# Radon and thoron anomalies along Mat fault in Mizoram, India

Hari Prasad Jaishi[1], Sanjay Singh[1], Raghavendra Prasad Tiwari[2] and Ramesh Chandra Tiwari[1,*]

[1] *Department of Physics, Mizoram University, Aizawl 796 004, India.*
[2] *Department of Geology, Mizoram University, Aizawl 796 004, India.*
[*] *Corresponding author. e-mail: ramesh_mzu@rediffmail.com*

In this study, radon and thoron concentrations in soil gas has been monitored using LR-115(II) solid state nuclear track detectors since 15th July 2011 to February 2012. The study was carried out along Mat fault in Serchip district, Mizoram, India at two different sites – Mat Bridge (23°18′N, 92°48′E) and Tuichang (23°13′N, 92°56′E). The results obtained have been correlated to the seismic events that occurred within 800 km from the measuring sites over the mentioned period of time. Anomalous behaviour in radon concentrations have been observed prior to some earthquakes. Interestingly, some thoron anomalies were also recorded.

## 1. Introduction

Earthquake has become a major topic which draws the attention of many researchers as it is one of the most devastating natural calamities and till today there is no established technique evolved which can predict earthquakes exactly. However, variations in some of the gases like $CO_2$, He, $H_2$, Rn, $CH_4$ and $N_2$ and highly volatile metals such as Hg, Sb and As could be possibly used to predict earthquakes as they release out from the active-fault region (Vaupotic *et al.* 2010). Of all these, variations of radon concentration along the active fault region is the most widely used as a possible precursor to earthquakes (Sac *et al.* 2011).

The history of the relationship between radon concentration and earthquake dates back to the year 1966. It was observed that there was an increase in radon concentration in the Russian wells before the Tashkent earthquake of 1966. Later in the year 1974, Birchfard and Libby installed the first site to measure radon concentrations in the soil. After that, it was well known that the radon concentrations in the soil and underground water could be used as a possible precursor to earthquakes (Vaupotic *et al.* 2010). Studies relating to the variation of radon concentration (underground and well water) and its correlation to seismic events have been studied in different parts of the globe (King *et al.* 1981; O'Neil and King 1981; Shapiro *et al.* 1981; King 1986; Sano *et al.* 1986; Sugisaka and Sugiura 1986; Igarashi and Wakita 1990; Honkura and Isikara 1991; Monnin and Seidel 1991; Wakita 1996; Zmazek *et al.* 2002, 2003; Walia *et al.* 2005; Kuo *et al.* 2006; Ghosh *et al.* 2009; Vaupotic *et al.* 2010). As far as known to the authors, the studies on radon and thoron anomalies as a precursor to earthquakes had not been done in the northeastern region in general and Mizoram, in particular. However, some authors (Dwivedi *et al.* 1995; Srivastava *et al.* 1996) recorded radon data in dwellings. Ghosh *et al.* (2009, 2011) have done the soil radon study and its correlation to seismic events at Darjeeling and Jalpaijuri respectively in the state

