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ORIGINAL PAPER

Seasonal variation of radon in the Bozkov cave

Katerina Rovenska,
Lenka Thinova

Abstract. Measurement of the radon concentration has been performed in the Bozkov dolomite cave since 2002. Radon concentration was obtained by two means: continuous measurement by a Radim3 monitor at 30 min intervals and a 6 month average by LR115 solid-state nuclear track detector (SSNTD) in a diffusion chamber placed at 8 points along the cave tour path. The radon concentration shows diurnal, seasonal, and yearly variations. The concentration maximum in the cave, in contrast to the dwellings, occurs in the summer time and equals to thousands of Bq/m^3. At the same time, high variability of radon concentration occurs. Statistical analysis of a long time series of radon concentration was performed and the meteorological data were taken into account. The annual effective dose from radon for the cave guide (2006 y, working time spent in the cave 414 h) was 3.05 mSv. The dose was calculated using the mean value of radon concentration obtained by SSNTD as written above.

Key words: radon • cave • long-term measurement • data • analysis

K. Rovenska✉
National Radiation Protection Institute,
28 Bartoskova Str., 140 00 Praha, Czech Republic
and Czech Technical University in Prague,
Faculty of Nuclear Sciences and Physical Engineering,
Department of Dosimetry and Applications
of Ionizing Radiation,
7 Brehova Str., 110 00 Praha, Czech Republic,
Tel.: +420 226 518 117, Fax : +420 241 410 215,
E-mail: katerina.rovenska@suro.cz

L. Thinova
Czech Technical University in Prague,
Faculty of Nuclear Sciences and Physical Engineering,
Department of Dosimetry and Applications
of Ionizing Radiation,
7 Brehova Str., 110 00 Praha, Czech Republic

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Introduction

Public open caves in the Czech Republic are underground workplaces with a high probability of elevated radon concentration (thousands of Bq/m^3). Thus, caves constitute a special case for radiation protection in workplaces. Paper focusing on the dose assessment for cave guides in the Czech Republic was published elsewhere [1].

To fulfill the Czech National Radiation Protection Standards and Methodology the radon concentration in the public open caves is measured by SSNTD (Kodak LR115) and the concentration is integrated per 6 months. Dose from radon has been evaluated on the basis of SSNTD results.

The reasons why to measure radon continuously in the cave were the following:

– To check the integral averages from SSNTD.
– To see the cave dynamics and its connection with meteorological and other parameters.

Bozkov dolomite caves were chosen for this kind of measurement which started in 2002 because of good relationship with the cave staff and mainly their own interest in the radon measurement.

Cave description

The Bozkov dolomite cave (BDC) is one of the 13 of public open caves in the Czech Republic and the only cave system in the North Bohemia accessible to the public. The BDC are situated on the northern slope of the Bozkov village in the hilly landscape of the Krkonose foothills. Cave originated in the karstic mass in the area of Zelezny Brod crystalline region originated in the Silurian period [2].

The entrance into the underground space was discovered by dolomite miners in the 1940s. Attractive items of the sightseeing route include underground lakes with crystal-clear blue-greenish water. The cave and their surrounding is a protected area conditioned by the nature and landscape protection law.

The average temperature in the cave is between 7.5–9°C, relative humidity is near to 100%. Cave tour is 350 m long and takes 45 min. The BDC has been continually monitored due to radon concentration since 2002.

Methods of measurement

Radon

Radon has been monitored in two ways in the cave. Continuously by a Radim3 continuous monitor at 30 min response intervals and as an integral for 6 months by SSNTD. Radim3 consists of a small diffusion chamber and a semiconductor detector. Radon concentration is determined by spectrometric measurements of the ^{218}Po alpha activity. Statistical error is equal to ± 20%. Power supply is necessary for operating of the monitor. Blackouts often stopped the data acquisition and it was necessary to restart the device manually. Effect of humidity is compensated up to 90% relative humidity (RH) by the device itself. Comparison of the measured data with a bare Radim3 and Radim3 in a plastic box with a desiccant (anhydrous $CaCl_2$) is described later in this text. Radim3 monitors were placed in main public accessible halls near to the SSNTD detectors.

In the case of an integral measurement of radon concentration, the cave has been monitored by SSNTD using a Kodak LR115 foil as free detectors and since 2004 enclosed in the plastic diffusion chamber called RamaRn. There are eight SSNTDs for summer starting on 1st April and ending on 31st October and four SSNTDs for winter season (lower concentration) placed along the cave tour path. The exact places were chosen according to the stops for the explanation. The concentration was integrated per 6 months according to the summer and winter regime in the cave.

