Slovenian approach in managing exposure to radon at workplaces

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Abstract. Radon was surveyed in all the kindergartens and schools, major hospitals, water plants, wineries, spas, in a number of other public buildings, and karst caves with emphasis on the Postojna Cave (Slovenia). In addition to radon, also the concentration of radon short-lived decay products, equilibrium factor between radon and decay products, and unattached fraction of decay products have been monitored. Effective doses were calculated and used as a criterion to require remediation.

Key words: radon • kindergartens • schools • wineries • spas • water plants • hospitals • karst caves • mitigation

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Introduction

First measurements of radon (^{222}Rn) at workplaces in Slovenia were carried out by the Jožef Stefan Institute in the Žirovski Vrh uranium mine in 1969 [8]. Once a regular radon monitoring had been introduced and being performed by the mine company radiation protection service, our attention was extended to other workplaces, such as underground mines [7], show caves [6], spas [5] and a phosphate mill [1]. These measurements were limited, all based only on using alpha scintillation cells, and no radiation doses were calculated. The situation changed in 1991 when the national radon survey in Slovenia was initiated. In the first years, practically all the kindergartens and schools were surveyed, the measurements were then extended to major hospitals, water plants, karst caves with emphasis on the Postojna Cave, wineries and spas, and eventually to a number of other public buildings, such as bus and railway stations, health care centres, university premises, police and customs offices, and others. In addition to radon (Rn), also concentration of radon short-lived decay products (RnDP), equilibrium factor (F) between Rn and RnDP, and unattached fraction (f_{unatt}) of RnDP have been monitored.

In this review, levels of the measured parameters at the workplaces surveyed will be presented, the effective doses discussed and examples of mitigations undertaken described. For some workplaces, dose conversion factors (DCF_D) were calculated, applying dosimetric models based on the measured f_{unatt} values, and were compared with the value DCF_E = 5 mSv·WLM^{-1} (working level month), resulted from the epidemiologic studies and recommended for workplaces by the International Commission on Radiological Protection (ICRP) [2].

Methods

Radon measurements

Several complementary techniques have been used. Radon scintillation cells [8, 19] were in use to obtain instantaneous radon concentrations. Average radon concentrations have been measured by exposing the Karlsruhe track etch detectors [12]. After exposure, detectors are sent back to Karlsruhe for etching and data evaluation. AlphaGuard radon monitors (Genitron, Germany) were used to follow diurnal variations of Rn concentration only, while various EQF radon devices (Sarad, Germany) also of those of RnDP concentration, F between Rn and RnDP, and unattached fraction of RnDP. All these devices have been checked at intercomparison experiments organized regularly by the Slovenian Nuclear Safety Administration [9] and were recently calibrated in the Radon Chamber at the Henryk Niewodniczański Institute of Nuclear Physics, Polish Academy of Sciences, Kraków, Poland [24].

Calculation of effective doses

Effective doses have been calculated using the general formula [10]:

$$E = \frac{C_{Rn} \times F}{3700} \times \frac{t}{170} \times DCF \quad (1)$$

where E stands for effective dose (mSv); C_{Rn} for radon concentration (Bq·m^{-3}); F for equilibrium factor; t for time (h) spent at a place with C_{Rn}, and DCF for dose conversion factor (mSv·WLM^{-1}, with 1 WLM being 170 h exposure to radon decay products at a concentration of 3700 Bq·m^{-3}). Depending on the measuring technique used, C_{Rn} values have been taken either as obtained with scintillation cells or read from the track etch detectors or calculated from continuous measurements. If concentration of radon decay products (C_{RnDP}) is known from EQF devices, C_{RnDP} is taken instead of the product $C_{Rn} \times F$. For F, either the value of 0.40 was used, as recommended by ICRP [2], or the values read from the EQF devices instead. For DCF, 5 mSv·WLM^{-1} [2], was used, or was calculated within the dosimetric approach, using the Porstendörfer's empirical Eq. (2) below [11] for nasal breathing, based on the measured unattached fractions (f_{unatt}) of radon decay products:

$$DCF_D = 23 \times f_{unatt} + 6.2 \times (1 - f_{unatt}) \quad (2)$$

The following scenarios have been applied in using Eq. (1):

1. F = 0.40 and DCF = DCF_E = 5 mSv·WLM^{-1},
2. C_{RnDP}, as obtained from EQF devices, and DCF = DCF_E,
3. C_{RnDP}, as obtained from EQF devices and DCF = DCF_D, with DCF_D calculated from Eq. (2).

