ESTIMATES OF THE DOSE OF RADON AND ITS PROGENY INHALED INSIDE BUILDINGS

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ABSTRACT

The concentration of radon in the air in buildings ranged from 1.87 ± 3.24 Bq/m³ to 14.27 ± 1.50 Bq/m³ with a mean of 6.31 ± 3.47 Bq/m³ while that of the progeny of radon varied from 0.007 to 0.057 WL (average: 0.025). The mean indoor concentration of radon was considerably less than the lower levels prescribed by EPA (148 Bq/m³), WHO (100 Bq/m³), EEC (400 Bq/m³), ICRP (200–600 Bq/m³) and NRPB (200 Bq/m³). The annual effective equivalent dose of indoor radon (< 0.8 mSv/y) that the bronchial and pulmonary regions of human lungs are exposed to (<0.8 mSv/y) is less than the UNSCEAR and WHO recommended global lower average dose value of 1 mSv/y. The lifetime fatality risk of exposure to the progeny of radon (PAEC) varied from 0.03×10^{-4} to 0.19×10^{-4}, with an average value of $0.08 \pm 0.04 \times 10^{-4}$.

Keywords: radon, indoor, equilibrium-equivalent radon concentration, equivalent dose, lifetime fatality risk

Introduction

The noble radioactive gas radon tends to migrate readily in air or water in spite of the fact that its relatively short half-life (3.82 days) restricts the time for which it can migrate (Choubey and Ramola 1997). The presence of radon in soil, water and rock has greatly facilitated our ability to identify and predict the occurrence of earthquakes, volcanic activity and fault dislocation. Coincidently, its presence at high levels in indoor air could be a health hazard for humans because it is carcinogenic (Karimdoust and Ardebili 2010) and can cause lung cancer (Folger et al. 1994). Radon and its short-lived decay products (^{218}Po, ^{214}Po and ^{214}Bi etc.) in buildings is the major source of public exposure to natural radioactivity, making up almost 50% of the worldwide mean effective dose (UNSCEAR 2000b; Somlai et al. 2007). Two of the α-emitting daughters of ^{222}Rn (^{218}Po and ^{214}Po) contribute over 90% of the total radiation dose attributable to exposure to radon (Gillmore et al. 2001). When radon decays after inhalation or ingestion, it releases energy that can damage DNA in the cells of sensitive organs like lungs and stomach and can cause cancer. Thus, naturally occurring radon in buildings has been identified as a human lung carcinogen (IARC 1988; WHO 2009) and is considered to be the second leading cause of lung cancer after smoking tobacco (Marley et al. 1998; WHO 2005). Recent studies have also provided information on the risks of exposure to lower levels of radon (Lubin and Boice 1997; NRC 1999; EPA 2004). Further, ICRP (1990) recommends that exposure to high levels of radon should be considered to be an occupational hazard and remedial actions need to be initiated in such situations. In recent years, substantial attention has been paid to radon, particularly the problems of exposure to radon and its progeny in building and dwellings. Measurements of levels of radon in the air in dwellings worldwide have been made and reported (Srivastava 2004; Oufnia et al. 2005; Pauloa et al. 2005). In the open air the concentration of radon gas is very low and does not pose a significant health hazard. However, radon is a problem when released into an enclosed or poorly ventilated spaces like dwellings, buildings, caves and mines, where this gas can accumulate and reach relatively high concentrations and become a health hazard. Emanation and migration of radon and its progenies in an indoor environment (in the earth and atmosphere) has been identified as the main source of the radiation from natural radioactive sources that people are exposed to. Indoor concentrations of radon and its short-lived progeny depend mainly on the entry or production rate from various sources and the ventilation rate. However, the level of radon in an indoor environment can also depend on the nature of building materials, soil, water used for drinking and other domestic features (Sohrabi 1998).

Thus, in the present investigations, a RAD7 radon analyzer system was used to study variation in the level of radon in the staff room of the Department of Environmental Science, Bangalore University, Bangalore. The annual effective dose of radon inhaled by the inhabitants was also calculated in order to determine their exposure dosage to radiation.

