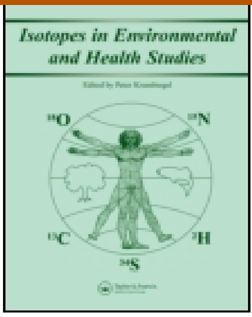

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Radon daughters' concentration in air and exposure of joggers at the university campus of Bangalore, India

G.V. Ashok, N. Nagaiah* and N.G. Shiva Prasad

Department of Physics, Bangalore University, Jnanabharathi, Bangalore, India

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The concentration of radon daughters in outdoor air was measured continuously from January 2006 to December 2006 near the Department of Physics, Bangalore University campus, Bangalore. The concentration was measured by collecting air samples at a height of 1 m above the ground level on a glass micro fibre filter paper with a known air flow rate. The results show that the radon progeny concentration exhibits distinct seasonal and diurnal variations that are predominantly caused by changes in the temperature gradient at the soil–atmosphere interface. The concentration was found to be high from 20.00 to 8.00 hrs, when the turbulence mixing was minimum and low during the rest of the time. In terms of the monthly concentration, January was found to be the highest with September/August being the lowest. The diurnal variations in the concentrations of radon progeny were found to exhibit positive correlation with the relative humidity and anti-correlation with the atmospheric temperature. From the measured concentration, an attempt was made to establish the annual effective dose to the general public of the region and was found to be 0.085 mSv/a. In addition, an attempt was also made for the first time to study the variation of inhalation dose with respect to the physical activity levels. Results show that in the light of both the effect of chemical pollutants and radiation dose due to inhalation of radon daughters, evening jogging is advisable.

Keywords: atmosphere; diurnal variations; inhalation dose; natural radioactivity; radon daughters; Radon-222

1. Introduction

Radon-222 is a ubiquitous radioactive inert gas and a member of the U-238 decay chain. It is released by the decay of Radium-226 and escapes from the soil grains due to alpha recoil and reaches the atmosphere through the soil pores. In the atmosphere, it continuously undergoes spontaneous radioactive decay and decays into four solid, short-lived radio nuclides, namely ^{218}Po, ^{214}Pb, ^{214}Bi and ^{214}Po, of which the polonium isotopes are alpha emitters. These are commonly designated as RaA, RaB, RaC and RaC^1, respectively. The concentration of radon and its daughters constitutes the dominant part of atmospheric radioactivity.

The primary hazards of radon are due to the inhalation of its decay products, which tend to collect on the aerosol particles in the atmosphere. The dose for the respiratory tract and the lungs is predominantly caused by the deposition of Rn progeny via aerosol particles. The alpha

*Corresponding author. Email: nagaiahn@rediffmail.com

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particles emitted by the decay of deposited Rn daughters bombard the sensitive lung tissues, and continuous exposure may lead to malignant transformation, which results in lung cancer [1–3]. Chromosome aberrations in peripheral lymphocytes were also reported for individuals living in the dwellings of high radon concentrations of 80–13,000 Bq/m^3 [4]. It has been established that the dose due to the inhaled radon progeny accounts for more than 50% of the total radiation dose that the general public receive from natural sources [5]. Hence the measurement of radon daughters' concentrations in air is important.

Bangalore (12°15′ and 13°13′ N latitude and 77°3′ and 77°56′ E longitude) is one of the major cities of India and is located in the southern part of Karnataka state. It received the world's attention by establishing major information technology and computing technology industries. In addition, a large number of granite quarries have been established in and around the city recently and several thousands of people are engaged in quarrying activities. Rock crushing industries produce a lot of air pollution and water pollution through the emission of rock dust. In view of the large-scale industrialisation, which can enhance the background radiation levels prevailing in this part of the country, there was a need for a detailed study aimed at establishing the baseline data on background radiation levels in the environment of Bangalore. Therefore, we have initiated a study on the background radiation levels and distribution of radionuclides in different environmental matrices of Bangalore. The measurement of concentration of radon daughters in air (indoor and outdoor) serves as one of the important aspects of background radiation measurements. The potential alpha energy concentration (PAEC) of radon daughters in air was measured continuously from January 2006 to December 2006 near the department of Physics, which is located in an open, bare and flat land of the Bangalore University campus. The PAEC in air of any mixture of radon progeny is the sum of the potential alpha energy of all the daughter atoms present per unit volume of air and is expressed in the unit working level (WL). 1 WL (radon) corresponds to a PAEC of short-lived radon daughters in equilibrium with a radon air concentration of 3700 Bq/m^3. From the measured concentration, an attempt was made to estimate the inhalation dose to the general public of the study area. In addition, an attempt was also made for the first time to estimate the inhalation dose in relation to the physical activity level.

