detection in even small laboratories as rapid detection of plague bacilli is particularly germane to plague epidemiology since untreated bubonic plague rapidly progress to septicaemic or pneumonic state.


1. Kulichenko, A. N., Narkina, O. V., Gintsburg, A. L., Popov, Iu. A. and Ddrozodov, I. G., *Genetika*, 1994, **30**, 167–171.
2. Fields, K. A., Plano, G. V. and Straley, S. C., *J. Bacteriol.*, 1994, **176**, 569–579.
3. Robins-Browne, R. M., Miliotis, M. D., Cianciosis, S., Miller, V. C., Falcow, S. and Morris, I. G. Jr., *J. Clin. Microbiol.*, 1989, **27**, 644–650.
4. Sambrook, J., Fritsch, E. F. and Maniatis, T., *Molecular Cloning*, Cold Spring Harbor Laboratory Press, USA, 1989.
5. Batra, H. V., Tuteja, U. and Agarwal, G. S., *Curr. Sci.*, 1996, **71**, 787–791.
6. Straley, S. C., Plano, G. V., Skrzypek, E., Haddix, P. L. and Fields, K. A., *Mol. Microbiol.*, 1993, **8**, 1005–1010.
7. Skrzypek, E. and Straley, S. C., *J. Bacteriol.*, 1995, **177**, 2530–2542.
8. Straley, S. C. and Perry, R. D., *Trends Microbiol.*, 1995, **3**, 310–317.
9. Plano, G. V. and Straley, S. C., *J. Bacteriol.*, 1995, **177**, 3843–3854.
10. Starley, S. C., Skrzypek, E., Plano, G. V. and Bliska, J. B., *Infect Immun.*, 1993, **61**, 3105–3110.
11. McDonough, K. A., Schwan, T. G., Thomas, R. E. and Falkow, S. J., *Clin. Microbiol.*, 1988, **26**, 2515–2519.
12. Panda, S. K., Nanda, S. K., Ghosh, A. *et al.*, *Curr. Sci.*, 1996, **71**, 794–799.
13. Norkina, O. V., Kulichenko, A. N., Gintsburg, A. L., Tuchkov, I. V., Popov, Yu. A., Aksenov, M. V. and Drosdov, I. G., *J. Appl. Bacteriol.*, 1994, **76**, 240–245.
14. Cao, L. K., Anderson, G. P., Ligler, F. S. and Ezzell, J., *J. Clin. Microbiol.*, 1995, **33**, 336–341.


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# Correlation of alpha-logger radon data with microseismicity in N-W Himalaya

