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ORIGINAL PAPER

Background outdoor radon levels in Slovenia

Janja Vaupotič,
Ivan Kobal,
Milko J. Križman

Abstract. Radon (^{222}Rn) activity concentration in outdoor air was measured by exposing track etch detectors at 60 points. Values were found in the range of 3.7–41.0 Bq·m^{-3}, with a geometric mean (GM) of 11.8 Bq·m^{-3} and geometric standard deviation (GSD) of 2.2. An outdoor radon map of Slovenia was drawn, showing the majority of elevated values to be in the south-west part of the country that is covered by carbonates.

Key words: radon • outdoor air • solid-state nuclear track detectors (SSNTD) • outdoor radon map

J. Vaupotič✉. I. Kobal
Department of Environmental Sciences,
Radon Center,
Jožef Stefan Institute,
39 Jamova Str., SI-1000 Ljubljana, Slovenia,
Tel.: +386 1 477 3213, Fax: +386 1 477 3811,
E-mail: janja.vaupotic@ijs.si

M. J. Križman
Slovenian Nuclear Safety Administration,
16 Železna Str., SI-1000 Ljubljana, Slovenia

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Introduction

The national radon survey in Slovenia, started in 1991, and has been conducted in several steps, including radon indoors, in soil and outdoors. In the first years, radon activity concentration was measured in indoor air of a thousand randomly selected dwellings [8], and practically in all the kindergartens (730 buildings) and schools (890 buildings) in the country [17]. In subsequent years, radon was surveyed mainly at workplaces in different environments: in five major spas, 26 major hospitals, 10 major water supply plants [17], eight major wineries [18], in several show caves, focusing mainly on the largest, Postojna Cave [19], and in about 100 public buildings (bus and railway stations, health care centres, university premises, police and customs offices, and others). In the last step, radon was measured in soil gas at about a hundred points over the entire country and a map of radon potential of soil was made [20].

Finally, in this work, radon in outdoor air was measured at 60 points distributed almost uniformly over the country. Information on radon background levels is essential to assess anthropogenic contributions [15]. Outdoor radon may also contribute to radon levels in houses, because in some parts of the country radon levels outdoors are higher than indoors. In the present paper, measurements are described and results presented and commented. This was the first nation-wide outdoor radon survey, while previous outdoor measurements were limited only to uranium [6, 7] and mercury [9] mining and milling sites.

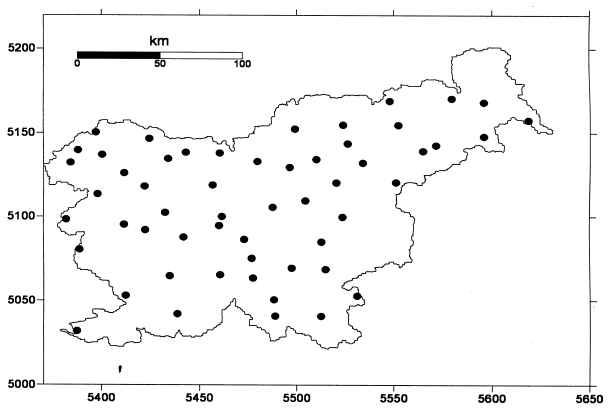

Fig. 1. Measurement points for the outdoor air radon survey in Slovenia.

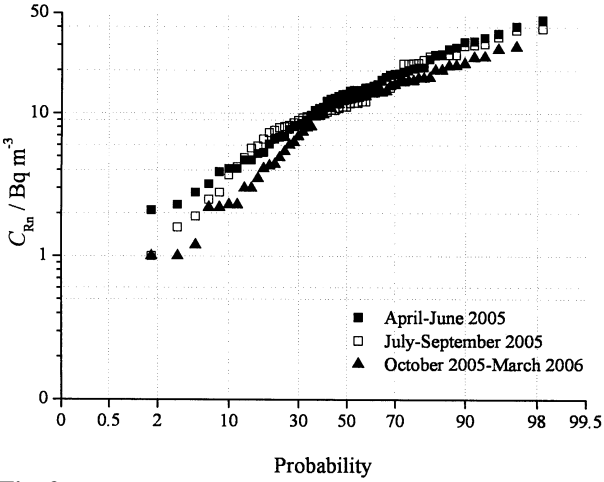

Fig. 2. Lognormal plots of radon concentrations in outdoor air obtained by three measurement campaigns at 60 points in Slovenia.