2. Materials and methods

In order to understand the diurnal variation of radon daughters' concentration in air in the environment of Bangalore, air samples were collected with time intervals of 2 hrs for a period of 2 days in every week between January 2006 and December 2006. During this period air samples were collected at a height of 1 m above the ground level using an air flow metre. One end of it consists of an arrangement for fixing the filter paper and a knob for adjusting the air flow rate. At the other end, there is a provision for connecting it to a suction pump. In this method, air was drawn through a glass micro fibre filter paper (Pore size of 0.7 μm) by using a suction pump at the constant flow rate (40 LPM) for a sampling period of 30 min. The air flow rate and sampling period were kept constant during the measurement period. At the end of the sampling period filter paper was alpha counted using an alpha counting system of known efficiency (30%). The alpha counts at the three different counting intervals, 2–5, 6–20 and 21–30 min, were noted (C_1, C_2 and C_3, respectively). Activities of RaA, RaB, RaC and the mean radon daughters' concentration Rd were calculated using Kusnetz equations as modified by Raghavayya [6]. The original equations by Kusnetz are worked out on the assumptions that there is an equilibrium condition, and the transfer is instantaneous, which is not realised in actuality. The modification introduced by Raghavayya takes into consideration the non-equilibrium condition as well as delay in the transfer. The radon progeny concentration in WL depends on WL factor $F(T, \tau)$ which is a function of sampling time T, counting delay time τ and equilibrium ratios b and c for RaB and RaC, respectively. The average of $F(T, \tau)$ corresponding to a specified value of T and τ and a number of possible variations of b and c was taken as a representative WL factor. The following are modified equations which were used to calculate the activities of RaA, RaB, RaC and the mean radon daughters' concentration Rd for a sampling period of 30 min and counting intervals of 2–5, 6–20 and 21–30 min:

$$\text{RaA} = \frac{(4.25C_1 - 2.06C_2 + 1.95C_3)}{VE}\text{Bq/m}^3, \quad (1)$$

$$\text{RaB} = \frac{(-0.35C_1 + 0.01C_2 + 0.24C_3)}{VE}\text{Bq/m}^3, \quad (2)$$

$$\text{RaC} = \frac{(-0.22C_1 + 0.37C_2 - 0.50C_3)}{VE}\text{Bq/m}^3, \quad (3)$$

$$R_\text{d} = \frac{(0.05C_1 - 0.02C_2 + 0.04C_3)}{VE}\text{mWL}, \quad (4)$$

where V and E are the air sampling rate (liters/min) and the efficiency (%) of the alpha counting system, respectively.

3. Results and discussion

A typical diurnal variation of radon progeny concentration in the ground level atmosphere observed is shown in Figure 1. The concentration is high during the early morning hours (4–8 hrs) and at night. The existence of higher concentration of radon daughters in air during morning and night at the ground level may be attributed to the diurnal radon variation in the uppermost soil layer which in turn is mainly governed by the diurnal inversion of the temperature gradient at the soil/air interface