Material and methods

RAD7 analyzer is an active, high performance, continuous radon-measuring technique (Fig. 1), which is extensively used because it is rugged and simple to use, produces a long-term integrated read out and is highly

sensitive to alpha-particle radiation. In the present study, the surface deposited/airborne/ambient radon activity inside the staff room was recorded by the RAD7 radon analyzer using a continuous 1-day protocol. Grab sampling may not give an accurate value of the radon levels because radon concentrations change significantly and rapidly. The RAD7 detector collects the α-emitters electrostatically and analyses them spectrally.

Ambient air is sucked in by a pump at a rate of 1 l/min, and passes through a drierite/desiccant and filter prior to entering the solid-state detector, which measures the concentration of radon. The RAD7 determines the concentration of radon in air by detecting the alpha decaying radon progeny, ^{218}Po and ^{214}Po, using a solid-state, passivated ion-implanted planar silicon (PIPS) detector. The radon monitor (RAD7) uses a high electric field above a silicon semi-conductor to attract the positively charged polonium daughters, ^{218}Po^{+} (t1/2 = 3.1 min; alpha energy = 6.00 meV) and ^{214}Po^{+}(t1/2 = 164 ls; alpha energy = 7.67 meV), which are then used as a measure of the concentration of ^{222}Rn in the air. The concentration of radon was measured every hour for 1 day (24 hours), using the continuous monitoring mode. Finally, ^{222}Rn activities are expressed in terms of Bq/m³ (disintegrations per second per m³) with 2σ-uncertainties. One Becquerel corresponds to one radioactive disintegration per second and Becquerels per cubic metre (Bq/m³) is the unit of expression used to define the concentration of radioactive gases, such as radon.
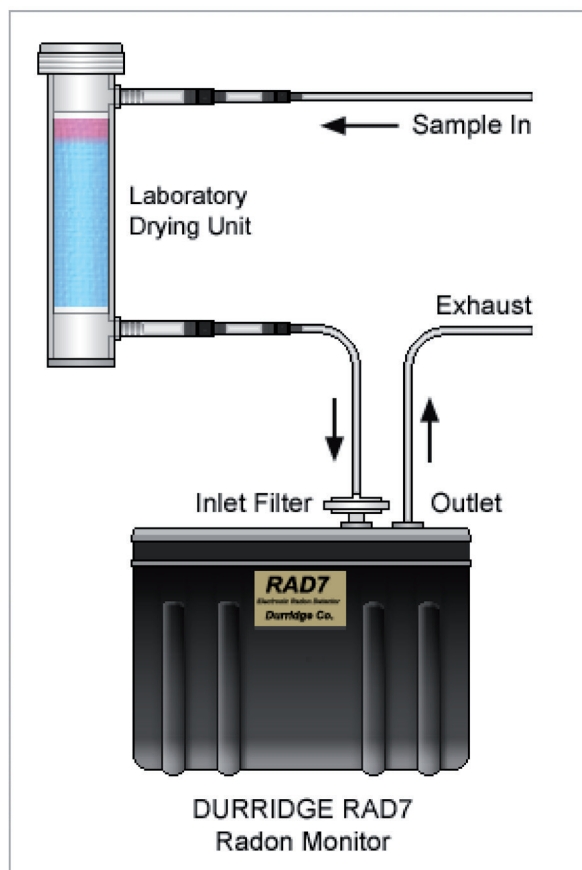

Fig. 1 Experimental set-up for the measurement of radon in air.

There is a desiccant drying tube, containing anhydrous $CaSO_4$, at the interface between the ambient air and the detector, which maintains the relative humidity (RH) of the incoming air below 10% throughout the measurement. If it goes above 10% then desiccant should be replaced, as the sensitivity of the particle detector is lowered significantly when the relative humidity is higher than 10%. Inlet filters at the top of the RAD7 remove the progenies of ^{220}Rn and ^{222}Rn, so that only the concentration of the gas is measured. The detector operates at external relative humidities ranging from 0% to 95% and an internal humidity of 0–10%, with a sensitivity of 4 Bq/m³ and an upper linear detection limit of 800 kBq/m³. In other words, the sensitivity of the instrument is 0.8 counts per hour per Bq/m³ and 0.4 counts per hour per Bq/m³ in normal and sniff modes, respectively. The dynamic range of the instrument is 4–400,000 Bq/m³ (0.1–10,000 pCi/l).