Both of the detector types, RamaRn and Radim3, are under metrological control. RamaRn detectors are, after the exposition in the cave, sent back to the producer for etching and radon concentration evaluation. Radon concentration values from Radim3 monitor are read out directly in the cave via a computer program and processed in a spreadsheet.

Meteorological data

Meteorological data were obtained from the Liberec meteo-station which is owned and operated by the Czech Hydrometeorological Institute (CHMI), Prague. The Liberec station is 20 km straight-line from the Bozkov village. There are no other closer data available for the measured period. The semi-professional meteo-station carries out proper measurements near the cave since 2008.

Results

The acquired data are not complete in time because of the power supply blackouts as mentioned above. The most consistent data were obtained from the place called

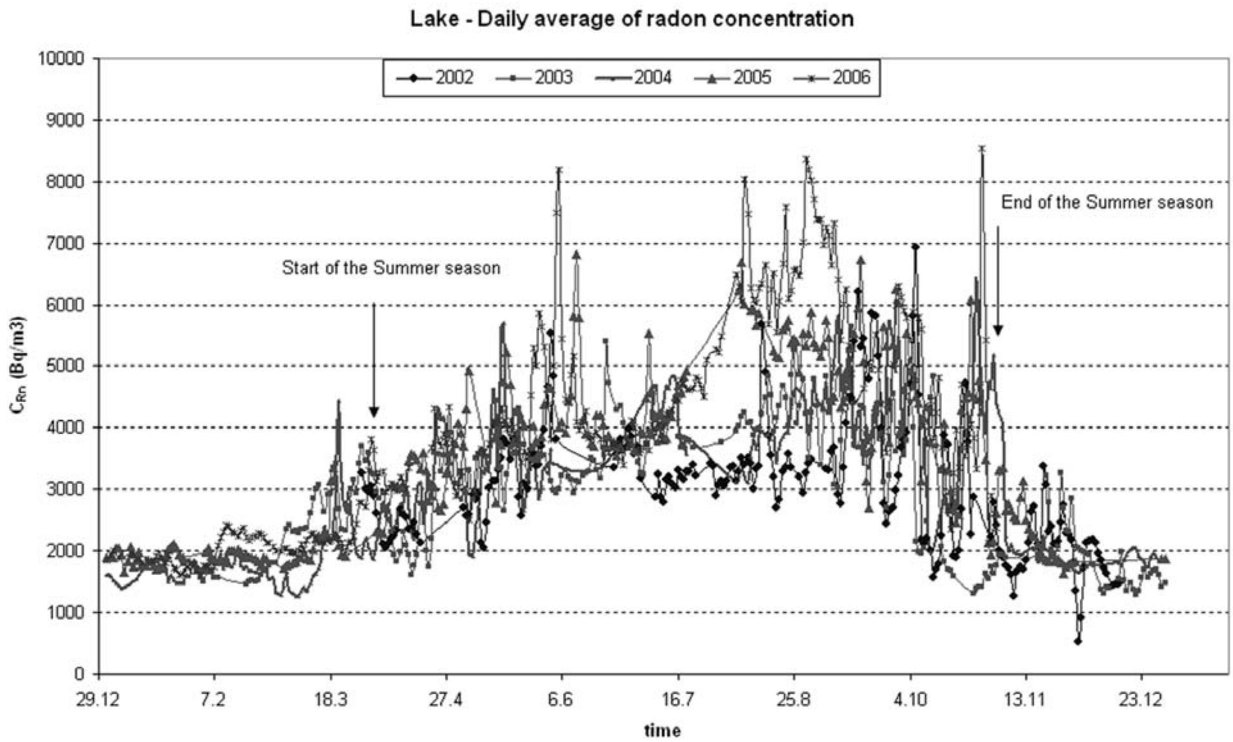

Fig. 1. Interannual variation of radon concentration.