For official dosimetry, as required by the Slovenian Radiation Protection Administration, the scenario 1 has been used explicitly, while scenarios from 2 and 3, for the special purposes only. Based on the continuous monitoring, two averages of the measured parameters were calculated: (i) *gt* average (gross total): over the entire period of measurement, and (ii) *gw* average (gross working): during working hours only over the entire period of measurement. The *gt* averages may be considered as an equivalent to the radon concentrations obtained with track etch detectors (provided they are exposed for the period of the continuous measurement). Both *gt* and *gw* averages have been used in Eq. (1) depending on the purpose of the study. Scenario 3 has been applied only when the role of f_{unatt} in dose calculations have been investigated.

Radon levels and effective doses at various workplaces

Kindergartens and schools

In a selected room, closed overnight prior to air sampling, of each of 730 kindergartens with 65 000 children [25] and 890 schools with 280 000 pupils [26], radon concentration was measured with alpha scintillation cells. Results are shown in Fig. 1. It appeared that the majority of elevated radon levels were found in buildings in the western and southern part of the country (Fig. 2a), covered by carbonates and crossed by several tectonic faults (Fig. 2b). In 46 kindergartens and 77 schools the national radon limit for dwellings of 400 Bq·m^{-3} [3] was exceeded. In all the rooms of these buildings, radon was checked using alpha scintillation cells. Using the same method, radon sources were identified [13]. Then, in several rooms with highest radon levels, track etch detectors were exposed for three months in autumn, winter and spring, and continuous measurements of Rn and RnDP concentrations, F and in some cases also f_{unatt}, were carried out for 1–3 weeks. An example of results of such a measurement is shown in Fig. 3. Annual effective doses for the personnel as well as

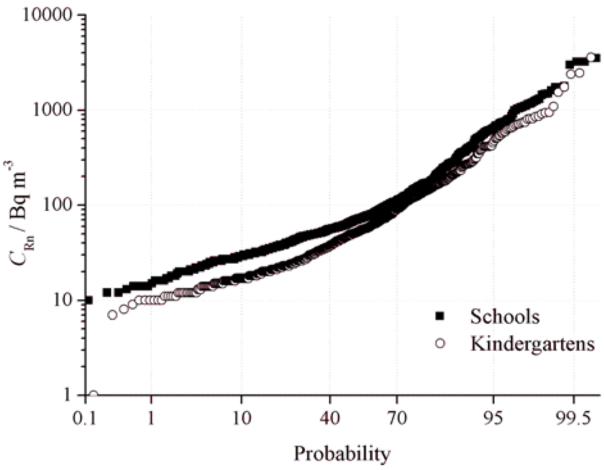

Fig. 1. Lognormal plots of radon concentrations in 730 kindergartens and 890 schools, obtained in wintertime with alpha scintillation cells in rooms closed overnight prior to measurement.

