Original Article

Indoor ^{222}Rn Levels and Effective Dose Estimation of Academic Staff in İzmir-Turkey*

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Abstract

Objective To investigate the annual effective doses from indoor radon received by academic staff in the Faculty building.

Methods Measurements of indoor radon concentrations were performed in the Arts and Sciences Faculty of Dokuz Eylül University for two surveys of about 1 month duration respectively using the SSNTD (Solid State Nuclear Track Detectors) method with LR115 detectors. Time integrated measurements comprised different locations inside the faculty building: classrooms, toilets, canteen and offices. Homes of academic staff were also tested for radon.

Results The arithmetic mean radon concentration is 161 Bq m^{-3} with a range between 40 and 335 Bq m^{-3} in the Faculty. Six offices and three classrooms have a radon concentration above 200 Bq m^{-3}. The results show that the radon concentration in classrooms is generally higher than in offices. Based on the measured indoor radon data, the annual effective doses received by staff in the Faculty were estimated to range from 0.79 to 4.27 mSv, according to UNSCEAR methodology. The annual effective doses received by staff ranged from 0.78 to 4.20 mSv in homes. On average, the Faculty contributed 56% to the annual effective dose.

Conclusion Reported values for radon concentrations and corresponding doses are within the ICRP recommended limits for workplaces.

Key words: Indoor radon; Solid state nuclear track detectors; School; Annual effective dose

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INTRODUCTION

Radon (^{222}Rn), is a naturally occurring radioactive noble gas, colorless, odorless, and tasteless. It is formed in rocks and soils by an alpha decay of ^{226}Ra, which is in turn a decay product of ^{238}U. As ^{238}U is present, as traces, in varying amount in the earth crust, hence, radon is a part of man's environment. Among the natural radon isotopes (^{219}Rn, ^{220}Rn, and ^{222}Rn), ^{222}Rn is given significant importance, because the half-life of ^{219}Rn (3.92 s, called actinon) and ^{220}Rn (55.6 s, called thoron) is much shorter than that of ^{222}Rn (3.82 d).

The short-lived daughters (^{218}Po and ^{214}Po) of radon constitute a major health hazard for man. Namely, these radioactive isotopes emit alpha particles with energies 6-7.78 MeV and attach to the aerosol particles that are present in the air. When the aerosols are inhaled, the decay process occurs inside the lung and the energy of decay will be

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deposited in the tissue lining of the lung. It has been well established that exposures to relatively high concentration of radon may lead to lung cancer in many cases[1-4]. Presently, the natural radioactive radon gas has been identified to be the second leading cause of lung cancer after tobacco smoking[5] and it is well known that more than 50% of the total radiation dose to the world population from natural sources comes from the inhalation of ^{222}Rn or rather, from its short-lived decay products[6].

Keeping in view the importance of the subject, numerous indoor radon surveys have been carried out at the international level over the past few decades[6]. In Turkey, too, a considerable amount of radon data has been reported for dwellings[7]. Exposure in schools is one of the main radon exposures for the general population after that in dwellings, since school buildings are workplaces of high occupancy times for students and staff[8-10]. More recently, the scientific community has devoted a growing concern about the presence of ^{222}Rn in educational buildings such as kindergartens, primary schools (Table 1), but to our knowledge, no data are available for Turkey in the international literature.

The aim of this preliminary study were to assess the level of indoor radon concentration in the Arts and Sciences Faculty of Dokuz Eylül University and to estimate the contribution of school radon to the annual effective doses received by academic staff in the Faculty. To take into account the radon problem in the Faculty, the homes of academic staff were checked for radon and the annual effective doses, received in the Faculty and at home calculated for each individual. In this paper, the results of these measurements and dose estimations are reported and evaluated from the health point of view.

MATERIALS AND METHODS

Solid state nuclear track detectors, SSNTDs, are becoming very popular for the indoor measurements of ^{222}Rn and its daughters. These small and inexpensive detectors allow for the long-term measurements of alpha activity of indoor radon and also provide the possibility of large-scale surveys simultaneously for many measurements. The period of measurement, ranging from some months to a year, blunts the effects of any short-time variations of ^{222}Rn concentration on the measurement results. In the present study, Kodak-Pathé LR115 Type II detectors (from Dosirad, France) are used for measuring the indoor concentrations of ^{222}Rn in the dwellings.

