ANALYSIS OF LONG-TERM MEASUREMENTS OF RADON IN A DOLOMITE CAVE

Kateřina Rovenská[1,2] and Lenka Thinová[2]
[1]National Radiation Protection Institute, Bartoškova 28, 140 00 Praha 4, Czech Republic
[2]Czech Technical University, Faculty of Nuclear Sciences and Physical Engineering. Břehová 7, 115 19 Praha 1, Czech Republic

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 Radim3 monitor in 30-minute interval and 6-month average by LR115 SSNTD in the diffusion chamber placed at 8 points along the cave tour route. The radon concentration shows diurnal, seasonal, and yearly variations. The concentration maximum in the caves, in contrast to the dwellings, is in the summer time. At the same time, high variability of radon concentration occurs. Statistical analysis of the long-time series of radon concentrations was performed; the meteorological data were taken into account. In-situ and laboratory gamma spectrometric measurements are also included in this paper. The annual effective dose from radon for the cave guide (year 2006, working time spent in the cave 414 h) was 3.05 mSv; radon concentration used was obtained by SSNTD as described above.

Introduction

Public open caves 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. Several papers focusing on the dose assessment for cave guides have been published (Rovenská, 2008).

To fulfill the Czech national radiation protection standards and methodology, the radon concentration in the public open cave is measured by SSNTD Kodak LR 115 with the concentration integrated over a6 month time interval. The dose from radon has been evaluated on the basis of SSNTD results.

As far as one is interested in the dynamics of radon in the cave, one needs continuous record of radon concentration and other quantities that may influence the concentration. The development of the radon concentration time series is influenced by the temperature difference between the outside and the inside air, changes in pressure, strength of radon source, velocity and direction of air flow and other possible factors (i.e., local releasing of air pockets with high concentration, etc.) Study of the data could help the better understanding of the processes in the cave. Bozkov dolomite caves were chosen for this kind of measurement, which started in 2002**.**

Cave description

Bozkov dolomite caves (BDC), originated in Silurian period, are one of 13 of the 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 Krkonoše foothills. Caves originated in karstic mass in the area of Zelezny Brod crystalline regions.

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 bluegreenish water. The caves and their surroundings is a protected area; protected both by nature and by landscape protection law.

The average temperature in the cave is between 7.5 – 9 °C, the relative humidity is near 100%. The cave tour is 350 m long and takes 45 minutes. Figure 1 shows the map of the cave on which measurement points are depicted with the red points. The BDC has been continually monitored since 2002.