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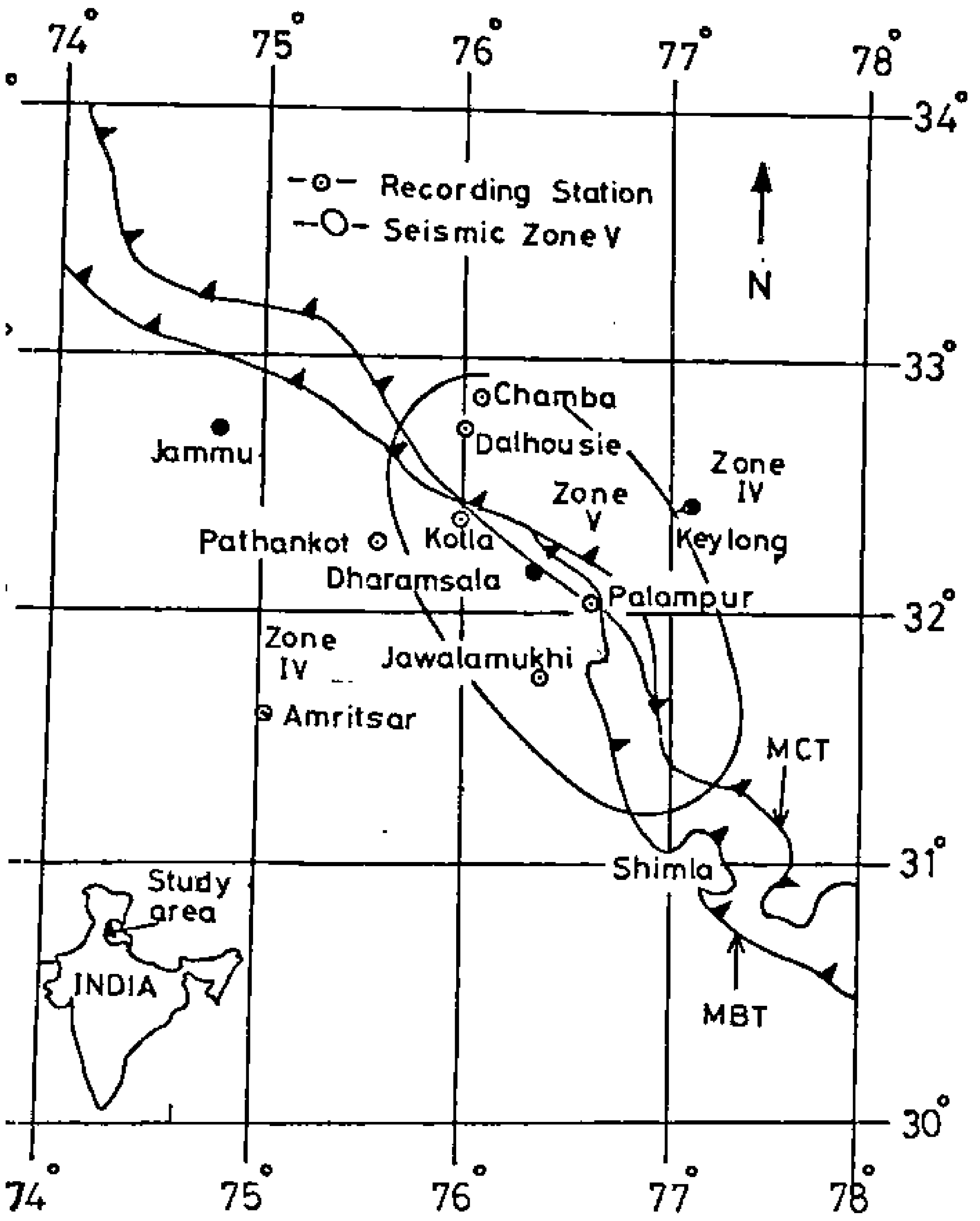
**Six alpha-logger stations have been set up in the Kangra and Chamba Valleys of Himachal Pradesh (India) in N-W Himalaya to monitor radon emanation continuously. Time series radon data is recorded at all the stations from March–April 1993 to August 1995. A number of impulsive radon spikes are recorded at all the stations, most of which are correlatable with seismic activity reported by the India Meteorological Department (IMD) seismic network. All the stations manifest a unique response to seismic activity in the region. This may be due to different geological formations beneath and different diffusion rates of radon emanation at each station. Average emanation rate of radon is observed to be maximum at Jawalamukhi and minimum at Pathankot. Palampur and Jawalamukhi are found to be the most sensitive to seismic activity in the region and record the maximum number of radon spikes. Meteorological analysis of radon data revealed that radon emanation is affected up to 15% by meteorological variations.**

RADON is established as a useful geochemical precursor[1–9] in earthquake prediction research since the observation of increase of anomalous radon in a deep well in Tashkent before the 1966 Tashkent earthquake[10]. The physical bases of the radon anomalies, prior to an impending earthquake, have yet to be fully understood in terms of a comprehensive theoretical model. However, it is understood that the buildup of stresses prior to a seismic event can alter the radon concentration at a position where such premonitory changes can be measured. If the earth's deformation, prior to an earthquake, releases increased amounts of radon, the temporal increase at the surface of the earth can be used to anticipate seismic activity.

The northern boundary of the Indian sub-continent, extending from the Hindukush in the west to the hills of Assam and Burma in the east, constitutes a region where the Indian plate collides with the Eurasian plate and has thus been the scene of a large number of major earthquakes in the past. During the last two decades, the N-W Himalaya has recorded five earthquakes of magnitude more than 5, viz. Kinnaur (19 January 1975), Dharamshala (14 June 1978), Dharchula–Bajang (29 July 1980), Jammu–Kathua (14 August 1980) and Dharamshala (26 April 1986). The Hindukush area and the Kangra valley of Himachal Pradesh (India) are considered to be highly seismic zones in the N-W Himalayan belt which is traversed by several major thrust faults.

