Indoor radon levels in workplaces of Adapazarı, north-western Turkey

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The main objective of this study is to assess the health hazards due to radon gas accumulation and to compare the concentrations in different kinds of workplaces, in the city of Adapazarı, one of the most important industrial cities of Turkey. For this purpose, radon activity concentration measurements were carried out in schools, factories, offices and outdoors using CR-39 solid state nuclear track detectors (SSNTD). Results show that the mean radon activity concentrations (RAC) in schools, offices and factories were found to be 66, 76 and 27 Bq/m^3, respectively, with an outdoor concentration of 14 Bq/m^3. The average concentrations were found to decrease as follows for different types of industries: automotive > electronic > metal > textile. Because the maximum measured radon concentrations are 151 Bq/m^3 in the schools, 173 Bq/m^3 in the offices and 52 Bq/m^3 in the factories, the limits of ICRP are not exceeded in any of the buildings in the region. In addition, the estimated mean annual effective doses to the people in the workplace, students, office workers and factory workers have been calculated as 0.27, 0.63 and 0.20 mSv/y, respectively for the region.

1. Introduction

Radon is the heaviest gas in the natural decay series of uranium, thorium and actinium. ^{222}Rn (usually called radon), since it can decay to solid (^{218}Po, ^{214}Pb, ^{214}Bi, ^{214}Po) in the lung is the most important isotope for human health. It has a half-life of 3.825 days and is ubiquitous in the environment. ^{222}Rn emanates from soil and rock, which is also the main source of radon in the atmosphere. The concentration of atmospheric ^{222}Rn, therefore, depends on the rate of diffusion from the ground and advection/diffusion in the air (Rahman *et al.* 2009). The primary natural sources of indoor radon are soil, building materials (sand, rocks, cement, etc.), radon dissolved in and transported by water, natural energy sources such as gas, coal, etc., which contain traces of ^{238}U (Banman *et al.* 1982). The design of the building is the important factor affecting the concentration of indoor radon. This is why the ventilation system, the heating and cooling system, the sanitary fittings, etc., all play an important role in the contribution of radon inside the buildings (Rahman *et al.* 2009). Concentrations of radon in a building vary with time both diurnally and seasonally. These variations are primarily due to the effect of meteorological changes on radon levels in soil gas and also to weather-related changes to building ventilation (IAEA 2003). Relatively higher indoor radon levels have been observed during the winter season (Durrani and Ilic 1997).

Although radon is chemically inert and electrically uncharged, when the resulting atoms, called

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radon progeny, are formed, they are electrically charged and can attach themselves to tiny dust particles in indoor air. Alpha particles from the decay of radon progeny that are deposited in the lungs cannot reach any other organs, so it is likely that lung cancer is the only potential important cancer hazard posed by radon in indoor air (BEIR-VI 1999).

Recently, radon investigations have been concentrated specifically in workplaces all over the world. However, there have not been any significant radon studies for the workplaces in Turkey. The goals of this study are to determine the radon concentrations and effective radiation doses exposed by radon in workplace buildings at the city centre of Adapazarı, and to find the relationship of the radon concentrations between different types of workplaces.

2. Survey area

For this research, the city of Adapazarı was chosen for several reasons. First of all Adapazarı is one of the most important economical centre in Turkey along with its high population (242,000). Adapazarı is located at the northwestern part of the country (map is shown in figure 1) and it carries the common climatic and geographical characteristics within the big cities. The precipitation in this region is high and is humid for all seasons. The soil structure generally consists of clay and sand in large part of the region. The region lies along the North Anatolian Fault.

2.1 *Characteristics and properties of the buildings*

This research has been performed for three types of workplaces: schools, offices and factories. Before the research was started, a survey form was prepared for the participants containing questions about the type of structural material, age of the building, work hours, holidays, etc. All of the state school buildings, including primary, elementary and high schools were covered under this investigation.

The building material of the schools is concrete so the thermal insulation is not perfect. Because of high humidity, all buildings are regularly aerated. The schools in this region of Turkey are active for eight months out of the year and the school buildings are used only on weekdays for educational purposes.

The offices investigated for this research have been selected randomly, each carrying one to ten workers per office. On average, these workers work 9 hours per day and 6 days per week. The office buildings are reinforced with concrete. Note that the offices have better thermal insulation compared to the schools and are also regularly aerated due to high humidity.