Action level for radon inhaled indoors

If the concentration of radon goes above the "Action level" attempts should be made to reduce it because of its adverse effect on human health. In this context, the Environmental Protection Agency (EPA) report that if a person is exposed to an indoor radon level of 4 picocuries per litre (4 pCi/l) or 148 Becquerel per cubic meter (148 Bq/m³), the probability of developing lung cancer is 13–50 persons per 1000. Furthermore, exposure to a radon level of 20 pCi/L (740 Bq/m³) is as hazardous as smoking a pack of cigarettes a day. Therefore, EPA recommends a rigid 4 pCi/l (= 148 Bq/m³) as the action-level for air-borne radon and that a radon action level of lower than this should be maintained in the air in residences (EPA 1986). EPA recommends that it be reduced to a lower level if a home is at or above the threshold value. For conversion, multiply pCi/l (non-SI terminology) by 37 to get Bq/m³ (SI terminology). WHO suggests that house owners take action when radon levels exceed 100 Bq/m³, which is a much more conservative figure than the Environmental Protection Agency (EPA) action level of 148 Bq/m³ (EPA 1991), which has been the USA standard for many years (WHO, 2009). Similarly, the Economic European Community (EEC) has prescribed a level of 400 Bq/m³ for indoor radon in built dwellings, ICRP (International Commission on Radiological Protection) recommend a range of action levels for radon of 200–600 Bq/m³ (ICRP 1993b, 1994), NRPB (National Radiological Protection Board, U.K.) a threshold limit value of 200 Bq/m³ for houses and 400 Bq/m³ for workplaces (NRPB 1990) and the Irish reference level is 200 Bq/m³ (ICRP 1993b).

Radon dosimetry / Equivalent dose

Although there are large uncertainties in assessing the dosimetry and epidemiological aspects for converting an exposure to radon to a radon dose (Chen 2005), it is nevertheless essential to be able to estimate the ra-

don dose from the radon concentration because of its harmful effects on the human body. The equilibrium level, time spent indoors and the conversion coefficient (effective dose received by adults per unit ^{222}Rn activity per unit of air volume) of the recorded dose are the major factors determining the level of the dose (ed.) received by bronchial and pulmonary tissues of human lungs. Hence, in the present study we used six different methods to compute the annual effective equivalent dose or inhalation dose attributable to exposure to indoor radon using different radon dose conversion and equilibrium factors.

Method 1:

Concentrations of radon decay products or their equivalent equilibrium concentrations (EECs) can be obtained from radon data using calculation procedure of Kranrod et al., (2009). The concentration of radon recorded indoors (A_{Rn}) in Bq/m^3 can be expressed in terms of equilibrium-equivalent radon concentration (EEC_{Rn}) by using relation (1) (Choubey and Ramola 1997) and the equivalent dose received by bronchial and pulmonary tissues in human lungs by using a dose conversion factor (DCF) of 1.0×10^{-5} mSv per Bqh/m^3 (ICRP 1987; Choubey and Ramola 1997) and equilibrium factor (F) of 0.45 in equation (2):

$EEC_{Rn} = F \times A_{Rn}$ (1)
Equivalent dose $= EEC_{Rn} \times DCF$ (2)

Method 2:

Recommendations in the United Nations Scientific Committee's publication on the Effects of Atomic Radiation (UNSCEAR 2000b, 2006; Abd El-Zaher and Fahmi 2008; Abd El-Zaher 2011) can be used to calculate the annual effective dose from exposure to radon. The effective indoor dose (H_E) was calculated using a conversion factor of 9.0 nSv/h per Bq/m^3 (UNSCEAR, 2000b), an indoor occupancy factor of 0.8 (Chen and Moir 2010) and an equilibrium factor of ^{222}Rn indoors of 0.4 in equation (3):