**Keywords.** Radon; thoron; LR-115(II) detectors; correlation; seismic events.

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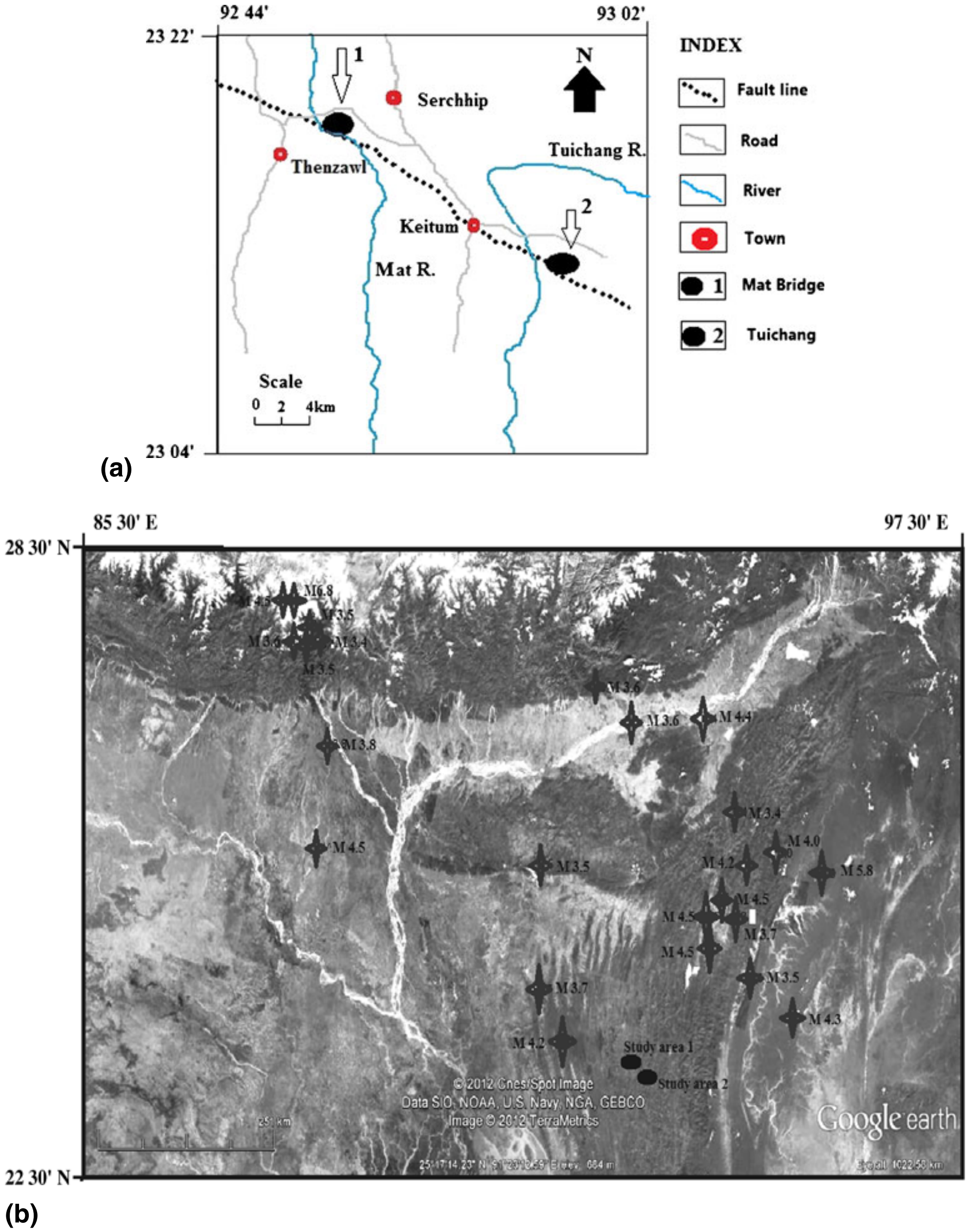

Figure 1. (**a**) Location map of the study area and (**b**) spatial distribution of earthquakes around the study area.

of West Bengal which is the nearest possible sites of measurements from our measuring sites.

Mat fault is the most prominent fault in Mizoram state. It obliquely cuts across the general north–south trend of the Indo-Burmese arc. It trends NW–SE and is traceable across entire Mizoram on the satellite as well as on the geological maps. Mat River crosses the Mat fault and follows it for considerable distance. Most pronounced part of this fault is in Serchhip district along Serchhip–Thenzawl road (Malsawma *et al.* 2010). Figure 1 shows the geological settlement of the study area. Hence, this part has been selected for monitoring of radon and thoron anomaly and their possible correlation with the occurrence of earthquakes. This study aims to correlate radon and thoron anomalies to seismic events.

## 2. Materials and methods

Radon and thoron measurements in the soil were carried out using LR-115 Type II films, manufactured by M/S Kodak Pathe, France at two different sites Mat Bridge and Tuichang separated by a distance of 35 km approximately. The cellulose nitrate films were cut into a size of 3 cm×3 cm

