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Conference Article

Soil Radon-222 Measurement Around Bakreswar Geothermal Region of West Bengal – Health Concerns

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ABSTRACT

The radioactive gas radon (²²²Rn) is the predominant terrestrial ionizing radiation that leads to natural radiation exposure. Its occurrence is controlled by the presence of generally weak concentration levels of uranium disseminated in all soils and rocks at the surface, besides other factors such as local geological and atmospheric features that control its release and dissipation into the surrounding air. Inhalation of air containing excess radon is considered harmful on account of radiological hazard posed by its short-lived chemically reactive radioactive decay products. The present work deals with radon estimation in top-soil airs in the Bakreswar geothermal area of West Bengal, India. This region is characterized by several geological faults and very high heat-flow of approximately 230 mW/m². Radon measurements were made at several locations scattered around Bakreswar and Tantloi. Radon exhalation rate from soil was also observed continuously for 24 hours at three different locations on three sides of the hot spring Agnikunda, and inhalation doses estimated for indoor radon at each of these three locations.

1. Introduction

Radon-222 released from ground surface to the atmosphere contributes between 50 to 70% of the total ionizing radiation received by man [1]. Therefore study of environmental radon at a place assumes great significance because of the possibility of radiation over-exposure. According to USEPA [2], exposure to environmental radon is the second leading cause of lung cancer in the US and probably worldwide. Of all the 39 isotopes of radon, Rn-222 is present in the environment in an appreciable level due to its comparatively longer half-life of 3.82 days. Although the production of radon through decay of ²²⁶Ra (T_{1/2} – 1602 years) may be large, only a small fraction of the radon produced in the earth's crust enters the pore spaces in soil and hence may be free to migrate away from its site of production, either by diffusion and advection along joints and faults in the crust, or being carried by carrier gases like carbon dioxide, methane, etc. or by groundwater circulating deep inside the crust, and can eventually reach the atmosphere [3]. The mean distance that Rn-222 may travel between its generation and decay through diffusion or advection depends upon the property of the soil where it is generated. In particular, the diffusion length depends on the soil diffusion coefficient, which in turn is related to permeability, porosity, grain size and soil water content [4-6].

Several factors influence human exposure to radon in a region. These are the average uranium concentration level in soils and sediments, local geology, soil composition, type of materials used for constructing buildings, ventilation, drinking water source and atmospheric conditions [1, 7]. Although radon accumulation due to depleted indoor air circulation in dwellings may cause greater exposure, the release of Rn-222 from soil is a major factor influencing the indoor radon levels in many regions [8-9]. While radon concentration in groundwater is greater than that in soil gas, the relatively low solubility of radon leads to its escape into the surrounding atmosphere. Radon escape into air from soils occurs mostly by molecular diffusion or through convection. Exhalation rate is measured as the average activity from a given surface per unit area per unit time. In fact, it is this radon exhaled into the atmosphere that is inhaled by people.

Thus, in principle, measurement of Rn-222 concentration in soil and exhalation of radon into the atmosphere from soil can be useful to identify potential regions with threat to high exposure. The radon exhalation rate in a region depends upon the geophysical parameters and attending meteorological conditions [10]. In the present work, Rn-222 concentrations have been measured at 49 different locations in Bakreswar-Tantloi Geothermal Region of West Bengal and Jharkhand, India. Furthermore, Rn-222 exhalation rates have been measured continuously for 24 hours at three locations near the Agnikunda hot spring of Bakreswar, to determine the overall average exposure level for assessment of health risk.

2. Experimental Methods

2.1 Geology of the Study Area

Bakreswar Geothermal Region is located along the extreme eastern fringe of the Son-Narmada-Tapti (SONATA) lineament, the mega mid-continent lineament extending from Gujarat to West Bengal. In Jharkhand and West Bengal in the east, the SONATA lineament is cut by a north-south trending fault (Fig. 1). The hot springs of Bakreswar (23°52'30" N, 87°22'30" E) in Birbhum, West Bengal, and Tantloi (24°02'25" N, 87°17'30" E) in Dumka, Jharkhand, lie along this N-S fault [11,12]. This region, characterized by a very high heat flow of 230 mW/m², is in the Archaean Chhotanagpur Gneissic Complex (CGC) which contains Precambrian granites and gneisses, Gondwana sedimentary rocks and Rajmahal volcanic rocks. Gases like helium, hydrogen sulphide, sulphur dioxide, etc. rise from the interior of the earth to the surface of the hot springs through an intricate network of fissures and faults with a gas flux of 3.5 slpm and at a pressure of 1.6 bar. The spring gas as well as the soil air of Bakreswar and Tantloi are characterised by presence of high concentration of helium as well as high radon flux 3.