Table 1. Indoor ^{222}Rn Concentrations (C_R) in Schools and Annual Effective Doses (AED) from Different Countries

Country	C_R (Bq m^{-3})	AED (mSv y^{-1})	Reference Date (y)	Author
Greece	45-958		2007-2008	Clouvas et al., 2009[11]
	38-695		1999-2010	Clouvas et al., 2011[12]
	10-89	0.03-0.39	1999-2000	Papaefthymiou and Georgiou, 2007[13]
Italy	15-1 390			Venoso et al., 2009[10]
	6-1 450	0.15-0.68	1993-1995	Gaidolfi et al., 1998[9]
	10-108	0.16-1.8	1994-1995	Malanca et al., 1998[14]
	13-1 181	1.8-2.39	1992	Malisan and Padovani, 1994[15]
Slovenia	90-30 000	3.7-6.7	1999-2000	Vaupotic et al., 2001[16]
	16-3 700		1995	Vaupotic, 2001[17]
	40-4 609			Vaupotic and Kavasi, 2010[18]
	10-4 690		1992-1994	Vaupotic et al., 2000[19]
Poland	3-139	0.1		Bem et al., 1999[20]
Kosovo	11-492		2003	Bahtijari et al., 2006; 2007[21-22]
Kuwait	8-26	0.2-0.65	2003-2004	Maged, 2006[23]
Pakistan	22-228	0.55-0.71		Rafique et al., 2010[24]
	18-168	0.49		Rahman et al., 2010[25]
	27-213	0.16-1.74	2001-2001	Khan et al., 2005[26]
Nigeria	17-192	0.13-0.45	2008	Obed et al., 2011[27]
Ireland	10-4 948		1998-2004	Synnott et al., 2006[28]

The radon measuring device used in the study consists of a plastic cup of 7 cm height, 7.2 cm diameter at one end and 5 cm at the other end, where LR-115 detector with dimensions 1.2 cm x 1.2 cm was fixed. The response of the track detectors placed into the cup-type measuring device is obviously determined by the cup geometry and the position and registration sensitivity of the detector[29]. The theoretical basis of radon measurements for the measuring devices of the specific geometry was developed by Fleischer and Mogro-Campero[30] and Somogyi et al.[29]. It is generally accepted that the LR-115 is sensitive to alpha energies between 1.7 and 4.1 MeV and has a critical angle equal to 40° for under normal chemical etching conditions[31]. Accordingly, the energy limits and the critical angle are used to define the sensitive volume of the measuring devices. Under our geometry configuration, assuming that the radon gas is uniformly distributed in the cup air while the short lived radon daughters are deposited completely on the internal cup walls, one can note that the majority of registered alpha tracks is quite closely proportional to ^{222}Rn gas in the indoor air. However, the radiation induced damage of the human respiratory tract is mainly the result of the potential alpha energy concentration (PAEC) of the short lived radon daughters. On the other hand, the measurement of ^{222}Rn gas concentration may serve as a surrogate for direct measurement of the decay product concentrations in the determination of exposure[6]. Thus, the radiation exposure of the PAECs is calculated from the measured radon concentrations, assuming an appropriate equilibrium factor[31].

Assuming the track density is proportional to ^{222}Rn exposure, radon concentrations in indoor air [C_o(Bq m^{-3})] using the LR 115-II nuclear track detector was calculated by the following equation[32]

$$C_o=D_o/k \qquad (1)$$

where D_o (tr cm^{-2} d^{-1}) is the net detector track density of the radon alpha particles, and k (Bq^{-1} m^3 tr cm^{-2} d^{-1}) is the detector sensitivity coefficient, that is calibrated.

The net track density is the difference between the observed track density (determined by counting the number of tracks per unit area) and average track density (or 'background') found on unexposed material. The measured net track density is converted into radon concentrations (Bq m^{-3}) using the calibration factor (0.0386 Bq^{-1} m^3 tr cm^{-2} d^{-1}). To determine the calibration factor, a set of unexposed LR-115 detectors was installed for 15 d inside a radon calibration chamber with an equilibrium radon concentration of 3.2 kBq m^{-3}[33] at the Health Physics Department of the Çekmece Nuclear Research and Training Centre, ÇNAEM, which participated in the National Radiological Protection Board (NRPB) of inter-comparisons (1989, 1991, 1995, 2000)[34].