Radon monitoring work was started in 1989 at Palampur in Kangra valley using the track-etch technique and emanometry. The results of the studies are reported elsewhere[8–9,11]. Under Himalayan Seismicity Project of the Department of Science and Technology (DST), Government of India, six alpha-logger probes were installed at Palampur (32.10°N, 76.51°E), Pathankot (32.30°N, 75.64°E), Kotla (32.35°N, 76.02°E), Dalhausie (32.60°N, 76.00°E), Chamba (32.55°N, 76.10°E) and Jawalamukhi (31.87°N, 76.33°E) (Figure 1). Some of these stations are situated in close proximity to the main boundary thrust (MBT) of the Himalaya. The Kangra and Chamba valleys in Himachal Pradesh are enclosed between the middle Siwaliks and the Dhauladhar range and the Pir Panjal and the Dhauladhar ranges of lesser

/a, respectively. Our monitoring stations fall in :r Himalaya and lesser Himalayan zone. Average ı content present in the Siwalik is 3–10 ppm, igher than the world average of 2.1 ppm (ref. 12).




Radon-monitoring stations using alpha-logger probes. The ıst faults of N-W Himalaya are demonstrated as MCT (main rust) and MBT (main boundary thrust). All the stations are ithin high seismicity zone V, except for Pathankot which is phery.

Alpha-logger probe (manufactured by Alpha-Nuclear Co, Toronto, Canada) is a portable, battery powered, microprocessor based data acquisition and control system. The unit is designed to measure near surface radon gas fluctuations over relatively short intervals of time. It consists of a silicon-diffused junction for the detection of the alpha particles and can record radon alpha counts in 15 min increments over a period of 40 days non-stop. The detector unit is placed inside a covered augur hole about 60 cm in depth. The detector is separated from the soil surface at the bottom of hole by a 6.4 cm gap, and the air in the gap shields the detector from the impact of direct alpha particles emanated by radon isotopes and their daughters. The recorded data is retrieved with the aid of a laptop IBM compatible PC. The software supplied with the system provides the facility to sum up any number of 15 min counting intervals for better counting statistics.

Except for the Jawalamukhi station, which became operational in January 1994, all the other five radon-monitoring stations became operational during March–April 1993. At some of the stations, due to severe weather conditions the battery power pack got discharged before its stipulated period of 40 days and the recorded data of a few weeks were lost. The radon data was retrieved and compiled after 4 weeks, generally.

Alpha-logger probe at Palampur station is found to record maximum number of radon spikes (Figure 2). A correlation analysis has been made to separate signal and noise from the data collected, following a specific technique. For each data set that covered a period of

