Importance of detailed measurements in assessment of safe levels of radon

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Abstract: In a school in the Žirovski vrh area, a classroom with an indoor radon concentration of more than 3000 Bq m^{-3} was found. The floor in the room was the major radon source. After a new floor was built with a concrete slab and perforated tubes underneath, the indoor radon concentration was reduced to 250 Bq m^{-3}.

Key words: radon, indoor air, schools, elevated concentrations, mitigation

Introduction

The Slovene indoor radon programme was introduced in 1990 by the Slovenian Radiation Protection Administration at the Ministry of Health and was executed in three stages. In the first stage, instantaneous indoor radon concentrations under 'closed conditions', and gamma dose rates were measured in all 730 kindergartens and play schools (Vaupotič et al., 1994; 1998). In the second stage similar measurements were carried out in all 890 elementary and high schools (Bilban and Vaupotič, 2001; Vaupotič et al., 2000; Vaupotič, 2001: Popit and Vaupotič, 2002), and in the third stage three month average indoor radon concentrations were obtained in 1000 randomly-selected dwellings by exposing etched track detectors (Ilić et al., 1995).

In the second stage, the indoor radon concentration in 25 schools was found to exceed 1000 Bq m^{-3}. Some of these schools are located in the area of the Žirovski vrh uranium ore deposits. The uranium mine was in operation from 1984 to 1990. The Slovene Nuclear Safety Administration initiated an additional radon survey in all 19 schools in the broader Žirovski vrh area (Vaupotič, 2001). Among them was the Ret-OS elementary school in which a fast radon screening in the second stage showed a value of only 79 ± 13 Bq m^{-3}. During the additional radon survey in this school, all the ground floor classrooms were examined. Everywhere radon levels were low, less than 400 Bq m^{-3}, with the only exception of classroom-1 in which it exceeded 3000 Bq m^{-3}. A thorough inspection of the whole school confirmed that the enhanced concentration was limited to this classroom. The Slovenian Radiation Protection Administration issued a decree to the management of the school requiring radon mitigation accompanied by radon monitoring.

This paper discusses radon monitoring in the Ret-OS elementary school, with special emphasis to measurements before, during and after mitigation of the high radon level classroom-1.

Scientific paper

EXPERIMENTAL

Alpha scintillation cells were used to measure instantaneous indoor radon concentration (VAUPOTIČ ET AL., 1992) while to obtain long-term averages, KfK etched track detectors were exposed for 2 to 3 months (URBAN AND SCHMITZ, 1993). For continuous radon monitoring AlphaGuard (Genitron, Germany) and for continuous radon and radon decay products monitoring EQF 3010 and EQF 3020 (Sarad, Germany) instruments were used. Gamma dose rates were measured by a portable ASP-1 scintillation counter (Eberline, USA) and by exposing thermoluminescent dosimeters (MIHELIČ ET AL., 1985). Samples of the building material were analysed for radioactivity by gamma spectrometry at the Department of Low and Medium Energy Physics at the Jožef Stefan Institute.

All measuring devices have been regularly checked at the intercomparison experiments organised annually by the Nuclear Safety Administration at the Slovene Ministry of the Environment (KRIŽMAN, 1997; 2000; 2001).

RESULTS AND DISCUSSION

The Ret-OS elementary school was built of stone in 1938. It is a two-story building with a basement under only part of it. The building was renovated two years before our radon survey and in each of the classrooms on the first floor a slab of poured concrete was built, except in classroom-1, in which the elevated radon level was found. Thus, from the very beginning, the floor was suspected as the major source of high radon concentration in the room.