$H_E = C_{Rn} \times F \times T \times DCF$ (3)

where
H_E = effective indoor dose rate in mSv/y,
C_{Rn} = is the arithmetic mean radon concentration in Bq/m^3,
F = 0.4 is the typical recommended equilibrium factor value used for indoor radon (ICRP 1993b, 1994; UNSCEAR 1999),
T = Indoor occupancy time of 7000 h or 80% of office occupancy (0.8 × 24 h × 365.25 = 7012.8 h/y).
DCF = a recommended value of 9 nSv (Bqm^{-3} h)$^{-1}$ or 9 nSv/Bqhm^{-3} or 9.0×10^{-6} mSv/h per Bq/m^3 was used to convert radon equilibrium-equivalent concentration to population effective dose (UNSCEAR 2000b; Chen and Moir 2010) as it lies between the dosimetric and

epidemiological dose conversions (IARC 1988; UNSCEAR 2000b; WHO 2009).

Method 3:

Method 3 involved estimating the annual effective dose (Dy) due to a particular concentration of radon using equation (4) or (5) (Örgün et al. 2008; Ali Asghar Mowlavi et al. 2012):

$Dy = E_f \times C_f \times O_f \times Q_{Rn} \times T$ (4)

or

$ED(mSv/y) = A_c \times D_f \times O_f \times E_f \times 24\,h \times 365 \times 10^{-6}$ (5)

where
E_f = 0.4, indoor radon decay product equilibrium factor,
C_f or D_f = 9.0 nSv/Bq h m^{-3}, radon effective dose coefficient factor,
O_f = 0.8, indoor occupancy factor, which is the fraction of the time people spend indoors – it means, during a year ($T = 365 \times 24$ h) people spend about 7008 h indoors in homes and offices,
Q_{Rn} or A_C = the radon concentration in Bq/m^3.

Method 4:

The effective equivalent dose due to exposure to indoor radon can be expressed in two different ways as indicated by equation (6) and (7) (Martinez et al. 1998). In addition, equation (6) in terms of the equilibrium factor (F) can also be expressed by equation (7) (Farid 1993, 1995):

$H_E = C_{Rn}d_0 + d_1 C_E$ (6)
$H_E = C_{Rn}\,(d_0 + d_1 F)$ (7)

where
C_E is equivalent concentration of radon in Bq/m^3,
F = 0.4, the typical value of the equilibrium factor used for indoor radon,
d_0 and d_1 = the effective dose equivalent conversion factors for radon and radon progeny, respectively.
The recommended values (Mauricio et al. 1985; WHO 1988; Planinic and Faj 1989, 1990; Faj and Planinic, 1991;) are d_o = 0.33 µSv y^{-1}/Bq m^{-3} and d_1 = 80 µSv y^{-1}/Bq m^{-3}. In the present study equation (7) was used.

Method 5:

The CEC (1990) recommends that a conversion ratio of 1 Bq/m^3 of ^{222}Rn corresponding to an effective equivalent dose of 0.05 mSv/y can be used to calculate the effective equivalent dose (Maged 2009).

Method 6:

It is possible to estimate the effective dose (mSv/y) due to the inhalation of radon and its progeny by using a conversion coefficient of 9 nSv/Bq h m^{-3}, equilibrium factor of 0.6, outdoor occupancy factor of 1760 h and a dose coefficient for radon dissolved in blood of

0.17 nSv/Bq h m^{-3} in equation (8) (UNSCEAR 2000a; Shashikumar et al. 2009).

$$Dose = (0.17 + 9 \times 0.6)C_R \times 1760 \times 10^{-6} \quad (8)$$

where
C_R = is the arithmetic mean radon concentration in Bq/m^3.