Assuming the validity of Poisson statistics, the detection limit L_D is defined by $L_D=2.71+3.29\sigma_B$ based on the Currie criteria[35] in the case of a well-known background track density where σ_B is the background standard deviation (the square root of the total number of alpha tracks on the counted surface area of the detector). The Minimum Detectable Concentration (MDC) for radon corresponds to L_D expressed in activity concentrations unit by using the calibration factor. The corresponding minimum detectable concentration (MDC) for radon by using the calibration factor is estimated 24 Bq m^{-3} for a one-month exposure. The precision of the detectors is improved by counting a relatively larger detector area (about 100 mm^2).

Buca district of Izmir, located on the Neogene limestones and the district at issue is in a depression as morphologically (tectono-carstic)[36]. The Faculty was built in 1998 and it is a four-storey building that does not have a basement. The building has reinforced concrete construction roofs and brick walls with cement plastering. The building is heated by a central heating system, generally from November to March. Staff offices have air conditioning, while classrooms are ventilated naturally by opening window and doors. During winter, doors and windows are opened during breaks.

In this work, sampling was performed for two surveys of about 1 month duration respectively: the first one from 14 September 2010 to 22 October 2010 (1. Term) and the second one from 03 January 2011 to 07 February 2011 (2. Term). Selected locations and number of detectors installed for investigation are shown in Table 2. Radon measuring devices were installed inside the rooms at a height of approximately 1.5 m from the ground for an exposure period of about 30 days with their sensitive surfaces facing the air. Care was taken for setting detectors, away from open windows, doors, radiators, fans, etc. where excessive air movement could affect the radon concentration. The offices and homes of the staff were surveyed simultaneously in both surveys. In each home, detectors were installed in one selected room only, usually a bedroom. The data relative to the occupancy time of the school and homes were collected in specific forms.

At the end of the exposure period, the radon dosimeters with LR-115 detectors were retrieved and processed under the usual laboratory conditions. The chemical etching of the LR-115 detectors was done in 10% NaOH solution at 60 °C for 95 min in a constant temperature etching unit with an accuracy of ± 1 °C. Following the etching, detectors were then washed with distilled water and dried. Counting of the alpha tracks was done using a binocular research microscope at a magnification of 10x10. Background track density for the unexposed detector was separately evaluated and subtracted from the observed values.

RESULTS AND DISCUSSION

Indoor Radon Concentrations

In this study, radon concentrations were calculated in the Dokuz Eylül University, Arts and Sciences Faculty Building and homes of academic staff. A total of 47 locations were investigated, namely 6 in classrooms, 4 in toilets, 1 in canteen, 18 in offices of academic staff, 18 in homes of academic staff for two measuring periods. Radon activity concentrations in Faculty Building and homes of academic staff are tabulated in Table 3-4. As may be seen in these tables, ^{222}Rn activity concentrations ranged from 62±5 to 300±12 Bq m^{-3} in the offices of academic staff, from 137±8 to 335±13 Bq m^{-3} in the classrooms during the first monitoring period, ranged from 77±5 to 328±14 Bq m^{-3} in the offices of academic staff, from 124±7 to 307±12 Bq m^{-3} in the classrooms during the second monitoring period.

In the homes of academic staff ^{222}Rn activity concentrations ranged from 52±4 to 305±12 Bq m^{-3} with a geometric mean of 107 Bq m^{-3} during the first monitoring period and from 77±5 to 328±14 Bq m^{-3} with a geometric mean of 122 Bq m^{-3} during the second monitoring period. It is well known that the radon concentration in the indoor air depend strongly on geological and geophysical conditions, it may vary with building ageing, height above the ground, ventilation pattern, architectural style of building (materials of construction and soil concentration), heating systems, the meteorological conditions such as temperature, barometric pressure, wind speed, rainfall and even variation of the living

Table 2. Location and Number of Detectors Installed in the Faculty Building

Item	Staff office	Classroom	Canteen	Toilet	Total
First floor	4	0	1	0	5
Second floor	5	2	0	4	11
Third floor	5	2	0	0	7
Fourth floor	4	2	0	0	6

Table 3. Summary Statistics of Radon Concentration Levels (Bq m^{-3}) on Different Floors of the Faculty Building