Experimental

Radon activity concentration in outdoor air was measured by exposing Radonlab (Radonlab Ltd. Laboratories, Norway) detectors, based on a CR-39 foil, in three periods: March–June 2005, July–September 2005 and October 2005–March 2006, as proposed for the survey by the Slovenian Nuclear Safety Administration. Detectors were exposed at the same 50 points (mostly near meteorological stations), at which gamma dose rate is being monitored continuously with thermoluminescent dosimeters, and at which radon was measured in soil gas in our previous study [20]. Except for the mountainous areas, the points are almost uniformly distributed over the country in an irregular grid with mostly 20 × 20 km squares (surface area 20 thousand km^2). Additional track etch detectors were exposed at 10 sites where elevated radon levels in outdoor air were expected due to coal, mercury and uranium mining, or where our previous studies had revealed elevated radon levels in indoor air [17]. Thus, in total there were 60 measurement points (Fig. 1). At each point, a pair of detectors was fixed at a height of 1.5 m above ground. Initially, the detectors were exposed by our technicians during their visits to each site and, after exposure, collected and mailed back to our laboratory by the persons either responsible for meteorological stations or who owned the land on which the detectors were exposed. The same persons were mailed detectors for the second and third periods; they exposed them and mailed them back to the Institute. All the detectors were then mailed to Radonlab for development and data evaluation.

Results and discussion

Results are shown in Fig. 2. Data of all the three measurements fit well a lognormal distribution. According to the *t*-test, they do not differ significantly (Table 1), although higher values in winter and lower in summer have sometimes been observed [1, 3, 10, 13]. Radon concentrations outdoors ranged from 3.7 to 41.0 Bq·m^{-3}. The overall GM of 11.8 Bq·m^{-3} (Table 2) is slightly higher than the world average of 10 Bq·m^{-3} [15, 16]. It

Table 1. Comparison of outdoor air radon concentrations (Bq·m^{-3}) at 60 points in Slovenia obtained in different periods (*N* – number of readings, AM – arithmetic mean, ASD – arithmetic standard deviation)

Period of measurement	*N*	AM	ASD	*t*-value	*p*-value
March–June 2005	119	15.4	13.6	1.400	0.163
July–September 2005	120	13.2	10.3		
July–September 2005	120	13.2	10.3	0.296	0.767
October 2005–March 2006	118	12.8	10.0		

Table 2. Radon concentrations (Bq·m^{-3}) in outdoor air at 60 points spaced out in Slovenia, and their distribution with respect to lithological units; given are: MIN – minimum; MAX – maximum; MEDIAN – median value; AM – arithmetic mean; GM – geometric mean; ASD – arithmetic standard deviation; GSD – geometric standard deviation

Number of points	Classification	MIN	MAX	MEDIAN	AM	ASD	GM	GSD
60	Entire Slovenia	3.7	41.0	12.4	14.5	10.3	11.8	2.2
Lithological unit								
23	Carbonates	4.6	47.2	18.8	18.9	9.5	16.3	1.8
8	Clastic sediments	9.1	24.8	11.8	13.6	5.3	12.9	1.4
11	Tertiary sediments	3.2	17.4	13.1	12.1	4.3	11.2	1.6
10	Gravel deposits	6.2	18.8	12.9	12.5	3.5	12.0	1.4
5	Clay-gravel deposits	6.5	13.2	8.1	9.0	2.8	8.6	1.3
3	Sea and lake sediments	4.0	8.8	6.1	6.5	2.5	6.2	1.5

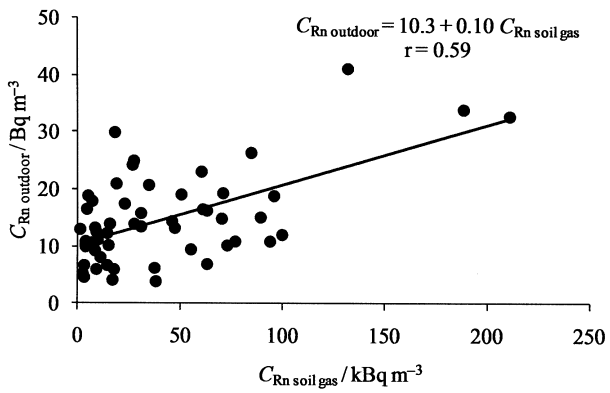

Fig. 3. Relationship between radon concentration in outdoor air and that in soil gas obtained in a previous study at the same points in boreholes at 80 cm depths [20].

is also similar to the average values observed during long-term monitoring in Munich, Germany (radon equilibrium equivalent concentration of 6.9 Bq·m^{-3} [5]) and in the whole of Germany of 9 Bq·m^{-3} [4], in Milan, Italy (15 Bq·m^{-3} in winter and 5 Bq·m^{-3} in summer [13]), and in Cyprus (11 Bq·m^{-3} [12]), but higher than at 13 places in the Czech Republic (radon progeny concentration in the range of 1–3 Bq·m^{-3} [2]), and lower than in Bucharest, Romania (radon progeny concentration in the range of 5–22 Bq·m^{-3} [1]).