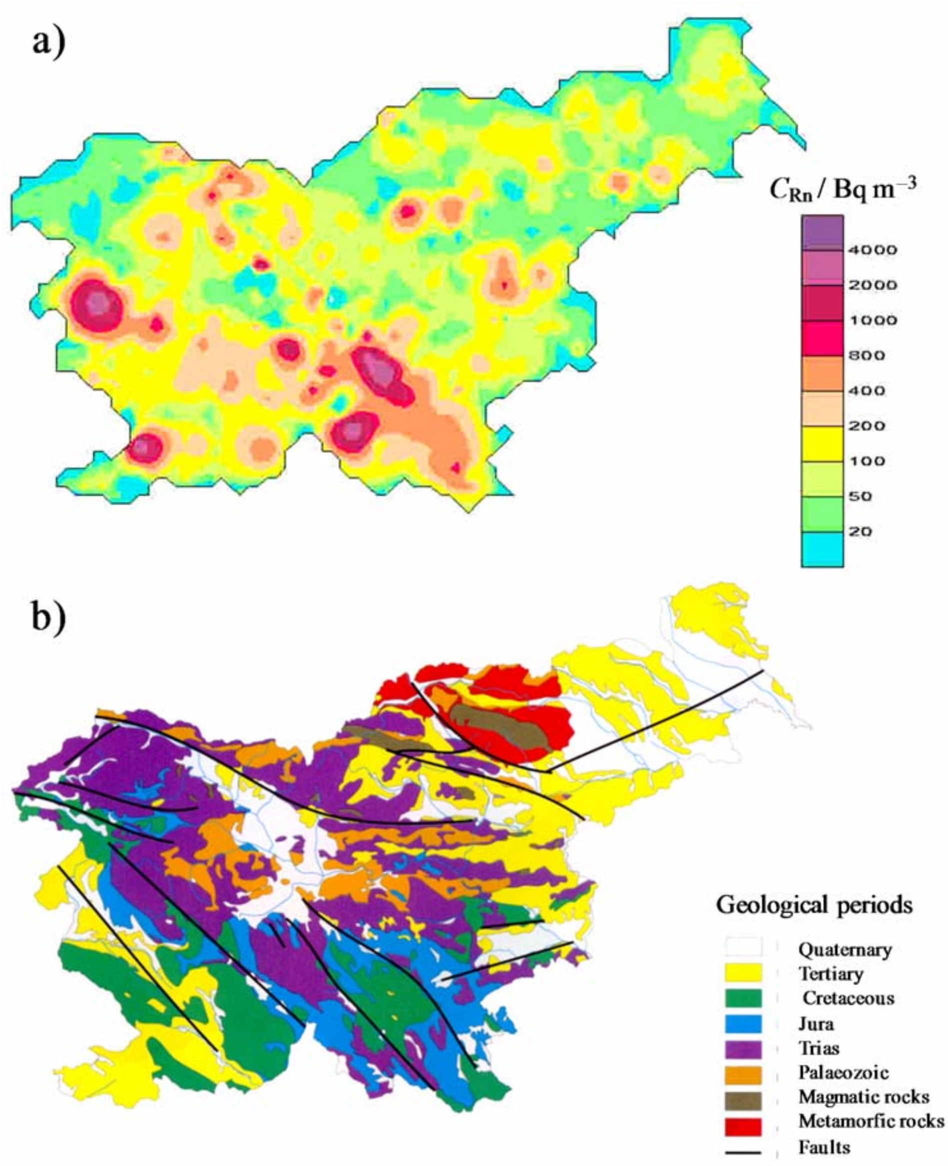

Fig. 2. Maps of Slovenia with; a – spatial distribution of radon concentrations in 730 kindergartens and 890 schools, shown as iso-concentration contours; b – geological units.

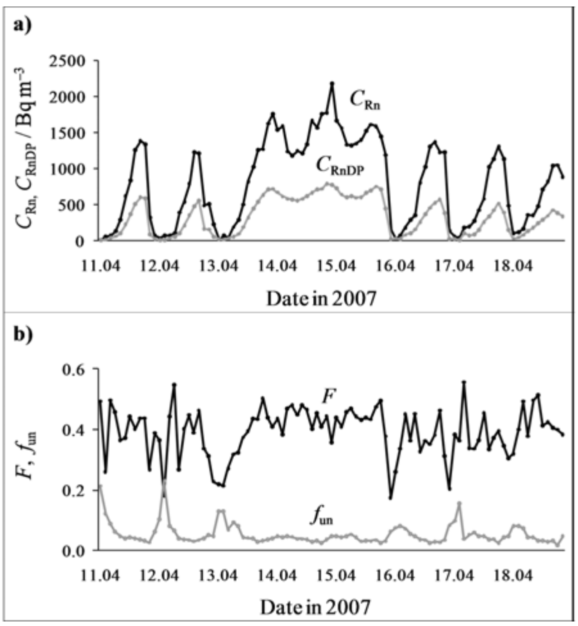

Fig. 3. Results of a continuous measurement of concentrations (C_{Rn} and C_{RnDP}, respectively), F between Rn and RnDP and unattached fraction (f_{unatt}) of RnDP.

for children and students were calculated, applying scenario 1 for Eq. (1), and if the doses of the personnel exceeded 6 mSv, the Slovenian Radiation Protection Administration required from the management to undertake mitigation measures.