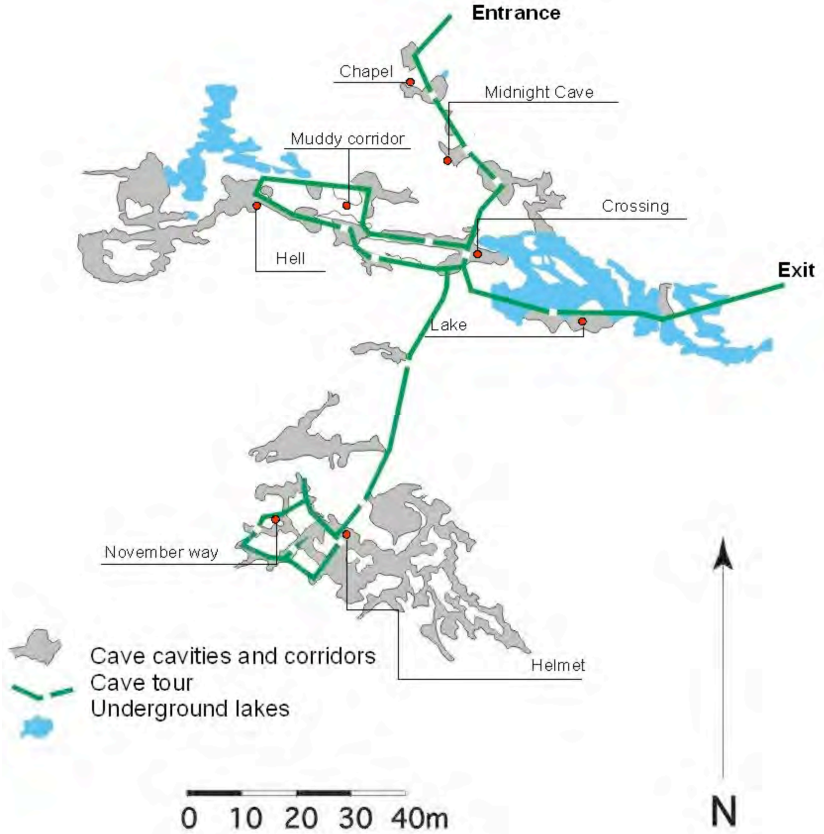

Figure 1: Map of the Bozkov dolomite cave, red points are SSNTD measuring points

Methods of measurement

Radon

Radon has been monitored in two ways in the cave. Continuously, by a Radim3 continuous monitor with 30-minute response intervals and as an average for 6 months by SSNTD (also called alpha track detectors). Radim3 consists of a small diffusion chamber and semiconductor detector. Radon concentration is determined by spectrometric measurement of the RaA alpha activity. Statistical error is equal to ± 20%. A power supply is necessary for operating the monitor. Blackouts often stopped the data acquisition and it was necessary to start the device manually. The effect of humidity is compensated up to 90% RH by the device itself.

In case of an averaged measurement of radon concentration, the cave has been monitored by SSNTD using Kodak LR115 foil as free detectors and since 2004 enclosed in the plastic diffusion chamber called Ramarn. There are 8 SSNTDs for summer starting on 1st of April and ending on 31st of October and 4 SSNTDs for winter season (lower concentration) placed along the cave tour route. The concentration was integrated per 6 months according to the summer and winter use in the cave.

Meteorological data

Meteorological data were obtained from the Liberec meteo-station, which is owned and operated by the Czech Hydro-meteorological Institute. The Liberec station is 20 km, straight-line, from the Bozkov village.

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

Annual variations

The annual variation is demonstrated on the Fig. 2 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 the Fig. 3, from which the variation is also visible.

