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The Study of Radon Diffusion in Air and Soil

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ABSTRACT

The radon diffusion studies in air and soil at varying thickness are carried out with alpha detectors (Solid State Track Detector and Alphameter-400) using U-rich ore as a radon source. The influence of temperature on the diffusion rate in air and soil is also investigated in the temperature range 30 to 125°C using radon emanometer with ZnS (Ag) as the detector. For both air and soil the radon content increases upto 40 cm thickness and decrease exponentially thereafter. The phenomenon of back diffusion in case of ^{222}Rn is effective upto 40 cm thickness of the medium. The diffusion rate is found to increase with the temperature.

INTRODUCTION

RADON-222, an inert gas with a half life of 3,8 days is continuously formed by the decay of its parent ^{226}Ra. Radon emanates from mine faces, uranium ore stockpiles and tailings and is liberated by drilling blasting and crusting operations. The important characteristic for release of radon include (i) the amount of present ^{226}Ra or ^{224}Ra atom to escape, (ii) prosity and permeability of the medium and (iii) degree of water saturation(7). Release of radon to the environment involve two mechanism, liberation from individual grains in which it is formed and transport through the bulk medium to a free surface. The fraction of radon atoms that escape from mineral grain is termed the emanation co-efficient(1, 4, 6). The transport rate is usually characterized by the diffusion coefficient in the bulk medium(2, 5). In the present work, the diffusion of radon through soil and air at varying thickness has been studied with alpha detectors (SSNTD and alphameter-400). The influence of temperature on the diffusion rate in air and soil is also investigated using radon emanometer with ZnS(Ag) as the detector.

THEORY

Let N_0 be the concentration of radon in the source. The concentration N of radon at any time t, x cm away from the source junction inside the rock can be expressed by Fick's Law of diffusion(2) :

$$\frac{\delta N}{\delta t} = D \frac{\delta^2 N}{\delta x^2} - \lambda N \qquad .. (1)$$

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The term $N\lambda$ denotes the rate of decay of radon, being the decay constant of radon (2.1×10^{-6} sec^{-1}) and D the diffusion constant (cm^2 sec^{-1}).

$$\text{For a study rate } D \frac{\delta^2 N}{dx^2} - \lambda N = o \qquad \text{...(2)}$$

This equation gives the solution

$$N = \exp\{-\sqrt{(\lambda/D)}\, x\} + C_2 \exp\{\sqrt{(\lambda/D)}\, x\} \qquad \text{...(3)}$$

Using the following boundry conditions

$$\text{At } X = 0,\; N = N_o$$
$$\text{and at } X = \infty,\; N = o$$

The solution comes out to be

$$N = N_o \exp\{-\sqrt{(\lambda/D)}\, x\} \qquad \text{...(4)}$$

The number of radon atoms crossing unit area of cross-section of the rock into the detector per unit time is :

$$-D\left(\frac{dN}{dx}\right)_{x=h} = N_o \sqrt{(\lambda/D)} \exp\{-\sqrt{(\lambda/D)}\, h\} \qquad \text{...(5)}$$

If S is the area of cross section of the rock specimen, total number of radon atoms passing through per unit time is

$$N_o S \sqrt{(\lambda/D)} \exp\{-\sqrt{(\lambda/D)}\, h\} \qquad \text{...(6)}$$

If A is the concentration of radon in the detector at any time, we have the rate of change of radon concentration in the detector is

$$\frac{dA}{dt} = N_o S \sqrt{(\lambda/D)} \exp\{-\sqrt{(\lambda/D)}\, h\} \text{ or } \frac{dA}{dt} = K - A \qquad \text{... (7)}$$

$$\text{where } K = N_o S \sqrt{(\lambda/D)} \exp\{-\sqrt{(\lambda/D)}\, h\} \qquad \text{...(8)}$$

In the above treatment, we have not taken into consideration the effect of the accumulation of radon in the detector chamber, because of this the concentration gradient of radon in the rock section changes with time and, therefore, the rate of diffusion is affected. This may be considered to be equivalent to a back diffusion taking place from the detector chamber to the source chamber while the rate of diffusion is constant and the back diffusion is supposed to be proportional to the concentration of radon in the detector chamber at any time.

The rate of change of radon in the detector chamber can, therefore, be expressed as

$$\frac{dA}{dt} = (K - A\,\lambda) - A\,\lambda' \qquad \ldots(9)$$

where $A\,\lambda'$ refers to back diffusion and λ' is a constant

$$\text{or} \quad \frac{dA}{dt} = K - A\,(\lambda + \lambda')$$

$$= K - A\,\lambda\,(1 - \lambda'/\lambda)$$

$$= K - AZ\,\lambda$$

$$\text{where} \quad Z = 1 + \frac{\lambda'}{\lambda}$$

or in other words, radon may be considered to decay with different constant $Z\,\lambda$.