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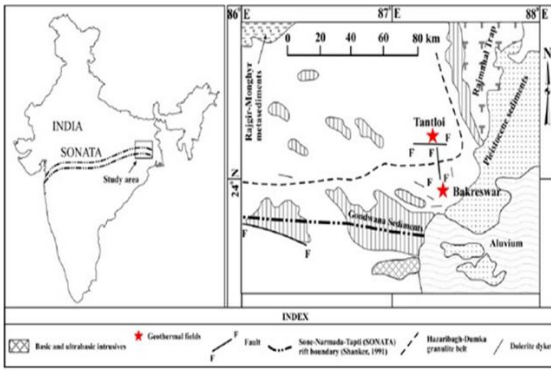


Fig. 1 Location of study area

3.2 Measurement of Radon Concentration in Soil Gas

The concentration of Rn-222 in soil gas was measured using AlphaGuard PQ 2000 PRO radon monitor, Alpha Pump and soil gas probe manufactured by Genitron Instruments, Germany. The AlphaGuard is a pulse counting ionisation chamber having active volume 0.56 litre. It is designed to monitor continuous radon concentrations in a large range spanning from 2 to 2×10^6 Bq/m³. The experimental set-up for soil gas analysis is schematically described in Fig. 2. The soil probe was inserted at a depth of 1 m into the ground. Using the gas transfer Alpha Pump soil gas was allowed to diffuse into the ionization chamber of the Alpha Guard at a rate of 0.5 L/min. Readings were recorded at 10 minute intervals. Activity recorded in the first three cycles was discarded to allow for count stabilization. The average of subsequent three closely similar values was considered as representative of Rn-222 concentration in soil gas for that measurement.

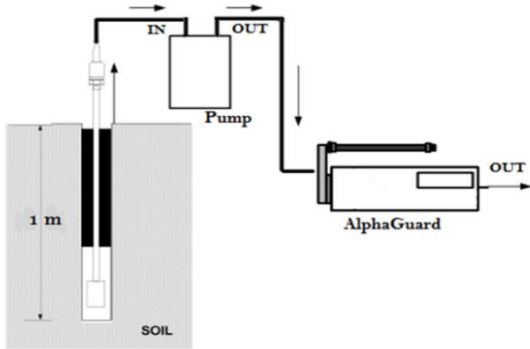


Fig. 2 Set-up for measurement of soil ²²²Rn concentration

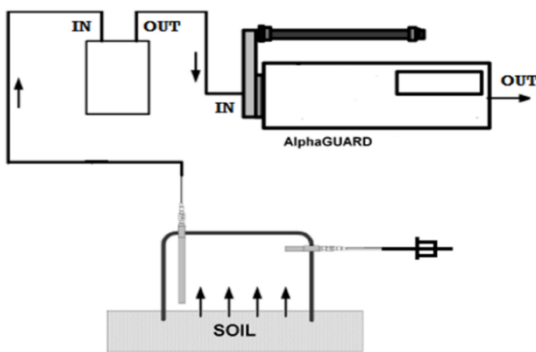


Fig. 3 Set-up for determination of soil ²²²Rn exhalation

3.3 Measurement of Radon Exhalation Rate from Soil

Radon exhalation rate from soil was measured with the AlphaGuard and AlphaPump together with the radon exhalation chamber provided with the instrument. The exhalation chamber is essentially a rectangular box having dimensions 0.57 m x 0.37 m x 0.165 m with an open base. The base was plugged into the soil so that radon exhaled from beneath could accumulate in the covered volume. The top face of the box has two corrugated nozzles. These nozzles were initially closed with tygon tubing provided with pinchcock so as to shut communication of the internal volume with outside atmospheric air. The box was left undisturbed in this state for 1 hour to allow radon exhaled out of the soil below to accumulate in the enclosed volume. Thereafter the Alphaguard and Alpha pump were brought in communication with the exhalation chamber as shown in Fig.