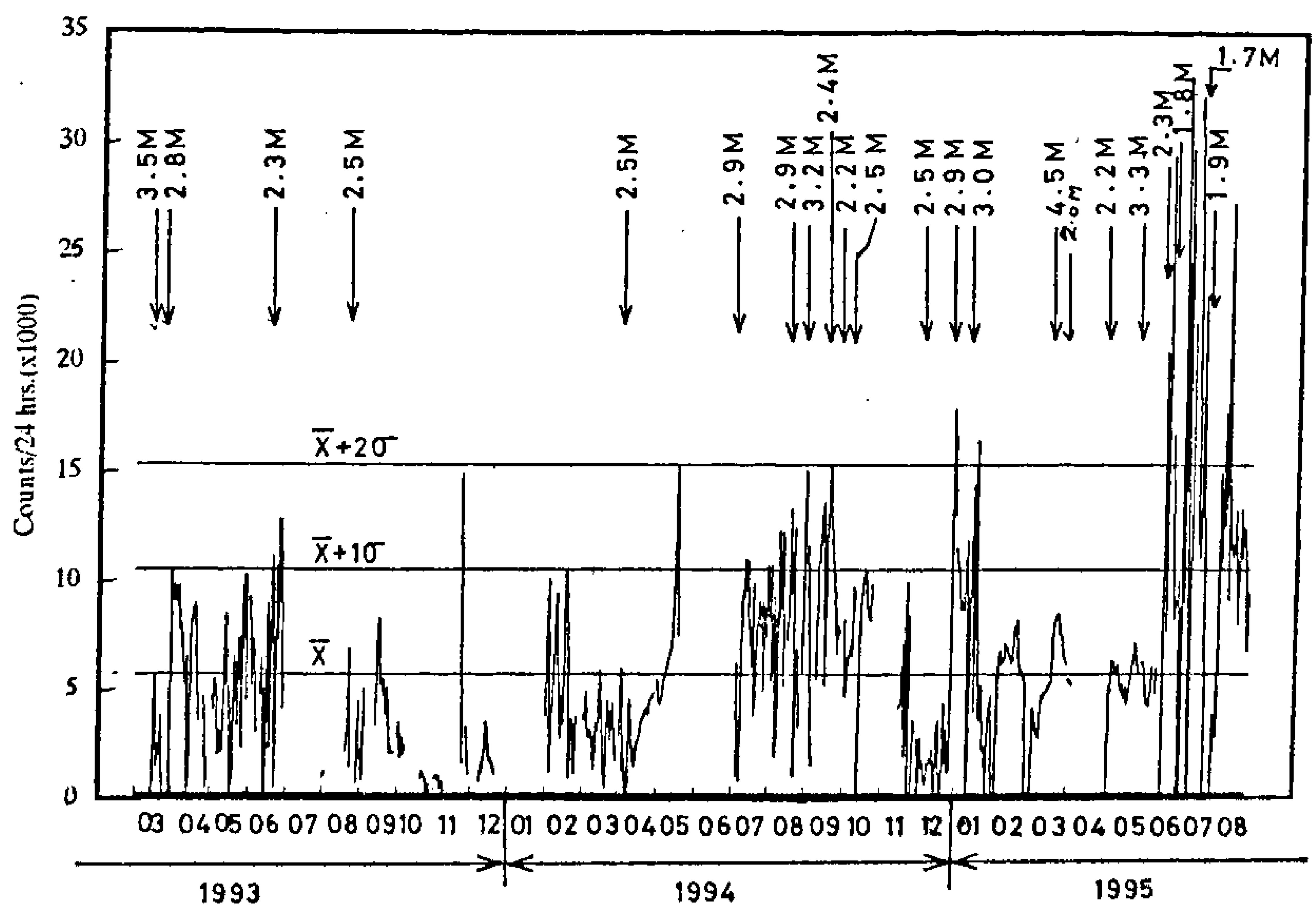



**Figure 2.** Alpha-logger radon data for Palampur station (arrows represent the seismic events recorded by IMD network).

**Table 1.** Analysis of alpha-logger radon data in soil–gas

| Station | Total events (a) | Total Rn anomalies (b) | Rn anomalies preceding events (c) | Rn anomalies not preceding events (d) | Events not preceding anomalies (e) |
|---|---|---|---|---|---|
| Palampur | 22 | 16 | 10 | 06 | 12 |
| Jawalamukhi | 23 | 20 | 10 | 10 | 13 |
| Kotla | 13 | 08 | 06 | 02 | 07 |
| Dalhausie | 14 | 10 | 04 | 06 | 10 |
| Chamba | 14 | 12 | 08 | 04 | 06 |
| Pathankot | 12 | 11 | 07 | 04 | 05 |

**Table 2.** Confidence level (sensitivity) of various radon-monitoring stations

| Station | Signal% (c/a) | Noise% (d/b) | Confidence level (signal/noise) |
|---|---|---|---|
| Palampur | 45.4 | 38.0 | 1.20 |
| Jawalamukhi | 43.5 | 50.0 | 0.87 |
| Kotla | 46.1 | 25.0 | 1.84 |
| Dalhausie | 29.0 | 60.0 | 0.48 |
| Chamba | 57.0 | 34.0 | 1.70 |
| Pathankot | 60.0 | 36.0 | 1.70 |