The highest AM (18.9 Bq·m^{-3}) and GM (16.3 Bq·m^{-3}) values were found over carbonates (Table 2), covering almost half of the country, mostly on the south and west, where the majority of elevated radon levels were previously found in indoor air [2] and soil gas [20]. In order to seek support for the latter relationship, results of outdoor radon in this study were plotted versus the radon data in soil gas previously obtained [20]. A relatively good correlation was obtained, with a correlation coefficient of about 0.6 between the outdoor air and soil gas radon levels (Fig. 3), in agreement also with some other studies [14, 21].

A map of outdoor air radon levels was constructed, based on the one-year average data (Fig. 4). The regions with elevated values are seen in the south-west part of the country that is covered by carbonates. Higher values in the regions of uranium mining at Žirovski Vrh, mercury mining at Idrija and coal mining at Kočevje are not ascribed to geology alone, but also to local meteorological conditions, especially to temperature inversions, that occur frequently in winter. Elevated values, although expected, were not found in the granite region near Maribor at the Austrian border, where gamma dose rate is a factor of 2 to 3 fold higher than elsewhere in the country. Clearly, emanation from the compact granite is lower. Thermal and mineral waters rich in ^{226}Ra are abundant in the most north-easterly part of the country, but elevated outdoor radon levels were not observed because of the surface layer of clay which, if it is not dry, is a good barrier to radon transport to the atmosphere [11]. The regions of elevated radon levels coincide well with those of elevated indoor air [17] and soil gas [20] levels.

We are aware of the limitations posed on the track etch technique when applied outdoors. In contrast to indoors, the detectors are unavoidably exposed for at least three months to substantial changes of air temperature, humidity and precipitation, both rain and snow. However, during detector manipulation (storage, exchange and mailing), we kept them indoors for the shortest possible time, thus minimizing the contribution from indoor air. On average, radon concentrations

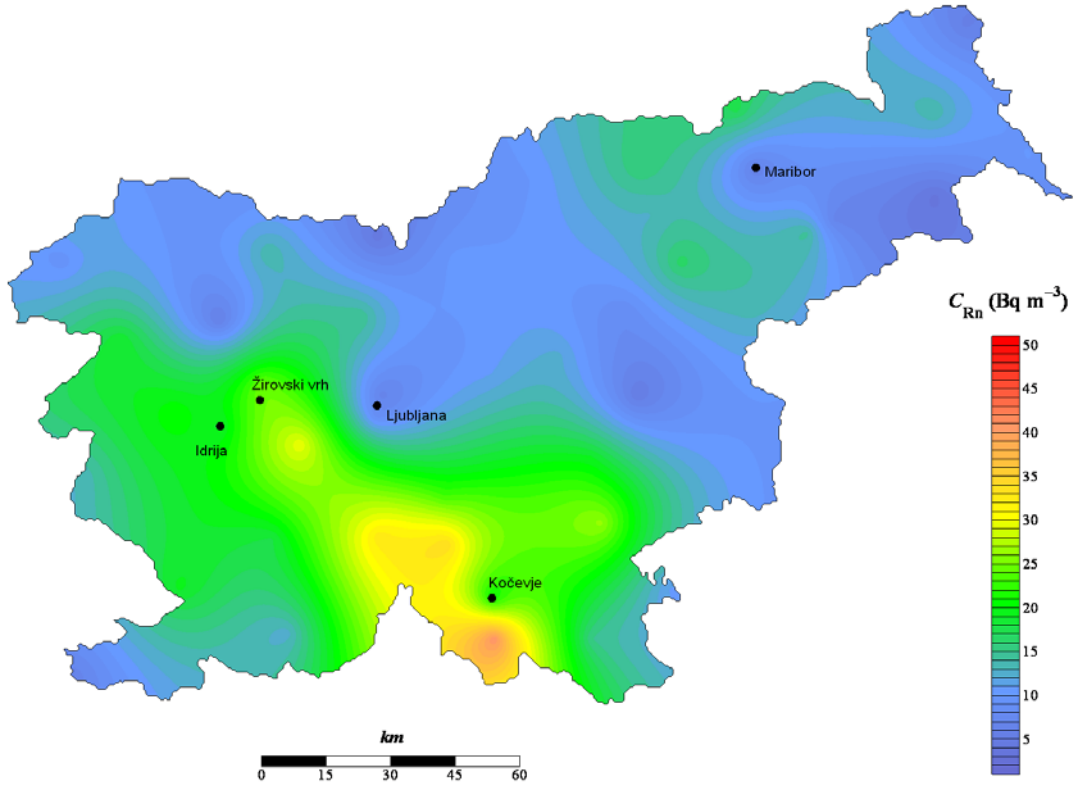

Fig. 4. Map of Slovenia with contours of iso-concentrations of radon in outdoor air.

obtained with a detector pair at a given place differ by less than 10% in about one third of places, 10–30% in another third of places, and more than 50% in the other third of places. Although radon concentrations did not generally differ significantly between seasons at the same place, they differed substantially at a few places, most probably due to an extra exposure during improper storage, exchange or mailing of detectors.