Floor No.	Site	1. Term				2. Term			
		Min.	Max.	AM±SD	*N*	Min.	Max.	AM±SD	*N*
4	Staff office	74±5	250±10	155±17	4	106±7	209±10	146±17	4
	Classroom	-	-	-	-	252±10	307±12	280±16	2
3	Staff office	101±7	203±10	164±20	5	103±7	259±10	175±21	5
	Classroom	137±8	167±8	152±11	2	124±7	148±9	136±11	2
2	Staff office	111±7	188±9	151±20	5	77±5	239±11	145±20	5
	Classroom	200±10	335±13	268±17	2	291±12	291±12	291±12	1
	Toilet	40±4	132±8	76±12	4	ND	99±7	60±9	4
1	Staff office	62±5	300±12	194±22	4	81±6	328±14	196±23	4
	Canteen	68±5	68±5	68±5	1	80±6	80±6	80±6	1

Note. *N*, number of cases; AM, arithmetic mean; SD, arithmetic standard deviation; min, minimum value; max, maximum value; ND, non-detectable. The quoted errors are the standard deviations of the track density.

Table 4. Radon Activity Concentrations in the Homes of Staff in the First and Second Terms

Home No.	Location	Activity concentrations (Bq m^{-3})	
		1. Term	2. Term
1	Balçova	60±5	98±7
2	Hatay	82±6	61±5
3	Bornova	52±4	lost
4	Bornova	54±4	149±9
5	Şirinyer	90±5	102±6
6	Yeşilyurt	86±6	lost
7	Karşıyaka	241±10	319±13
8	Buca	116±7	126±8
9	Buca	159±8	134±8
10	Bornova	167±8	191±10
11	Buca	305±12	277±11
12	Evka 3	142±7	53±5
13	Bornova	69±5	114±8
14	Buca	122±7	lost
15	Buca	97±7	52±4
16	Mavişehir	97±7	141±8
17	Bayraklı	192±10	lost

habits of the occupants[37-41]. Two of the homes, three of classrooms and six of offices were having a concentration of radon more than the Action Level (200 Bq m^{-3}) as recommended by European Commission for future dwellings[42], while the radon concentrations were below the activity level of 400 Bq m^{-3} given by the Turkish Atomic Energy Commission and the International Commission on Radiological Protection: 500 Bq m^{-3} for workplaces[8]. Results obtained in the current study compared reasonably well with measurements from other countries, as shown in Table 1.

The frequency distributions of indoor radon concentrations both in homes and offices were studied. The measured histogram was compared with the normal and log-normal distribution functions using Kolmogorov-Smirnov test values for the goodness-of-fit. Application of the Kolmogorov-Smirnov test shows that in both cases, a normal as well as a log-normal distribution cannot be rejected (P>0.05) for homes and offices. However, the P-values for a log-normal distribution were somewhat higher than those for a normal distribution for homes, by contrast with offices. Consequently, based on the results of Kolmogorov-Smirnov test values, we found that the frequency distributions obtained for homes can be better fitted

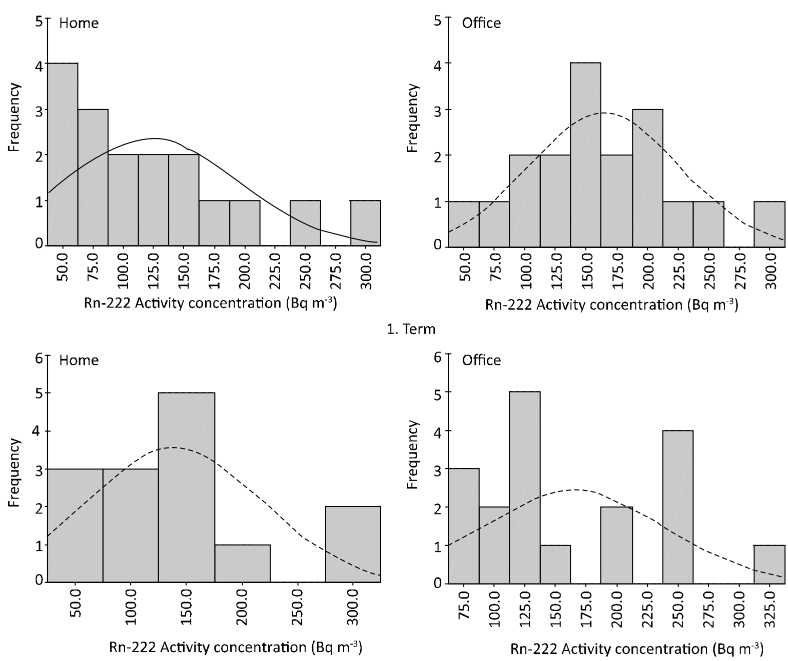

Figure 1. Frequency distributions of ^{222}Rn activity concentration (Bq m^{-3}). Also shown are fits of the ^{222}Rn activity concentration to a normal distribution and to a log-normal distribution.