Dosimetry of radon progeny / daughters

The exposure to radon radiation is normally expressed as working level (WL), which is the total energy of α-radiation radiated, when radon and radon progeny reach radioactive equilibrium, provided the radon concentration in the air is 100 pCi/l. In other words, working level is a measure of the concentration of radon progeny, based on the pooled average concentration of radon and can be calculated using the reverse-variance-weighted method for determining the expected exposure to radon in various indoor environments (Bodansky 1989). In the present study, the indoor radon concentration was converted into the equilibrium equivalent concentration (EEC), which was further converted into radon progeny or potential alpha energy concentration (PAEC) using formulae (9) (Shashikumar et al. 2009), (10) (Örgün et al. 2008) or (11) (ICRP 1993a; Upadhyay et al. 2007). Further, the WLM (working level month, WLM/y) is calculated assuming 80% occupancy, which is equivalent to WL times 40:

$$R_N(mWL) = \frac{C_R \times F_R}{3.7} \quad (9)$$

or

$$PAEC(WL) = \frac{A_C \times E_F}{3700} \quad (10)$$

or

$$C_R(Bq/m3) = \frac{PAEC(WL) \times 3700}{F} \quad (11)$$

where
R_N or $PAEC$ = radon progeny concentration (WL or mWL),
F_R or E_f or F = the equilibrium factor between indoor radon and radon progeny,
A_C or C_R = mean concentration of radon gas (Bq m^{-3}).

The annual effective dose due to exposure to radon (^{222}Rn) and its progeny, and average lifetime fatality risk were determined using generic relations (ICRP 1993b; Sannappa et al. 2003). ICRP assumes 80% indoor occupancy (7000 h/year) and an indoor equilibrium factor of 0.4 between radon and its decay products for dwellings, the annual exposure at home to radon progeny per unit radon concentration of 1.56×10^{-2} mJ h m^{-3} per Bq m^{-3} and effective dose per unit exposure at home to radon

progeny of 1.1 mSv (mJ h m^{-3}). Under these circumstances, a radon concentration of 1 Bq m^{-3} corresponds to an annual effective dose of 1.716×10^{-2} mSv. One WLM corresponds to the exposure of an individual to radon progeny of 1 WL concentration (2.08×10^{-2} mJ m^{-3}) for 170 h, which results in 1 WLM being equivalent to 3.54 mJ hm^{-3}. In a home with a PAEC of 1mWL, the annual exposure in WLM is ($365 \times 24 \times 0.8/170 \times 1000$) = 0.0412 WLM. Hence, the dose in terms of working level per month (WLM) can be calculated. The WLM was then converted into annual effective dose by using dose conversion factors: the radon daughter dose conversion factor (ICRP 1993a) for members of the public is 3.88 mSv per WLM (~3.9 mSV per WLM). The lifetime risk associated with exposure to indoor radon was calculated using 1 WLM = 10×10^{-6} cases/year. If the risk persists for 30 years, the lifetime fatality risk is 3×10^{-4} cases/ WLM (Nikolaev and Ilic 1999). Hence, the conversion factors of 3×10^{-4} per WLM and 3.88 mSv per WLM (ICRP 1993b) were used to estimate the lifetime fatality risk and the annual effective dose, respectively.

Results and discussion

Temporal variation in the concentration of indoor radon and their respective equivalent dose were obtained using six different methods. The potential alpha energy concentration (PAEC), annual exposure, lifetime fatality risks and annual effective dose due to exposure to radiation from radon progeny are discussed below. Concentration of indoor radon ranged from 1.87 to 14.27 Bq/m^3 of air with an average value of 6.31 ± 3.2 Bq/m^3 over a period of 24 hours. The mean indoor concentration of radon (and in turn short-lived radon progeny) recorded was considerably less than the action levels prescribed by EPA (i.e., 148 Bq/m^3), WHO (i.e., 100 Bq/m^3), EEC (i.e., 400 Bq/m^3), ICRP (200–600 Bq/m^3) and NRPB (200 Bq/m^3).