**Table 3.** Events correlated with radon anomalies occurring at Palampur

| Date of Rn anomaly | Date of event | Lat°N | Long°E | Depth (km) | M |
|---|---|---|---|---|---|
| 17–03–93 | 22–03–93 | 32.04 | 76.06 | 15.0 | 3.5 |
| 23–03–93 | 23–03–93 | 32.41 | 76.35 | 10.5 | 2.8 |
| 21–06–93 | 24–06–93 | 32.86 | 76.02 | 06.0 | 2.3 |
| 23–08–93 | 28–08–93 | 32.54 | 76.76 | 15.0 | 2.5 |
| 02–04–94 | 10–04–94 | 31.55 | 76.90 | 15.0 | 2.5 |
| 05–07–94 | 07–07–94 | 31.42 | 76.90 | 15.0 | 2.9 |
| 19–08–94 | 19–08–94 | 31.72 | 76.63 | 19.0 | 2.9 |
| 31–08–94 | 08–09–94 | 32.54 | 76.43 | 15.0 | 3.2 |
| 20–09–94 | 25–09–94 | 32.23 | 76.47 | 15.0 | 2.4 |
| 28–09–94 | 02–10–94 | 32.64 | 75.86 | 57.0 | 2.2 |
| 09–10–94 | 15–10–94 | 32.05 | 76.66 | 15.0 | 2.5 |
| 12–12–94 | 20–12–94 | 32.18 | 76.35 | 15.0 | 2.5 |
| 30–12–94 | 05–01–95 | 32.33 | 77.06 | 36.0 | 2.9 |
| 13–01–95 | 19–01–95 | 32.95 | 76.05 | 15.0 | 3.0 |
| 21–03–95 | 24–03–95 | 32.60 | 75.91 | 18.0 | 4.5 |
| 27–04–95 | 04–05–95 | 31.43 | 76.95 | 15.0 | 2.3 |
| 05–05–95 | 10–05–95 | 32.83 | 76.02 | 12.0 | 2.0 |
| 01–06–95 | 07–06–95 | 31.42 | 76.58 | 15.0 | 3.3 |
| 19–06–95 | 22–06–95 | 32.55 | 76.38 | 01.0 | 2.3 |
| 25–06–95 | 28–06–95 | 33.00 | 76.42 | 15.0 | 1.8 |
| 15–07–95 | 21–07–95 | 31.47 | 76.81 | 65.0 | 1.7 |
| 23–07–95 | 05–08–95 | 32.92 | 75.60 | 19.0 | 1.9 |

one year, a mean value of radon concentration and corresponding standard deviation were calculated. If one or more measured radon values deviated from the yearly average by more than twice the standard deviation, an event was assumed to have occurred in the respective time series. The event was called a radon anomaly if it preceded an earthquake and satisfied the above criterion. It is a purely arbitrary and relative definition. The average radon concentration level from March 1993 to August 1995 is calculated to be 5728 counts per day with a standard deviation of 4802. Results are given in Tables 1 and 2.

The first radon anomaly was recorded on 17 March 1993 under normal weather conditions. This anomaly was followed by an earthquake of a magnitude of 3.5 on 22 March 1993 in the Kangra valley. With a sudden decrease in the radon value again on 23 March, an event of 2.8 M was recorded on the same day. A radon anomaly occurred on 21 June when air and soil temperature were showing a rising trend. This anomaly was followed by a seismic event of magnitude 2.4 on 24 June in N-W Himalaya. Due to the battery failure, there are some data gaps but a number of radon spikes are evident in the radon spectrum recorded over the time window of 29 months (Figure 2). Most of these spikes are correlated with seismic events which occurred in the region as summarized in Table 3. For correlation purposes, the radon data is compared with the seismic data supplied by the Seismology Division of IMD, New Delhi which is running its network in the Kangra valley.

The Kangra valley experienced the heaviest rainfall in July and August 1993, the peak monsoon season. Radon emanation was lowest during the rainy season after heavy rainfall in the last week of June. There i a positive anomaly corresponding to the seismic even of magnitude 2.5 which occurred on 28 August. Ther is no seismic event during the time window Septembe 1993 to March 1994 in the grid (32–33°N, 76–77°E despite the fact that four radon anomalies are recorde in the data.

Radon values show large scale fluctuations durin April and May 1994. The sharp peak on 2 April i followed by the seismic event of magnitude 2.5 on 1 April. However, the sharp radon peak of May 16 is nc followed by any corresponding seismic event. The rado level shows a rising trend during July to October 199 and a number of events corresponding to positive anoma lies are recorded during this period. The peaks on July, 19 August, 31 August, 20th September, 28th Sep tember and 9 October 1994 are followed by events c magnitude 2.9, 2.9, 3.2, 2.4, 2.2 and 2.5 on 7 July, 1 August, 8 September, 25 September, 2 and 15 Octobe respectively. No seismic event is recorded durin November 1994 although there is a peak.