3. The AlphaGuard radon monitor was set in 10 minute diffusion mode. The Alpha pump was set at a slow displacement capacity of 0.03 L/min. Radon concentration readings were noted every 10 minutes for 1 hour duration. Thereafter the AlphaGuard was removed. The soil gas accumulated in the exhalation chamber was pumped out by operating the AlphaPump at a higher displacement rate of 1 L/min for half an hour. Then, soil gas was again allowed to accumulate in the exhalation chamber for 1 hour, and the same procedure was followed. This was continued for 24 hours.

Finally, radon exhalation rate E_{Rn} from soil is calculated according to the following relation [13]:

$$E_{Rn} = \frac{C_{avg} \times V}{t_{acc} \times S} \tag{1}$$

where,

C_{avg} = Average Rn concentration

t_{acc} = Accumulation time

V = Volume of radon exhalation chamber (0.035 m³)

S = Surface area covered by the chamber (0.211 m²)

3. Results and Discussion

²²²Rn concentration in soil gas was measured at forty nine locations scattered around Bakreswar and Tantloi. Radon concentrations were found to vary from 0.586 kBqm⁻³ to 255 kBqm⁻³, with an average of 52.722 kBqm⁻³, and a standard deviation of 45.07 kBqm⁻³ from the average. Soil radon concentrations at different locations are shown in Fig. 4.

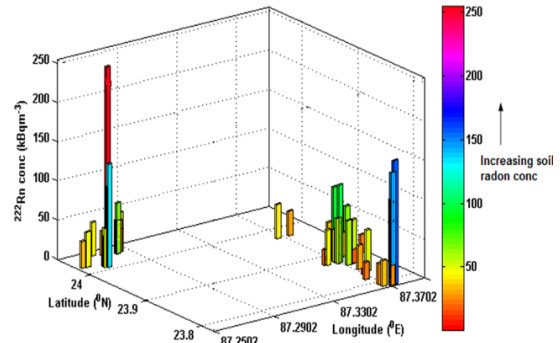


Fig. 4 Measured soil ²²²Rn concentration at different locations

It can be seen from the following (Fig. 5) that ²²²Rn concentrations in soil gas at seven (7) locations are quite higher than the standard deviation from the average.

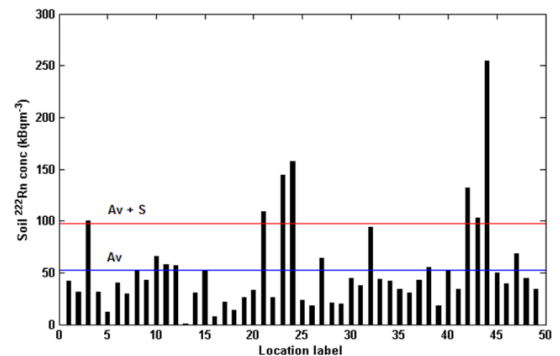


Fig. 5 Soil Rn concentration profile

However, these are the values of radon concentration in soil at a depth of about 1 m from the earth surface. Only a part of this radon travels through the cracks and pores in the soil to come out into the atmosphere, and it is this part that would be inhaled by humans. Hence, it is the radon exhalation rate from soil that determines potential human exposure to radon from soil. In order to understand the effects of physical and meteorological parameters on soil radon exhalation rate and ²²²Rn concentration in air, simultaneous measurements of ²²²Rn concentration, ambient temperature, relative humidity and air pressure were carried out continuously for 24 hours in early January, 2017 at three spots on three sides of the Agnikunda hot spring, using the set-up described in Fig. 3. The three positions are designated as Position A (23.8871°N, 87.3773°E), Position B (23.8794°N, 87.3751°E) and Position C (23.8735°N, 87.3762°E). It can be seen from the following (Figs. 6-8) that radon exhalation rate increases with radon concentration in soil gas.