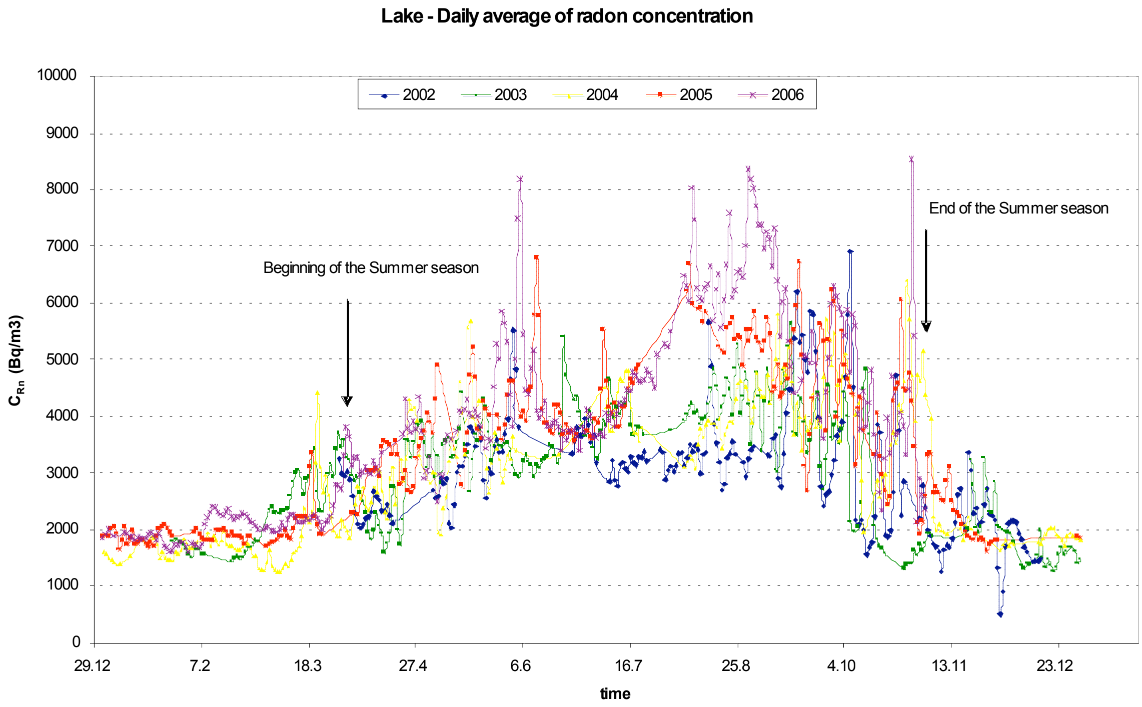

Figure 2: Interannual variation of radon concentration

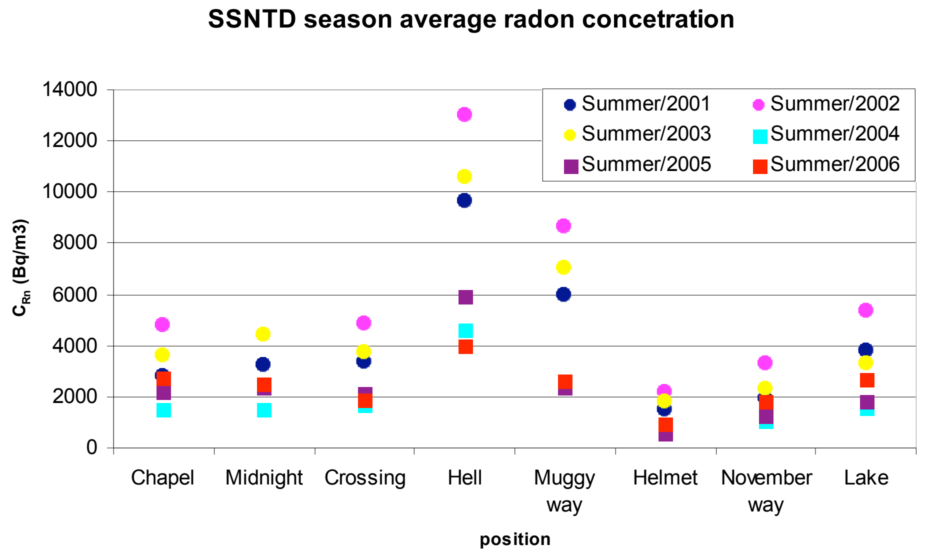

Figure 3: Interannual variation measured with SSNTD, circles - free SSNTD, squares - SSNTD in diffusion chamber (Thinová, 2008)

Seasonal variations

The highest radon concentration in the cave is found in the hot summer time. Assuming that in the lower inaccessible parts of the cave some of the radon sources (sediments and rocks with high content of ^{226}Ra) are present, the increase in concentration is caused by the stack effect[1] determined by outside and inside temperature difference. A one-year progress of the radon concentration and temperature difference is shown in the Fig. 4.

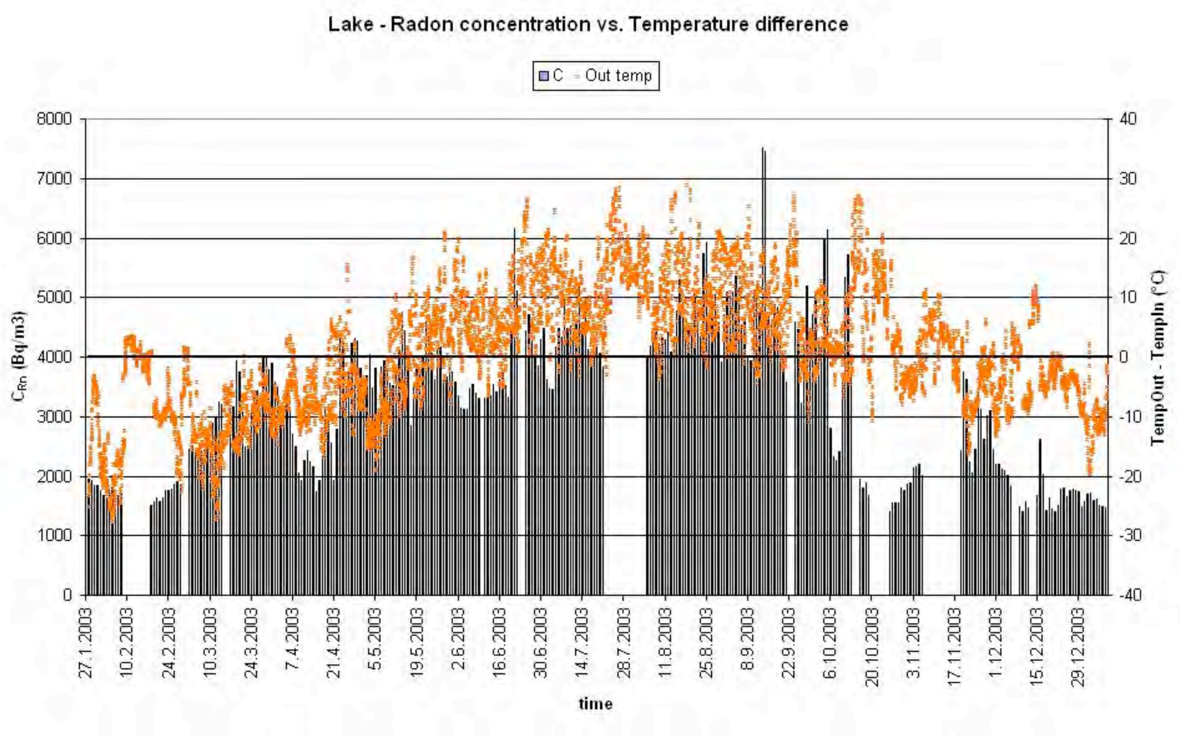

Figure 4: Seasonal variation of radon concentration corresponding to the temperature difference

[1] Stack effect is caused by the cold cave air escaping into the outer atmosphere.