During December 1994, radon emanation was below average and does not show any positive radon anomaly. A negative peak on December 12 corresponds to an event of 2.4 M on 20 December. After this low radon value there is a sudden rise in radon emanation, impulsive increase touching its peak value on 5 January 1995. This sharp rise in activity is reflected by seismic events of magnitude 2.9 and 3.0 on 5 January and 19 January 1995, respectively. Radon fluctuations were quite predominant during February and March 1995. There was a sharp rise in the radon value on 21 March followed by an event of 4.5 M on 24 March. During May–June

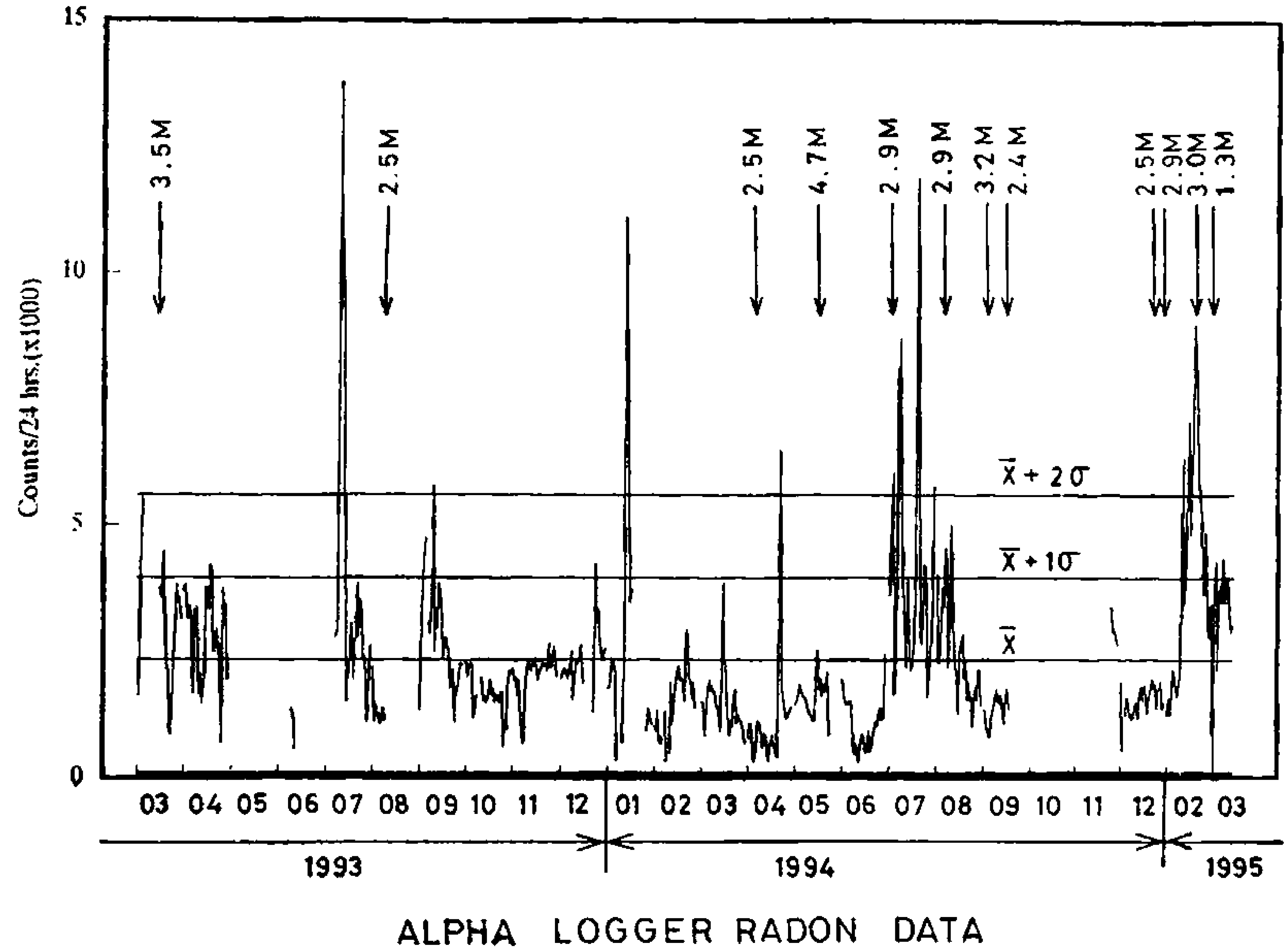



**Figure 3.** Alpha-logger radon data for Pathankot station (arrows represent the seismic events recorded by IMD network).

