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Correlation Study of ^{222}Rn Production Rate and Exhalation Rate with Geophysical Process at Mat Fault in Mizoram

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Abstract: The production rate of ^{222}Rn gas within 5 cm depth from the ground surface was assessed from soil sample collected at Mat fault, Mizoram (India). Simultaneously, the ^{222}Rn exhalation rate of Mat fault was measured using a ZnS(Ag) scintillation counter (Model: SMARTRnDuo, BARC, India). The nature of relationship between the two rates was analysed during the anomalous and non-anomalous period of ^{222}Rn data at the continuous monitoring station (CMS) in order to reveal the geophysical behaviour of the region.

Keywords: ^{222}Rn, ZnS(Ag) alpha scintillation, ^{222}Rn , production/exhalation rate, geophysical process, correlation.

1. Introduction

Radon is a radioactive noble gas with three naturally occurring isotopes viz. radon (^{222}Rn; $T_{1/2} = 3.8$ days), thoron ($^{220}Rn; T_{1/2} = 55.6$ s) and actinon

($^{219}Rn\,; T_{1/2} = 3.6$ s). In the earth crust, they were released to the soil pore space from the soil matrix by their respective parent nuclei i.e. ^{238}U, ^{232}Th and ^{235}U by the process of emanation and then get transported to the surface by diffusion/advective process. ^{222}Rn and ^{220}Rn are mentioned to have a diffusion length of 1 m and 1 cm respectively, in typical soil and the equation of diffusion was given by equation (1.1)[1,2].

$$\frac{\partial C_p}{\partial t} = S - \nabla . F_p - \lambda C_p , \tag{1.1}$$

where S is the radon activity released into a unit volume of the pore space per unit time by emanation process, F_p is the local flux giving the activity of radon crossing per unit pore area per unit time and C_p is the pore space radon concentration (radon activity per volume of pore space) at any point and given time.

Their earthbound origin makes especially ^{222}Rn as one of the most monitored terrestrial gas as a tracer, premonitory gas for seismic activity, global budget estimator etc.[3-11], while ^{219}Rn often get neglected due to its extremely small half-life ($T_{1/2} = 3.6$ s). The present study investigates the nature of the correlation between ^{222}Rn production rate of 5 cm depth with its exhalation rate of three different sampling depths to observed any favourable geophysical signal due to geophysical phenomena. The intervening geophysical phenomena of the region were depicted by the anomaly period of the continuous ^{222}Rn data at the CMS, Department of Physics, Mizoram University, Mizoram (India). The study reveals the significance of the assessed ^{222}Rn production and exhalation rate of the same depth (5 cm depth) in identifying geophysical phenomena while no distinctive correlation was observed between the two rates at the other three successive sampling depths during the said phenomena.

A tectonically active fault-Mat fault (Mizoram, India) (Fig. 1) was selected for obtaining the ^{222}Rn data and visited once a month for six months. According to seismic hazard zonation map of India[12], the region belongs to Zone V (highest seismic level) and is of the six most active region of the world. On the other hand, its precursory measurement especially by monitoring radon anomaly is of a great challenge for the present-day researcher of the region due to limited kinds of literature and assessed data originated from the region. Hence the authors hope the analysis and data of the present study would serve as a reference and baseline data for future studies carried out in the region related to seismic studies.

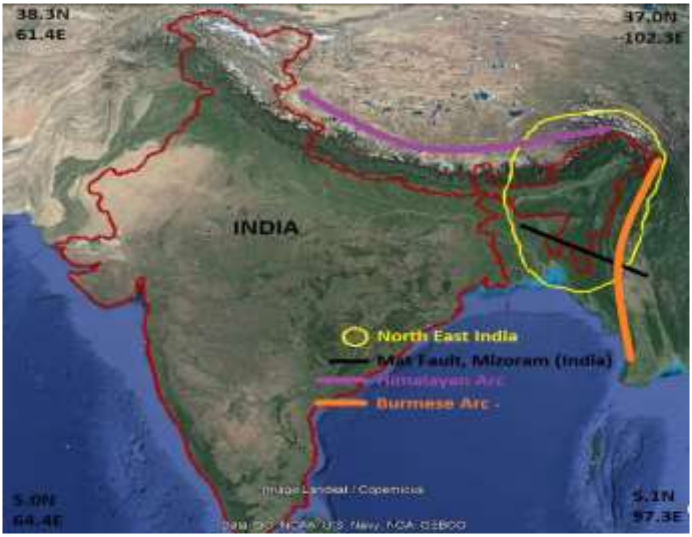

Figure 1. Location Map of the Study Area

2. Materials and Method

An indigenously developed and calibrated; ZnS(Ag) based scintillation counter (Model: SMARTRnDuo, BARC, Mumbai, India) was deployed for measurement of all radon data. At the CMS the sample gas of 5 cm depth (accessed by a soil probe of length 5 cm) was circulated by the inbuilt pump of the instrument after every 15 minutes through a progeny filter (Fig. 2a). The progenies free sample gas enter into the scintillation cell (153 cm^3) and was counted 5 minutes for alpha particles, delayed for the following 5 minutes and again counted for another 5 minutes during each 15 minutes cycle.

