Evidence of Radon Emission Associated with 7th October 2023 Earthquake off the Coast of Madang in Papua New Guinea

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Abstract: Radon is the only radioactive gas which is a progeny of Radium. Prior to earthquake, a large amount of radioactive radon gas is also emitted along with other gases from within the earth. Radiation due to radon gas is observed using Radon Eye+2 instrument in the UNITECH campus. Radon emission is observed to be low during dry season compared to wet season. A correlated variation is observed between radon emission and humidity. Emission of radon gas is observed during seismically active periods. A large peak of 565 Bq/m^3 was observed prior to a series of earthquakes on the 7th October 2023 ranging from 5.1 to 6.9 magnitude off the coast of Madang Province approximately 183 km from Lae which is higher than the safe limit of 148 Bq/m^3 radiation. Excess radon emission is observed ten days prior to the earth earthquake. The detection of radon emission prior to earthquake can be used as a tool for the prediction of earthquakes.

Keywords: Radon gas, Inhalation dose, Earthquake.

1. Introduction

Radon is the only radioactive gas with half-life 3.82 days which is the decay product of radium (^{226}Ra) that is a part of ^{238}U series. ^{226}Ra is found in Uranium ores, phosphate rocks, shale, granite and schist and a small amount in lime stone. Radon gas emits due to tectonic stress in fault regions. It is believed that radon escapes through the cracks and cavities formed during earthquake. Papua New Guinea is located in the tectonically active region. This has resulted in frequent earthquakes. Radon emission in the atmosphere during earthquake period is reported in many studies [1, 2, 3]. Radon concentration in ground water is found to increase prior to earthquake [4]. Emanation of radon is linked with atmospheric electric field and ionospheric disturbances [5]. Radon and its progenies are the major contributors responsible for inhalation and ingestion radiation dose to the population. Radon inhalation is the second largest cause of lung cancer after tobacco smoking.

In this paper, we have studied the seasonal variation of radon emission and its association with humidity in the atmosphere by measuring indoor radon gas and humidity using Radon Eyeplus2 instrument. We also calculated the average inhalation dose to human. The radon emission associated with earthquake on 7th October 2023 in Madang Province is also studied.

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2. Materials and Methods

2.1 Measurement of Radon using Radon Eyeplus2

Fig. 1: Radon Eyeplus2 instrument for the measurement of Radon gas

Radon Eye Plus Two is a real time detector with sensitivity of 0.5 cpm/pCi/l. It consists of a passive diffusion chamber which allows air to pass through it. The photodetector placed inside the chamber counts the amount of daughter nuclei of Rn atoms in the air sample. The detector is sensitive to alpha particles emitted by Rn and its progeny. Then new samples are filled in the chamber in about 30-45 minutes.

3. Results and Discussion

3.1 Seasonal Variation Radon

The Radon Eyeplus2 instrument is installed in the laboratory and continuous measurements of radon and humidity were done from 10th October 2022 to 21st July 2023. The smoothened variation of radon and humidity for the period of study are given in Fig. 2. A correlated variation with correlation coefficient 0.74 is obtained between the two. The radon emission was observed to be low during the dry season where humidity was low compared to the wet season.

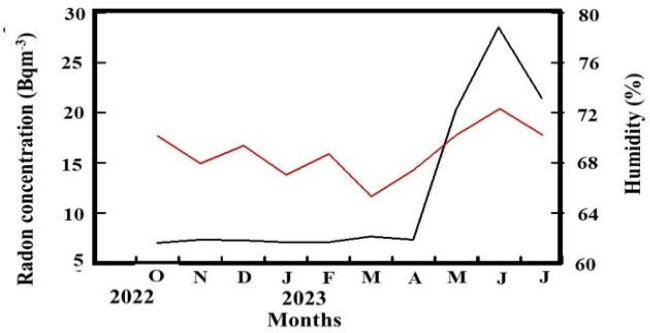

Fig. 2: Variation of Radon and Humidity for the period 10th October 2022 to 21st July 2023.