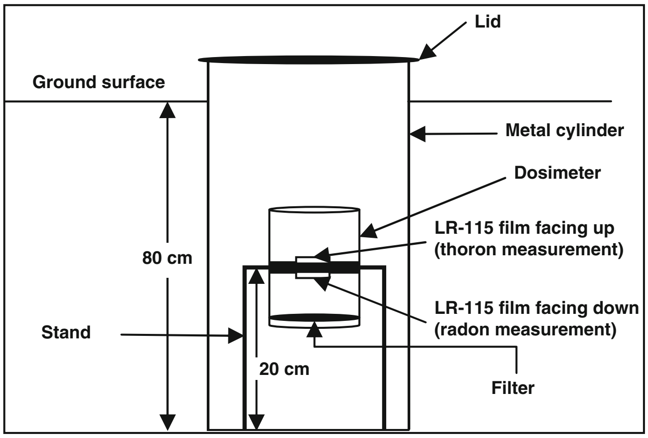

Figure 2. Radon and thoron measurements in soil.

and loaded in the dosimeters which provide three modes of exposures (two bare modes and one filter mode) to determine radon and thoron along with their progeny simultaneously. In our case we use only two modes – bare mode to detect thoron and its progeny and filter mode to detect radon. Holes were dug 80 cm below the surface and 30 cm in diameter, total of five holes on each site 2 m apart from each other. Figure 2 shows the method of measuring radon and thoron in the soil. Metal cylinders with the bottom open and top with a lid were inserted on these holes. The dosimeters containing the films were then placed inside the cylinders. Each dosimeter contains two films. The films were exposed for a period of 15 days after which they were removed and replaced by new films. The recovered films from the soils were then chemically etched in 2.5 N NaOH solutions for 1 h in a constant temperature bath. The purpose of the etching process is to enlarge the alpha track registered from radon gas in the soil. The temperature of the etching bath during this process was kept stable at 60 °C. After etching, the films were washed in running water and then kept in the distilled water for 2 h. Immediately after the completion of this process the sensitive layer of the films were stripped. The stripped LR-115 films are then dried and used for track counting using a spark counter.

## 3. Results and discussion

Radon and thoron concentrations in soil have been measured after every 15 days using a SSNTD, LR-115(II) films at two different measuring sites, Mat Bridge and Tuichang in Serchhip district, Mizoram (India). Apart from the seismic events, the meteorological parameters, viz., rainfall, temperature, humidity, pressure and wind velocity also influence radon exhalation (Kraner *et al.* 1964; Pearson 1967; Gabelman 1972; Steele 1981; Singh *et al.* 1988; King and Minissale 1994; Singh and Virk 1994; Sharma *et al.* 2000; Virk *et al.* 2000; Mukherji *et al.* 2001; Zmazek *et al.* 2003; Walia *et al.* 2005; Ghosh *et al.* 2011). In a study in NW Himalaya, a group of authors (Virk and Singh 1992; Sharma *et al.* 2000; Walia *et al.* 2005) reported that the radon concentration is maximum in the summer rainy season (July–September) and minimum during the winter season (November–February). This may be due to the capping effect of the wet soil layers at the surface which prevents radon from escaping into the atmosphere (Kraner *et al.* 1964; Jaacks 1984; Hesselbom 1985; Singh *et al.* 1988; Virk *et al.* 2000). Due to nonavailability of meteorological data near the selected sites as of now, we are unable to carry out such analysis at present. The radon concentrations have been recorded from 15 July 2011–February 2012 and thoron concentrations from October 2011–February 2012. Figure 3 represents the radon concentrations at Mat Bridge and Tuichang over the said period of time and figure 4 represents the thoron concentrations for the same sites. Dobrovolsky *et al.* (1979) and Fleischer (1981) proposed the relationship between the magnitude (M) of the earthquake and the epicentre distance (D) within which the earthquake prediction zone can be manifested.

$$D = 10\exp 0.43M \text{ km}, \quad \text{(Dobrovolsky } et\ al.\ 1979) \qquad (1)$$

$$D = (10\exp 0.48M)/1.66 \text{ km for } M > 3 \quad \text{(Fleischer 1981)}. \qquad (2)$$

In the present investigation, attempts have been made to understand the relationship between radon anomaly and the epicentre distance of an earthquake. The concentrations have been calculated in terms of Bq/m$^3$. Even though the pits are separated 2 m apart, large variation in radon concentration were observed between the two pits. The maximum variation in radon concentration was recorded during the month of August at both the sites. At Mat Bridge, the maximum variation was recorded to be 6212 Bq/m$^3$ and at Tuichang 1946 Bq/m$^3$. This variation may or may not be due to the capping effect. However, the authors are unable to explain clearly the reason at this juncture. The plotted value of radon concentration is the average of all five pits measurements. The locations of earthquakes over the mentioned period of time and its epicentre distances from the measuring sites have been highlighted in table 1. Radon concentration at both the sites tends to show similar characteristics except that an increase in radon concentration was observed at Mat Bridge (which occurred on 45th day of the observation