Hospitals

Radon was measured in 201 rooms (116 in basement, 84 in ground floor, 1 in a karst cave) of 26 major hospitals [15]. In total, 207 grab samples were taken with alpha scintillation cells and 215 track etch detectors were exposed for a month. In five rooms, radon concentration was higher than 1000 Bq·m^{-3} and was lower anywhere else. Continuous measurements of 7–10 days were carried out in 12 rooms with highest radon levels. Results of one of them, with extremely high radon and radon decay product concentrations, are shown in Fig. 4. 1025 persons were included into dose calculations (using the first scenario for Eq. (1)) and only for four, annual effective doses were higher than 6 mSv. In five rooms with highest radon levels mitigation measures have been successfully undertaken.

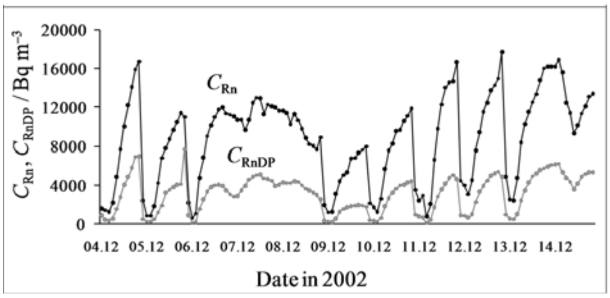

Fig. 4. Time series of concentrations of Rn and RnDP obtained with continuous measurement in a hospital room with high radon level.

Water supply plants

Radon was monitored at 34 underground places in 10 major water supply plants [14]. Concentrations were in the range 37–2600 Bq·m^{-3}; only at one place it was higher than 1000 Bq·m^{-3}. Only for one place, annual effective dose of more than 6 mSv was estimated and were lower anywhere else. Despite elevated radon levels at some places doses were low because of usually short attendance times at these places.

The Postojna Cave

Because of the elevated radon levels, in 1995 a regular radon monitoring was introduced in the Postojna Cave [20]. Radon concentrations at the railway station and lowest point along the tourist guided path in the cave in summer and winter for several years are shown in Table 1. Due to the chimney effect, radon levels are much higher in summer than in winter. The effective doses of the

Table 1. Average radon concentrations at the railway station and the lowest point in the Postojna Cave in summer and winter for several years

Period	Railway stadion C_{Rn}/Bq·m^{-3}	Lowest point C_{Rn}/Bq·m^{-3}
	Year 2001	
January–March	510 ± 90	2340 ± 190
April–June	1400 ± 130	3900 ± 310
July–September	3650 ± 210	5980 ± 480
October–December	1300 ± 120	2340 ± 190
	Year 2002	
January–March	300 ± 20	1100 ± 110
April–June	1950 ± 200	3150 ± 310
July–September	3070 ± 310	3950 ± 400
October–December	1100 ± 110	2500 ± 250
	Year 2003	
January–March	290 ± 20	1250 ± 120
April–June	2150 ± 210	3430 ± 350
July–September	2550 ± 260	3920 ± 390
October–December	920 ± 40	1700 ± 170
	Year 2004	
January–March	380 ± 20	1600 ± 80
April–June	2490 ± 130	3230 ± 170
July–September	2930 ± 150	3770 ± 200
October–December	1300 ± 50	1820 ± 90

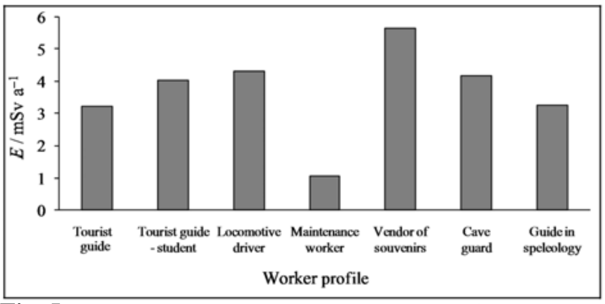

Fig. 5. Annual effective doses for different worker's profiles in the Postojna Cave.

personnel working in the cave are calculated based on radon concentrations at the two points mentioned above, and using scenario 1 for Eq. (1). Doses are reported semi-annually and annually to the Slovenian Radiation Protection Administration. If a person receives in the first half of a year more than 6 mSv, her/his working time in the cave is limited in the second half of the year. By obeying this rule, annual effective doses are acceptably low, as evident from Fig. 5 for various workers' profiles for two years.

Wineries

At 20 underground workplaces in eight biggest wineries, radon concentrations in the range 33–456 Bq·m^{-3} (measured with alpha scintillation cells and track etch detectors) have been found; only at one place it was higher than 1000 Bq·m^{-3}, and only for one place, annual effective dose of more than 6 mSv was estimated and were lower anywhere else [17].