The equilibrium-equivalent concentration of radon (EEC$_{Rn}$) varied from 0.84 to 6.42 Bqh/m^3 with a mean value of 2.84 ± 1.42 Bqh/m^3. The estimate of equivalent dose using Method 1 yielded an effective equivalent dose ranging from 0.074 to 0.562 mSv/y with an average value of 0.249 ± 0.125 mSv/y, Method 2 an effective equivalent dose that varied from 0.047 to 0.360 mSv/y, with an average value of 0.159 ± 0.080 mSv/y, Method 3 an effective equivalent dose that varied from 0.038 to 0.288 mSv/y, with an average value of 0.127 ± 0.064 mSv/y and Method 4 an effective equivalent dose that ranged from 0.061 to 0.461 mSv/y, with an average value of 0.204 ± 0.102 mSv/y. In contrast, Method 5 gave an effective equivalent dose that ranged between 0.094 and 0.713 mSv/y, with an average value of 0.315 ± 0.158 mSv/y and Method 6 an effective equivalent dose that ranged between 0.018 and 0.140 mSv/y, with an average value of 0.062 ± 0.031 mSv/y (Fig. 2A). It is evident from Fig. 2B that the calculated annual effective equivalent dose due to exposure to indoor
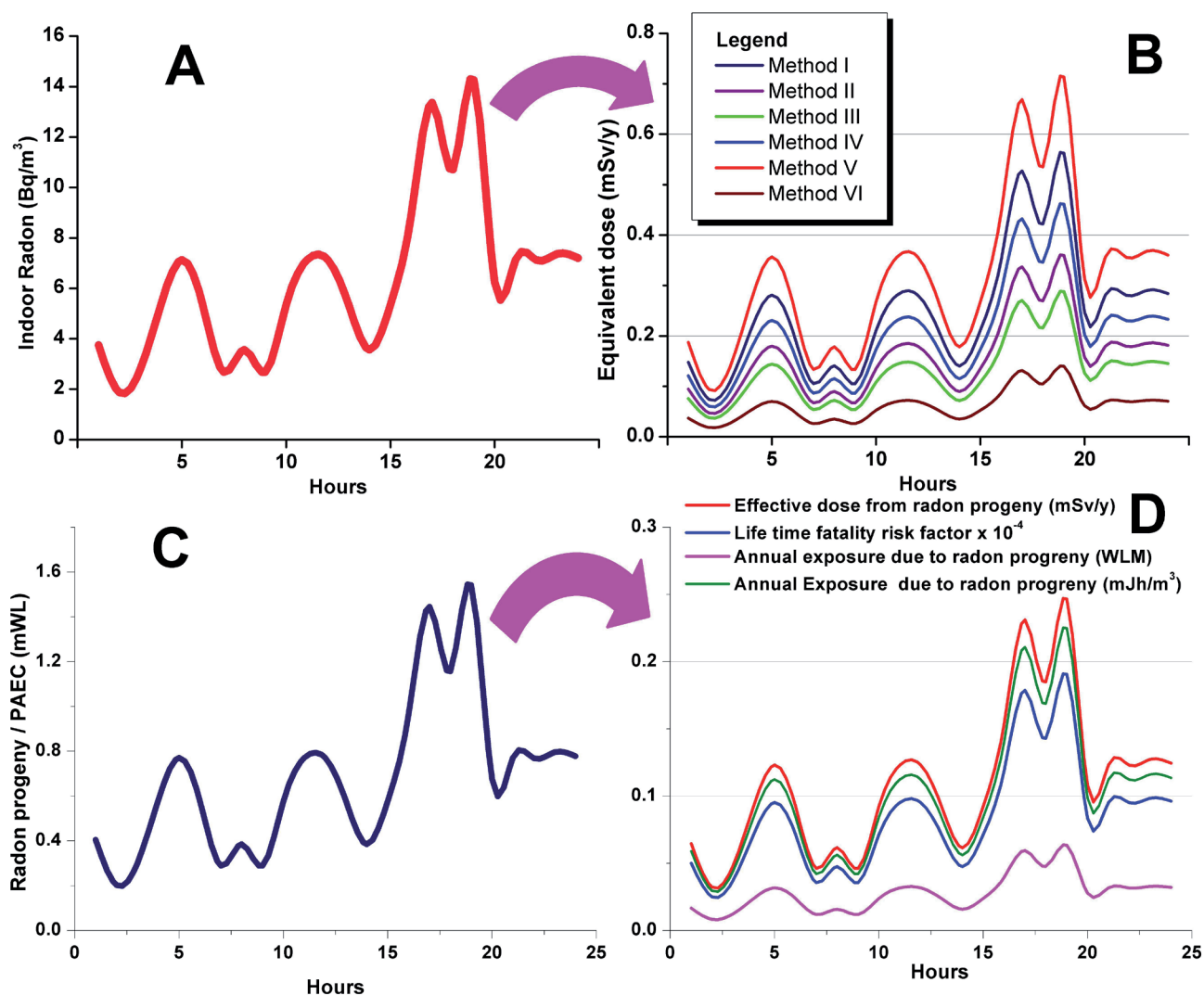
Fig. 2 Temporal variation in (A) the concentration of indoor radon, (B) equivalent dose due to exposure to radon, (C) PAEC or concentration of radon progeny and (D) annual exposure, life time fatality risk and annual effective dose due to exposure to radiation from radon progeny.