The industrial factories are located in the same research area (2 km away from the city centre), and the soil characteristic of this area is the same with other workplaces investigated. The main industrial factories in Adapazarı are: automobile, metal, heavy machine, textile, electronic, furniture and food. The selected factories have 20–500 workers

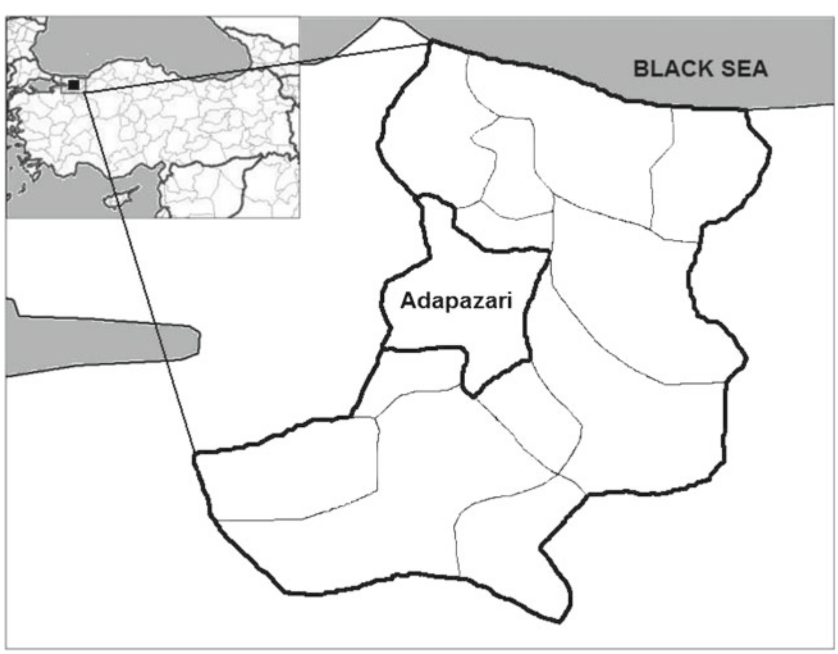

Figure 1. Survey region, the city of Adapazarı.

Table 1. *The radon concentrations measured in the region.*

Place	Number of measurements	Min. RAC (Bq/m^3)	Max. RAC (Bq/m^3)	Mean RAC (Bq/m^3)	St. deviation (Bq/m^3)
School	45	33	151	66	32
Office	37	45	173	76	26
Factory	36	15	52	27	24
Outdoor	9	5	18	14	4

employed on location. The workers work 8 hours per day and 6 days per week. The factories are made of prefabricated materials with steel construction and have large volumes, usually with one single large storey. These buildings do not have enough thermal insulation and they were mostly well ventilated depending on the amount of chemicals used.

Table 2. *Average radon concentrations for different industry types.*

Industry type	Number of structure	Average RAC (Bq/m^3)	St. deviation (Bq/m^3)
Automotive	8	32	14
Electronic	6	39	4
Metal	6	26	12
Textile	4	8	3
Various	12	26	13
Total	36	27	13

3. Materials and methods

For this survey, passive radon detectors of CR-39, and solid state nuclear track detector (SSNTD) were used. The survey was carried out from winter to spring. The detectors were installed in 45 schools, 37 offices, 36 factories and 9 outdoor locations. The detectors were setup in one classroom in each school, one working room in each office and one for each of the factories. All detectors were placed on the first floor (ground floor) and about 1 m above the ground. In order to understand the radon concentration differences between the buildings, the ventilation systems, the frequency of the aeration, thermal insulation, the working hours, and the building construction features have been carefully considered during our evaluations. The detectors were also placed in many outdoor fields in order to obtain regional radon distribution in the research area. After 75 days of radon exposure, the CR-39 detectors were etched in 25% NaOH at 80°C locally during 6 hours and the number of tracks in each film was counted by the automatic reader microscope, at the Department of Radioactivity Analysis in the Çekmece Nuclear Research and Training Center (CNRTC) in Istanbul. A calibration factor of 2.58 tracks cm^{-2} h^{-1} kBq^{-1} m^{-3} was used to calculate the radon concentration (Radosys 2000).

In order to estimate the annual indoor mean effective dose E (mSv/y) of radon and its progeny, the UNSCEAR-2000 recommended conversion factors were applied to our calculations (UNSCEAR 2000; Maged 2006). According to the UNSCEAR model, the annual effective dose, E, is

$$E\,(\text{mSv/y}) = C \times F \times H \times T \times D, \qquad (1)$$

where C is the ^{222}Rn concentration (in Bq/m^3), F is the equilibrium factor between radon and its decay products which is assumed to be 0.4 for the buildings (UNSCEAR 2000), H is the occupancy factor, T is the number of hours in a year (8760 h/y) and D is the dose conversion factor (9.0 nSv/Bq/m^3/h). In the present case, the value of H was calculated for each type of labour by considering the working hours for workplaces in Turkey. The equilibrium equivalent concentration (EEC) of the atmosphere can be obtained by multiplying the concentration of the gas (C) and the equilibrium factor (F).