Spas

At all 47 workplaces surveyed with alpha scintillation cells and track etch detectors in five biggest spas, radon concentration was below 200 Bq·m^{-3}, as a result of efficient ventilation based on air conditioning [21]. No concern about elevated exposure of personnel to radon is needed under present working regime.

Other public buildings

Radon has been also monitored at 64 workplaces in other 24 public buildings, such as: health care centres, community, post, customs and police offices, bus and railway stations, university premises [27]. First, radon was checked with alpha scintillation cells, then track etch detectors were exposed for about two months during a heating season, and in selected rooms, continuous measurements were carried out. Results obtained with track etch detectors are shown in Fig. 6. Radon concentrations ranged from 61 to 1800 Bq·m^{-3}, with six rooms (about 9.5%) of more than 1000 Bq·m^{-3}. For 15 persons (2.5%), of total 528 included into dose calculation applying the first scenario, the annual effective dose was more than 6 mSv. Managements of six rooms with highest radon levels were asked to undertake mitigation measures.

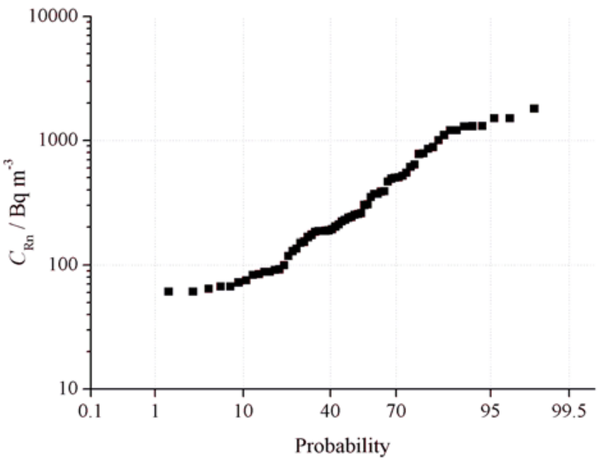

Fig. 6. Lognormal plot of radon concentrations obtained with track etch detectors in 64 rooms of 24 public buildings.

Unattached fraction of Rn decay products at workplaces

The unattached fraction (f_{unatt}) of RnDP has been measured in 13 kindergartens [16], 16 schools [23], four wineries [17] and most frequently and thoroughly in the Postojna Cave [18]. In Table 2, the average values of f_{unatt} in kindergartens, schools and wineries, and the resulting DCF_D values, calculated using Eq. (2), are given. They are by factors of 1.74, 1.64 and 1.65, respectively, higher than the ICRP value DCF_E = 5 mSv·WLM^{-1}. In the Postojna Cave, f_{unatt} values are significantly higher (Table 3) than in kindergartens, schools and wineries. They are lower in winter than in summer and lower at the railway station than at the lowest point. The resulting DCF_D values are for different seasons also given in Table 3. They are by factors 1.6–1.7 in winter and 3.2–3.6 in summer higher than 5 mSv·WLM^{-1}. The reason for higher values in the Postojna Cave is most probably much lower concentration of aerosols in the size range 10–1000 nm to which RnDP attach [3]. The DCF_D values have not been used in dose estimates needed to decide whether mitigation measures are to be undertaken or not, but merely they contribute to the discussion on the gap between DCF_D and DCF_E values, still remained unresolved.

Table 2. Unattached fraction (f_{unatt}) of radon short-lived decay products in kindergartens, schools and wineries and the DCF_D calculated using Eq. (2)

Place	f_{unatt}	DCF_D mSv·WLM^{-1}	DCF_D/5
Kindergartens	0.15	8.7	1.7
Schools	0.12	8.2	1.6
Wineries	0.12	8.3	1.7

Table 3. Unattached fraction (f_{unatt}) of radon short-lived decay products at the lowest point in the Postojna Cave in winter and summer of several years, and the dose DCF_D calculated using Eq. (2)

Season, year (site)	f_{unatt}	DCF_D mSv·WLM^{-1}	DCF_D/5
Summer, 1998	0.58	15.9	3.2
Winter, 1998	0.10	7.9	1.6
Summer, 1999	0.60	16.3	3.3
Winter, 1999	0.14	8.6	1.7
Summer, 2001	0.68	18.2	3.6

