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NOTES

A Laboratory Study of Diffusion of Radon through Soil

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The diffusion of radon through soil thickness up to 1 m has been studied. An anomalous effect, i.e. increase in radon concentration as soil thickness increases, is observed up to a soil thickness of 40 cm. This effect is attributed to the phenomenon of back-diffusion. The variation of back-diffusion coefficient with soil thickness is studied. The experimental results are in agreement with computed results determined by considering the back-diffusion.

The mode of diffusion of radon through different media has been studied as an aid to the interpretation of anomalies encountered in radon survey. The diffusion of radon and thoron through soil and rock has been studied by many workers[1-5]. The present study is aimed at finding the diffusion of radon through soil of thickness less than 1 m and the results will be useful in the interpretation of anomalies observed with thin soil.

Theory—Let N_0 be the concentration of radon emitted by the source. The concentration N of radon at any time t, x cm away from the source soil junction inside the soil can be given by the relation[3]

$$N=N_0\exp\left\{-\left(\frac{\lambda}{D}\right)^{1/2}\cdot x\right\} \qquad \ldots(1)$$

The number of radon atoms crossing per unit area of the cross-section of the soil into the detector per unit time is given as

$$-D\left(\frac{dN}{dX}\right)_{x=h}=N_0\left(\frac{\lambda}{D}\right)^{1/2}\exp\left\{-\left(\frac{\lambda}{D}\right)^{1/2}\cdot h\right\}$$

If S is the area of cross-section of the soil specimen, total number of radon atoms passing through per unit time is given as

$$N_0S\left(\frac{\lambda}{D}\right)^{1/2}\exp\left\{-\left(\frac{\lambda}{D}\right)^{1/2}\cdot h\right\} \qquad \ldots(2)$$

If A is the concentration of radon in the detector at any time, then the rate of change of radon concentration in the detector is given by

$$\frac{dA}{dt}=N_0S\left(\frac{\lambda}{D}\right)^{1/2}\exp\left\{-\left(\frac{\lambda}{D}\right)^{1/2}\cdot h\right\}-A\lambda \qquad \ldots(3)$$

or

$$\frac{dA}{dt}+A\lambda=K$$

where

$$K=N_0S\left(\frac{\lambda}{D}\right)^{1/2}\exp\left\{-\left(\frac{\lambda}{D}\right)^{1/2}\cdot h\right\} \qquad \ldots(4)$$

In Eq. (4), the effect of accumulation of radon in the detector chamber has not been considered; because of this, the concentration gradient of radon in the soil column changes with time. Hence, the rate of diffusion is affected. This may be considered to be equivalent to a back-diffusion taking place from the detector to the source, while the rate of diffusion is constant and the back-diffusion is 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

$$\frac{dA}{dt}=(K-A\lambda)-A\lambda'$$

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

or

$$\frac{dA}{dt}=K-A(\lambda+\lambda')=K-Z\lambda A \qquad \ldots(5)$$

where

$Z=1+\lambda'/\lambda$

or, in other words, radon may be considered to decay with a different decay constant $Z\lambda_0$.

Using the boundary condition that $A=0$ at $t=0$, Eq. (5) is solved to yield

$$A=\frac{K}{Z\lambda}[1-\exp(-Z\lambda t)]$$

or

$$A\lambda=\frac{K}{Z}[1-\exp(-Z\lambda t)] \qquad \ldots(6)$$

The alpha activity in the detector chamber is also contributed by the alpha-active daughter products of radon. The two alpha-active daughter products of radon are Ra A and Ra C′. The half-life of Ra D (22.2 yr) may be considered to be too long and, therefore, the contribution to the alpha activity below Ra D may be neglected.

If $A_1\lambda_1$ and $A_2\lambda_2$ are the respective activities of Ra A and Ra C′, the alpha counting rate (T) in the detector chamber at any time may be considered to be the sum total of the activities of the individual isotopes Rn, Ra A and Ra C′, i.e.

$$T = R(A\lambda + A_1\lambda_1 + A_2\lambda_2) \qquad \dots (7)$$

where R is a constant.

Experimental details—The source of radon is a pitch-blender sample placed in the cavity of a steel base chamber. Aluminium cylinders of inner diameter 5.1 cm and of different lengths, were used for the diffusion column. These columns were then filled with dry soil having the same packing density. On the other end of the cylinder, an Alphameter-400 and plastic track detector (LR-115 type II) were in tandem to record the alpha activity due to radon. The experimental arrangement is shown in Fig. 1. The radon which diffuses through the soil column was collected by the alpha detector. In order to study the diffusion of radon in soil columns of varying lengths, the count rate was re-