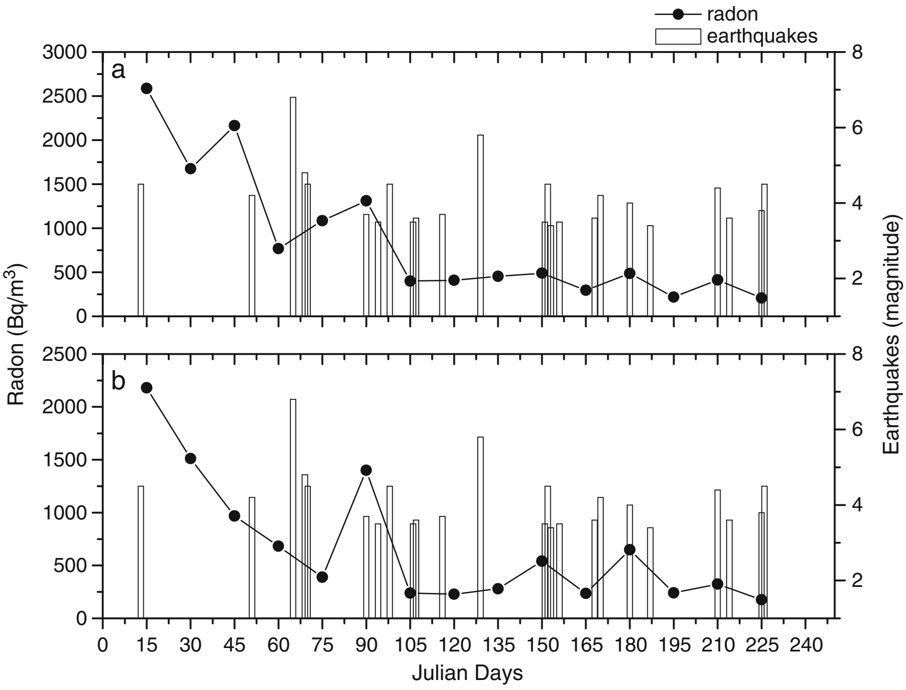

Figure 3. Radon concentration and the corresponding earthquakes. (**a**) Mat Bridge and (**b**) Tuichang.

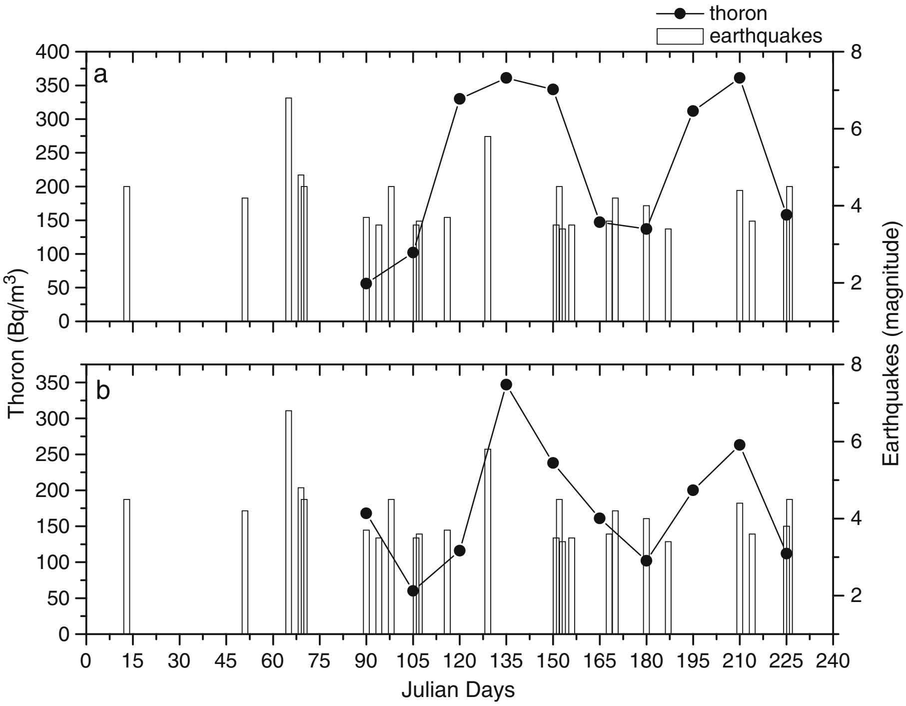

Figure 4. Thoron concentration and the corresponding earthquakes. (**a**) Mat Bridge and (**b**) Tuichang.