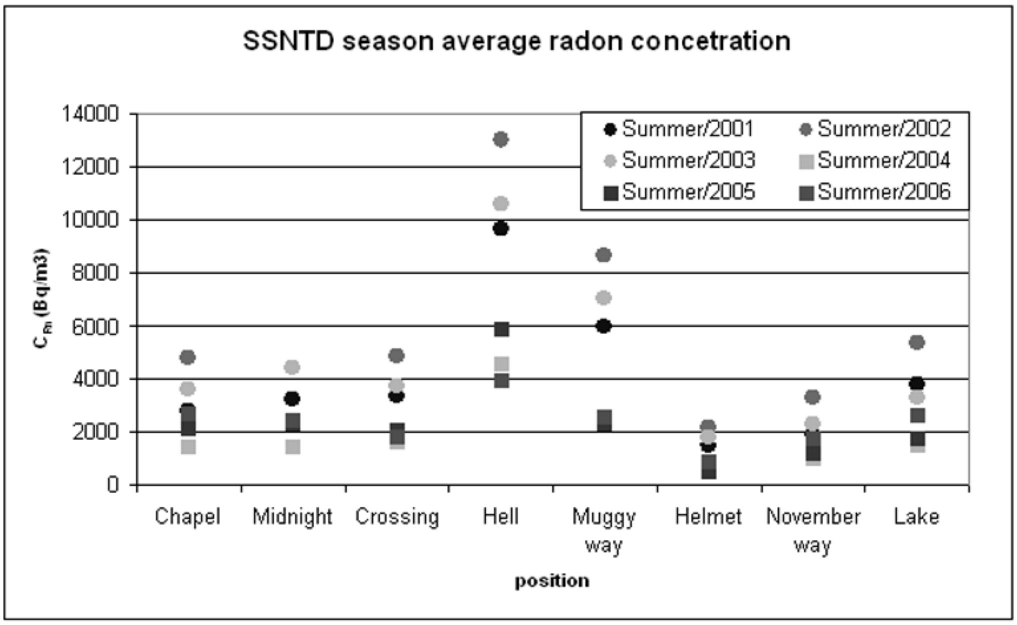

Fig. 2. Interannual variation measured with SSNTD, 2001–2003 – bare SSNTD, 2004–2006 – SSNTD in a diffusion chamber [2].

the Lake and Hell. The results of analysis of the data from these two places are described in this section.

Interannual variations

The interannual variations are demonstrated in Fig. 1, which compares the daily radon concentration average from the Lake for the years 2002–2006. Summer averages measured by SSNTD for these years are shown in Fig. 2, from which the variation is also visible. Track detectors enclosed in the diffusion chamber – RamaRn [3] have been used since 2004. The bare track detectors were used in the years 2001–2003.

Seasonal variations

The highest radon concentration in the cave is present in the hot summer time. The increase in concentration is caused by the stack effect determined by the outside and inside temperature difference. One-year progress of the radon concentration and temperature difference is shown in Fig. 3, also in Fig. 10 where this fact is depicted.

Diurnal variations

Equally to the seasonal variations, the diurnal ones are influenced mainly by the temperature difference. The dependence of radon concentration on the out-