Radon mitigation

Slovenian Radon Center

The Slovenian Radon Center was established in order to undertake mitigation measures efficiently and at high technical level. This is the place where experts in radon measurement and dosimetry from the Jožef Stefan Institute and Nova Gorica University and building and construction experts and engineers from the Slovenian National Building and Civil Engineering Institute work jointly on diagnosing the radon problem in a building of high radon levels, designing mitigation measures, surveying all steps of remodelling and eventually checking its successfulness. In 1997, the Center, supported by Rutgers University, Eastern Regional Radon Training Center, New Brunswick, NJ, USA, organized a one week training course on Diagnosing and Mitigating Radon Problems in Buildings for about 15 attendees from Slovenia and neighbouring countries. In order to increase the general awareness on radon problem in homes and at workplaces, the Center has used all the means of mass media (TV, radio, newspapers). In addition, after every particular radon campaign was finished (e.g., wineries, police offices, hospitals), the report was presented to the management and employees, in case of kindergartens and schools also to parents.

Examples of mitigations

If in a kindergarten or in a school radon concentration exceeded national radon limit for homes of 400 Bq·m^{-3} or at a workplace radon concentration higher than the national radon limit of 1000 Bq·m^{-3} for workplaces [3] was found, the Slovenian Radiation Protection Administration required from the management to order a thorough radon survey at all workplaces, needed to estimate annual effective doses of the personnel. If these doses exceeded 6 mSv, the Administration issued a decree to the management, requesting mitigation measures to be undertaken.

In realizing radon mitigation in a building, the following activities are performed:

– Radon is checked in all the rooms using alpha scintillation cells.
– Air samples are taken and analysed at potential radon sources, being crakes and holes in the floor, under-floor channels, water sinks.
– Track etch detectors are exposed for three months in autumn, winter and spring in rooms with concentrations higher than 400 Bq·m^{-3}.
– Continuous measurements of Rn and RnDP concentrations and F (in some cases also f_{unatt} for research purposes only) are carried out for 1–3 weeks in selected rooms with highest radon levels.
– Effective doses are calculated and reported to the Slovenian Radiation Protection Administration.
– Mitigation measures are designed.

Table 4. Gross total (*gt*) and gross working (*gw*) averages of the measured parameters in kindergartens and schools, MIN – minimum value, MAX – maximum value, GM – geometric mean, GSD – geometric standard deviation

Parameter	MIN	MAX	GM	GSD
		Kindergartens		
C_{Rn}^{gw} (Bq·m^{-3})	131	1226	392	1.99
C_{Rn}^{gt} (Bq·m^{-3})	128	1473	478	2.03
C_{RnDP}^{gw} (Bq·m^{-3})	39	743	163	2.27
C_{RnDP}^{gt} (Bq·m^{-3})	37	1118	249	2.41
F^{gw}	0.20	0.61	0.41	1.30
F^{gt}	0.20	0.81	0.50	1.41
f_{unatt}^{gw}	0.08	0.24	0.15	1.34
f_{unatt}^{gt}	0.08	0.25	0.15	1.39
RH^{gw} (%)	27.3	78.2	42.4	1.26
RH^{gt} (%)	27.0	77.4	40.7	1.26
T^{gw} (°C)	19.7	27.2	23.2	1.07
T^{gt} (°C)	19.3	26.1	22.5	1.08
		Schools		
C_{Rn}^{gw} (Bq·m^{-3})	108	6615	641	3.28
C_{Rn}^{gt} (Bq·m^{-3})	109	7598	700	3.29
C_{RnDP}^{gw} (Bq·m^{-3})	42	2364	324	3.17
C_{RnDP}^{gt} (Bq·m^{-3})	45	2943	441	3.07
F^{gw}	0.27	0.78	0.47	1.33
F^{gt}	0.33	0.83	0.59	1.30
f_{unatt}^{gw}	0.03	0.19	0.12	1.43
f_{unatt}^{gt}	0.03	0.18	0.12	1.43
RH^{gw} (%)	32.1	75.6	47.9	1.28
RH^{gt} (%)	30.1	75.8	46.8	1.29
T^{gw} (°C)	8.6	25.4	20.9	1.23
T^{gt} (°C)	7.2	25.5	20.4	1.27

- During or after every remodelling step, radon is checked, either by grab sampling or 2–4 days continuous monitoring.
- After remodelling is finished, radon is checked to see the successfulness of mitigation.
- Then, radon is checked exposing track etch detectors during the first heating season after mitigation and after that regularly every five years.