period, figure 3a) whereas no such observation was recorded at Tuichang (figure 3b). This increase in radon concentration may be treated as an anomaly before the signal earthquake of M6.8 (which occurred on 65th day of the observation period at a distance of 674 km from the measuring site; 20 days after the anomaly was observed). However, an earthquake of M4.2 (which occurred on 51st day of the observation period at a distance of 260 km) was also recorded just 6 days after the anomaly was observed, but this may not be considered as a signal earthquake because the epicentral distance does not fall in the earthquake preparation zone as per equation (2). Our results

Table 1. *Details of locations of earthquakes observed from the measuring sites. (source: usgs/imd)*

| Date | Days (Julian) of occurrence of earthquake | Latitude and Longitude | Distance of epicentre (km) | | Magnitude | Region |
|---|---|---|---|---|---|---|
| | | | Mat Bridge | Tuichang | | |
| 28.07.2011 | 13th day | 25.3°N, 88.6°E | 481 | 497 | 4.5 | India (W. Dinajpur)–Bangladesh Border region |
| 04.09.2011 | 51st day | 25.2°N, 94.3°E | 260 | 261 | 4.2 | Ukhrul, Manipur |
| 18.09.2011 | 65th day | 27.7°N, 88.2°E | 674 | 689 | 6.8 | Sikkim–Nepal Border region |
| 22.09.2011 | 69th day | 23.7°N, 94.9°E | 218 | 208 | 4.8 | Myanmar |
| 23.09.2011 | 70th day | 24.4°N, 93.8°E | 159 | 158 | 4.5 | Imphal |
| 13.10.2011 | 90th day | 24.0°N, 91.5°E | 158 | 175 | 3.7 | India (Tripura)–Bangladesh Border region |
| 17.10.2011 | 94th day | 27.3°N, 88.4°E | 628 | 644 | 3.5 | Sikkim |
| 21.10.2011 | 98th day | 24.8°N, 94.0°E | 206 | 207 | 4.5 | Imphal |
| 29.10.2011 | 106th day | 27.4°N, 88.4°E | 636 | 652 | 3.5 | Sikkim |
| 30.10.2011 | 107th day | 26.9°N, 92.3°E | 403 | 414 | 3.6 | Assam–Arunachal Pradesh Border region |
| 08.11.2011 | 116th day | 24.7°N, 94.2°E | 211 | 209 | 3.7 | Ukhrul, Manipur |
| 21.11.2011 | 129th day | 25.1°N, 95.3°E | 324 | 320 | 5.8 | Myanmar–India Border region |
| 13.12.2011 | 151st day | 25.2°N, 91.5°E | 250 | 264 | 3.5 | India(Meghalaya)–Bangladesh Border region |
| 14.12.2011 | 152nd day | 27.7°N, 88.0°E | 687 | 703 | 4.5 | India(Sikkim)–Nepal Border region |
| 15.12.2011 | 153rd day | 25.7°N, 94.1°E | 298 | 300 | 3.4 | Assam–Nagaland Border region |
| 18.12.2011 | 156th day | 24.1°N, 94.3°E | 177 | 171 | 3.5 | India–Myanmar Border region |
| 30.12.2011 | 168th day | 26.5°N, 92.8°E | 356 | 365 | 3.6 | Assam |
| 01.01.2012 | 170th day | 23.5°N, 91.8°E | 105 | 120 | 4.2 | Southern Tripura |
| 11.01.2012 | 180th day | 25.3°N, 94.7°E | 294 | 293 | 4.0 | India (Manipur)–Myanmar Border region |
| 18.01.2012 | 187th day | 27.3°N, 88.5°E | 621 | 636 | 3.4 | Sikkim |
| 10.02.2012 | 210th day | 26.6°N, 93.7°E | 380 | 386 | 4.4 | Assam–Nagaland Border region |
| 14.02.2012 | 214th day | 27.3°N, 88.2°E | 642 | 658 | 3.6 | India (Sikkim)–Nepal Border region |
| 25.02.2011 | 225th day | 26.3°N, 88.7°E | 533 | 549 | 3.8 | Bangladesh–India (WB) Border region |
| 26.02.2012 | 226th day | 24.7°N, 93.7°E | 181 | 188 | 4.5 | Manipur |

