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INDOOR RADON CONCENTRATIONS IN THE SOUTHEASTERN ALPINE AREA OF SWITZERLAND

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Abstract — The distribution of indoor radon concentrations in the southeastern Alps of Switzerland was studied with passive etched track detectors. Median radon gas levels of 928, 267 and 171 $Bq.m^{-3}$ for the cellar, ground floor and first floor, respectively, were found in a sample of 100 single-family dwellings. The arithmetic mean exceeds 300 $Bq.m^{-3}$ for the living quarters and leads to an estimated annual effective dose equivalent in the range of 9 $mSv.y^{-1}$ to the population living in this area. The log-normal distribution of the measured values predicts that for the most affected upper 1 percentile of the houses even the effective dose equivalent limit of 50 $mSv.y^{-1}$ for occupational exposure is exceeded. Studies on air exchange rates and radon exhalations from the ground into the cellar of selected homes allow us to indentify unequivocally the soil as the dominant radon source in this alpine region.

INTRODUCTION

In the winter of 1981/82 our institute measured the time averaged radon gas concentration in 123 single-family homes(1). The purpose of this pilot study was to make a preliminary survey of the radon concentrations in Swiss single-family dwellings. The measurements have revealed anomalous radon concentrations in some regions of Switzerland, but there is considerable uncertainty about the realiability of these results due to the small size sample of the investigated dwellings and to the extreme local and temporal variability of the indoor radon concentration(2). A national survey in order to improve our knowledge about indoor radon was therefore started in 1983 and is still continuing. In order to give a realistic estimate of the population weighted exposure to radon and radon decay products in Switzerland, the final results from the national survey have to be awaited. However, a more detailed survey carried out in the southeastern part of Switzerland, one of the most affected regions, is presented in this contribution.

MATERIALS AND METHODS

In each of a total of 100 single-family homes three passive radon dosemeters of the Karlsruhe-type(3) were placed in the cellar for the determination of the source strength, living room (generally the ground floor) and a bedroom (generally the first floor), respectively. The measuring period was 120 days during the summer of 1986. Details of the method and its calibration are reported elsewhere(2,3). A complementary passive method for short-time indoor radon gas concentrations determination and exhalation rate measurements based on activated carbon(4) was used to assess the contribution from the soil to the indoor radon gas concentration in the cellar of selected houses.

A compact equipment for survey of air renewal (CESAR) based on the method of the constant tracer gas concentration (100 ppm N_2O) as described elsewhere(5) was used for the determination of air exchange rates.

The region of interest (Figure 1) was selected by reviewing information from the pilot survey(1).

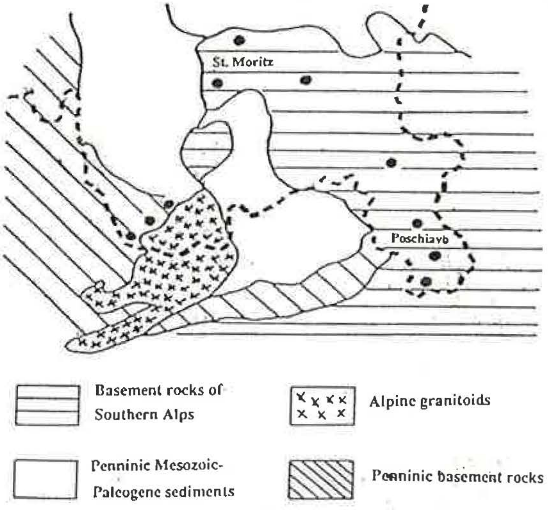

Figure 1. Simplified tectonic map of the southeastern alpine region of Switzerland (modified from Ref. 9). Circles denote groups of measurements.

Persons in charge of supervising meteorological stations and primary school teachers were chosen as participants and asked to organise measurements of dwellings in their villages.

RESULTS

The area selected for this study is situated in the southeastern part of Switzerland and is characterised by a complex local geology. In the lower Austro-alpine nappes of southeastern Switzerland, Variscan granitoides with relatively high uranium and thorium contents dominate over basement rocks$^{(6)}$. A simplified tectonic map of the region is shown in Figure 1.