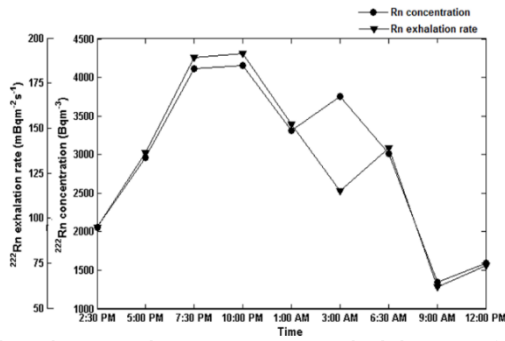


Fig. 6 Relation between soil ²²²Rn concentration and exhalation rate from soil for Position A

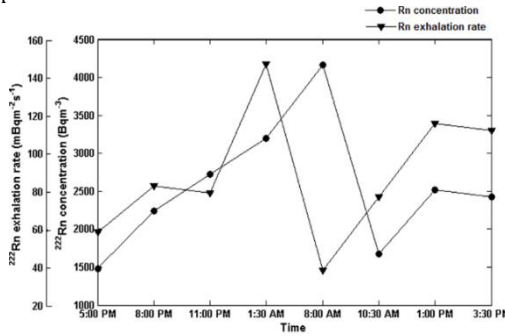


Fig. 7 Relation between soil ²²²Rn concentration and exhalation rate from soil for Position B

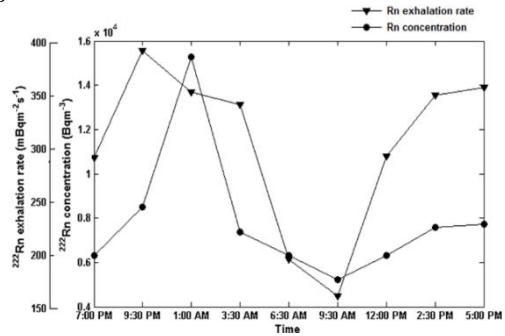


Fig. 8 Relation between soil ²²²Rn concentration and exhalation rate from soil for Position C

The diurnal variations of ²²²Rn exhalation rate from soil along with temperature, pressure and relative humidity at the three locations have been shown in Figs. 9-11.

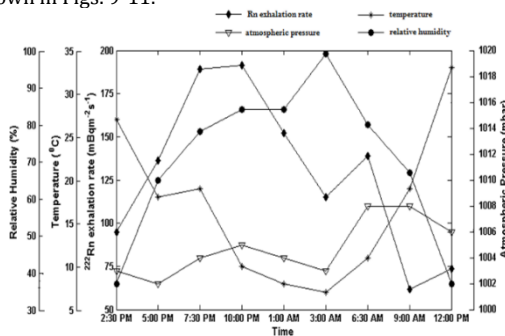


Fig. 9 Diurnal variation of soil ²²²Rn exhalation rate with temperature, pressure and relative humidity for Position A

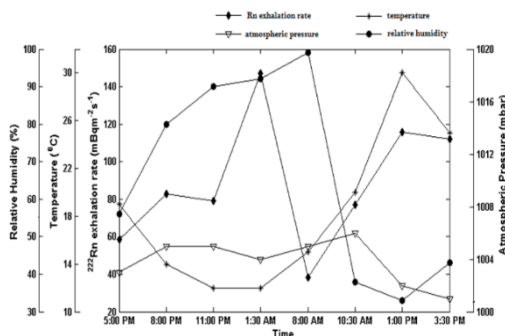


Fig. 10 Diurnal variation of soil ²²²Rn exhalation rate with temperature, pressure and relative humidity for Position B

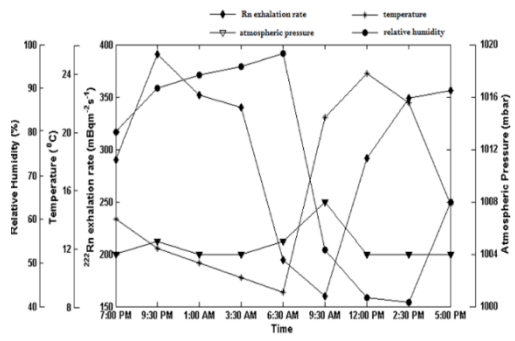


Fig. 11 Diurnal variation of soil ²²²Rn exhalation rate with temperature, pressure and relative humidity for Position C