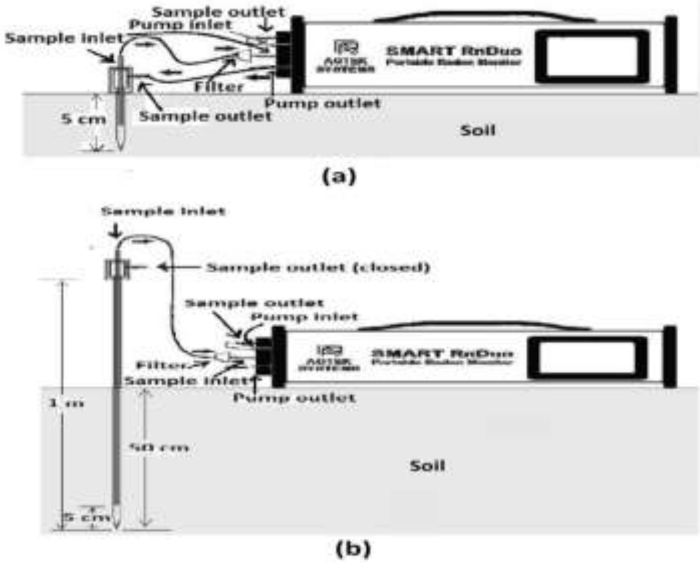

Figure 2. Experimental set-up of the monitoring instrument for measurement of radon data at (a) the CMS and (b) Mat fault

Alpha counts of the first 5 minutes attribute to alpha particles due to decays of ^{222}Rn and ^{220}Rn gases, the delayed 5 minutes ensured the $T_{1/2} = 55.6$ s ^{220}Rn gases to decay out while the last 5 minutes count attribute only to ^{222}Rn and marginal long live alpha particles. At the end of the 15 minutes cycle, the counted gases were released back to the soil probe through a tube by the inbuilt pump to clear space for the newly arrived sample gas in the scintillation cell. In this way perturbation in ^{222}Rn concentration was easily detected. Moreover, the CMS was designed in such a way that the meteorological influence on the ^{222}Rn exhalation was minimised, hence any observed ^{222}Rn anomaly was assumed to be perturbation due to geophysical phenomena. Such that the radon data at the CMS was adopted for categorising the radon data at Mat fault into anomaly and non-anomaly period data.

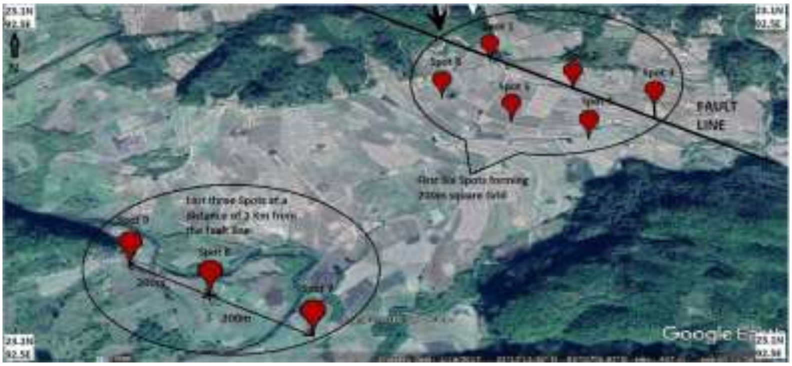

Figure 3. Formation of sampling spots at Mat Fault

At the fault, the radon data were assessed from a rectangular grid of 9 spots (1000 m x 400 m) within the fault (Fig. 3). At each spot radon data of the three depths were measured using a soil probe of 1 m length by inserting it at the desired depth. The operating manual of the instrument was the same as that of the CMS except that the counted sample gas was released into the atmosphere and was not circulated to obtain only the in-situ counts. For each depth of the spots, the instrument was operated for 15 minutes each on every field visit. Details procedure for measuring the radon data at the CMS and Mat fault has been given by Thuamthansanga and group[2].