During the second stage of radon survey, the Ret-OS elementary school was found to show low radon concentration and the *hot spot* was discovered by subsequent, more detailed measurements in all the schools in the Žirovski vrh uranium ore deposit area. Alpha scintillation cells were used to measure radon in all the classrooms and at potential radon sources (VAUPOTIČ, 2002A; 2002B), and additionally etched track detectors were exposed in some of them. Gamma dose rates measured in five classrooms ranged from 70 to 172 mSv per

Table 1. Radon concentrations in the Ret-OS elementary school prior to mitigation. Instantaneous values were obtained using alpha scintillation cells, and 3-month average values by etched track detectors

Room	Instantaneous Bq m^{-3} *21.12.1995*	3-month average Bq m^{-3} *13.09.1995 – 11.12.1995*	3-month average Bq m^{-3} *11.12.1995 – 17.01.1996*
Classroom-1	3700 ± 100	600 ± 50	2100 ± 170
Classroom-2	79 ± 13	68 ± 10	130 ± 10
Gym	570 ± 50	185 ± 10	470 ± 40
Basement	845 ± 120		660 ± 60

month. A selection of the obtained radon concentrations are collected in Table 1. It was confirmed that the radon level is high only in the classroom-1, in which the floor slab was not rebuilt during the renovation of the school. Therefore, we focused our investigations only on this classroom.

An etched track detector was exposed for the period February 10 to May 10, 1995. During the period March 16–26, 1995 radon concentration was recorded continuously by the AlphaGuard instrument. The curve in Figure 1 shows the expected diurnal run with a high maximum every morning and during the weekends. From these data, different averages of radon concentration were calculated and are collected in Figure 2. Daily averages during teaching hours only (black squares) are usually higher than 24-hour daily averages (empty squares). The 11-day (duration of continuous measurement) average (thin line) is 2490 Bq m^{-3}. Considering the broken line (overall average during teaching hours, 2850 Bq m^{-3}) and the thick line (3-month average concentration, 1600 Bq m^{-3}), we see that the etched track detectors underestimated the exposure of teachers and pupils during the occupancy hours by a factor of two for this particular week. Hence, the results from etched track detectors should be interpreted with a caution.

Week long continuous monitoring of radon and radon decay products in classroom-1 were later repeated several times under different meteorological conditions. An example of such a measurement in the winter period December 11–20, 1995, is presented in Figure 3. The shape of the radon curve is similar to that in Figure 1, with a 9-day average radon concentration of 2386 Bq m^{-3} and average radon decay products concentration of 1320 Bq m^{-3}, giving an equilibrium factor of 0.55.

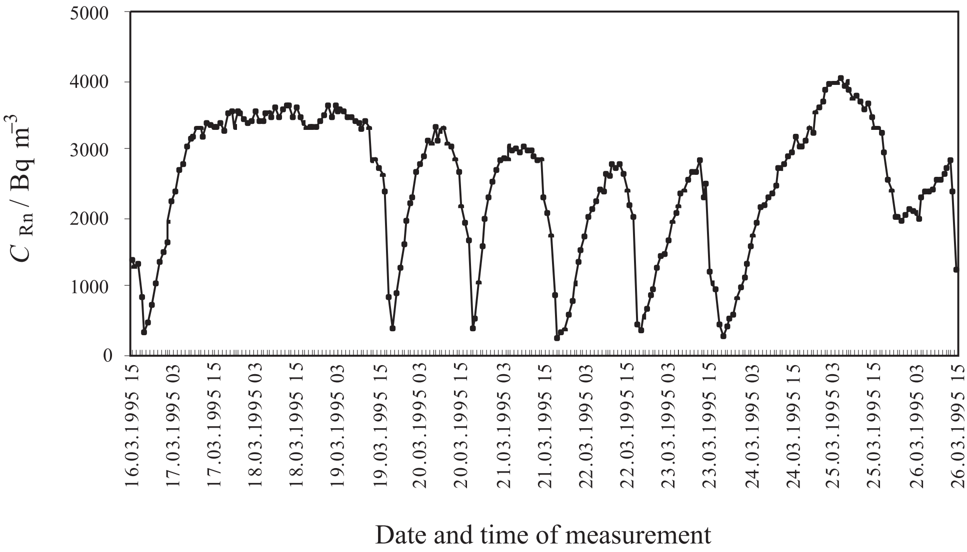

Figure 1. Diurnal variation of radon concentration in classroom-1 obtained by using the AlphaGuard device in the period of March 16–26, 1995, prior to mitigation