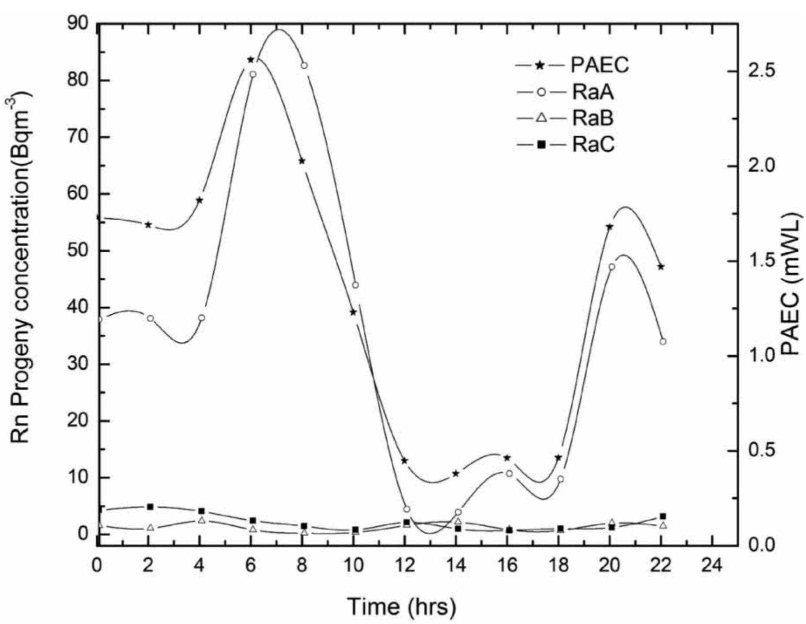

Figure 1. Typical diurnal variation of the concentration of individual radon progeny and PAEC.

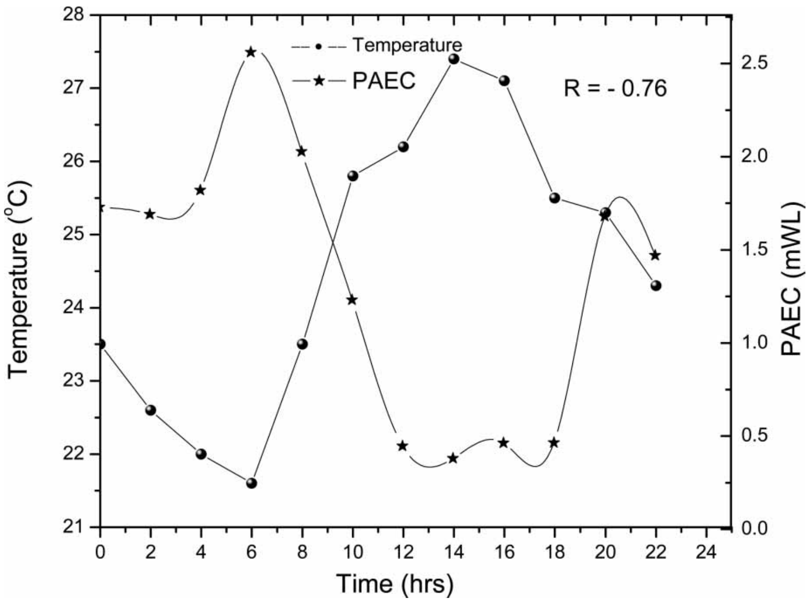

Figure 2. Diurnal variation of temperature and PAEC.

which induces a convective soil gas migration additional to the upward diffusion processes [7–9]. Figure 2 shows the typical variation of radon daughters' concentration and the temperature in the atmosphere observed with respect to time in a fair weather day. An anti-correlation coefficient of −0.76 was found between PAEC and the temperature. From this it can be well understood that the diurnally changing temperature at the ground level has a direct impact on the radon progeny concentration in the atmosphere.

As can be seen from Figure 1, the concentrations of RaA, RaB, RaC and PAEC vary from 4.43–82.62 Bq/m^3, 0.2–2.35 Bq/m^3, 0.78–4.82 Bq/m^3 and 0.38–2.56 mWL, respectively, and show significant diurnal variations of the order 23, 12, 6 and 7. The orders of variations are in the lower side of the reported factor of 10–100 [10]. Further, it can also be seen from the figure that the concentration of RaA (^{218}Po) is several times higher than RaB and RaC. This is due to the fact that ^{218}Po, being positively charged and immediate daughter of radon, attaches itself to the aerosol particles and hence contributes significantly to its atmospheric concentration.

Again, to understand the cause for the diurnal variation of radon daughters' concentration in air, the relative humidity in air with respect to time was noted during the measurement period. Figure 3 shows the variation of PAEC and relative humidity with time. A direct correlation with a correlation coefficient of 0.75 was found to exist between relative humidity and PAEC. This positive correlation may be attributed to the increase in the concentration of attached radon progeny in air as the content of water or humidity in the lower atmosphere increases. This may be due to the reason that the aerosol particles which carry with them the radon daughters have been known to be hygroscopic in nature. Also, humidity avoids the back radiations from the soil and opposes the formation of inversion layer near the ground [11].