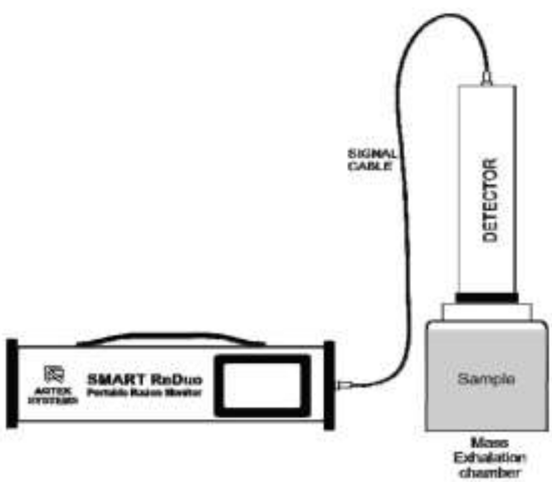

Figure 4. Set-up of the instrument for measurement of radon mass exhalation rate from soil sample

The collected soil sample within 5 cm from the ground surface was put in a metal cylinder of volume 5×10^{-4} m^3; the detector probe of the instrument was mounted on it and airtight using the provided slight tight mechanism (Fig. 4). In this mode, only ^{222}Rn gas enter the scintillation cell volume whilst all the other gas and progenies were cut off by the thoron discriminator places between the scintillation cell and the metal container. Hence only counts and concentration of ^{222}Rn gas was obtained. In this mode, the instrument was operated 12 hours with 60 minutes cycle and slope of the obtained ^{222}Rn concentrations was evaluated and substituted in equation (2.1) to obtained the mass exhalation rate (radon production rate) of the soil sample[13].

$$J_m = \frac{BV}{M}, \tag{2.1}$$

where J_m is the ^{222}Rn mass exhalation rate (production rate) of the soil sample, B is the slope of the ^{222}Rn concentration obtained within 12 hours with 60 minutes cycle, V is the effective volume (volume of detector + porous volume of sample + residual air volume of the mass exhalation chamber) in m^3 and M is mass of the soil sample in Kg.

3. Result and Discussion

Soil samples from Mat fault were collected between November, 2017 and April, 2018 with a frequency of once a month (November 16, 2017; December 15, 2017; January 17, 2018; February 27, 2018; March 27, 2018 and April 18, 2018). Simultaneously the radon exhalation rate of 5 cm, 50 cm and 1 m depths were also measured from the same spots where the soil samples were taken. After assessing the radon production rate from the collected soil sample they were categorised into anomaly period and non-anomaly period data, as well as the radon exhalation data's, using the CMS data. Such that radon data generated on November 16, 2017; December 15, 2017 February 27, 2018; April 18, 2018 were categorised as anomaly period data (represented by a vertical red dash line in Fig. 5) while those of January 17, 2018 and March 27, 2018 were taken as non-anomaly period data (represented by a vertical green solid line in Fig. 5).

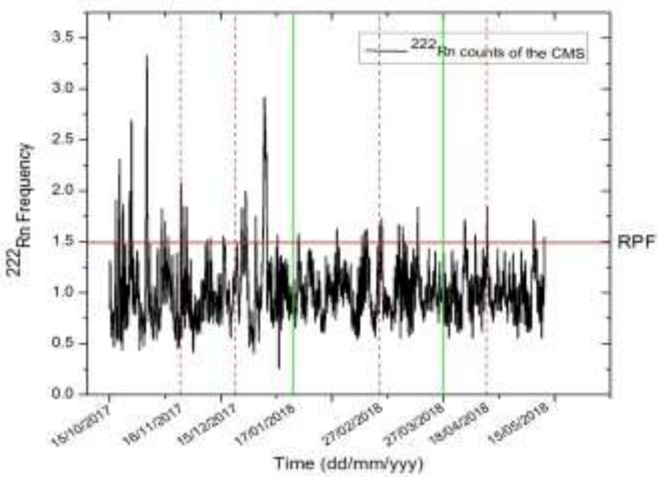

Figure 5. ^{222}Rn data of the CMS categorizing ^{222}Rn data of Mat fault into anomaly and non-anomaly period data; where data of Mat fault belonging to anomaly period and non-anomaly period were indicated by a vertical dashed red line and solid green line, respectively

^{222}Rn data of the CMS were extracted and plotted against time and its base counts (equilibrium state) was obtained by taking the average of all local minima counts of the ^{222}Rn frequency versus time curve (Fig. 5). Again the Radon Peak Factor (RPF) was assigned by taking an average of all the diurnal peak of the said curve and was found to be 1.5 times the base count represented by the horizontal red line in Fig. 5. Every raise of ^{222}Rn counts at the CMS above the RPF was taken as ^{222}Rn anomaly due to intervening geophysical processes of the region. Hence if the ^{222}Rn data at Mat fault were generated by the time ^{222}Rn data at the CMS rose above the RPF they were categorised as anomaly period data otherwise a non-anomaly period data[2]. Now each radon production rates were correlated with their respective sampling spot exhalation rates of the three depths and the obtained correlation coefficients were in turn correlated with geophysical phenomena depicted by radon data at the CMS. A details correlation of radon data's with geophysical phenomena of the region was given in Table I. From Table I, it was obvious the ambiguous nature of the correlation between the radon production and exhalation rate by showing zero, a positive and negative correlation coefficient at different sampling depths.

