Radon Levels in Manita peć Cave (Croatian National Park Paklenica) and Assessment of Effective Dose Received by Visitors and Tourist Guides

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How far from Glasgow is this beauty?

This is the only cave open for visitors among 70 others speleological objects inside NP Paklenica. With 175 m in length is not very long cave, but famous for numerous cave ornaments[1]. Manita peć cave is very popular due to vicinity of numerous tourist places on the Adriatic coast (around 11 000 people visits the cave every year).

Caves in karst areas are mostly made of limestone which in average contains 1.3 - 2.5 ppm uranium ^{238}U, and since radon ^{222}Rn ($T_{1/2}$=3.825 days) is one of the uranium progeny we can expect elevated radon concentrations in some caves.

Radon concentration in caves is under the influence of many parameters:

- radon exhalation rate from the cave surfaces
- shape and size of the cave
- air exchange rate inside/outside and reversely

In the last three decades, radon concentrations were measured in the caves throughout the world [2-8], and in our neighboring countries [9-13]. Hakl[14] systematize radon concentrations in caves and concluded that distribution of analyzed data is log-normal, with arithmetic mean of 2.8 kBq m^{-3} and values were in range of 0.1 and 20 kBq m^{-3}.

In the Republic of Croatia, radon in pits and caves is extensively measured since 2004. Detectors are set up during the speleological researches with the purpose of exploring physical and chemical properties of the karst underground. Until today, radon concentrations were measured in about twenty caves and pits in the Velebit and Žumberak mountains [15-16]. Another cave, Đurovića cave is located near the control tower of the Dubrovnik airport, which makes it very interested for the tourist. Obtained average radon concentration during monitoring period (in the late autumn 2008, spring and summer in 2009) were 9.5, 17.9 and 25.0 kBq m^{-3}, respectively[17].

Active detectors?....Passive detectors?.......Both?

In June 2010 we started a fifteen months monitoring of natural radioactivity from radon and it's short lived progeny by means of solid state nuclear track-etched detectors. We used the method with two LR 115 type II films per detecor cup in order to determine radon concentration and equilibrium factor *F* in every climatic season of the year [18].

Additional measurements were performed during summer period because of the intense tourist activities in this time of the year. Daily variations of radon and radon progeny were monitored by AlphaGUARD measuring system [19] connected to the Radon WL Meter TN-WL-02.

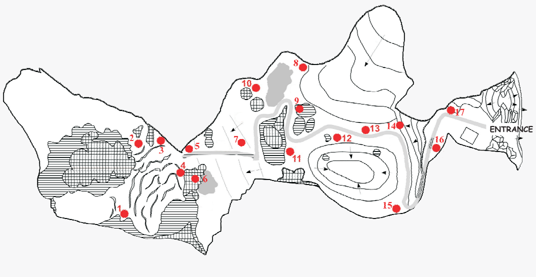

Figure 1. Ground plan of Manita peć cave, with marked measuring locations of radon detectors. (picture is received by courtesy of NP Paklenica)

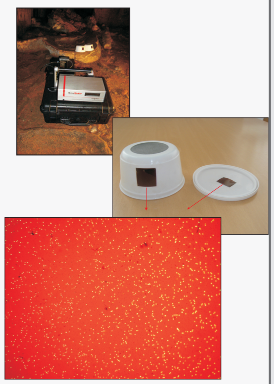

Figure 2. *On the top:* AlphaGUARD measuring system connected to the Radon WL Meter TN-WL-02. *On the right:* two detector cups with LR 115 type II detectors. *Detail:* etched detector surface under the microscope, revealing alpha tracks.

Radon concentrations

Average values of radon concentration on all measuring locations for two successive summers in 2010 and 2011 was 1.1 kBq m^{-3} which was much higher than in other climatic seasons. Obtained value categorize Manita peć cave among caves with lower radon concentration than the world average (2.8 kBq m^{-3}) [14].

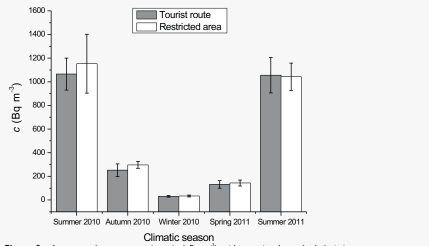

Figure 3. Average radon concentrations (c / Bq m^{-3}) with associated standard deviations, along the tourist route and inside restricted area in Manita peć, according to the climatic seasons.

Equilibrium factor

Was determined using method with two LR 115 II detectors[18]; average equilibrium factors for each monitoring season are shown in Figure 4.

Results of our measurements are in good agreement with measurements of equilibrium factors in other karst caves [20-21].