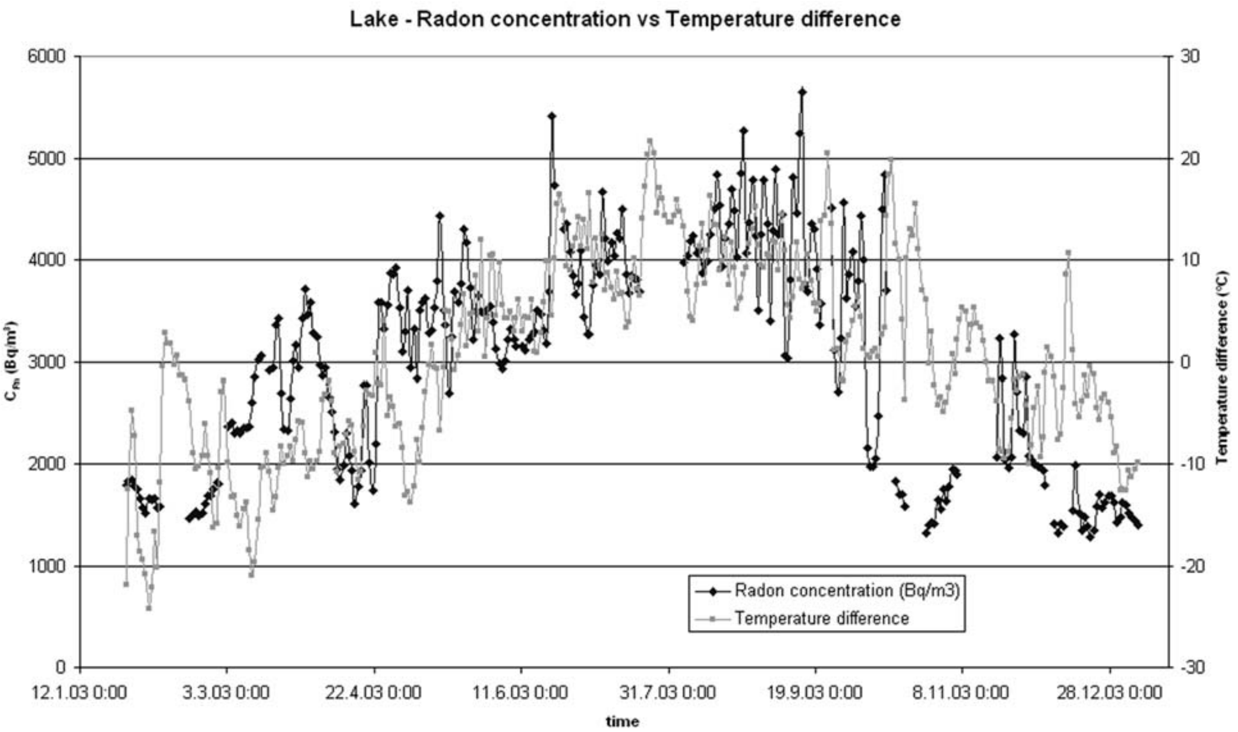

Fig. 3. Seasonal variation of radon concentration corresponding to the temperature difference.

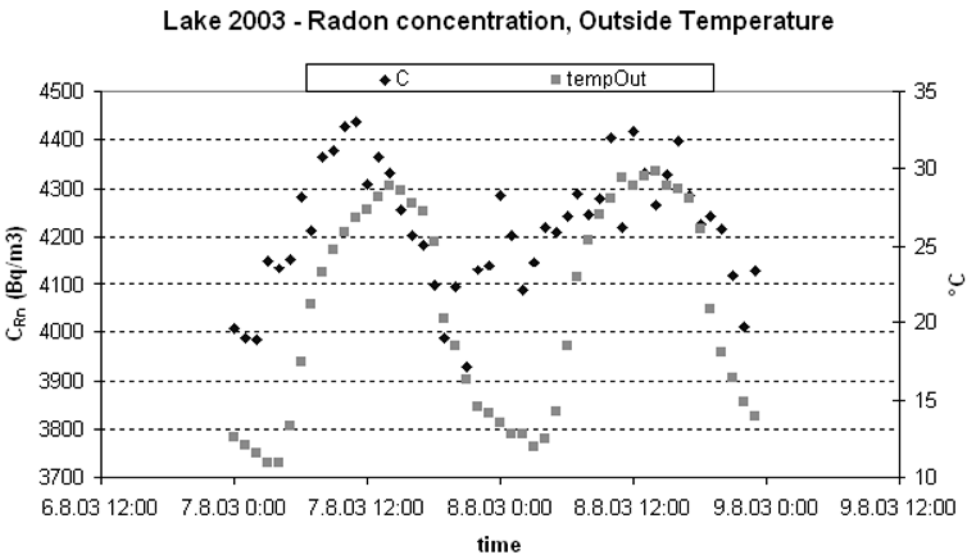

Fig. 4. Summer season, high positive temperature difference.

side temperature is depicted in graphs in Figs. 4 and 6. Table 1 shows the parameters of measured intervals. Three typical were chosen – hot summer with high outside temperature, winter during which the temperature