Conclusion

Radon concentrations in outdoor air measured at 60 points all over the country have an overall GM of 11.8 $Bq \cdot m^{-3}$, with a GSD of 2.2. With respect to the lithological units, the highest values (GM = 16.3 $Bq \cdot m^{-3}$) were observed over carbonates in the western and southern parts of the country. A map of outdoor radon was made. It has been concluded that the regions of low and high radon concentrations outdoors coincide well with those for indoor air and soil gas.

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References

1. Baciu AC (2005) Radon and thoron progeny concentration variability in relation to meteorological conditions at Bucharest (Romania). J Environ Radioact 83:171–189
2. Burian I, Otahal P (2009) Radon and its decay products in outdoor air. Appl Radiat Isot 67:881–883
3. Fisenne IM, Keller HW (1996) Continuous indoor and outdoor measurements of ^{222}Rn in New York City: city as a source. Environ Int 22;S1:S131–S138
4. Gerhke K, Kümmel M, Dushe C (2008) Background radon levels in Germany and how to take them into account in radiological evaluations. In: Strand P, Brown J, Jolle T (eds) Proc of the Int Conf on Radioecology and Environmental Radioactivity, 15–20 June 2008, Bergen, Norway. Part 1, pp 92–95
5. Hötzl H, Winkler R (1994) Long-term variation of outdoor radon equilibrium equivalent concentration. Radiat Environ Biophys 33:381–392
6. Kobal I, Škofljanec M, Kristan J (1980) Outdoor and indoor radon concentrations in air in the territory of Slovenia, Yugoslavia. In: Proc of the Symp Natural Radiation Environment III. 1978 Houston, Texas, USA. Technical Information Center/US Department of Energy, CONF--780422. Vol. 2, pp 1415–1523
7. Križman M, Ilić R, Skvarč J, Jeran Z (1996) A survey of indoor radon concentrations in dwellings in Slovenia. In: Glavič-Cindro D (ed) Proc of the Symp on Radiation Protection in Neighbouring Countries in Central Europe, 4–8 September 1995, Portorož, Slovenia, pp 66–70
8. Križman M, Stegnar P (1992) Environmental impact of the Žirovski vrh uranium mine on the enhancement of outdoor radon concentration. Radiat Prot Dosim 45:723–728
9. Križman M, Stegnar P, Miklavžič U (1996) Mercury processing – a new source of technologically enhanced natural radioactivity. Environ Int 22;S1:S251–S258
10. Oikawa S, Kanno N, Sanada T *et al*. (2003) A nationwide survey of outdoor radon concentration in Japan. J Environ Radioact 65:203–213
11. Ota M, Iida T, Yamazawa H *et al*. (2007) Suppression of radon exhalation from soil by covering with clay-mixed soil. J Nucl Sci Technol 44:791–800
12. Sarrou I, Pashalidis I (2003) Radon levels in Cyprus. J Environ Radioact 68:269–277
13. Sesana L, Caprioli E, Marcazzan GM (2003) Long period study of outdoor radon concentration in Milan and correlation between its temporal variations and dispersion properties of atmosphere. J Environ Radioact 65:147–160
14. Shweikani R, Hushari M (2005) The correlation between radon in soil gas and its exhalation and concentration in air in the southern part of Syria. Radiat Meas 40:699–703
15. UNSCEAR (1993) Exposures from natural sources of radiation. In: Annex A. United Nations Scientific Committee on the Effects of Atomic Radiation, United Nations, New York, pp 45–54
16. UNSCEAR (2006) Sources-to-effects assessment for radon in homes and workplaces. In: Annex E. United Nations Scientific Committee on the Effects of Atomic Radiation, United Nations, New York, p 203
17. Vaupotič J (2003) Indoor radon in Slovenia. Nucl Technol Radiat Prot 2:36–43
18. Vaupotič J (2008) Comparison of various methods of estimating radon dose at underground workplaces in wineries. Radiat Environ Biophys 47:527–534
19. Vaupotič J (2008) Nanosize radon short-lived decay products in the air of the Postojna Cave. Sci Total Environ 393:27–38
20. Vaupotič J, Žvab P, Gregorič A, Kobal I, Kocman D, Kotnik J, Križman M (2008) Radon mapping in Slovenia based on its levels in soil gas. In: Book of abstracts of the 33rd Int Geological Congress, 6–14 August 2008, Oslo, Norway. Abstracts Sl.:s.N
21. Zhuo W (2005) Soil radon flux and outdoor radon concentrations in East Asia. Int Congress Series 1276:285–286