show that at Tuichang (figure 3b), no increase in radon concentration was observed (as in case of Mat Bridge, figure 3a) before the strong earthquake of M6.8 from the starting day of measurement. In fact the radon concentration tends to decrease. This abrupt decrease may be either due to additional compression closing cracks and pores (Singh *et al.* 1991; Ramola *et al.* 2008) or from expansion causing temporary undersaturation of the pore volume (Whitcomb 1983). An anomalous increase in radon concentration which results due to crustal deformation in the region (Walia *et al.* 2009) was observed at both the sites which occurred on 90th day of the observation period (figure 3). This can be treated as an anomaly before the earthquake of M5.8 (129th day of the observation period; 39 days after the anomaly was observed) which occurred at a distance of 324 km from Mat Bridge and 320 km from Tuichang. Some series of earthquakes; M3.7 (occurred on 90th day, 158 km from Mat Bridge and 175 km from Tuichang), M3.5 (occurred on 94th day, 628 km from Mat Bridge and 644 km from Tuichang) and M4.5 (occurred on 98th day, 206 km from Mat Bridge and 207 km from Tuichang) happen close to each other but these events cannot be correlated to the anomaly observed as the epicentral distances do not fall in the earthquake preparation zone in accordance with equation (2). Interestingly some thoron anomalies were also recorded in both the sites. There was a sudden increase in thoron concentration approximately 1 week before the earthquake of M5.8 which occurred on 129th day of the observation period (figure 4) at a distance of 324 km from Mat Bridge and 320 km from Tuichang. The thoron concentration reaches a maximum value 7 days after the earthquake. Other interesting observation is that abrupt increase in thoron concentrations have been observed just prior to the M4.4 earthquake which occurred on 210th day of the observation period (380 km from Mat Bridge, 386 km from Tuichang). However, no significant changes in radon concentration were observed during the same period. The reason may be due to the carrier gases which play a dominant role in controlling the transport of radon gas towards the earth surface fault zone (Etiope and Martinelli 2002). This can also be understood on the basis of closer and shallower gas source which provide small amount of radon/thoron gas to the surface due to micro factures before moderate earthquake. Such small amount of gas may not increase radon concentration due to its original relatively high background level rather increases thoron concentrations (Yang *et al.* 2005).

## 4. Conclusion

In our study, some rise and fall in radon concentration have been recorded prior to the earthquakes of M6.8 and M5.8. We observed unusual behaviour in radon concentrations. Sharp fall in radon concentration were recorded just before the large earthquake of M6.8 at Tuichang. On the other hand, out of all the thoron anomalies recorded it was found that an increase in thoron concentrations was associated with the earthquakes. The M6.8 earthquake was the largest that occurred in the region over the mentioned period of time. Due to topographic difficulties LR-115 films are replaced at 15 days interval do not appear to be sufficient enough to pinpoint or correlate with seismic activity. However, the recorded data shows certain positive radon and thoron anomalies which preceded the earthquakes. The present study shows the usefulness of such data in further studies. In future, authors will try to carry out daily recording of data. The unusual anomalies observed in the present investigation may provide soil radon/thoron database and preliminary trends of their response to seismic activity in the selected fault region; the most prominent fault in Mizoram, but does not provide sufficient evidence for correlation or predicting earthquakes. Therefore the present work needs further investigation. Long term and continuous observation is necessary to confirm a relation between the seismic events and radon concentration.

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## References

Dobrovolsky I P, Zubkov S I and Miachkin V I 1979 Estimation of the size of earthquake preparation zones; *Pure Appl. Geophys.* **117** 1025–1044.

Dwivedi K K, Srivastava A, Ghosh S, Sinha D, Laldawngliana C, Lalramengzami R and Saxena A 1995 Measurements of indoor radon in some dwellings in Aizawl (India); *Indoor Environ.* **4** 362–364.