Indoor radon concentrations

Figure 2 shows the radon gas concentrations in the cellar, ground floor and first floor in 100 typical single-family homes situated in the geological area mentioned above on a log/probability scale. As expected from the many parameters influencing radon source strength and behaviour, the values fit a log-normal distribution fairly well. The sample size is limited, but not small in relation to the size of the investigated area (1700 km^2), population density (23 inhabitants per km^2) and number of dwellings (ca. 10,000) as estimated according to the *Statistisches Jahresbuch der Schweiz*$^{(7)}$. Table 1 shows the numerical values of concentrations and the estimated annual effective dose equivalents for the means as well as for the upper percentiles. The dose commitments are calculated using UNSCEAR 82 conversion factors for non-occupational exposure of 29.5 μSv.y^{-1} per Bq.m^{-3} of radon gas$^{(8)}$. To assess the collective dose from radon and its decay products, the arithmetic mean of the measured dwellings is used. The sample yields a value of 318 (± 35) Bq.m^{-3} for the living quarters (ground floor and first floor weighted each 50%).

The estimated exposure for the upper 1% fraction (51.2 mSv.y^{-1}) even exceed the effective dose equivalent limit of 50 mSv.y^{-1} for occupational exposure$^{(10)}$. Thus the radon levels in this region have to be considered high enough to justify the need for special action for the higher percentiles and additional measurements.

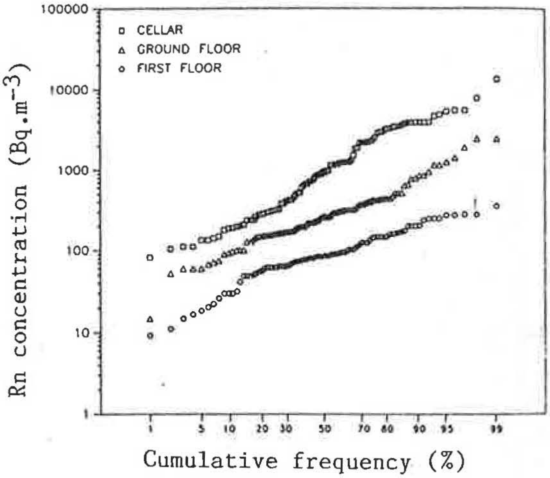

Figure 2. Distribution of the time averaged indoor radon concentrations in a sample of 100 single-family houses situated in the alpine area of southeastern Switzerland. The data for the first floor are displaced by division with a factor of 2 to avoid confusing overlap of the plot.

Table 1. Mean values and upper percentiles for indoor radon concentrations and resulting annual effective dose equivalents for a sample of 100 dwellings in the southeastern Alps of Switzerland.

		Percentile		
	geometric mean (SD)	Upper 10	Upper 5	Upper 1
		Radon concentration (Bq.m^{-3})		
Cellar	928 (3.4)	4400	6993	15355
Ground floor (a)	267 (2.5)	681	1240	2368
First floor (b)	171 (2.1)	463	629	1110
Living area (a + b) : 2	219	572	934	1739
		Annual effective dose equivalents (mSv)**		
Ground floor	7.9	20.0	36.5	69.8
First floor	5.0	13.7	18.5	32.7
Living area	6.45	16.9	27.5	51.3

** Assuming 80% occupancy.

The contribution of the soil

The marked decrease in the indoor radon concentrations from the cellar to the ground floor and from the ground to the second floor, respectively, indicates the importance of soil gas radon. An analysis of the radon distribution with the calculation of the differences between cellar and ground floor, and ground floor and first floor, for each home, is shown in Table 2. Despite the large fluctuations in the radon concentrations between different houses, a statistically relevant decrease of the average indoor radon concentration from the cellar to higher floors can be detected.