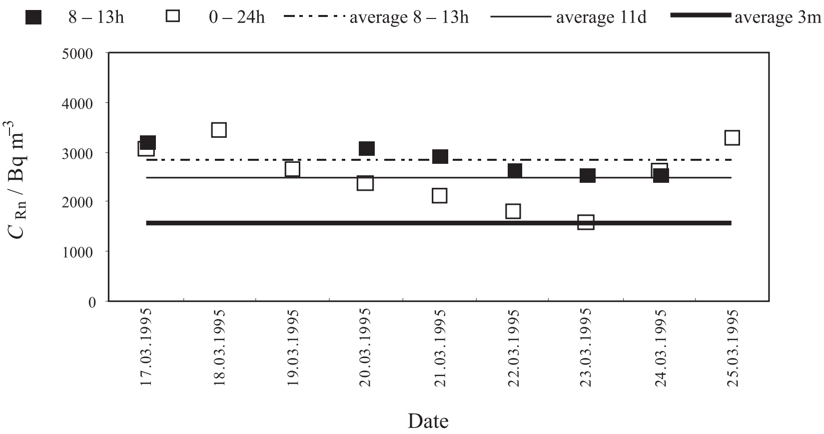

Figure 2. Average radon concentrations calculated from the data in Figure 1, and compared with the average value obtained by etched track detector: full squares: (8–13h)-daily average, during teaching hours only; broken line: (8–13h)-daily averages averaged over all working days; open squares: (0–24h) daily average, the whole day; thin line: (0–24h) daily averages averaged over the entire period of measurement, 11 days; thick line: average obtained by etched track detector in the period from February 10 to May 10, 1995

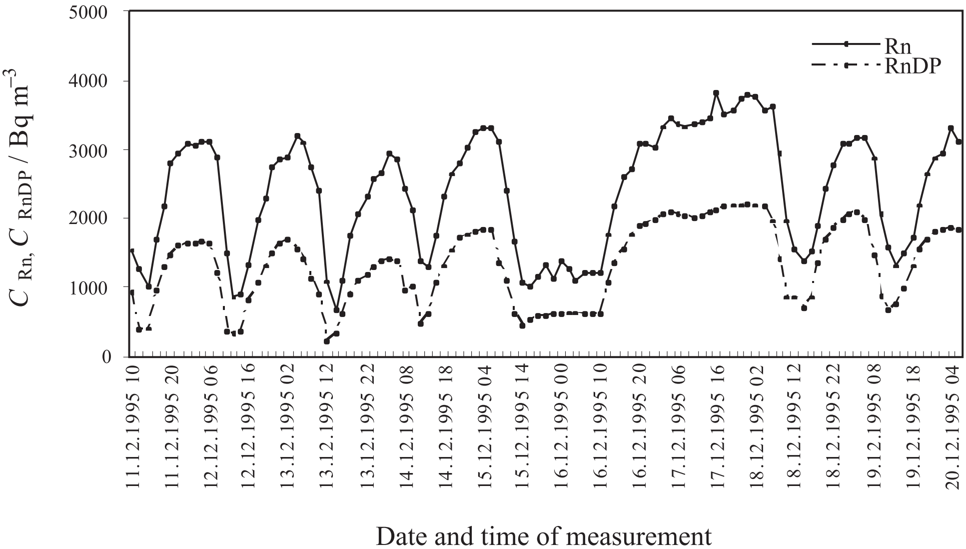

Figure 3. Diurnal variation of radon concentration in classroom-1 obtained by using EQF 3020 device in the period of December 11–20, 1995, prior to mitigation

Based on these results, in May 1996 the Slovenian Radiation Protection Administration required from the management of the school to undertake mitigation measures in classroom-1 during summer vacations.