The diurnal variations in the concentration of radon daughters (PAEC) were observed in different months for the entire measurement period. For the purpose of clarity, the observed variations for the alternative months are shown in Figure 4. Irrespective of months the same trend of diurnal variation is seen. The average daily pattern of radon progeny concentration featured a minimum in the late afternoon and a maximum in the early morning hours. This pattern was typically observed on sunny days of all the months, when the sky was clear, both at day and at night. Slight variations

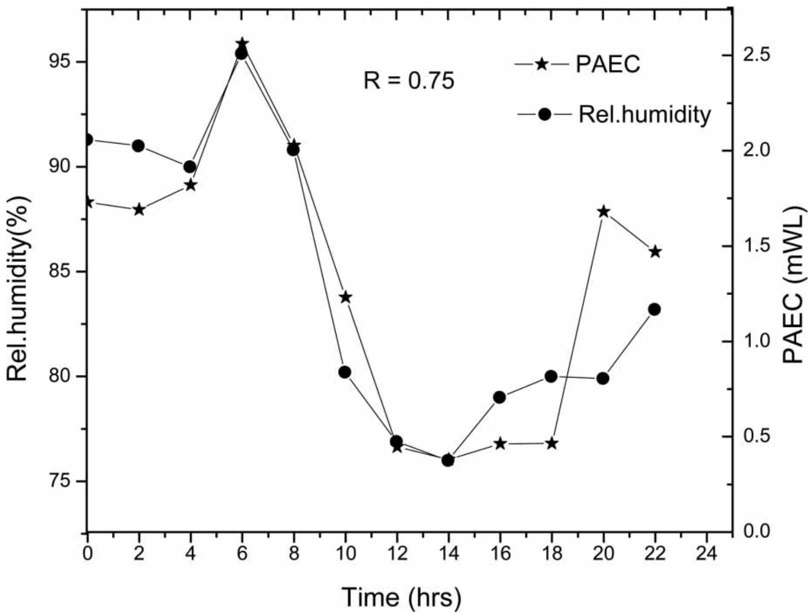

Figure 3. Diurnal variation of relative humidity and PAEC.

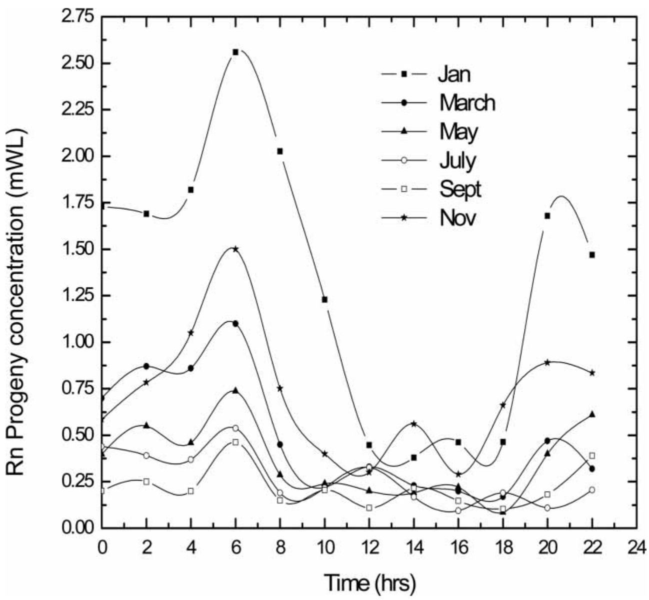

Figure 4. Monthly variations in progeny concentrations.

in the progeny concentrations depicted in Figure 4 may be attributed to the small changes occurred in atmospheric parameters like pressure, wind velocity, wind direction, etc. Moreover, the mean concentration of radon progeny gradually decreases as the summer begins. The concentration attained a maximum (1.09 mWL) in January, which has the highest atmospheric stability, and a minimum (0.20 mWL) in September. This reflects the direct relationship between atmospheric stability and radon progeny concentration.