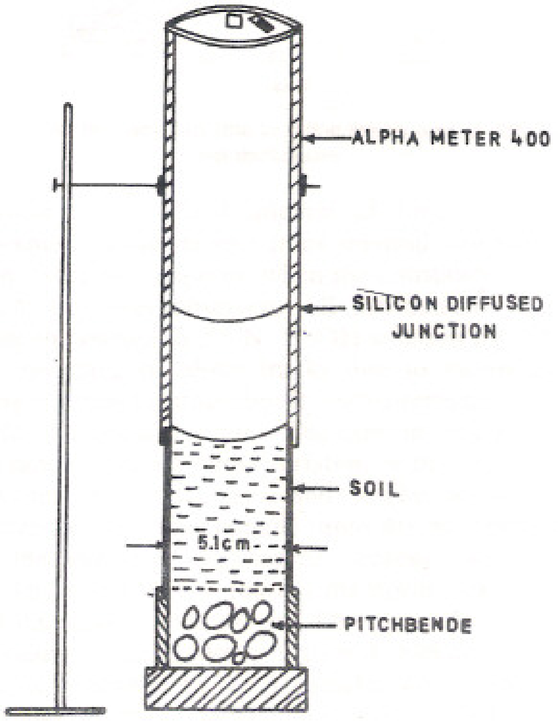

Fig. 1—Experimental set-up to study the diffusion of radon through soil

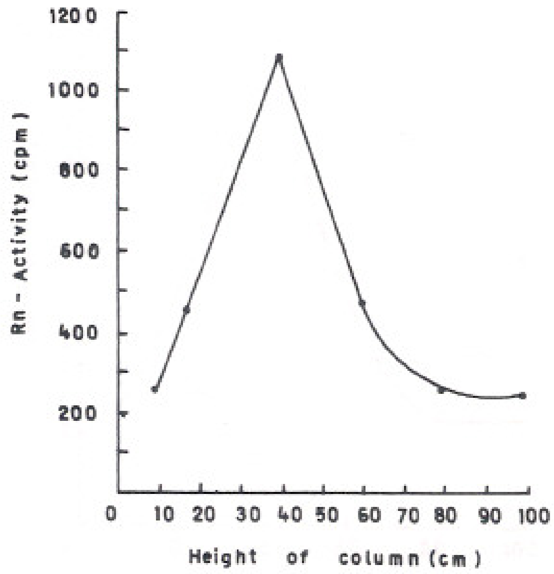

Fig. 2—Variation of radon activity with thickness of soil measured using Alphameter-400

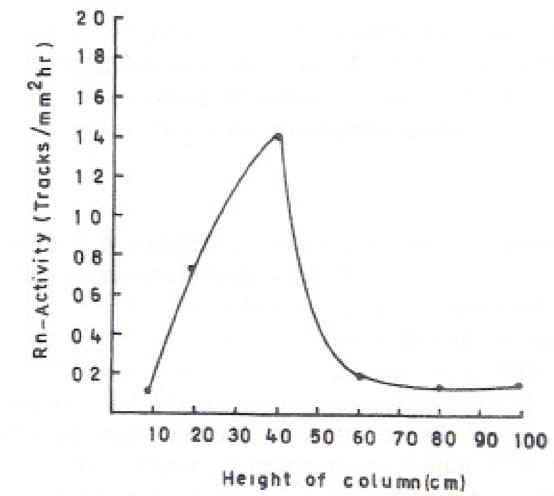

Fig. 3—Variation of radon activity with soil thickness measured using alpha-track etch method

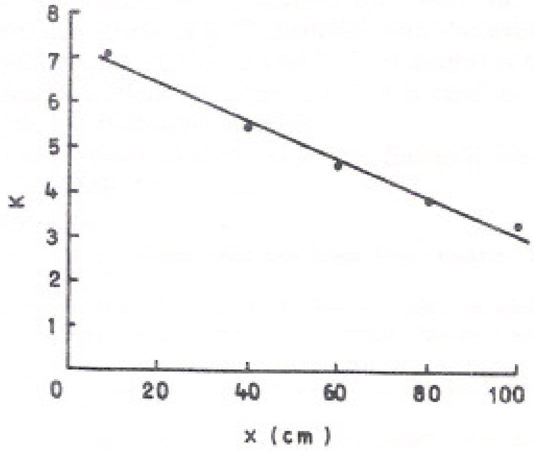

Fig. 4—Plot of K versus soil thickness (X)

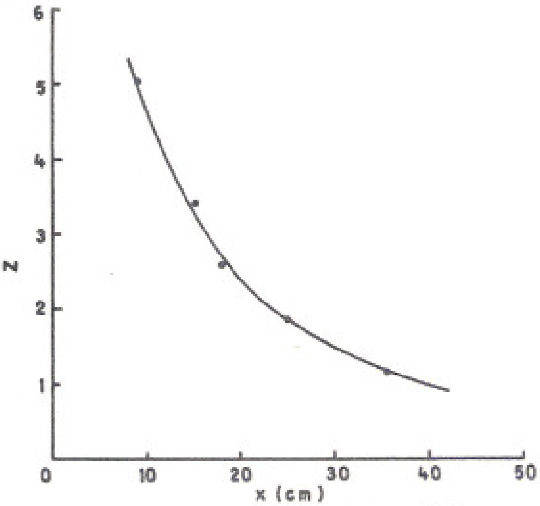

Fig. 5—Plot of Z versus soil thickness (X)