The two-day measurements in every climatic season using the AlphaGUARD measuring system gave average equilibrium factor for the monitoring period $F_{AlphaGUARD}$ = 0.50 ± 0.18.

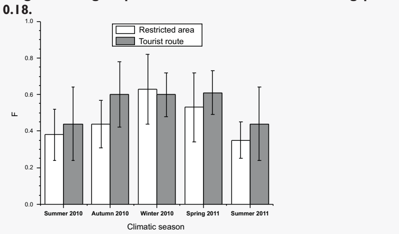

Figure 4. Average values of equilibrium factors *F*, for the tourist route (gray color) and restricted area (white color), according to the climatic periods.

How air temperature affects radon concentration?

Manita peć is a horizontally structured cave. Radon concentrations in such caves is mainly under the influence of temperature difference between air inside the cave (which is constant through out the year - around 10 °C) and the air outside the cave. Temperature gradient is the main mechanism of radon concentration reduction (during winter) or enhancement (during summer)[14]:

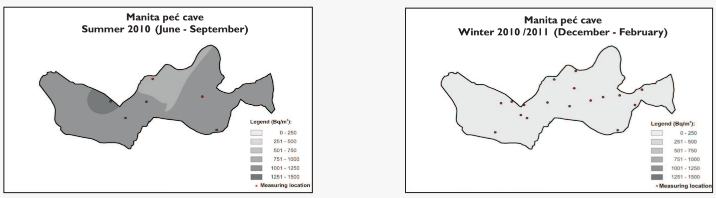

Figure 5. Spatial distribution of radon concentrations for two extremes in the cave: during the summer (on the left) and winter period (to the right).

Is radon concentration affected by visitors?

Daily variations in concentration of radon and radon short lived progeny, that would be a consequence of tourist activities inside the cave, are not detected.

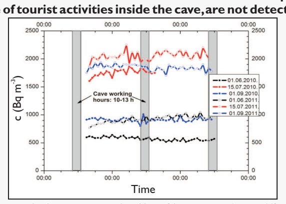

Figure 6. Time serie of radon concentration (o; c / Bq m-3) at measuring location M3 in Manita peć cave in the different climatic periods (legend) during the work hours of the cave (during enhanced human activity).

How are visitors and workers affected by radon?

VISITORS

The calculated average effective dose received by the visitor in half an hour visit of the cave in the first part of summer 2010 was 1.6 µSv and 2.2 µSv for the visitors in the second part of summer 2010. Similar values was obtained for the summer 2011.

TOURIST GUIDES

Largest dose in 2010 of 0.247 mSv was received by the tourist guide that spent 121.5 hours inside the cave (from the April to the October), while in 2011 the same tourist guide received the dose of 0.215 mSv for 106.5 working hours inside the cave.

These values are 50 times lower than 10 mSv per year which is maximum value for the occupational exposures[22-23].

Table 1. Time spent inside the Manita peć cave, *t* / h, average radon concentrations, *c* / Bq m^{-3} and average equilibrium factors *F*, with appropriate effective dose for every guide *E* / µSv (for the cave working seasons) during the years 2010 and 2011.

	Spring 2010.				Summer 2010.				Autumn 2010.				2010
	t	c	F	E_S	t	c	F	E_S	t	c	F	E_A	E (µSv)
guide 1	27			16,8	49,5			181,8	45			48,4	247,0
guide 2	12			7,5	16,5			60,6	12			12,9	81,0
guide 3	9			5,6	0			0,0	3			3,2	8,8
guide 4	13,5			8,4	7,5			27,5	0			0,0	35,9
guide 5	1,5			0,9	34,5			126,7	16,5			17,8	145,4
guide 6	0			0,0	45			165,3	13,5			14,5	179,8
guide 7	0			0,0	40,5			148,7	7,5			8,1	156,8
guide 8	0			0,0	25,5			93,6	15			16,1	109,8
guide 9	0	136	0,58	0,0	7,5	1113	0,42	27,5	15	257	0,53	16,1	43,7
	Spring 2011.				Summer 2011.				Autumn 2011.				2011
	t	c	F	E_S	t	c	F	E_S	t	c	F	E_A	E (µSv)
guide 1	27			16,8	46,5			157,9	37,5			40,4	215,0
guide 2	3			1,9				0,0				0,0	1,9
guide 3	1,5			0,9				0,0				0,0	0,9
guide 4	6			3,7	37,5			127,3	18			19,4	150,4
guide 5	7,5			4,7	51			173,1	33			35,5	213,3
guide 6	9			5,6	1,5			5,1				0,0	10,7
guide 7					18			61,1	22,5			24,2	85,3
guide 8					36			122,2				0,0	122,2
guide 9		136	0,58		34,5	1048	0,41	117,1	18	257	0,53	19,4	136,5

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