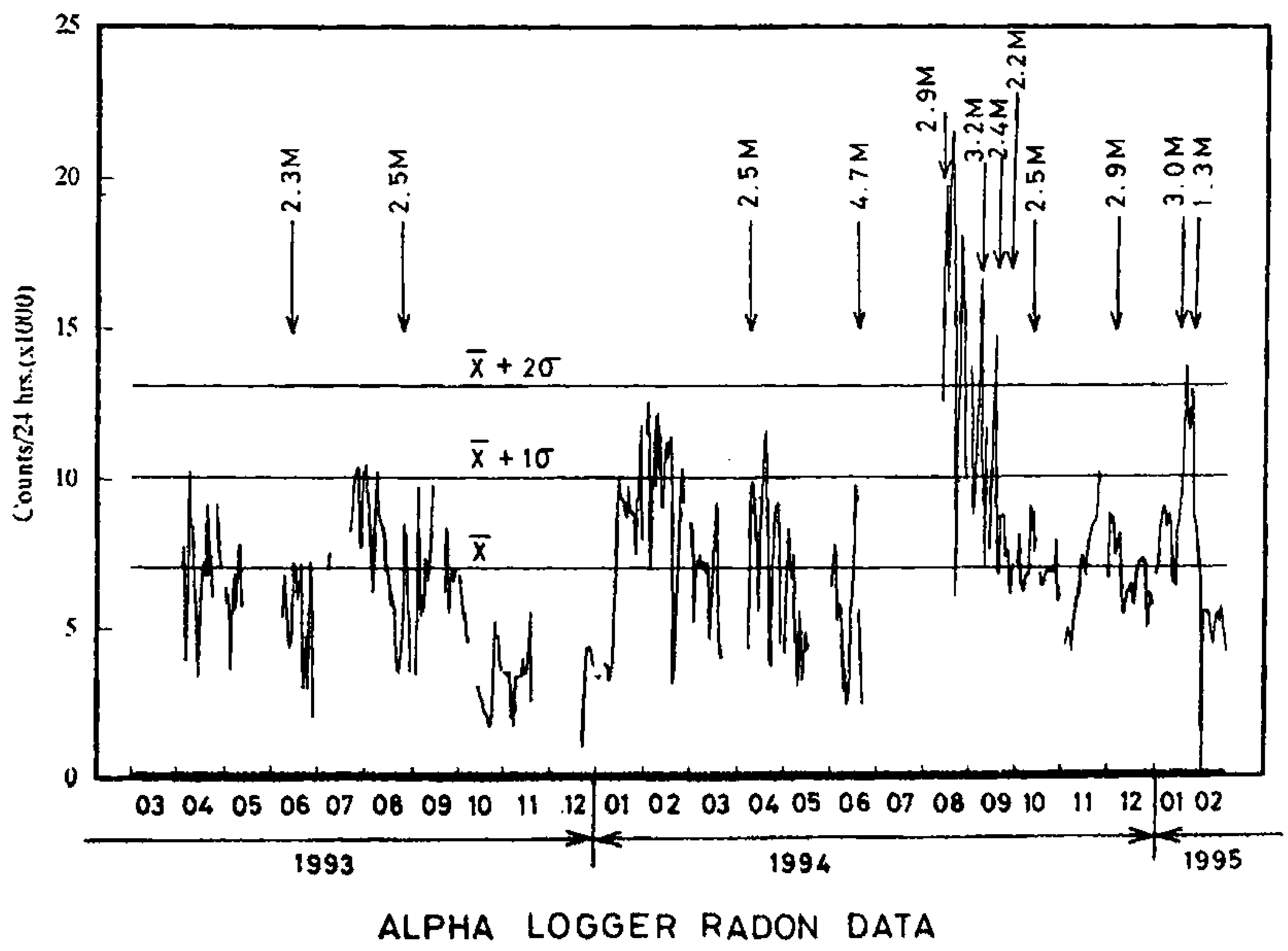



**Figure 4.** Alpha-logger radon data for Kotla station (arrows represent the seismic events recorded by IMD network).

radon activity shows a decreasing trend just touching average value but in July, even after the onset of the rainy season the radon value rose beyond $\bar{x}+2\sigma$. A number of radon spikes appear in the data set followed by events corresponding to these spikes (Figure 2). During August the radon value shows a decreasing trend while displaying a sharp peak left unidentified due to lack of IMD data for this period.