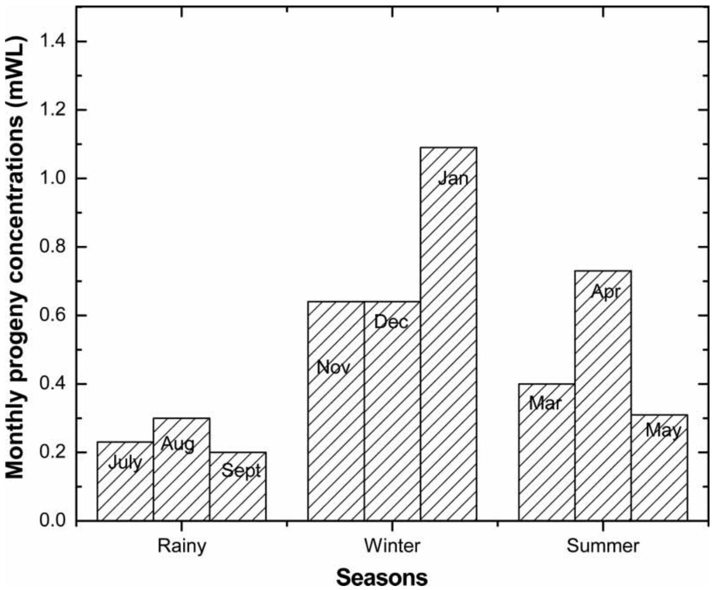

Figure 5. Seasonal variation of PAEC.

Figure 5 shows the seasonal variation of radon progeny concentration observed at the department of Physics, Bangalore University campus. The activity is high during the winter period (November–January) and then gradually decreases as the summer begins. The average concentrations during winter, summer and rainy seasons are 0.76 mWL, 0.45 mWL and 0.24 mWL, respectively. The higher radon daughters' concentration in air during winter followed by the drop in the activity during summer and monsoon may be attributed to several factors. Such factors are the intense temperature inversion which occurs in winter, the vertical mixing and dispersion which occurs in summer, the rain washout during monsoon [12] and the decrease in the emanation of radon from soil when the soil is saturated with water during monsoon [13]. The concentration of radon progeny observed in the present study is comparable with the levels observed elsewhere [12, 14–17].

3.1. *Radiation dose from inhaled radon daughters*

The PAEC measured near the department of Physics is found to range from 0.04 to 2.56 mWL with a mean value of 0.44 mWL. Using this, an attempt was made to establish the radiation dose to the population of the region due to radon daughters alone. For the purpose, the dose conversion factor (DCF) of 3.88 mSv/WLM for the general population (as distinct from the factor applicable to occupational workers) was used [18]. Working level month (WLM) is the cumulative exposure equivalent to 1 WL for a working month (170 hrs). The resultant radiation dose to the population of the region works out to be 0.085 mSv/a.

3.2. *Physical activity levels and the related inhalation dose*

It is known that the physical activity plays a significant role in preventing diabetes, cardiovascular diseases, cancer, etc. It is also proved that the probability of premature deaths is less in people who perform moderate–vigorous levels of physical activity regularly than those with a sedentary lifestyle regardless of age/population/subgroup [19, 20]. Hence, to live healthy, regular physical activities (moderate or vigorous) should be performed in a pollution free environment.

Since the net intake of air during higher physical activity levels increases, the department of public health in Toronto recommends to plan one's routine activities like jogging, running, etc., before 7.00 am or after 8.00 pm to minimise the exposure to both long-range pollutants (such as ozone) and locally derived pollutants like NO_2 and CO [21, 22]. It is observed in the environment of Bangalore that people knowingly or unknowingly used to perform their routine physical activities such as jogging, running, etc., during these periods in general and more in the early morning hours.

Unlike the industrial and urban chemical pollutants, radon and its daughters are ubiquitous air pollutants, which pose potential health hazards. The estimation of health risks from radon daughters requires an accurate estimation of the inhalation dose. It depends on three factors: the concentration of the radon daughters in air, the time that a person spends at that level of concentration and the amount of air that the person breathes at that time. Hence, as the breathing rate increases the dose per unit concentration of radon progeny increases [23].

Higher breathing rates lead to an increase of deposition efficiency due to impaction and to a decrease of the deposition efficiency due to deposition. But the combined effect results more than a proportional increase of dose with higher breathing rates [23, 24]. It was mentioned earlier that the concentration of radon progeny is higher during early morning hours. Hence, higher breathing rate during early morning hours yields a higher radiation dose to the people. To quantify the inhalation dose due to radon daughters, DCFs correspond to different breathing rates are needed. The current epidemiological approach to radon dosimetry does not give the DCFs for different breathing rates. Therefore a dosimetric approach has been adopted for comparison of dose during different physical activities and the DCFs for different breathing rates were calculated using the ICRP [25] lung deposition model [26]. The range of radon progeny concentration observed during the year (January 2006–December 2006) and the range of corresponding doses calculated by assuming 1-hr jogging are reported in Table 1.