In total, radon has been successfully mitigated so far in about 20 kindergartens, about 30 schools and about 10 other public buildings. In addition to applying scenario 1 for Eq. (1) as required for the purposes of the official dosimetry, for research purposes only, scenario 2 was used for dose calculations. Based on the continuous monitoring, the average *gt* and average *gw* were calculated for the measured parameters. The *gt* and *gw* averages for kindergartens and schools are shown in Table 4. For C_{Rn}, C_{RnDP} and F, the *gw*/*gt* ratio is always less than 1. Obviously, when applying the official dosimetry, the effective doses are overestimated and, hence, the authorities responsible for doses and hence for health are on the safe side from the radiation protection point of view. Nonetheless, this should not be generalized, because *gw*/*gt* ratios greatly depend on the working regime and working hours, which vary from one place to another [22].

In a school with high radon levels, there was a long corridor, with doors to enter classrooms, with an under-floor channel to convey tap water and central heating tubes. Radon concentrations in the channel air were from 15 to 21 kBq·m^{-3}, while those in selected rooms are shown, as both *gt* and *gw* averages, in Table 5: before, soon after (after installation of a fan to ventilate the under-floor channel continuously), and 5 years after mitigation measures were undertaken. Mitigation appeared to be very efficient in ground floor, but not so much in basement. Disappointedly, the situation wors-

Table 5. Gross total (*gt*) and gross working (*gw*) averages of radon concentrations (in Bq·m^{-3}) obtained with track etch detectors in various rooms of a school before, soon after and 5 years after mitigation measures have been undertaken. The floor is indicated: *g* – ground floor and *b* – basement

		Before mitigation		Soon after mitigation	5 years after mitigation
Room	Floor	C_{Rn}^{gt}	C_{Rn}^{gw}	C_{Rn}^{gt}	C_{Rn}^{gt}
1	*g*	1400	1800	27	790
2	*g*	790	1600	28	detector lost
3	*g*	1570	1350	42	2100
4	*g*	600	1480	79	560
5	*b*	3300	900	480	> 2500
6	*b*	4150	890	300	> 2500

ened afterwards and after 5 years it resembles to that before mitigation. The fans were not maintained properly and they eventually failed. After our inspection, the management had new fans installed and nowadays the levels are as low as soon after mitigation.

Conclusions

In 46 kindergartens (of total 730) and 77 schools (of total 890) the national radon limit for dwellings of 400 Bq·m^{-3} was exceeded. So far, radon levels have been successfully reduced in about half of them. Only in five (of total 201) rooms of 26 major hospitals the national radon limit for workplaces of 1000 Bq·m^{-3} was exceeded and only for four persons (of total 1025) the annual effective doses were higher than 6 mSv. In water plants radon concentration above the limit of 1000 Bq·m^{-3} was found only in one place (of total 10) and one person received annual dose more than 6 mSv. In the Postojna Cave, working time of employees has been limited in order to keep their annual effective doses under the acceptable levels. Radon levels at 20 underground workplaces in eight biggest wineries were low and only one person received annually more than 6 mSv. At all 47 workplaces in five biggest spas, radon concentration was below 200 Bq·m^{-3}. In 6 rooms (of total 64) in other 24 public buildings radon concentration was more than 1000 Bq·m^{-3}. For 15 persons (of total 528), the annual effective dose was more than 6 mSv. For those places, the management was asked to undertake mitigation measures.

The unattached fraction of radon decay products was the highest in karst caves and lowest in kindergartens and schools, with medium values in wineries. This study will be continued together with measurements of concentration and size distribution of non-radioactive aerosols in the size range of 1–1000 nm, aimed at better understanding the role of environmental conditions on the unattached fraction, the crucial parameter in radon dosimetry.

According to our experience in the Radon Center, radon problem at workplaces can be successfully managed only by a joint work of an interdisciplinary team composed of radon experts, civil engineers and architects, and governmental officers responsible for health affairs.

