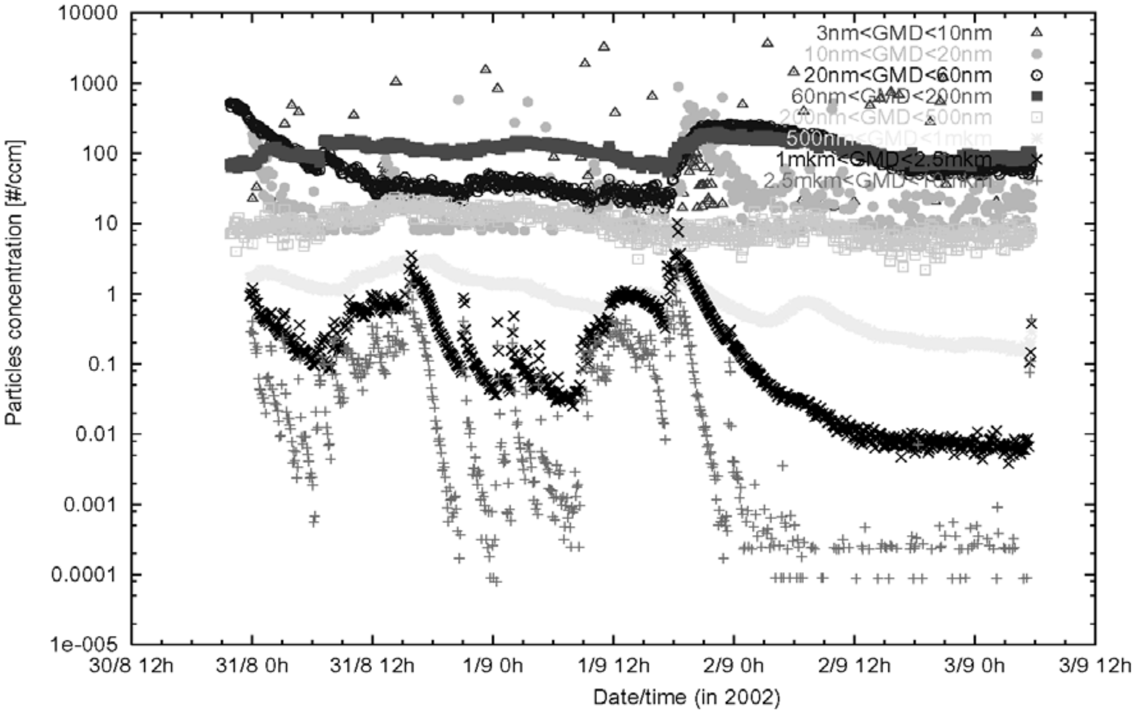

Fig. 5 Time profiles of aerosol particles size distribution (cave had been closed 1.9. at 8 p.m.). Preliminary results.

measurement has been carried out, but results are under investigation nowadays. Preliminary aerosols particle-size distribution is shown on Fig. 5.

Conclusions

Radon concentration vary seasonally (during summer reaches higher values) and daily (during day-hours is usually lower), therefore guides manners must be recorded more precisely and compare with real radon concentration. In fact, personal radon dosimeters for guides should be recommended (dosimeters are under testing nowadays). From preliminary aerosols results it should be concluded, that concentration of small- and middle-size aerosols seems to be stable, big-size aerosols are produced by visitors only (i.e. they comes from outside). All factors mentioned and measured must be taken into account for conversion factor specification and they should be used as input parameters for dose-in-lungs model calculation.

Acknowledgements

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