EXPERIMENTAL PROCEDURE

Aluminium cylinder of varying length (8, 20, 40, 60, 80 and 100 cm) each in 4.5 cm in diameter with screw cap on one end are depolyed vertically. About 100 gm of pitch blende is placed at the bottom of the cylinder in the cavity of screw cap. On the other end of the cylinder an alphameter-400 and LR-115 type 2 plastic track detector are attached. In order to study the diffusion rate in air column at the varying length, the count rate is recorded after a fixed interval of time for each length. These columns are then filled with the dry soil having the same packing density and the variation in radon content with time is recorded at each thickness.

Figure 1 shows the apparatus used to measure the radon diffusion through air and soil at different temperatures. It consists of an aluminium cylinder 45 cm in length and 4.5 cm in diameter with screw cap at one end having a cavity for the radon source. The other end of cylinder is closed with the brass lid consisting of two brass tubes connected to the scintillation cell with the rubber tubes through the hand operated rubber pump. The thermocouple is sealed in the centre of Al-cylinder through a small hole to record the temperature. The length of cylinder is wrapped with the heating elements. This system is placed vertically in the outer jacket 20 cm in diameter and the empty area in-between the two cylinders is filled with plaster of paris for insulation. The terminals of heating elements are connected to the voltage variable dimmerstate and the thermocouple terminals are connected to the microvoltmeter.

Firstly, 100 gm of the pitch blende ore is placed at the bottom of the cylinder in the screw cavity and the upper end is sealed with the lid. The variation of radon diffusion rate with time is monitored at room temperature (30°C). When the constancy in radon growth rate is reached, the radon diffusion rate is recorded at different

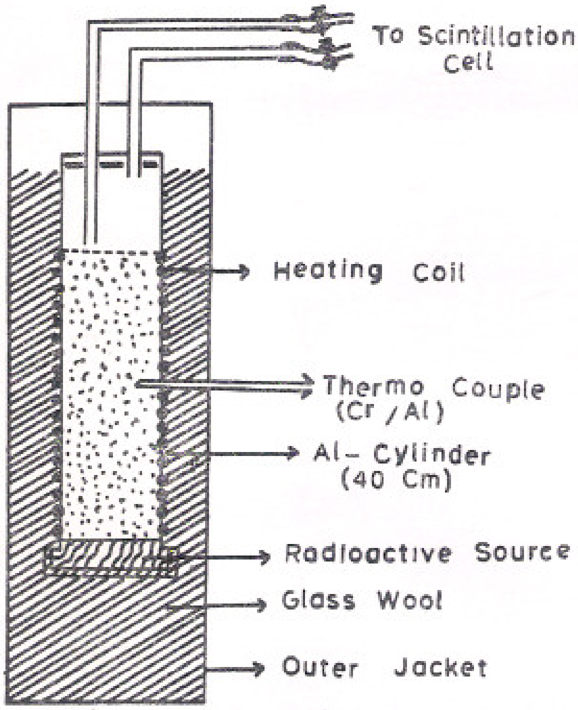

Fig. 1. Experimental set up to study the influence of temperature on diffusion of radon through soil and air at column height of 40 cm.

temperatures in the temperature range 30 to 125°C. For each observation the temperature of investigation is kept constant during the period of radon accumulation. The cylinder is then filled with soil and similar observations are taken in the corresponding temperature range.

RESULTS AND DISCUSSION

The radon concentration is found to increase with time in detector chamber after diffusing through the soil and air at each thickness. It is observed that, if the diffusion is left for a sufficient length of time, the radon concentration is reached a constant value at which the radon in the detector chamber is decaying at the rate at which it is escaping from the specimen The radon build up time in soil and air is almost same at corresponding thickness. For both the soil and air, the radon concentration increases on adding the identical layers upto the 40 cm and decreases exponentially thereafter (Figs. 2 and 3). At small thickness, the radon concentration is low which may be due to the accumulation of radon in the detector chamber.

Because of this the concentration gradient of radon in rock section changes with time and, therefore, the rate of diffusion is affected. This may be considered to be equivalent to a back diffusion taking place from the detector chamber to the source

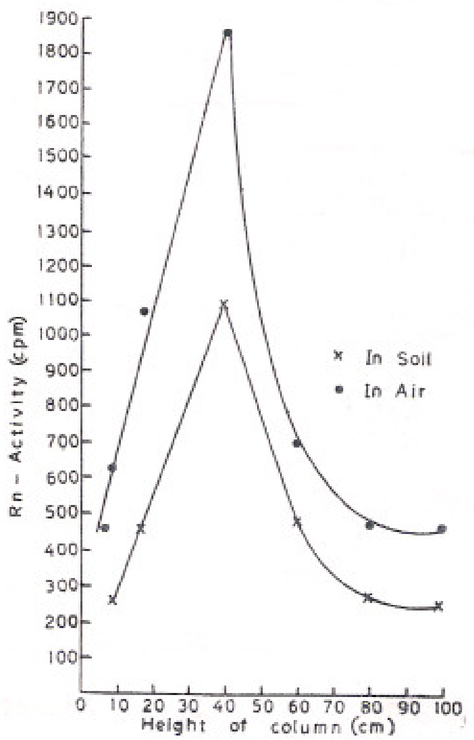

Fig. 2. Variation of alpha count rate with varying height of columns in soil and air using Alphameter-400.