4. Results and discussion

4.1 *Radon concentrations in buildings*

Table 1 shows the calculated mean, minimum and maximum radon concentrations within standard deviations in the schools, offices, factories and outdoor fields in Adapazarı. The outdoor radon concentrations were very close to each other. In addition, the average radon concentrations in factories have been found to be much lower than the school and the office buildings. The superior ventilation systems, very large open spaces, and doors and windows kept open for longer time in the factories are the main reason for this lower radon concentration. Table 2 shows the mean radon concentrations of different types of industrial facilities. The average radon concentrations for textile and metal industries have been determined to be the lowest in this industrial zone because these factories use very large ventilation systems to evacuate the chemicals from painting.

This research has been performed during the educational period. The average radon concentrations in school buildings have been determined to be less than the radon concentrations in office buildings. The better heat insulation in the office buildings is one of the main reasons that the radon gas concentration is higher compared to school buildings.

In ICRP report no. 65, the maximum action level for the radon exposure was recommended as 3–10 mSv/y (ICRP 1993). The radon concentrations corresponding to these dose levels are between 200 and 600 Bq/m^3 for both home and offices, and 500 to 1500 Bq/m^3 for workplaces. As seen in table 1, the maximum radon concentrations were found to be 151 Bq/m^3 in schools, 173 Bq/m^3 in offices, and 52 Bq/m^3 in factories, and these values are lower than the recommended ICRP dose limits.

Table 3 compares the recent radon gas exposure studies from other countries with this research for schools, offices and factories. As seen in table 3, the mean radon concentrations in other countries differ from this research based on the soil characteristics. Table 3 also shows that the radon concentration in Japan and in Adapazarı have some correlations.

4.2 *Dose estimation*

The annual effective radiation dose due to radon gas accumulation indoors have been calculated using equation (1) with the following considerations: (a) the occupancy factors given in table 4, (b) the average radon concentrations for each type of workplace given in table 1, and (c) the related factors

Table 3. *Radon concentration studies for the workplaces in different countries.*

Type of workplace	Country	Year	Average RAC (Bq/m^3)	Number of buildings	Reference
School	Kuwait	2006	16	25	UNSCEAR (2000)
	Japan	2006	28	185	Oikawa *et al.* (2006)
	Ireland	2004	93	3444	Colgan *et al.* (2004)
	Belgium	1992	120	421	Poffijn *et al.* (1992)
	Italy	2008	144	30	Venoso *et al.* (2009)
	Greece	2009	231	77	Clouvas *et al.* (2009)
	Iran	1990	256	16	Sohrabi *et al.* (1990)
	Turkey	2009	66	45	Present study
Office	Japan	2006	23	287	Oikawa *et al.* (2006)
	Hong Kong	2007	37	216	Mui *et al.* (2008)
	Pakistan	2009	64	105	Rahman *et al.* (2009)
	Turkey	2009	76	37	Present study
Factory	Japan	2006	10	178	Oikawa *et al.* (2006)
	Turkey	2009	27	36	Present study

Table 4. *Annual occupation and occupancy factors (H) for different types of labour.*

Type of workplace	Labour	Working hour per day	Working day per week	Working week per year	Annual occupation (h)	Occupancy factor
School	Teacher-staff	8	5	40	1600	0.18
School	Pupil	6	5	32	960	0.11
Factory	Worker	7	6	48	2016	0.23
Office	Officer	8	6	48	2304	0.26

Table 5. *Annual effective doses for different types of labour.*

Type of workplace	Labour	H	RAC (Bq/m^3)	EEC (Bq/m^3)	AED (mSv/y)
School	Teacher-staff	0.18	66	26	0.38
School	Pupil	0.11	66	26	0.27
Factory	Worker	0.23	27	11	0.20
Office	Officer	0.26	76	30	0.63

explained in the materials and methods section. Table 5 shows the annual effective doses for school staff, employees in the offices and factory workers in the Adapazarı area. The annual highest and lowest doses to humans have been determined as 0.63 and 0.20 mSv for offices and factories, respectively, depending on the occupancy and radon gas accumulation.

5. Conclusion

In conclusion, a survey consisting of 127 radon measurements has been performed in schools, offices, and in factories at Adapazarı. The results showed that:

- The average radon concentrations decrease in the following order: offices, schools and factories.
- The differences in radon concentration mostly originate from the frequency of indoor air changes, ventilation and insulation factors of these buildings.
- The average radon concentrations in different types of industrial facilities decreased as follows: automotive, electronic, metal and textile factories.
- The cause of the differences is mostly from the ventilation system and the usage of chemicals. Clearly, a better ventilation system has a big impact on decreasing the radon exposures in these industrial buildings.
- All the estimated effective doses delivered to the workers/students due to the indoor radon were found to be less than the lower limit of ICRP recommended action levels of 3–10 mSv/y.

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