3.2 Radon Emission during Seismically Active Period

3.2.1 Study Area: Five locations within the UNITECH campus were selected where the Radon Eyeplus2 instruments were installed. The locations are 1. Boys' Dorm, 2. Boys' dorm Emaru, 3. Adventist Residence College, 4. Girls' dorm and 5. Fly Drive. The study areas are selected randomly. In Adventist Residence College, the instrument is kept in a room in the ground floor and in other centers, the instrument is kept in the first floor.

3.2.2 Inhalation Dose Estimation: The radon concentrations in the five locations are measured using Radon Eye+2 instruments for two months duration. The Mean Effective Dose (H) for the inhabitants was calculated from the experimentally determined value of radon concentration (C_{Rn}) using the expression

$$H(mSv/y) = C_{Rn} \times F \times O \times DCF \quad (1)$$

where F is the global average (0.4) of equilibrium factor for Rn and its progeny, O is the global average indoor occupancy factor (7000h/y) and DCF is the dose conversion factor 9nSv/h/(Bq/m^3) for Rn and its progeny [6].

Table 1: The Radon concentration and Indoor Annual Effective Inhalation Dose in the five locations.

Location	Period of observation		Rn Conc. (Bq/m^{-3})	AED (mSv/y)
	Start	End		
Boys' Dorm	04/08/2023	21/09/2023	10	0.252
Boys' Dorm Emaru	04/08/2023	05/11/2023	17	0.428
Adventist Res. College	21/09/2023	05/11/2023	29	0.731
Girls' Dorm	06/08/2023	22/09/2023	7.26	0.183
Fly Drive	25/08/2023	01/11/2023	2.89	0.073
Mean			**13.23**	**0.33**
St. Dev.			**9**	**0.23**

The average radon gas concentrations and the indoor inhalation dose in 5 locations are presented in the table 3. The radon concentration was found to vary from 2.89 to 29 Bq m^{-3} with arithmetic mean 13.23±9 Bq m^{-3}. The most important factor of radiological concern, the annual inhalation dose resulting from radon and their progeny varied from 0.073 to 0.731 mSv with average value of 0.33±0.23 mSv. Indoor radon concentrations vary very widely depending on several factors all over the world. The global average of radon concentration is 40 Bqm^{-3} [7]. PNG is situated in the volcanic and earthquake prone region of 'ring of fire' in the pacific. Therefore, the houses are mostly made on pillars to resist the frequent tremors. Therefore, the possibility for accumulation of radon or thoron gas underneath the dwellings is very rare. The tropical weather conditions give ample chance for good ventilation and thereby dilution of indoor air. The common building materials used in the region may also not contribute much to the indoor radon.

The world average annual inhalation doses due to radon, thoron and their progeny have been reported to be in the range of 2 to 10mSv. The estimated inhalation dose to the inhabitants of dwellings in UNITECH was found to be much less. The estimated inhalation dose was found to be higher in Adventist Residence College location (Fig. 3) compared to other centres because in Adventist Residence College location, the instrument is kept closer to the ground.