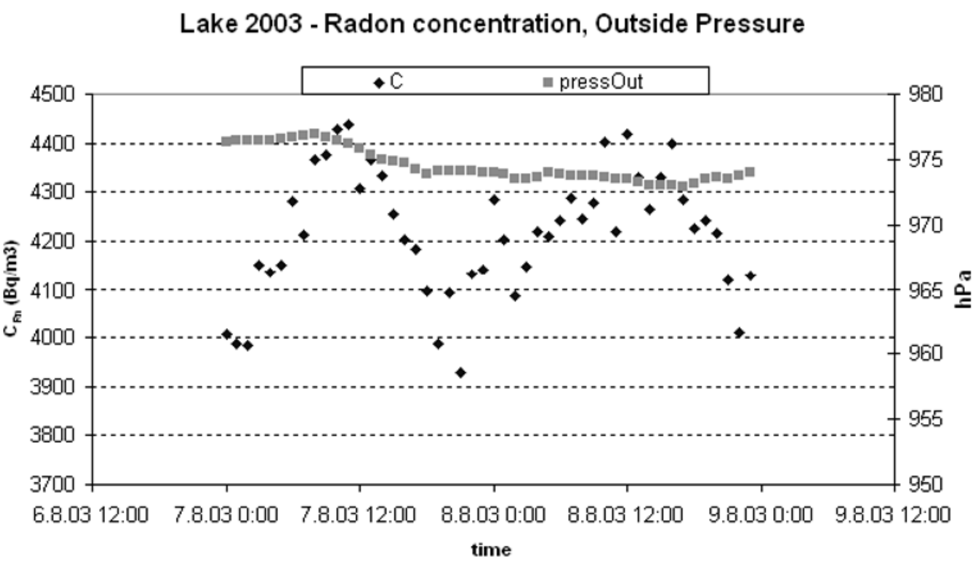

Fig. 5. Summer season, influence of pressure.

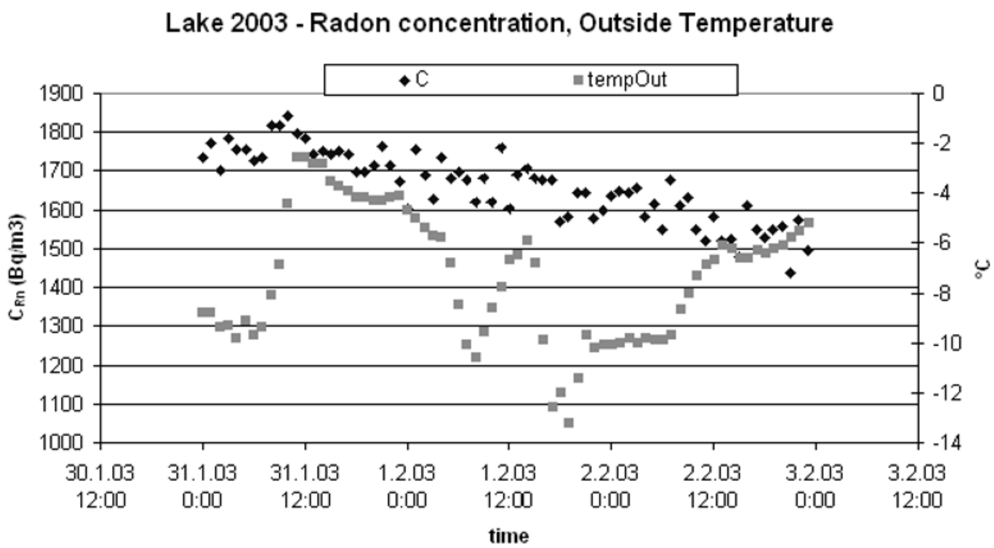

Fig. 6. Winter season, high negative temperature difference.

Table 1. Description of measured intervals in the Lake

Season	AvgC$_{Rn}$ (Bq/m^3)	AvgTempIn (°C)	AvgTempOut (°C)	AvgTemp difference
Summer	4220	10.7	21.0	10.0
Spring/Autumn	2850	10.8	9.3	–1.5
Winter	1660	9.7	–7.3	–17.0

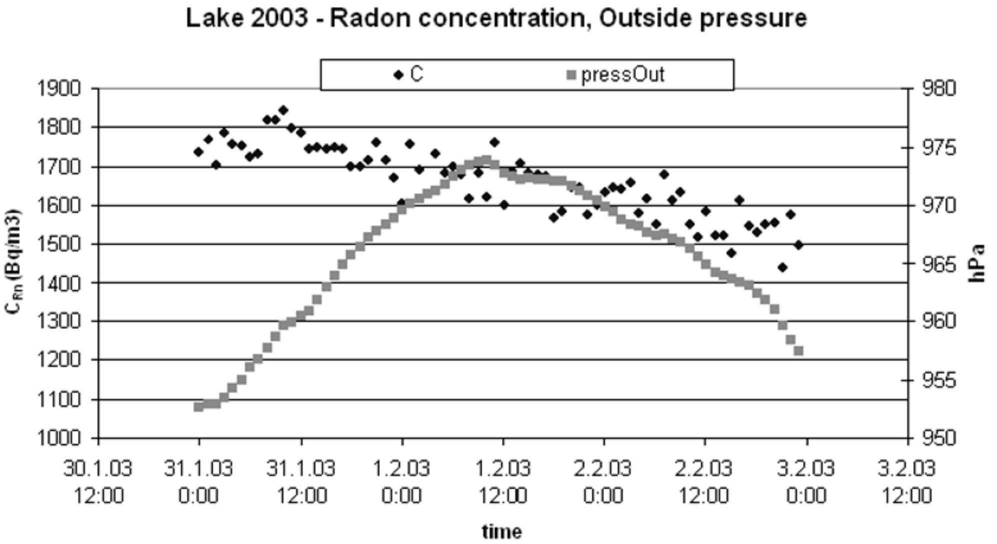

Fig. 7. Winter season, influence of pressure.