According to our experience with radon mitigation in kindergartens (VAUPOTIČ ET AL., 1994), the floor, not properly constructed initially and then not renovated, was suspected to be the major source of the enhanced radon

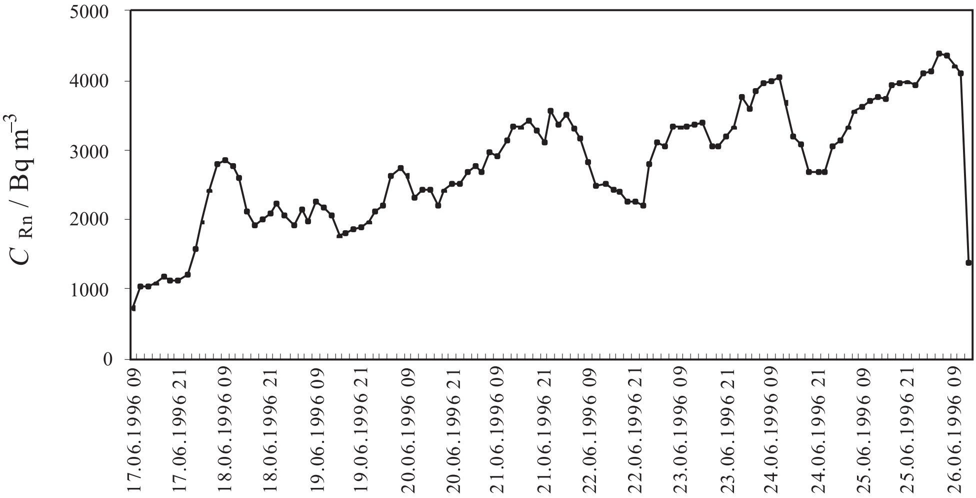

Figure 4. Diurnal variation of radon concentration in classroom-1 obtained by using the AlphaGuard device in the period of June 17–26, 1996, after removing the floor

concentration in classroom-1. In order to obtain more information, samples of the building material and surrounding soils were analysed by gamma spectrometry (Table 2). In no sample a ^{226}Ra content higher than somewhere else in Slovenia (Andjelov and Brajnik, 1996; Brajnik et al., 1992; Kobal et al., 1990) was found. Building material was thus ruled out as a significant radon source.

Reconstruction of the floor started in June 1996. First, the wooden parquet and a thin concrete layer were removed. The concrete layer was found to have been made very badly, showing numerous cracks and faults. Radon and radon decay products were monitored again in the period of June 17–26, 1996 (Figure 4). This time, the door and windows were kept closed during

Table 2. Results of high-resolution gamma spectrometric analyses of building material and surrounding soil

Sample	^{238}U Bq kg^{-1}	^{226}Ra Bq kg^{-1}	^{210}Pb Bq kg^{-1}	^{228}Ra Bq kg^{-1}	^{228}Th Bq kg^{-1}	^{40}K Bq kg^{-1}
Wall, plaster	33 ± 5	24 ± 6	< 76	16 ± 8	19 ± 4	240 ± 5
Wall, brick	48 ± 8	48 ± 1		45 ± 2	50 ± 1	640 ± 15
Concrete-1	25 ± 4	24 ± 6		13 ± 1	14 ± 1	180 ± 4
Concrete-2	22 ± 4	23 ± 1	< 38	12 ± 1	12 ± 1	160 ± 4
Soil-1	28 ± 5	25 ± 1		14 ± 1	14 ± 1	180 ± 4
Soil-2	20 ± 4	25 ± 1	< 27	16 ± 1	15 ± 1	220 ± 4
Soil-3	22 ± 2	23 ± 1	< 20	12 ± 1	12 ± 1	160 ± 3
Gravel	20 ± 3	17 ± 1		6 ± 1	7 ± 1	77 ± 3

measurements. No drastic increase in radon concentration was observed. A 9-day average radon concentration of 3000 Bq m^{-3} was again obtained. This meant that the floor had offered practically no barrier to radon exhalation from the ground.

The complete floor was removed. The foundation of the room was filled with gravel into which perforated plastic tubes 150 mm in diameter were buried, running from the inner wall toward the openings in the outer front wall. For the time being these tubes only enable natural air ventilation of the sub-floor space, but if necessary, fans can be installed. Over the gravel a poured concrete slab of high quality cement was constructed, covered first with a hydro insulator and then with a skim of cement onto which a wooden parquet was laid.