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References

1. Brajnik D, Křižman M, Kobal I, Stegnar P (1988) Sources of technologically enhanced natural radioactivity and their impact in Slovenia. Radiat Prot Dosim 24:551–554
2. ICRP (1994) Protection against radon-222 at home and at work. International Commission on Radiological Protection. Publication no. 65. Pergamon Press, Oxford
3. Decree on dose limits, radioactive contamination and intervention levels (2004) Uradni list Republike Slovenije – Slovenian Gazette, UL RS 49/2004
4. Iskra I, Remškar M, Kobal I, Vaupotič J (2009) Preliminary results of nanoparticle measurement in the Postojna Cave. In: Book of abstracts of the 17th Int Karstological School Classical Karst, 15–20 June 2009, Postojna, Slovenia, p 64
5. Kobal I, Fedina Š (1987) Radiation doses at the Radenci health resort. Radiat Prot Dosim 20:257–259
6. Kobal I, Smodiš B, Škofljanec M (1987) Atmospheric ^{222}Rn in tourist caves of Slovenia. Health Phys 52:477–479
7. Kobal I, Vaupotič J, Udovč H, Burger J (1990) Radon concentration in the air of Slovene underground mines. Environ Int 16:171–173
8. Kristan J, Kobal I (1974) A modified alpha scintillation cell for the determination of radon in uranium mine atmosphere. Health Phys 24:103–104
9. Križman M (2001) Report on the intercomparison experiment on radon and progeny in air. Slovenian Nuclear Safety Administration Report URSJV RP 47/2001
10. Nero AV Jr (1988) Radon and its decay products in indoor air: an overview. In: Nazaroff WW, Nero AV Jr (eds) Radon and its decay products in indoor air. Wiley, New York, pp 1–53
11. Porstendörfer J (1996) Radon: measurements related to dose. Environ Int 22;S1:S563–S583
12. Urban M, Schmitz J (1993) Radon and radon daughters methodology: basic aspects. In: Proc of the 5th Int Symp on the Natural Radiation Environment – tutorial session. Report EUR 14411 EN, pp 151–183
13. Vaupotič J (2002) Search for radon sources in buildings – kindergartens. J Environ Radioact 61:365–372
14. Vaupotič J (2006) Radon exposure at drinking water supply plants in Slovenia. Health Phys 83:901–906
15. Vaupotič J (2006) Radon survey and exposure assessment in hospitals. Radiat Prot Dosim 121:158–167
16. Vaupotič J (2007) Nanosize radon short-lived progeny aerosols in Slovenian kindergartens in wintertime. Chemosphere 69:856–863
17. Vaupotič J (2008) Comparison of various methods of estimating radon dose at underground workplaces in wineries. Radiat Environ Biophys 47:527–534
18. Vaupotič J (2008) Nanosize radon short-lived decay products in the air of the Postojna Cave. Sci Total Environ 393:27–38
19. Vaupotič J, Ančik M, Škofljanec M, Kobal I (1992) Alpha scintillation cell for direct measurement of indoor radon. J Environ Sci Health A 27:1535–1540
20. Vaupotič J, Csige I, Radolić V, Hunyadi I, Planinić J, Kobal I (2001) Methodology of radon monitoring and dose estimates in Postojna Cave, Slovenia. Health Phys 80:142–147
21. Vaupotič J, Kobal I (2001) Radon exposure in Slovenian spas. Radiat Prot Dosim 97:265–270
22. Vaupotič J, Kobal I (2002) Correlation between short- -term and long-term radon measurements. Isot Environ Health Stud 38:39–46
23. Vaupotič J, Kobal I (2006) Effective doses in schools based on nanosize radon progeny aerosols. Atmos Environ 40:7494–7507
24. Vaupotič J, Kobal I, Kozak K, Mazur J, Janik M, Kochowska E (2009) Calibration of radon measuring devices of the Radon Center in the IFJ-KR-600 Radon Chamber. Jožef Stefan Institute Report IJS-DP-10103
25. Vaupotič J, Križman M, Planinič J *et al.* (1994) Systematic radon and gamma measurements in kindergartens and play schools in Slovenia. Health Phys 66:550–556
26. Vaupotič J, Šikovec M, Kobal I (2000) Systematic radon and gamma-ray measurements in Slovenian schools. Health Phys 78:559–562
27. Žvab P, Vaupotič J, Dolenec T (2006) Reasons for elevated radon levels inside the building in Divača. Geologija (Ljubljana) 49:409–415