inside the case is much higher than in the outside, and spring/autumn period with nearly the same temperature inside the cave and outside the cave. The figures show that the time shift between changes in temperature and radon concentration is in the range of 2–12 h with the average of 7 h. The correlation is strongly dependent on the properties of period for which the correlation is evaluated. Figs. 5 and 7 shows the influence of outside pressure on the radon concentration.

Measurement in high RH

The authors compare the measurement with Radim3 placed in a plastic box with the desiccant (anhydrous $CaCl_2$) and in the free air in the cave. The data were acquired at the same time and at the same place (Hell). As can be seen from Fig. 8, the plastic box caused smoothing of the brief radon peaks. On the other hand, in the period without sudden concentration of peaks the

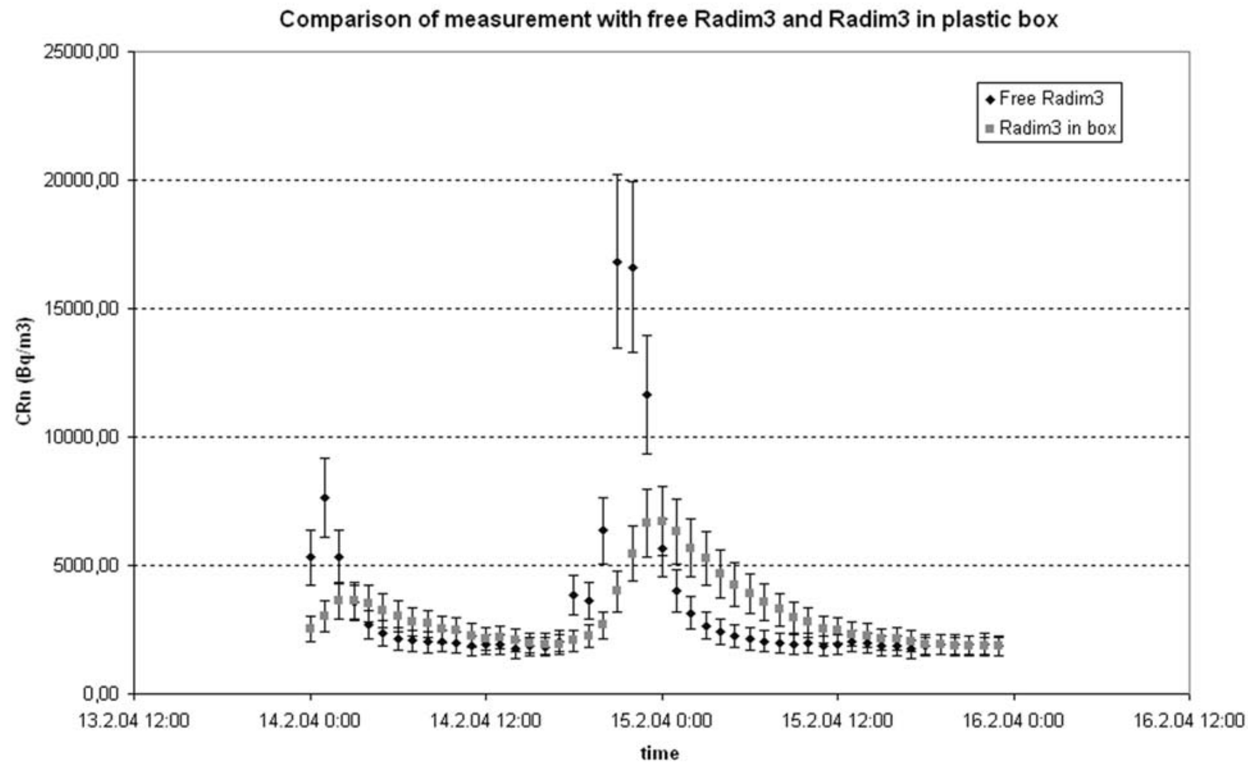

Fig. 8. Smoothing of radon concentration peaks due to the diffusion through a plastic box.