All stages of renovation were accompanied by measuring radon and radon decay products in the air. The last continuous measurement, carried out during the period September 20–30, 1996, under the normal working regime of the school, with regular classes in classroom-1, is shown in Figure 5. After remediation, radon measurements were performed several times using etched track detectors. Results are summarized in Table 3. These values and Figure 5 show a reduction of radon concentration by a factor of about 10 from the values before mitigation. Now, radon concentration never exceeds the national limit for homes (kindergartens and schools) of 400 Bq m^{-3} (ULRS, 2002; 2004).

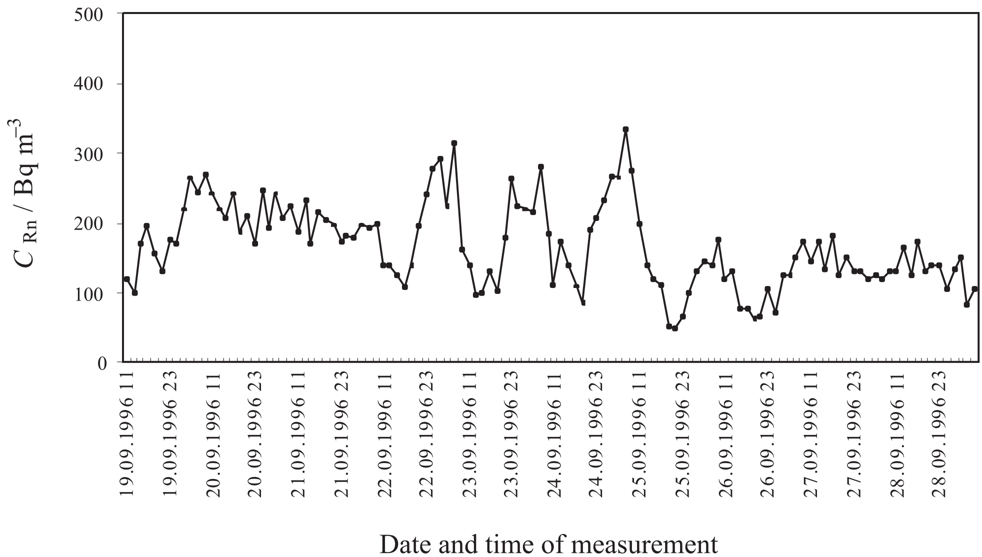

Figure 5. Diurnal variation of radon concentration in classroom-1 obtained by using the AlphaGuard device during a normal working regime in the period of September 19–28, 1996, after mitigation was completed

Table 3. Average radon concentrations obtained by etched track detectors in classroom-1 following mitigation

Period of measurement	Radon concentration Bq m^{-3}
07.04. – 16.06.1997	211 ± 15
16.06. – 17.09.1997	251 ± 15
15.12.1997 – 17.06.1998	223 ± 11
21.09.1999 – 15.06.2000	230 ± 15

Conclusions

In the radon survey in schools in the Žirovski vrh uranium ore deposit area, the highest indoor radon concentration was found only in one classrooms of the Ret-OS elementary school. After thorough monitoring of indoor air radon and radon decay products, and gamma spectrometric analyses of building materials and surrounding soil, the floor was suspected and then proved to be the major source of the elevated radon levels. The floor was rebuilt: a new concrete slab was made of a high quality cement under which perforated tubes were set to enable natural ventilation of the air in the sub-floor space. The renovation reduced the indoor radon concentration from about 3000 Bq m^{-3} down to below the national limit of 400 Bq m^{-3}.

It should be emphasised that after the results of measurements carried out according to the fast radon screening protocol in which only one room in every building was considered, the Ret-OS elementary school had been classified as a low radon level building with no additional radon monitoring planned. The high radon level classroom-1 was found subsequently, when all rooms in the school were systematically surveyed. This example clearly shows that the fast radon screening protocol is not adequate in old buildings, which are not uniformly constructed or have been partly remodelled in steps. In these cases radon should be checked in all rooms, or at least in all those with different construction characteristics, otherwise a high radon level room can easily be missed.

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