Table 1. Details of Correlation coefficient between ^{222}Rn production rate and exhalation rate of three different sampling depths during anomaly and non-anomaly periods of the CMS data

Dates of Measurement	Periods	Sampling Depths		
		5 cm	50 cm	1 m
16/11/2017	Anomaly	0.5	-0.3	0.1
15/12/2017	Anomaly	-0.5	0.7	0.3
17/01/2018	Non-Anomaly	-0.6	0.1	-0.2
27/02/2018	Anomaly	-0.3	-0.6	-0.1
27/03/2018	Non-Anomaly	-0.6	-0.2	0.4
18/04/2018	Anomaly	0.1	-0.04	0.5

This wasn't our interest and scope of the study but only nature (magnitude) of the correlation coefficient between the said rates during geophysical phenomena. To do so average of the mode of the correlation coefficient for each anomaly period and non-anomaly period were taken irrespective of the direction (Table 2).

Table 2. Average of Magnitude of the correlation coefficient of ^{222}Rn production and exhalation rate during anomaly and non-anomaly period between November, 2017 and April, 2018

Periods	Sampling Depth		
	5 cm	50 cm	1 m
Anomaly Period	0.3	0.4	0.3
Non-Anomaly Period	0.6	0.2	0.2

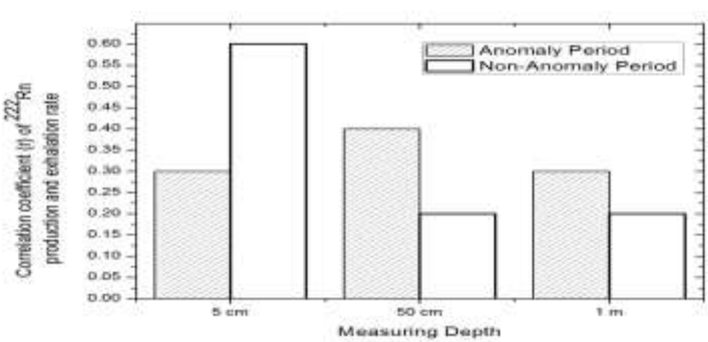

Figure 6. Plot, showing the average correlation coefficient (r) of ^{222}Rn production rate and exhalation rate of three different depths during anomaly and non-anomaly period between November, 2017 and April, 2018

At a sampling depth of 5 cm from the ground surface, a strong and weak correlation was observed between the radon production and exhalation rate during the non-anomalous and anomalous period, respectively. The observation suggested that during the non-anomalous period, due to absence of geophysical disturbance, the radon concentrations is in its equilibrium state such that its production rate and exhalation rate of 5 cm depth were in high proportion manifested by the strong correlation coefficient (0.6, Fig. 6). On the other hand, during the anomalous period, the equilibrium state of radon gets perturbed by geophysical processes and does the proportionality between its production and exhalation rate; depicted by the weak correlation coefficient (0.3, Fig. 6). From Table II, when correlated the radon production rate assessed at 5 cm depth to those radon exhalation rate measured at 50 cm depth and 1 m depth no distinctive correlation was observed between them to identify geophysical phenomena of the region. The reason behind this observation might be that the Radon production rate and exhalation rates were of different depths. Hence, the study shows that to observed significance distinction in nature of the correlation between radon production rate and exhalation rate during intervening geophysical phenomena both the rates might be assessed from the same depth.

4. Conclusion

The study reveals the presence of radon anomaly during geophysical phenomena of the region and the possibility of identifying the phenomena by correlating with the proportionality between the radon production and its exhalation rate. The absence of distinctive correlation between the radon production rate and its exhalation rate of 50 cm depth and 1 m depth suggested that both the rates might be assessed from the same depth. Though the analysis and data were immature to depict geophysical phenomena of the region with high accuracy, the study was the first of its kind for the region and Mizoram in particular and will serve as a reference for future study carried out in the region related to seismic activity. In general, it was concluded that the method adopted proof to be applicable for depicting geophysical processes of the region.

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