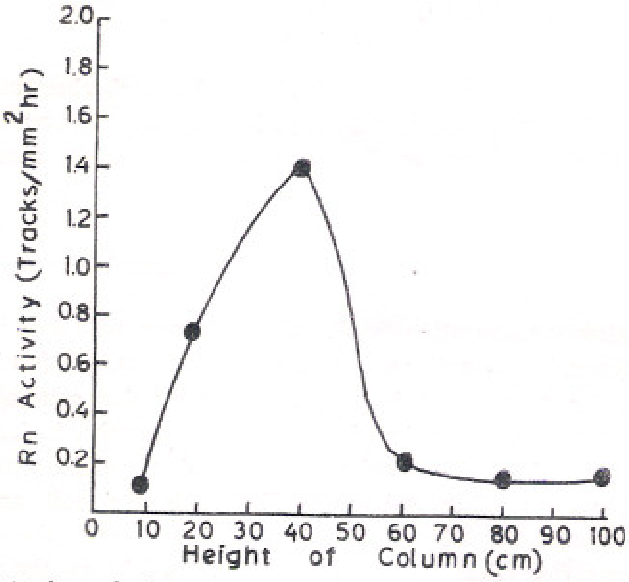

Fig. 3. Variation of track production rate with verying height of columns in soil using LR-115 type 2 plastic track detector.

chamber, while the rate of diffusion is constant. The back diffusion is supposed to be proportional to the concentration of radon in detector chamber. The rising trend in radon concentration upto 40 cm thickness shows that with the increase in thickness the effect of back diffusion is decreasing. This phenomenon is effective upto 40 cm thickness of the medium. Guedalia *et al.*(3) also observed an increase in the emanation of ^{220}Rn upto 6-7 cm of soil thickness.

The motion of diffusion is controlled by a diffusion coefficient D, the mean diffusion distance being $(D/\lambda)^{1/2}$. The flow of radon -222 is limited by its mean half life $(1/\lambda)$ of 5.5 days which implies the reduction in the concentration by a fraction 1/e for each time $1/\lambda$. For porous soil as diffusion medium, the mean diffusion distance for $D = 0.09$ cm^2/sec (determined by using eqn. 4) is calculated to be 2.70 m. This length implies the dilution of randon by a factor of 10^{21} in moving 100 m in soil. In case of air, with $D = 0.25$ cm^2/sec (eqn. 4), the mean diffusion distance is calculated to be 3.45 m.

The influence of temperature on the radon diffusion through air and soil column of each 40 cm in length is investigated in the temperature range 30-125°C using

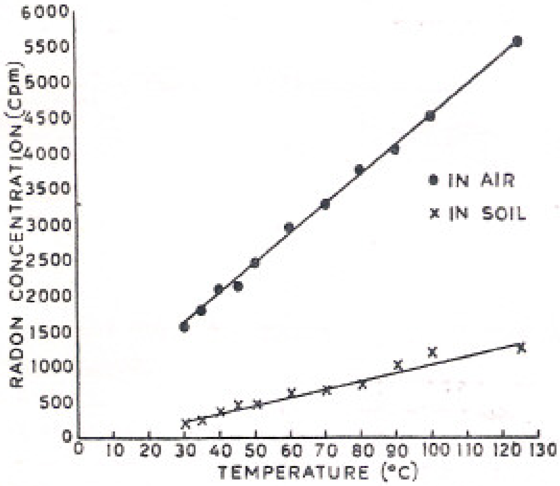

Fig. 4. Variation of radon diffusion in soil and air with temperature.

pitch blend as a source for both air and soil, the diffusion rate is found to increase with the increase in temperature (Fig. 4). This may be due to the fact that the diffusion coefficient is proportional to the atom jump frequency which depend exponentially on the temperature. □

CONCLUSIONS

The important conclusions from the radon diffusions studies in air and soil are :

(i) The radon diffusion rate is faster in air than in soil.

(ii) The phenomenon of back diffusion is observed experimentally and is effective upto 40 cm thickness of the medium.

(iii) The mean diffusion distance calculated for radon is 2.07 and 3.45 m in soil and air respectively.

(iv) The diffusion rate is found to increase with the temperature. □

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