Diurnal variations

Equally to the seasonal variations the diurnal ones are influenced mainly by the temperature difference. This dependence is depicted in following six graphs (see Fig. 5 – 10). Table 1 shows the parameters of measured intervals. The temperature difference was obtained as a difference between outside and inside temperature.

Table 1: Description of measured intervals in the Lake

Season	AvgC$_{Rn}$ (Bq/m^3)	AvgTempIn (°C)	AvgTempOut (°C)	Avg Temp difference
Summer	4220	10.7	21	10.0
Autumn	2850	10.8	9.3	-1.5
Winter	1660	9.7	-7.3	-17.0

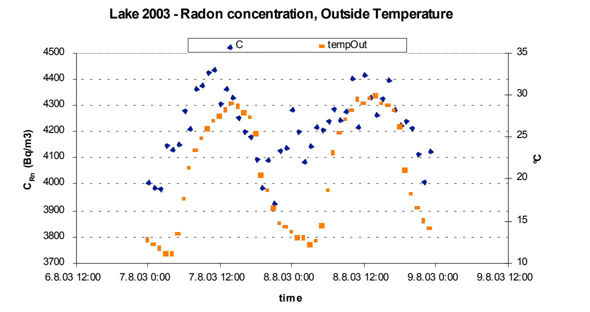

Figure 5: Summer season, Temperature difference high

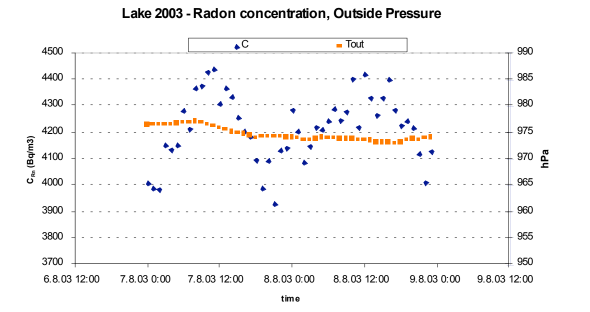

Figure 6: Summer season, influence of pressure

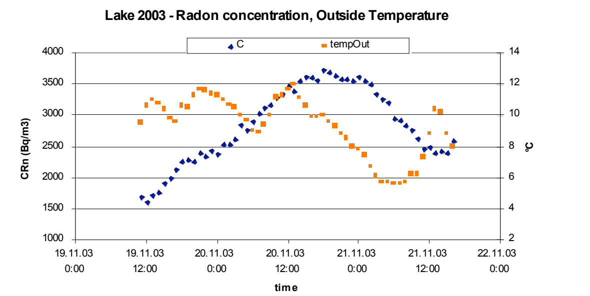

Figure 7: Autumn season, Temperature difference near zero

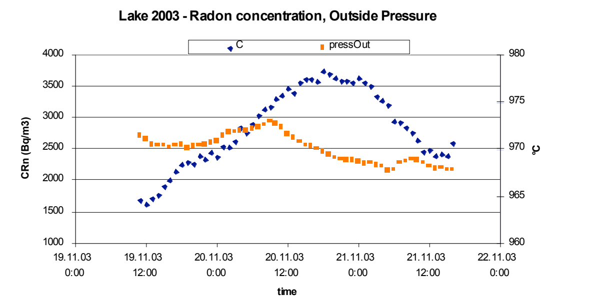

Figure 8: Autumn season, influence of pressure

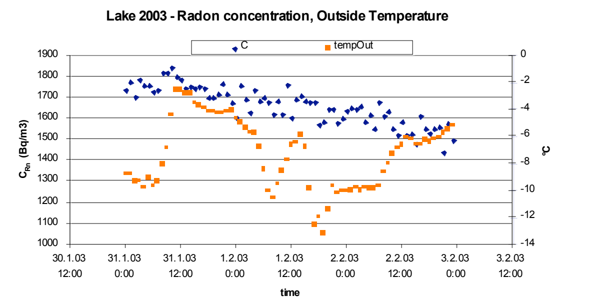

Figure 9: Winter season, Temperature difference high

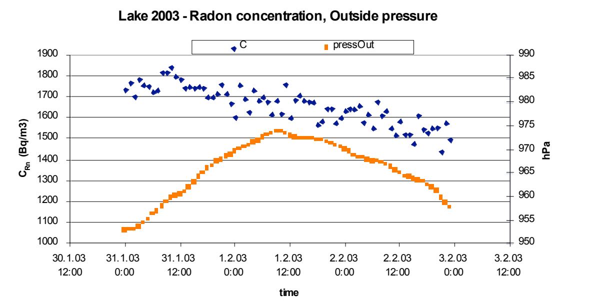

Figure 10: Winter season, influence of pressure

These figures show that the time shift between changes in temperature and radon concentration is in the range of 2 – 12 hours with the average of 7 hours. The correlation is strongly dependent on the properties of period for which the correlation is evaluated.

Measurement in high relative humidity

The following section will show the comparison of measurement with Radim3 placed in a plastic box with desiccant 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 11, the plastic box caused smoothing of the brief radon peaks. On the other hand, in the period without the sudden concentration peaks, the results from free Radim3 and enclosed Radim3 in the plastic box are in a good agreement (Fig. 12).

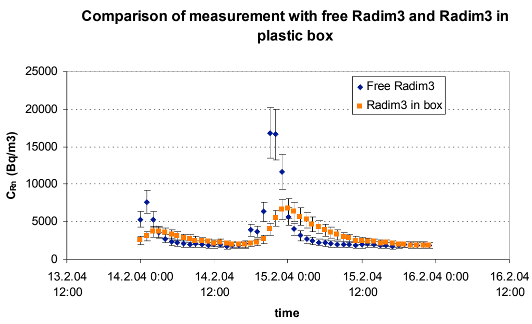

Figure 11: Smoothing of peaks

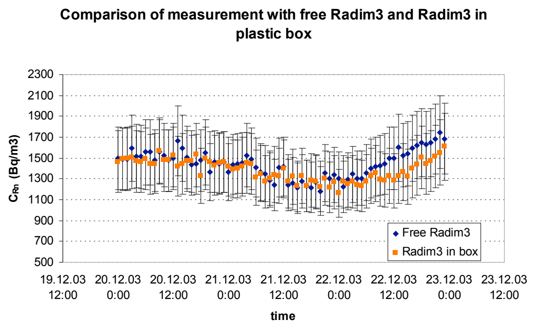

Figure 12: Good agreement of the measured data

The average concentration for the period shown in Fig. 11 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. 12 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