Table 2 shows the radon daughters' concentration at different time intervals in average in January 2006, common physical activity, breathing rate based on USEPA [27] and the effective doses at different intervals in a day. It is interesting to note that the concentration of radon progeny and breathing rates are coincidentally high during early morning hours. This results in higher radiation doses to the people who are engaged in greater levels of physical activities during early morning hours.

For instance, the average monthly concentration at 6.00 am in January is found to be 2.56 mWL. Hence, if a person jogs for 1 hr daily at 6.00 am, the dose delivered to him is 0.22 mSv/year.

Table 1. Range of radon progeny concentration and the resultant dose from 1-hr jogging.

Month (2006)	Range (mWL)	Dose (mSv/a)
January	0.38–2.56	0.033–0.22
February	0.24–1.47	0.02–0.12
March	0.17–1.1	0.014–0.094
April	0.41–1.29	0.035–0.11
May	0.19–0.73	0.016–0.06
June	0.20–0.65	0.017–0.055
July	0.11–0.54	0.009–0.046
August	0.04–0.61	0.003–0.052
September	0.10–0.46	0.008–0.039
October	0.2–0.8	0.017–0.068
November	0.29–1.5	0.025–0.13
December	0.28–2.41	0.024–0.2

Table 2. Inhalation doses due to routine physical activities during January 2006.

Period	Mean concentration of radon progeny in a month (mWL)	Common† physical activity	Breathing† rate (m^3/hr)	Dose conversion factor (mSv/WLM)	Inhalation dose (mSv/a)
6.00 am–7.00 am (1 hr)	2.56	Jogging (7.2–9.6 km/hr)	3.63	40.81	0.22
7.00 am–4.00 pm (9 hrs)	0.80	Sitting or standing	0.60	9.58	0.15
4.00 pm–7.00 pm (3 hrs)	0.46	Normal walking (2.4–4.8 km/hr)	1.45	18.34	0.05
7.00 pm–6.00 am (11 hrs)	1.67	Lying or resting	0.54	8.78	0.34

†Based on USEPA, 1997 [27].

Whereas, for monthly average concentration of 1.09 mWL, the average radiation dose from 24-hr outdoor exposure to radon progeny is 0.59 mSv/year (Breathing rate $= 0.75\ m^3$/hr, DCF $=$ 10.94 mSv/WLM) [25, 27]. This shows clearly that a person who jogs only 1 hr daily in the morning time receives about 1/3 of the total outdoor inhalation dose.

Similarly, the average monthly concentration at 6.00 pm was found to be 0.46 mWL. Therefore, a person receives a radiation dose of 0.04 mSv/year from 1 hr jogging during 6.00 pm. These results clearly show that a person receives a lesser inhalation dose if he does the same level of physical activity during evening time instead of early morning hours. Based on the calculation, the inhalation dose received by a person from his physical activity during early morning (6.00 am) is about five times higher than that received during evening physical activity (6.00 pm). Hence, in the light of both, the effect of chemical pollutants and the radiation dose due to inhalation of radon daughters, evening jogging is advisable.

Since the effective doses given in Tables 1 and 2 were calculated using the DCFs given by ICRP [25] human respiratory tract model, they should not be compared with the average dose obtained using ICRP [18].

4. Conclusion

The concentration of radon progeny is higher during morning hours and night times. Nocturnal accumulation of radon daughters and high concentrations during early morning hours confirms the strong influence of temperature and humidity on progeny concentrations. The concentration of radon progeny during winter is higher than in rainy and summer seasons. Since the average concentration of radon progeny in the study area is appropriate within the global average value, even higher levels of physical activities in the early hours do not pose significant inhalation dose to the people. The study highlights the importance of consideration of the inhalation dose from radon progeny in addition to the chemical pollutants' level while recommending routine physical activities of people. The radiation dose due to inhalation of radon progeny is not very significant in the Bangalore University campus. This data serves as the baseline data for this region and provides reference information useful for the reduction of indoor radon daughters' exposure to the levels comparable with the outdoor exposure.

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