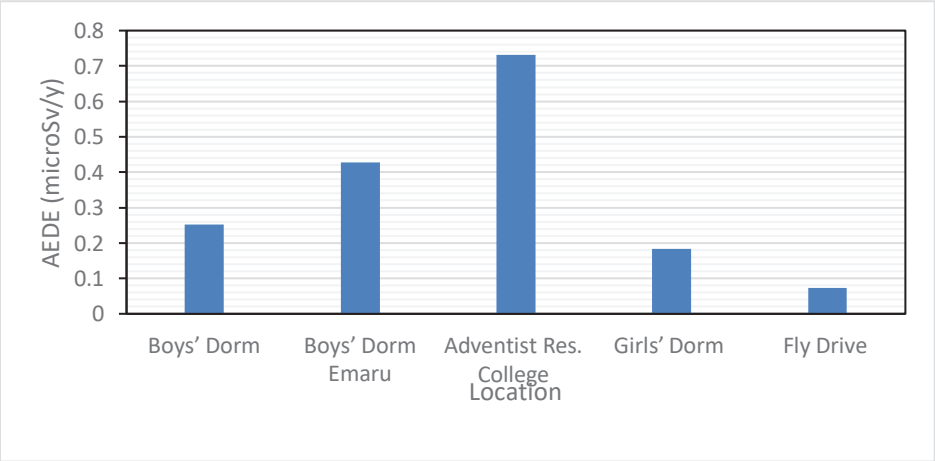

Fig. 3: The Annual Effective Inhalation dose in the five locations of Unitech campus.

3.3 Radon Observations during Earthquake Period

In the context of radon monitoring, the US Environmental Protection Agency recommends taking action to mitigate radon levels in buildings that exceed 143 Bq/m^3, as concentrations above this level are considered potentially hazardous. Radon testing was carried out at five locations, with four showing average and maximum levels within safe limits. However, at Location 3: Adventist Residential College, a maximum reading of 565 Bq/m^3 was recorded, significantly surpassing the safety threshold. This elevated radon level was attributed to a series of earthquakes on October 07, 2023, during which the PNGUOT Seismic Station recorded 12 earthquakes. Due to power outages, data from seven earthquakes with magnitudes ranging from 5.1 to 6.9 on the Richter Scale were obtained. These seismic events had their epicenter near Saidor, located just off the coast of the Madang Province, approximately 183km aerial distance from Lae. Figures 4 and 5 below show recorded tectonic activity on the date mentioned above.

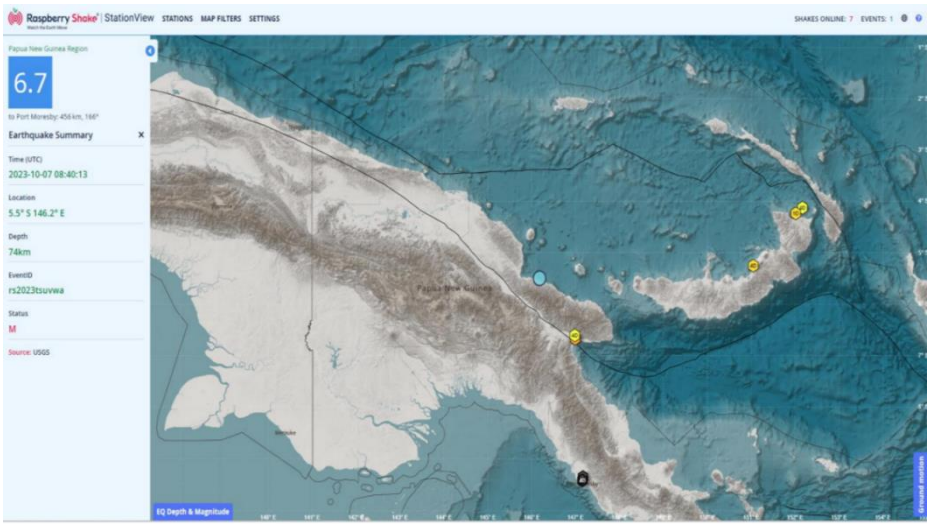

Fig. 4: Map of Papua New Guini. The epicenter of the earthquake is represented by the blue circle in Madang Province and the PNGUOT Seismic Center is represented by the yellow hexagon just below it.