Because of the inconsistent variation of the data, it was not possible to substitute for 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.

Gamma spectrometry analysis

Gamma spectrometry was performed on rock and sediments samples. Table 2 shows the spectrometry results. These values are little higher than the average content in other public open caves.

Table 2: Description of measured intervals (Thinová, 2007)

Activity (Bq/kg)				
		^{40}K	^{228}Th	^{226}Ra
Bedrock	Phyllite 01	385.0 ± 13.6	2.2 ± 0.6	3.3 ± 0.4
	Phyllite 02	261.1 ± 8.2	3.0 ± 0.3	7.7 ± 0.2
Sediments	Hell	468	15	51
	Crossing	378	20	29
	Lake	363	13	31

Radon concentration in water samples

Radon concentration in water was measured by Radim4. The measured activities are 7.6 Bq/l in average. This value is one of the highest among the water samples taken in public open caves. On the other hand, the average concentration in drinkable water in the Czech Republic is 15 Bq/l.

Summary

The processing of long time series of radon concentration showed the variability of concentration in year, during day and among the years. Therefore, it is not possible to substitute the missing data by the data from other period or other years. The strong correlation between concentration and temperature was shown in summer season when the temperature difference is very high. On the other hand the concentration in the cave is stable during cold months.

This study is a preliminary one. It is still necessary to compare the data with the air flow measurement, measurement of the seismicity and other measurable quantities.

References

1. Thinová L: Final report for the project VaV 12/2006: Correction of dose assessment for the underground workers, Praha 2007, in Czech.

2. Rovenská K., Thinová L.: Assessment of the dose from radon and its decay products in the Bozkov dolomite cave, in: Radiation Protection Dosimetry, 2008, doi:10.1093/rpd/ncn114.

3. Thinová L., Burian I.: Effective dose assessment for workers in caves in the Czech Republic – experiments with passive radon detectors, in: Radiation Protection Dosimetry, 2008, doi:10.1093/rpd/ncn118.