This confirms the predominant role of the soil as a radon source. The contribution from the soil to the indoor radon concentration in the cellar can be calculated if the radon exhalation rate from the soil, the air exchange rate, volume of the room and surface in contact with the soil are known. The mathematical relation according to Wicke$^{(1)}$ is:

$$C(rn) = \frac{e \times s}{n \times V} + C(rn)\ \text{outdoor}$$

where: $C(rn)$ = radon concentration in the room ($Bq.m^{-3}$)
s = exhalation surface (m^2)
e = radon exhalation rate ($Bq.m^{-3}.h^{-1}$)
V = volume of the room (m^3)
n = air exchange (h^{-1})

In a preliminary study, two rooms were investigated in order to assess the contribution from the soil to the indoor radon concentration of the cellar. The contribution from the outdoor air is negligible compared with the indoor radon concentrations. Measurements of radon exhalation rate, radon gas concentrations and air exchanges were performed simultaneously. The contribution of the soil to the radon concentration of the cellar can be calculated from these data according to the relation mentioned above. Thus the difference between measured radon concentrations and calculated ones can be attributed to sources different from the soil. The results are summarised in Table 3. In spite of the fact that only two experimental results are available at this stage, the dominant role of the soil as radon source in the southeastern Swiss Alpine area cannot be questioned.

Table 2. Average indoor radon concentrations for cellar, ground and first floor in a sample of 100 single-family homes in the southeastern Alps of Switzerland.

Mean radon concentration in $Bq.m^{-3}$ (SD of the mean)		
Cellar (a)	Ground floor (b)	First floor (c)
1826 (239)	416 (54)	219 (16)

Difference		SD of the mean difference	p*
b-a	- 1410	236	<<< 0.0005
c-b	- 197	44	<< 0.0005

* Probability of independence

DISCUSSION

Although a national survey of indoor radon levels in Switzerland is not yet finished, an analysis of the available data gives a reasonable estimate of the spread of radon concentrations in Swiss houses$^{(12)}$. The country can be divided into distinct regions where the differences in the indoor radon levels are highly significant$^{(2)}$. In the plains north of the Alps where the population centres are located, a mean radon gas concentration of approximately 50 $Bq.m^{-3}$ for the living quarters was found$^{(2,12)}$. Thus the indoor radon levels in this area are quite similar to the results obtained for other European countries$^{(8)}$. The situation with respect to the radon problem is more critical in the alpine area of Switzerland. The regional survey involving 100 single-family homes located in the southeastern alpine region presented here yielded a geometric mean indoor radon concentration of 219 $Bq.m^{-3}$ and an arithmetic mean value of 318 $Bq.m^{-3}$ for the living quarters during

Table 3. Contribution from the soil to the radon gas concentration of the cellar in two selected homes.

House	Measurement period	Exhalation rate from the soil ($Bq.m^{-2}.h^{-1}$)	Air exchange rate (h^{-1})	Surface in contact with the soil (m^2)	Volume of the room (m^3)	Rn concentration ($Bq.m^{-3}$) contribution from soil exhalation		Soil contribution (%)
						Calculated	Measured	
1	19.6.-30.7.86	508	0.52	19.2	40.3	465	482	96.5
2	21.5.-25.5.87	2606	0.06	36	189	8273	9848	84.0
2	26.5.-2.7.87	3373	0.07	36	189	9178	10123	90.7

the summer months. The estimated minimal annual exposures in the upper 5% of the homes (27.5 mSv.y^{-1}) clearly surpass the recommended limit of 20 mSv.y^{-1} for existing buildings(9).

Preliminary experiments show that the contribution from the ground to the radon concentration measured in the cellar of homes located in the alpine region range from 80 to 95% of the total. The high altitude of the region (1000-1900 m above sea level) results in a cold climate with long heating periods(13). Thus the efforts to save energy are particularly intensive in this region and may contribute to the increase of the indoor radon concentrations up to dangerous levels(13). Remedial actions to reduce radon infiltrations into dwellings in areas with elevated radon source strength may be needed.

ACKNOWLEDGEMENTS

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