Etiope G and Martinelli G 2002 Migration of carrier and trace gases in the geosphere: An overview; *Phys. Earth Planet. Int.* **129** 185–204.

Fleischer R L 1981 Dislocation model for radon response to distant earthquakes; *Geophys. Res. Lett.* **8** 477–480.

Gabelman J W 1972 Radon emanometry of Straks Salt Dome Calcasiea Parish, Louisiana; U.S. Energy Commission Rep. RME–414, 75p.

Ghosh D, Deb A, Haldar S, Sahoo S R and Sengupta R 2009 Radon time series and earthquake signals – a study by SSNTD at Matigara (Darjeeling), India; *e-J. Earth Sci. India* **2**(**2**) 76–82.

Ghosh D, Deb A, Sahoo S R, Haldar S and Sengupta R 2011 Radon as seismic precursor: New data with well water of Jalpaiguri, India; *Natural Hazards* **58**(**3**) 877–889.

Hesselbom A 1985 Radon in soil gas: A study of methods and instruments for determiningradon concentrations in the ground, Uppsala, Sweden; *Sveriges Geologiska Undersokning, Ser. C.* **803** 1–58.

Honkura Y and Isikara A M 1991 Multidisciplinary research on fault activity in the western part of the North Anatolian Fault Zone; *Tectonophys.* **193**(**4**) 347–357.

Igarashi G and Wakita H 1990 Groundwater radon anomalies associated with earthquakes; *Tectonophys.* **180** 2–4.

Jaacks J A 1984 Meteorological influence upon mercury, radon and helium soil gas emissions; Ph.D. Thesis, Colorado School of Mines.

King C Y 1986 Gas geochemistry applied to earthquake prediction: An overview; *J. Geophys. Res.* **91**(**B12**) 12,269.

King C Y, Evans W C, Presser T and Husk R H 1981 Anomalous chemical changes in well waters and possible relation to earthquakes; *Geophys. Res. Lett.* **8** 425–428.

King C Y and Minissale A 1994 Seasonal variability of soil-gas radon concentration in central California; *Radiat. Meas.* **23** 683–692.

Kraner H W, Schroeder G L and Evans R D 1964 Measurements of the effects of atmospheric variables on radon-222 flux and soil gas concentration; In: *The Natural Radiation and Environment* (eds) Adams J A S and Lower W M, Univ. Chicago Press, Chicago, pp. 191–215.

Kuo T, Fan K, Kuochen H, Han Y, Chu H and Lee Y 2006 Anomalous decrease in groundwater radon before the Taiwan M6.8 Chengkung earthquake; *J. Environ. Radioac.* **88** 101–106.

Malsawma J, Lalnuntluanga P, Wadekar A, Sangode S J and Tiwari R P 2010 Magnetic polarity stratigraphy of the Bhuban succession, Surma Group, Tripura–Mizoram Accretionary Belt, India; *J. Geol. Soc. of India* **76**(**1**) 119–133.

Monnin M M and Seidel J L 1991 Radon and geophysics: Recent advances; *Int. J. Radiation Application and Instrumentation. Part D. Nuclear Tracks and Radiation Measurement* **19**(**1–4**) 375–382.

Mukherji P, Chatterjee M and Sen K G 2001 Mathematical modelling of radon emanation for earthquake prediction; In: *Proc. 5th Int. Conf. Rare Gas Geochemistry* (eds) Hunyadi I, Csige I and Hakl J, Ep Systema, Debrecen, Hungary, pp. 27–35.

O'Neil J R and King C Y 1981 Variations in stable isotope ratios of groundwaters in seismically active regions of California; *Geophys. Res. Lett.* **8** 429–432.

Pearson J E 1967 Natural Environmental Radioactivity from Radon-222; Public Health Serv. Publ. 999-RH-26. U.S. Dept. of Health, Education and Welfare, Washinton D.C., 31p.

Ramola R C, Prasad Y, Prasad G, Kumar S and Choubey V M 2008 Soil-gas radon as seismotectonic indicator in Garhwal Himalaya; *J. Appl. Radiat. Isot.* **66** 1523–1530.

Sac M M, Harmansah C, Camgoz B and Sozbilir H 2011 Radon monitoring as the earthquake precursor in fault line in Western Turkey; *Ekoloji.* **20**(**79**) 93–98.