radon using all six different methods is below 0.8 mSv/y, which is less than the recommended/estimated global average dose from inhaling radon from all sources, which is approximately 1 mSv/y (WHO 1993; UNSCEAR 2000b;), and is slightly less than half the total natural exposure to radiation of 2.4 mSv/y (UNSCEAR 1988). The estimated annual effective equivalent dose corresponding to the concentration of radon measured was also less than the recommended action level of between 3–10 mSv/y (ICRP 1993b).

Results of this comparative account of the concentration of radon indoors and the corresponding equivalent dose of radiation along with the results obtained by other investigators are presented in Table 2. It is evident that the level of radon recorded indoors and the respective equivalent/inhalation doses are within permissible limits and those recorded in the present study are considerably less than those recorded by other investigators in different parts of the world. Choubey and Ramola (1997) state that radon entering through joints and cracks in buildings increases the indoor concentration of radon.

However, in houses/rooms built of brick and cement, the building materials contain very little uranium and coating the floor with cement reduces the entry of radon into the room from the earth's crust. Abd El-Zaher and Fahmi (2008) conclude that the concentration of radon in kitchens and bathrooms is relatively high compared to that in other rooms in the same dwelling and suggest that it can easily be reduced in these rooms by improving the ventilation. Cheol Min Lee et al. (2012) are of the opinion that the concentrations of radon recorded in these rooms are higher than in other indoor environments, where residents tend to spend most time. Although kitchens and bathrooms are constructed mainly of the same building materials (concrete and cement blocks), the materials used for lining these compartments differ from those used in rooms in the same apartment. Kenawy et al. (2000) state that ceramic materials are a potential source of radon, which mainly results from the decay of thorium and uranium in these materials, which are extensively used instead of the traditional painting materials used in living room and bedrooms (Songül and Güler 1999).

Table 2 A comparison of the concentration of radon and their corresponding equivalent doses recorded indoors on the campus of Bangalore University and those recorded by other investigators in different parts of the world.

Area	^{222}Rn concentration (Bq/m³)			Effective Equivalent dose (mSv/y)				Source
	Min	Max	Mean	Method	Min	Max	Mean	
Bhilangana Valley, Garhwal Himalaya, India	95	208	–	1	3.8	8.1	–	Choubey and Ramola (1997)
Alexandria, Egypt	50.93	105.36	–	2	1.26	2.63	–	Abd El-Zaher and Fahmi (2008)
Dwellings in different areas of Alexandria	36	53	44 ± 16	–	0.61	0.9	0.75	Abd-Elzaher (2012)
Mashhad, Iran	12.3	135.2	–	3	0.25	3.78	–	Ali Asghar Mowlavi et al. (2012)
Ezine (Çanakkale, Turkey)	9	300	67.9	3	0.4	5.2	–	Örgün et al. (2008)
Korea	–	–	50.17 ± 4.08	–	–	–	0.870	Cheol Min Lee et al. (2012)
In a house in Rajshahi, Bangladesh	3.3	37.8	–	4	0.120	1.313	0.516	Farid (1993)
Dwellings in Bangladesh	8.0	46.0	–	4	0.546	1.633	1.195	
Metropolitan zone of Mexico City	0.1*	32.25*	–	4	0.458	0.709	–	Martinez et al. (1998)
Dwellings on the campus of Kuwait University	8.7	23.4	14.8 ± 4.6	5	0.44	1.17	0.74 ± 0.23	Maged (2009)
Mysore, India	16.95	52.85	31.25	6	0.17	0.52	0.31	Shashikumar et al. (2009)
Pune	9.40	28.5	–	6	0.09	0.28	–	Nagaraja et al. (2006)
Kastamonu, Turkey	29	177	–	–	0.73	4.46	–	Kam and Bozkurt (2007)
Campus of Bangalore University	1.87	14.27	6.31 ± 3.16	1 2 3 4 5 6	0.074 0.047 0.038 0.061 0.094 0.018	0.562 0.360 0.288 0.461 0.713 0.140	0.249 0.159 0.127 0.204 0.315 0.062	Present study