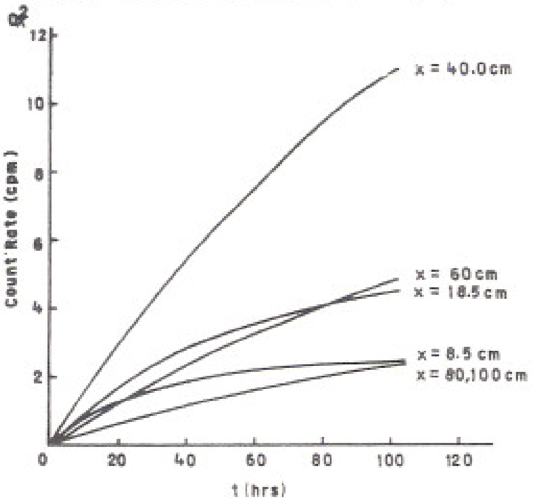

Fig. 6—Alpha count rate due to radon versus time at different soil thicknesses

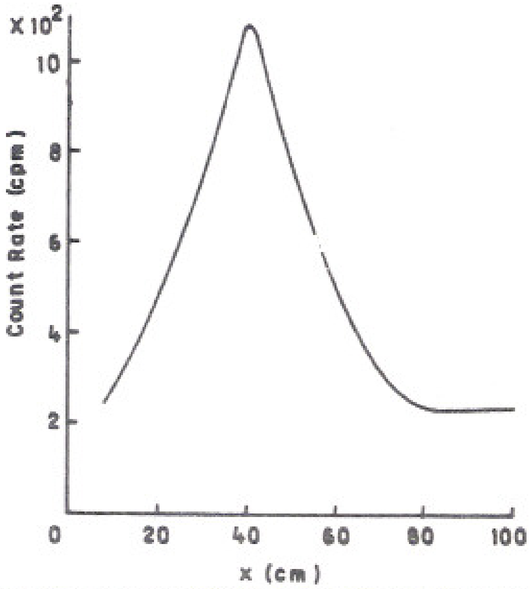

Fig. 7—Plot of computed values of radon activity with thickness of soil

corded after a fixed interval of time for each thickness. In the etched track method, the plastic films were also exposed when the constancy in the count rate was observed. All the detector films were the etched in 2.5 N NaOH solution for 2 hr, for revealing of alpha tracks due to radon and were scanned for track density measurements.

Results and discussion—The experimental results of radon concentration variation with soil thickness are shown in Figs 2 and 3. The radon concentration increases initially (upto 40 cm) contrary to the expected exponential decrease with soil thickness and then it follows the normal exponential decrease beyond 40 cm. This anomalous effect in radon concentration (up to soil thickness of 40 cm) is attributed to the accumulation of radon in detector chamber which gives rise to back-diffusion. Thus, the alpha activity of radon in detector chamber will be given by Eq. (5) which accounts for back-diffusion and not by Eq. (3). To study the effective contribution of back-diffusion, the value of back diffusion coefficient (Z) and the variations in decay constant of radon (Z) are calculated for different soil thicknessess using the relation[3]

$$T=\frac{3K}{2}[1-\exp(-Z\lambda t)] \qquad \ldots (8)$$

where K is computed from Eq.(4) and its variation with soil thickness is shown in Fig. 4.

The Z values and hence the decay constant are found to decrease exponentially with soil thickness (Fig. 5) indicating the decrease in back-diffusion with increase of soil thickness. To compare the results of radon variation with soil thickness, the temporal variation of radon is computed from Eq. (8) for different thicknesses using computed values of K and Z as shown in Fig. 6. Using data from Fig. 6, the authors have drawn the radon concentration variation with thickness for t= 100 hr, the theoretical curve (Fig. 7) matches with the experimental results of Figs 2 and 3. This confirms that anomalous effect in radon diffusion is only due to the back-diffusion phenomenon.

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References

1 Tanner A B, *Nautral Rad Env Symp Proc Houston Texas* (1980) 5.
2 Barreto P M C, *Proceedings of a panel on radon in uranium mining*, (International Atomic Energy Agency, Vienna) (1975) 129.
3 Ghosh P C & Seikh I A, *Indian J Pure & Appl Phys*, **14** (1976) 666.
4 Schroeder G L H W & Evans R D, *J Geophys Res* (*USA*), **70** (1965) 471.
5 Cudedial D, Laurent J L, Fountan J, Blane D & Druilhet A, *J Geophys Res* (*USA*), **75** (1970) 361.