to a log-normal distribution, and for offices can be better fitted to a normal distribution as mentioned earlier studies[13]. Figure 1 shows the fits made to the empirical frequency distributions, taking into account the values obtained for skewness and kurtosis coefficient, which are presented in Table 5.

The One Sample *t*-Test was used to evaluate the significance of the difference between mean values in radon concentrations obtained for 1. Term and 2. Term in homes. Statistical analysis showed that the average radon concentration in 2. Term was significantly higher than that of 1. Term (P<0.05). The apparent variation in indoor radon levels can be also seen from Figure 2A. A difference would not be surprising because the dwellings would have poorer ventilation during the cold winter period, when most of the doors and windows remain closed.

The mean radon concentrations measured in offices on different floors are tabulated in Table 3. As can be seen in Figure 2B & 2C also, there is a decrease in radon concentration from the ground to upper floor levels. The same trend was also observed in earlier studies[13,43] and it is explained with higher convective flow of soil gas into the ground offices, as ground offices are not protected by a basement. It is seen that decrease in radon concentration with floor levels deviate at third and fourth floor (Figures 2B, 2C). This situation may be explained that chemical substances in offices of Chemistry Department (the third floor) and natural stones in offices of Archaeology Department (the fourth floor) can contribute to radon concentrations. Differences in radon concentration between offices in the same floor can be attributed to the different air exchange rate with the outdoor environment in the different rooms, depending on their pattern of use.

Table 5. Summary Statistics for the ^{222}Rn Activity Concentration (Bq m^{-3}) Data on Homes and Offices

Items	1. Term		2. Term	
	Home	Office	Home	Office
Median	97	161	130	135
Arithmetic mean ± S.E.	123 ± 17	165±14	140±21	165±17
S.D.	71	61	78	74
Geometric mean	107	152	122	111
CV (%)	58	37	56	45
GCV (%)	67	40	64	67
Range	52-305	62-300	52-319	77-328
Skewness	1.287	0.4	1.239	0.7
Kurtosis	1.340	0.2	1.302	-0.5
Frequency distribution	Log-normal	Normal	Log-normal	Normal

Note. Median, arithmetic mean, standard error of arithmetic mean (S.E.), standard deviation (S.D.), geometric mean (GM), coefficient of variation (CV), geometric coefficient of variation (GCV), range, expressed in Bq m^{-3} and skewness, kurtosis of the frequency distributions of indoor ^{222}Rn activity concentrations.

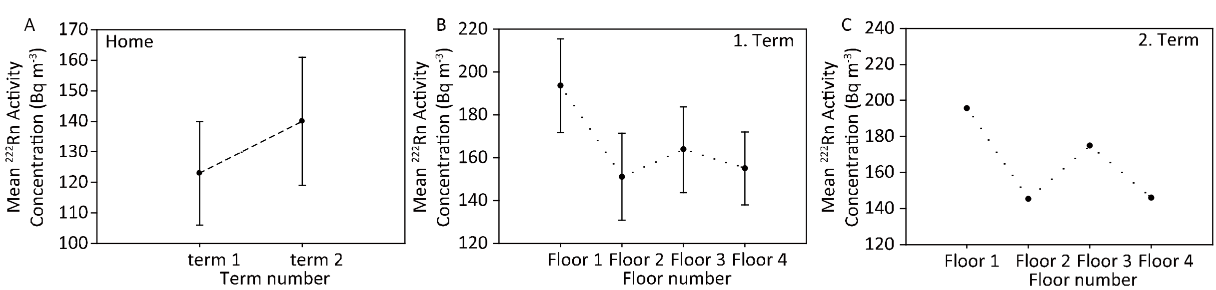

Figure 2. Mean ^{222}Rn activity concentrations in homes of academic staff for two terms (A) and the dependence of the mean ^{222}Rn concentration (Bq m^{-3}) on office storey level for two terms (B, C) (term 1: 14 September 2010 -22 October 2010, term 2: 03 January 2011-07 February 2011).