From Figs. 6-11 it can be seen that at all the three locations, soil ²²²Rn concentration and exhalation rate increases after sunset, becomes highest around midnight and then decreases until it reaches a minimum around noon. This may be due to the fact that the ground gets heated during the day (average temperature at noon ~ 25°C) and cooled during the night (average midnight temperature ~ 10°C), causing a large diurnal temperature variation near the earth surface, while the temperature underneath the soil remains more or less constant. Bakreswar, being a geothermal region with heat flow about 230 W/m², is expected to have quite high sub-surface temperature. Thus, the temperature gradient between the soil at a depth of few centimetres and the ground surface is higher at night than during the day. This can lead to appreciable diurnal variation of radon exhalation rate and concentration of radon in the lower atmosphere [14]. Also, the cracks and pores in the soil get heated throughout the day and increase in size considerably by sunset. This may be another reason for higher radon exhalation rates at night. Moreover, radon exhalation from soil increases with increase of the emanation factor, which in turn increases with moisture content of soil [15, 16]. Relative humidity was found to increase sharply in the night and early morning hours, as Figs. 9-11 show, and there was dew throughout the night, which increased moisture level in soil, and hence radon exhalation, at night.

In order to estimate the health risk due to such radon exhalation rates from soil, the inhalation exposure effective doses received by a person living in a house at each of the three locations A, B and C, have been considered separately. The contribution of indoor radon concentration from soil can be calculated from the following expression [8]:

$$C_{Rn} = \frac{E_{Rn} \times S}{V \times \lambda_v} \tag{2}$$

where,

C_{Rn} = ²²²Rn concentration in air (Bqm⁻³)

E_{Rn} = Average ²²²Rn exhalation rate at a particular position (Bqm⁻²hr⁻¹)

S = ²²²Rn exhalation area (m²)

V = volume of room (m³)

λ_v = air exchange rate (s⁻¹)

The maximum radon concentration inside the dwelling has been estimated by assuming the room as a cavity with $S/V = 2.0 \text{ m}^{-1}$, and air exchange rate of 0.5 hr^{-1} . Then the annual exposure to potential alpha energy, that is, effective dose equivalent E_p , in working level month (WLM) per year unit, has been determined from the expression [17]:

$$E_p (\text{WLM y}^{-1}) = \frac{8760 \times n \times F \times C_{Rn}}{170 \times 3700} \tag{3}$$

where,

C_{Rn} = radon concentration inside the building

8760 = number of hours in a year

n = the fraction of time spent indoors

170 = number of hours in a working month

F = indoor radon equilibrium factor between ²²²Rn and its progenies

$n = 0.8$ and $F = 0.4$ have been considered according to UNSCEAR [18].

From E_p , indoor inhalation exposure effective dose has been estimated by using the conversion factor 4 mSv WLM^{-1} [19], and presented in Table 1.

Table 1 Indoor inhalation exposure effective dose due to soil radon exhalation

Location	Average ²²² Rn exhalation rate (Bqm ⁻² hr ⁻¹)	Average ²²² Rn conc in air (Bqm ⁻³)	E_p (WLM y ⁻¹)	Indoor inhalation exposure effective dose (mSv y ⁻¹)
Position A	435.6	1742.4	1.94	7.76
Position B	315.7	1262.8	1.41	5.64
Position C	1089.7	4356.0	4.85	19.40

It can be observed that effective dose increases with increase in indoor radon concentration in air, which in turn increases with radon exhalation rate from soil.

4. Conclusion

Soil ^{222}Rn concentration was measured at forty nine locations in Bakreswar-Tantloi region, and average radon concentration in soil was found to be 52.722 kBqm^{-3} . Of these 49 places, very high ^{222}Rn activity has been observed at seven locations. Hence, it is expected that effective dose due to inhalation of radon at these places would be quite high also. But in order to determine the inhalation dose, radon exhalation rates from soil at these places should be determined.

Radon exhalation rates were estimated for 24 hours at three locations near Agnikunda hot spring of Bakreswar. Positive correlation has been observed between soil ^{222}Rn concentration and its exhalation rate; both are higher at night and lower during daytime. Radon exhalation rate from soil has been found to depend significantly on ambient temperature and relative humidity, whereas atmospheric pressure has negligible effect on radon exhalation. Using established models, average radon concentration in air has been determined from average radon exhalation rates at these three places, and inhalation dose inside a dwelling estimated. Inhalation dose has been observed to increase with radon exhalation rate from soil. Hence, inhabitants of regions with high soil radon exhalation rates are at higher risk of exposure both indoors and outdoors.

Radon exhalation rates from soil should be measured at more spots in this geothermal region, and also during different seasons, to have a complete picture of potential exposure risk.

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