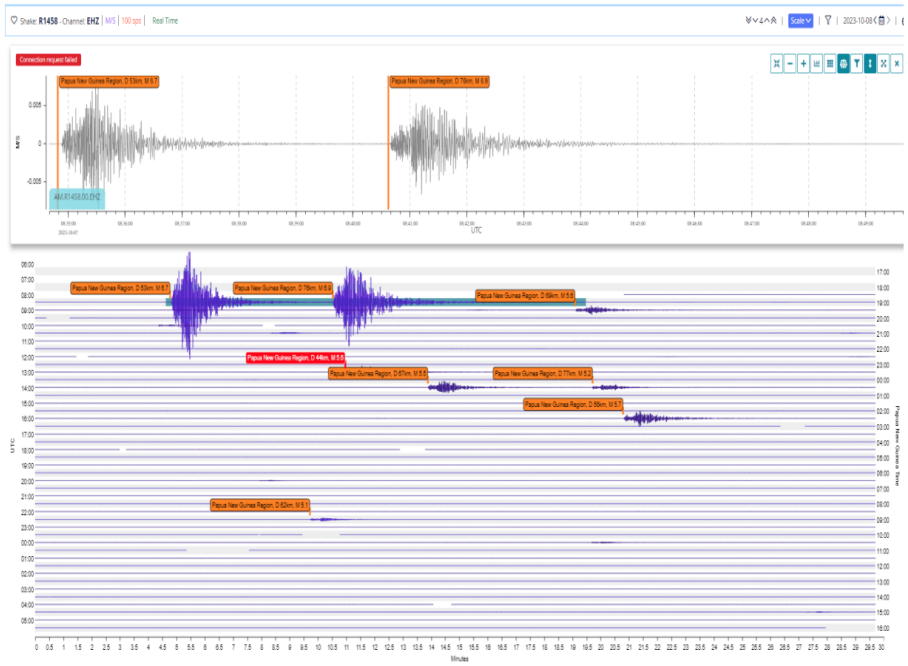

Fig. 5: Seismogram on 7th October 2023 on which date earthquake occurred.

The empirical relationship between earthquakes and indoor radon measurements is given by

$$M = 2.4log_{10}D - 0.43 \quad (2)$$

where M is the magnitude and D is the distance from the epicenter [8]. Radon gas can be detected up to a radial distance of 1132 km for an earthquake of magnitude 6.9. Since the radial distance from the epicenter and Lae is only 183 km, we can expect radon emission at Lae.

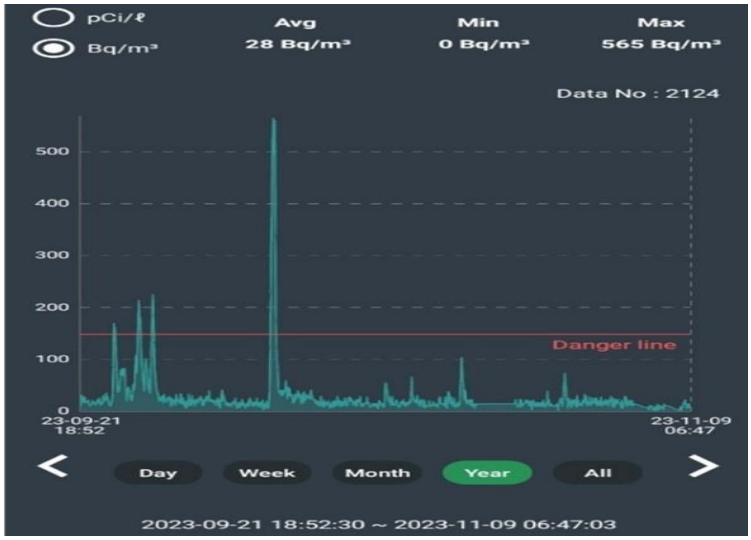

Fig. 6: Radon observation from 21/09/2023 to 09/11/2023 in Adventist Residence College