Sano Y, Nakamura Y, Wakita H, Notsu K and Kobayashi Y 1986 $^3$He/$^4$He ratio anomalies associated with the 1984 western Nagano earthquake: Possibly induced by a diapiric magma; *J. Geophys. Res.* **91** 12,291–12,295.

Shapiro H H, Melvin J D, Tombrello T A, Mendenhall H H, Larson P B and Whitcomb J H 1981 Relationship of the 1979 Southern California radon anomaly to a possible regional strain event; *J. Geophys. Res.* **86** 1725–1730.

Sharma A K, Walia V and Virk H S 2000 Effect of meteorological parameters on radon emanation; *J. Geophys.* **21** 47–50.

Singh B and Virk H S 1994 Investigation of radon-222 in soil–gas as an earthquake precursor; *Nucl. Geophys.* **8** 185–193.

Singh M, Ramola R C, Singh B, Singh S and Virk H S 1991 Subsurface soil gas radon changes associated with earthquakes; *Int. J. Radiat. Appl. Instrum., Part D.* **19**(**1–4**) 417–420.

Singh M, Ramola R C, Singh N P, Singh S and Virk H S 1988 Influence of meterological parameters on soil gas radon; *J. Assoc. Explor. Geophys.* **9** 85–90.

Srivastava A, Lalramengzami R, Laldawngliana C, Sinha D, Ghosh S, Dwivedi K K, Saxena A and Ramachandran T V 1996 Measurement of Potential Alpha Energy Exposure (PAEE) of radon and its progenies in dwellings in the north-eastern region of India; *Radiat. Meas.* **26**(**2**) 291–295.

Steele S R 1981 Radon and hydrologic anomalies on the rough creek fault: Possible precursor to the M5.1 eastern Kentucky earthquake, 1980; *Geophys. Res. Lett.* **8** 441–444.

Sugisaki R and Sugiura T 1986 Gas anomalies at three mineral springs and a fumarole before an inland earthquake, central Japan; *J. Geophys. Res.* **91** 12,296–12,304.

Vaupotic J, Riggio A, Santulin M, Zmazek B and Kobal I 2010 A radon anomaly in soil gas at Cazzaso, NE Italy, as a precursor of an $M_{\mathrm{L}} = 5.1$ earthquake; *Nukleonika.* **10** 895–899.

Virk H S and Singh B 1992 Correlation of radon anomalies with earthquake in Kangra Valley; *Nucl. Geophys.* **6** 293–300.

Virk H S, Walia V, Sharma A K, Kumar N and Kumar R 2000 Correlation of radon with microseismicity and meteorological parameters in Kangra and Chamba valleys of N–W Himalaya; *Geofisica Int.* **39** 221–227.

Wakita H 1996 Geochemical challenge to earthquake prediction; *Proc. Natl. Acad. Sci. USA* **93** 3781–3786.

Walia V, Lin S J, Hong W L, Fu C C, Yanf T F, Wen K L and Chen C H 2009 Continuous temporal soil–gas composition variations for earthquake precursory studies along Hsincheng and Hsinhua faults in Taiwan; *Radiat. Meas.* **44** 934–939.

Walia V, Virk H S, Yang T F, Mahajan S, Walia M and Bajwa B S 2005 Earthquake prediction studies using radon as a precursor in N–W Himalayas, India: A case study; *TAO* **16**(**4**) 775–804.

Whitcomb J H 1983 Modeling of tectonophysical distortion from measurements of long base-line geodetic data and other geophysical parameters; NASA Grant No. NAG5-22 Semi-annual report, March–August 1980 (Colorado Univ.), 20p.

Yang T F, Walia V, Chyi C C, Fu C C, Chen C H, Liu T K, Song S R, Lee C Y and Lee M 2005 Variations of soil radon and thoron concentrations in a fault zone and prospective earthquakes in SW Taiwan; *Radiat. Meas.* **40** 496–502.

Zmazek B, Todorovski L, Dmeroski S, Vaupoti J and Kobal I 2003 Application of decision trees to the analysis of soil radon data for earthquake prediction; *Appl. Radiat. Isot.* **58** 697–706.

Zmazek B, Zivcic M, Vaupoti J, Bidovec M, Poljak M and Kobal I 2002 Soil radon monitoring in the Krsko Basin, Slovenia; *Appl. Radiat. Isot.* **56**(**4**) 649–657.

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