Dose Estimation

The exposures and consequent doses from radon are estimated from the two season average radon concentrations and exposure times of staff (Tables 3-4). Accordingly, the average annual effective dose was calculated using the dose conversion factors of 9 nSv (Bq h $m^{-3})^{-1}$ with indoor occupancy factor assuming the equilibrium factor value of 0.4 based on the recent UNSCEAR report[6]. In UNSCEAR report the indoor occupancy factor is taken as 0.8 whereas the values of occupancy factor have been modified in the present case. These values were derived from questionnaires and selected based on the time spent by the staff in the office, classroom and home, separately. The occupancy factors evaluated on yearly basis were therefore taken as 0.15-0.53 in offices, 0.01-0.06 in classrooms and 0.23-0.60 in homes.

The annual effective doses received by staff in the Faculty and home are shown in Table 6. The effective doses received by staff in the Faculty ranged from 0.79 to 4.27 mSv y^{-1}, while the doses received at home are estimated to range from 0.78 to 4.20 mSv y^{-1}. The doses received from canteen and toilets were neglected because of relatively lower occupancy factors. The annual effective doses for staff at home and Faculty were added in order to get the total annual effective dose as shown in following equation:

$$AED_{tot}= AED_{home}+ AED_{clasroom}+ AED_{office} \quad (2)$$

The total annual effective doses received in the Faculty and at home range from 2.10 to 6.63 mSv y^{-1}.

According to the ICRP[8] and WHO[5] recommendations, the intervention limit for work places is 3-10 mSv y^{-1}. It has been observed that our faculty monitored for indoor radon concentration show values within the recommended action levels. Although staff spent less time in the Faculty than at their home, it is evident, that they receive higher doses in the faculty. On average, the highest contributions are received from the Faculty environment (56%), while the home contributes 44%.

The resulting annual effective dose calculated from the arithmetic mean was estimated to be 3.65 mSv y^{-1} for staff. In fact, the effective doses estimated by passive long-term measurements may overestimate the actual radon concentration to which staff is exposed. Namely, although the offices and classrooms were closed during night times, weekends and holidays, dosimeters average the concentration for the whole period of exposure. Nevertheless, this possible dose overestimation is on the safe side from the radiation protection point of view.

Table 6. Annual Effective Doses Received by Staff in Home (AED_{home}), in Classroom ($AED_{classroom}$), in Office (AED_{office}), Separetely. Total Annual Effective Doses (AED_{tot}) Received by Staff and Contribution (%) of Home and Faculty

No.	AED_{home} (mSv y^{-1})	$AED_{classroom}$ (mSv y^{-1})	AED_{office} (mSv y^{-1})	AED_{tot} (mSv y^{-1})	Home (%)	Faculty (%)
1	1.10	0.09	1.04	2.23	49.0	51.0
2	0.89	0.14	2.02	3.05	29.5	70.5
3	0.78	0.41	1.57	2.76	28.5	71.5
4	1.34	0.12	1.79	3.25	41.0	59.0
5	1.05	0.12	2.68	3.85	26.5	73.5
6	1.50	0.22	2.00	3.72	40.5	59.5
7	1.19	0.18	1.30	2.67	45.0	55.0
8	2.47	0.14	2.36	4.96	49.5	50.5
9	0.87	0.36	3.02	4.25	22.0	78.0
10	2.80	0.17	0.62	3.59	78.0	22.0
11	1.87	0.20	1.89	3.96	47.5	52.5
12	4.20	0.10	2.33	6.63	63.5	36.5
13	1.68	0.43	0.65	2.76	57.5	42.5
14	1.12	0.07	0.92	2.10	52.5	47.5
15	1.15	0.15	4.13	5.42	21.5	78.5
16	0.99	0.13	1.45	2.57	39.0	61.0
17	2.45	0.18	1.74	4.37	56.0	44.0

CONCLUSION

A difference was found between the ground and upper floor levels regarding radon concentration. Variations in radon concentration from one office to another in the same floor level may be explained by human activities. As the annual mean effective dose for staff at the Faculty is within the recommended levels for work places, the faculty building may be considered safe from radon health threats, according to the ICRP and WHO recommendations. According to the total mean annual effective dose for staff at home and Faculty, major contribute seems to come from the Faculty environment.

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