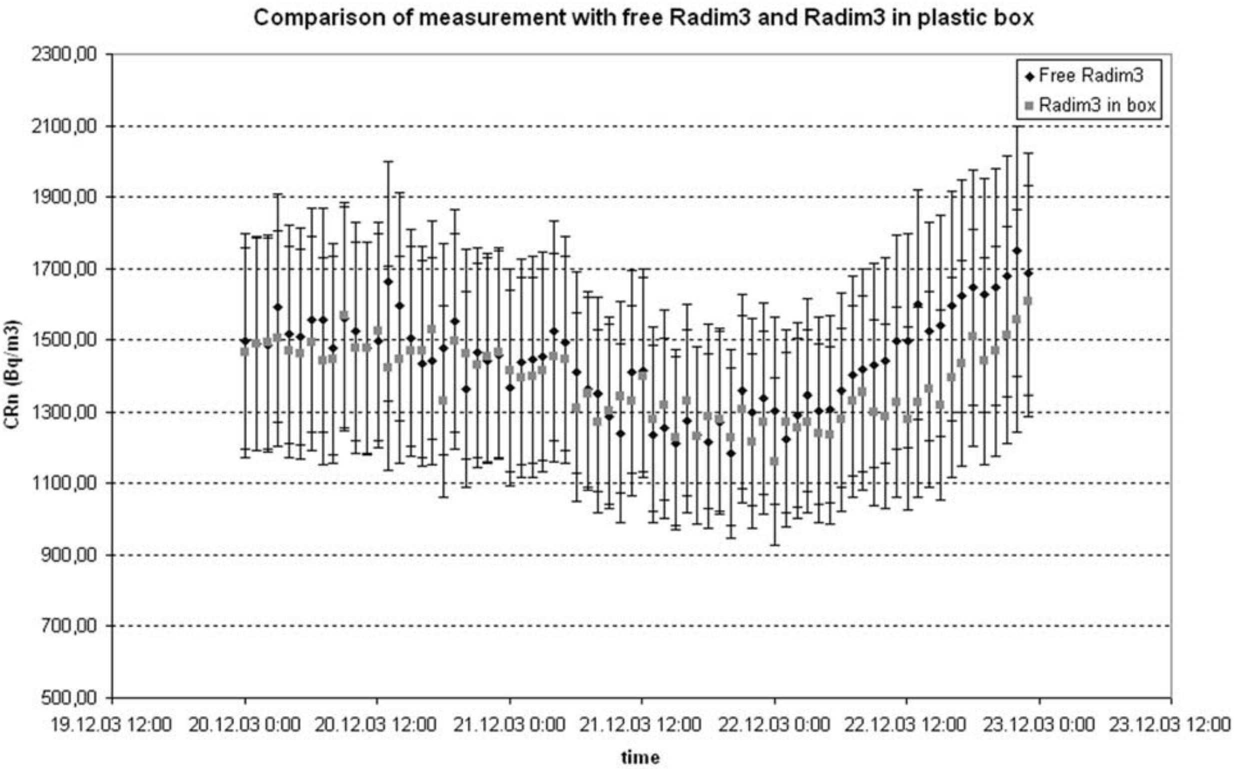

Fig. 9. Data measured with Radim3 in a box and free Radim3.

results from the free Radim3 and enclosed Radim3 in the plastic box are in good agreement (Fig. 9).

The average concentration for the period shown in Fig. 8 is 3420 Bq/m^3 for the free Radim3 and 3067 Bq/m^3 for the enclosed Radim3. The averages for the day after the peak maximum (second day of the interval shown) are 2287 Bq/m^3 for the free Radim3 and 3190 Bq/m^3 for the enclosed Radim3. Radon is diffusing through the plastic box and the peak is smoothed and delayed.

The average concentration for the period shown in Fig. 9 is 1444 Bq/m^3 for the free Radim3 and 1384 Bq/m^3 for the enclosed Radim3.