Note: * values in pCi/l

Another factor determining the high levels of radon and exhalation rates recorded in these compartments is that the narrow openings into these rooms means they are relatively poorly ventilated. Burning natural gas in houses (Karpinska et al. 2004) and supplying kitchens and bathrooms with water from underground sources are both potential sources of indoor radon (Sujo et al. 2004).

The concentration of radon progeny ranged from 0.20 ± 0.35 to 1.54 ± 0.16 mWL (mean: 0.68 ± 0.34 mWL) (Fig. 2C). The annual exposure of occupants of dwellings in the study area to radiation from radon daughters varied from 0.030 mJh m^{-3} (0.008 WLM) to 0.225 mJh m^{-3} (0.064 WLM) with an average value of 0.099 mJh m^{-3} (0.028 WLM). The life time fatality risk and annual dose radiation from radon progeny (PAEC) varied from 0.03 × 10^{-4} to 0.19 × 10^{-4} (average: 0.08 ± 0.04 × 10^{-4}) and 0.032 ± 0.056 to 0.247 ± 0.026 mSv/y (mean 0.109 ± 0.055 mSv/y), respectively (Fig. 2D). The concentration of radon progeny and monthly level of exposure were considerably less than those reported by Upadhyay et al. (2007), Örgün et al. (2008), Shashikumar et al. (2009), Abd-Elzaher (2012) and Oni et al. (2012), etc. Örgün et al. (2008) records PAEC values of 1.6 to 22.5 mWL and monthly exposure values of 0.1 to 0.9 WLM y^{-1}, while Shashikumar et al., (2009) record concentrations of radon progeny varying from 0.09 mWL to 3.92 mWL.

Abd-Elzahfer (2012) reports that the annual exposure of occupants in all areas he studied varied from 0.56 mJ h m^{-3} (0.15 WLM) in the region of Elmandara to 0.82 mJ h m^{-3} (0.23 WLM) in the region of Kingmaryut. The lifetime fatality risk and the annual effective dose of radiation received by occupants of offices range from 0.86 × 10^{-5} to 1.09 × 10^{-5} and 0.11 to 0.18 mSv/y, respectively (Oni et al. 2012). Upadhyay et al. (2007) record the concentration of radon daughters varying from 0.84 to 6.38 mWL, the annual exposure to radiation from radon daughters varying from 0.036 to 0.273 WLM, the life time fatality risk varying from 0.11 × 10^{-4} to 0.82 × 10^{-4} and the annual effective dose of radiation from radon (PAEC) varying from 0.14 to 1.06 mSv/y.

Conclusion

Radon is a naturally occurring, hazardous, radioactive pollutant that is always present in our surroundings and is one of the causes of lung cancer. It is evident that the indoor radon concentrations we recorded are considerably less than those reported by investigators in other parts of the world. Even the risk of a lifetime exposure to indoor radon in the study area is very low and the occupants of these dwellings are therefore, relatively safe. Proper regulatory standards, like natural and forced ven-

tilation, should be implemented in order to make dwellings more clean and safe. It is also should be kept in mind that only the atmosphere of a single closed staff room was monitored in this study. Therefore, a more extensive survey is required before drawing any definitive conclusions about the general indoor levels of radon and the dosages people are exposed to in buildings on the Bangalore University campus.

Acknowledgements

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