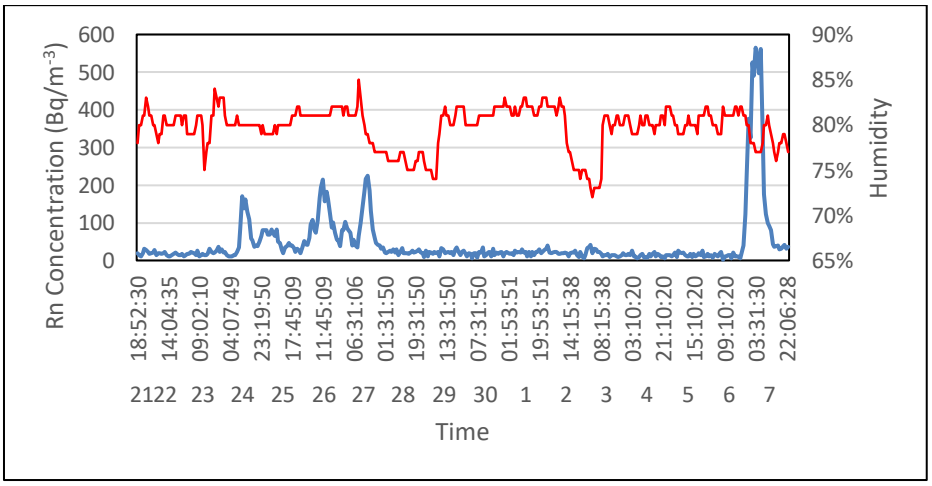

Fig. 7: Radon observations (blue) and humidity (red) from 21/09/2023 to 07/10/2023.

Fig. 6 gives the radon observations from 21/09/2023 to 09/11/2023 in Adventist Residence College. Radon observations and humidity from 21/09/2023 to 07/10/2023, a few days prior to the earthquake is drawn in Fig. 7.

In Fig. 7, we can observe that, about ten days prior to the earthquake, radon emission peak is observed to be 170 Bq/m^3 (above 4 standard deviations) on 24th, 214 Bq/m^3 (above 5 standard deviations) on 26th and 225 Bq/m^3 (above 5 standard deviations) on 27th September 2023 and these peaks obtained are statistically significant. It again started to increase on 6th October at 18:10 hours in the evening and reached a value of 565 Bq/m^3 and lasted till 13:30 on 7th October. Two major earthquakes occurred on 7th October, one at 19:05 (LT) with magnitude 6.7 and another at 19:11 (LT) with magnitude 6.9. Humidity variations are observed to be less during the earthquake precursor period.

Before the 2011 Tohoku-oki earthquake in Japan, radon anomaly observed prior to the earthquake, exceeded 3 standard deviations [9]. Planinic et al. (2004) derived an empirical relation by analyzing the radon peaks with magnitude >3M at epicentral distances < 200 km. The precursor time can be calculated using the relation [10]

$$\text{Log}(DT) = 0.63\,M + b \quad (3)$$

where b is 0.15 for gaseous geo-seismic precursors of earthquake, T is the precursor time (day), D is the epicentral distance and M is the magnitude. So, excess radon emission prior to earthquake can be used as a tool for earthquake prediction but further study has to be done to confirm this.

Though we have installed the radon monitoring instruments in five locations, we could be able to measure radon only in one location during earthquake period because of frequent power failures. The instrument installed in Adventist College has a power back up system.

4. Conclusion

The Unitech campus situated in Lae falls in the 'Ring of Fire' region which is tectonically active. The tectonic activity results in frequent earthquakes and volcanic eruptions. The soil in Lae region is influenced by volcanic activity, sediment deposition and organic matter decomposition. The radioactive radon gas which is a progeny of ^{238}U is measured in the regions of study using Radon Eye+2 instrument and the inhalation dose were calculated. The inhalation dose varies from 2.89 to 29 with an average value of 13.23 ± 9 Bq/m^3. The inhalation dose was found to be less than the world average value of 40 Bq/m^{-3}. Radon gas emission is found to be associated with earthquakes. Excess radon emissions greater than 100 Bq/m^3 were observed ten days prior to earthquake. A peak value of 525 Bq/m^{-3} of radon emission for a few hours was observed one day prior to a massive earthquake followed by a series of earthquakes on 7th October 2023. Further studies are required to study the actual relationship between radon emission and earthquakes which help in predicting earthquakes.

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