Comparison of the results of continuous measurement, average and SSNTD results

The data measured by the Radim3 monitor are due to black outs not consistent in time; there are intervals

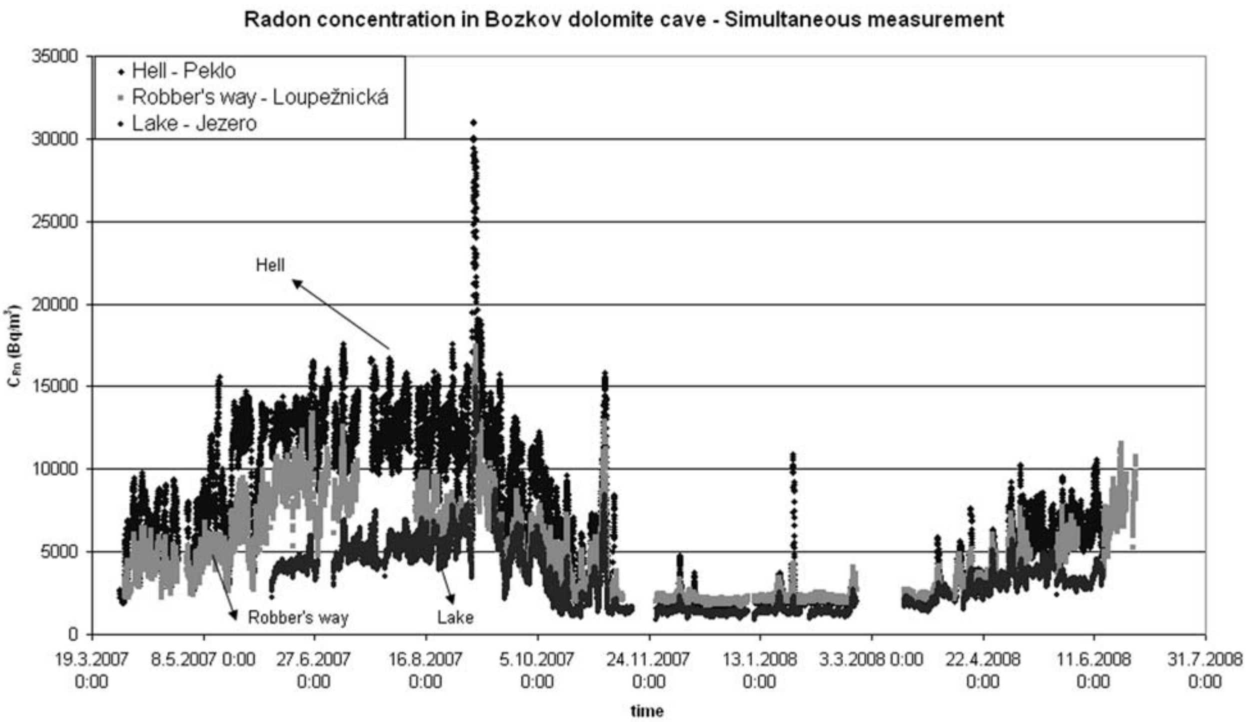

Fig. 10. Simultaneous measurement at three different places in the cave – Hell, Robber's way and Lake.

ranges from days to a month without data. Processing of the measured time series showed that it is not possible to substitute the missing data in a reliable way. Therefore, the comparison between the radon concentrations obtained by SSNTDs and from time series of continuous measurements is not relevant.

Simultaneous measurement of three different places in the cave

There are data available on one year simultaneous measurement of three different places in the cave – Hell, Lake and Robber's way (near to the Hell). The highest radon concentration occurs in the Hell (see Fig. 10), the lowest at the place called Lake which is the nearest to the exit out of the cave. As could be seen from Fig. 10, there is a really quick distribution of radon in the cave (e.g. period from 16th August 2007 to 24th November 2007). The reason is in the direction of air flow in the cave which is oriented towards the Lake and exit from the cave.

At this moment, the authors have not any explanation for the short and very high peaks of radon. Taking earthquake into account could be possible.

Summary

The processing of a long time series of radon concentration has shown the variability of concentration in year, during day and among the years. A comparison of radon concentration averages was not possible due to long intervals of missing data caused by black-outs. The substitution of missing data is not possible because of the radon concentration variability. The strong correlation between the concentration and temperature was shown in summer season when the temperature difference is very high. On the other hand, the radon concentration in the cave is stable during cold months. Quick distribution of radon concentration, visible in Fig. 10 may be due to mixing of air in the cave, or simultaneous release or "radon gas pockets".

This study is the preliminary one. It is necessary to compare the data with the air flow measurement, measurement of the seismicity and other measurable quantities. The local meteorological data are available since the end of 2008. The authors are trying to set up a new project in the co-operation with the Institute of Rock Structure and Mechanics of Academy of Sciences of the Czech Republic of on extensometry measurements on movement on the fault structure. The measurement results may help to answer lot of questions about the dynamics of the cave.

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