Alpha-logger radon data for other stations, viz. Pathankot, Kotla, Dalhausie, Chamba and Jawalamukhi are recorded as shown in Figures 3–7 respectively. Alpha-logger probe at Dalhausie was shifted to a new

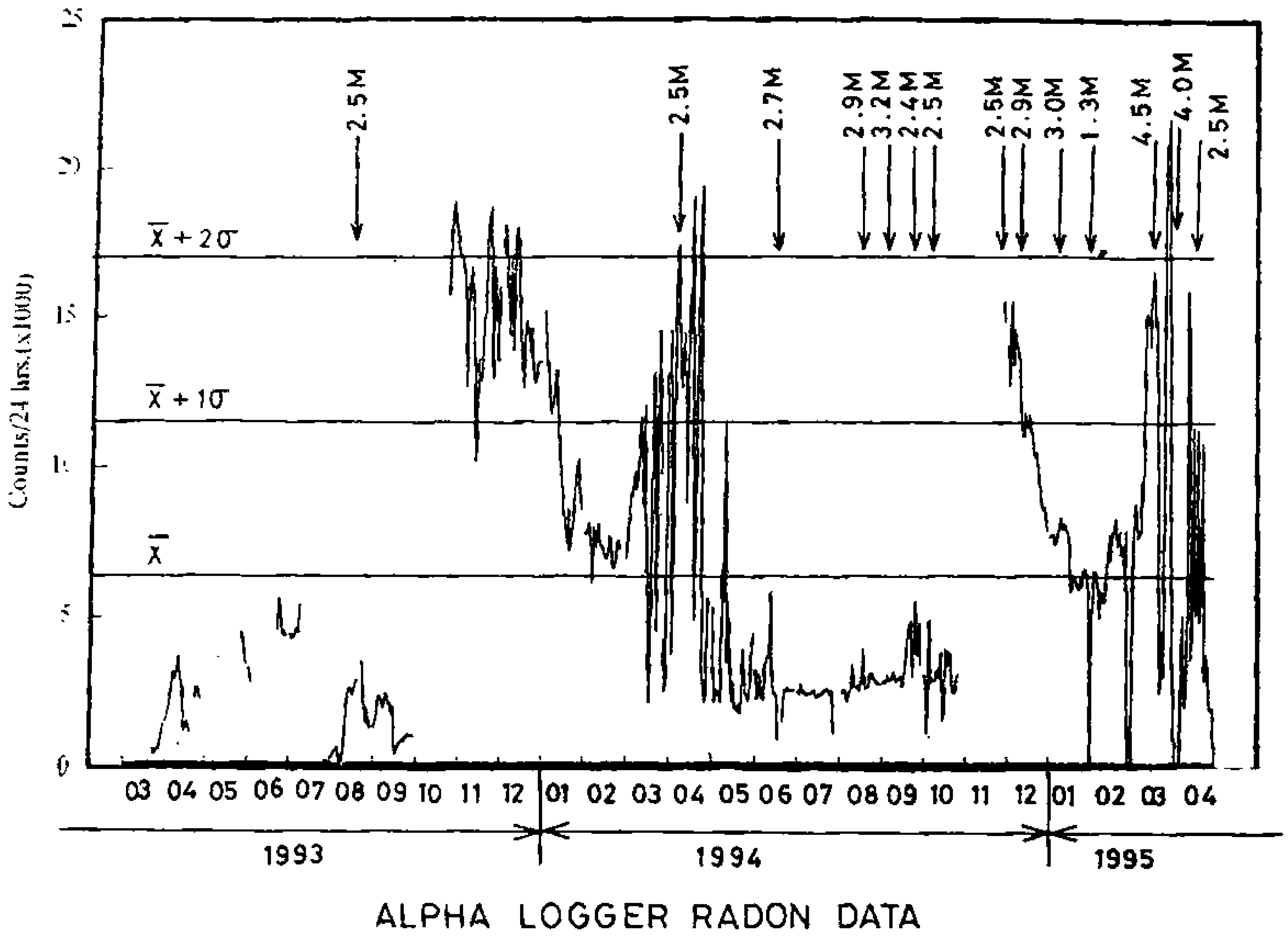



**Figure 5.** Alpha-logger radon data for Dalhausie station (arrows represent the seismic events recorded by IMD network).

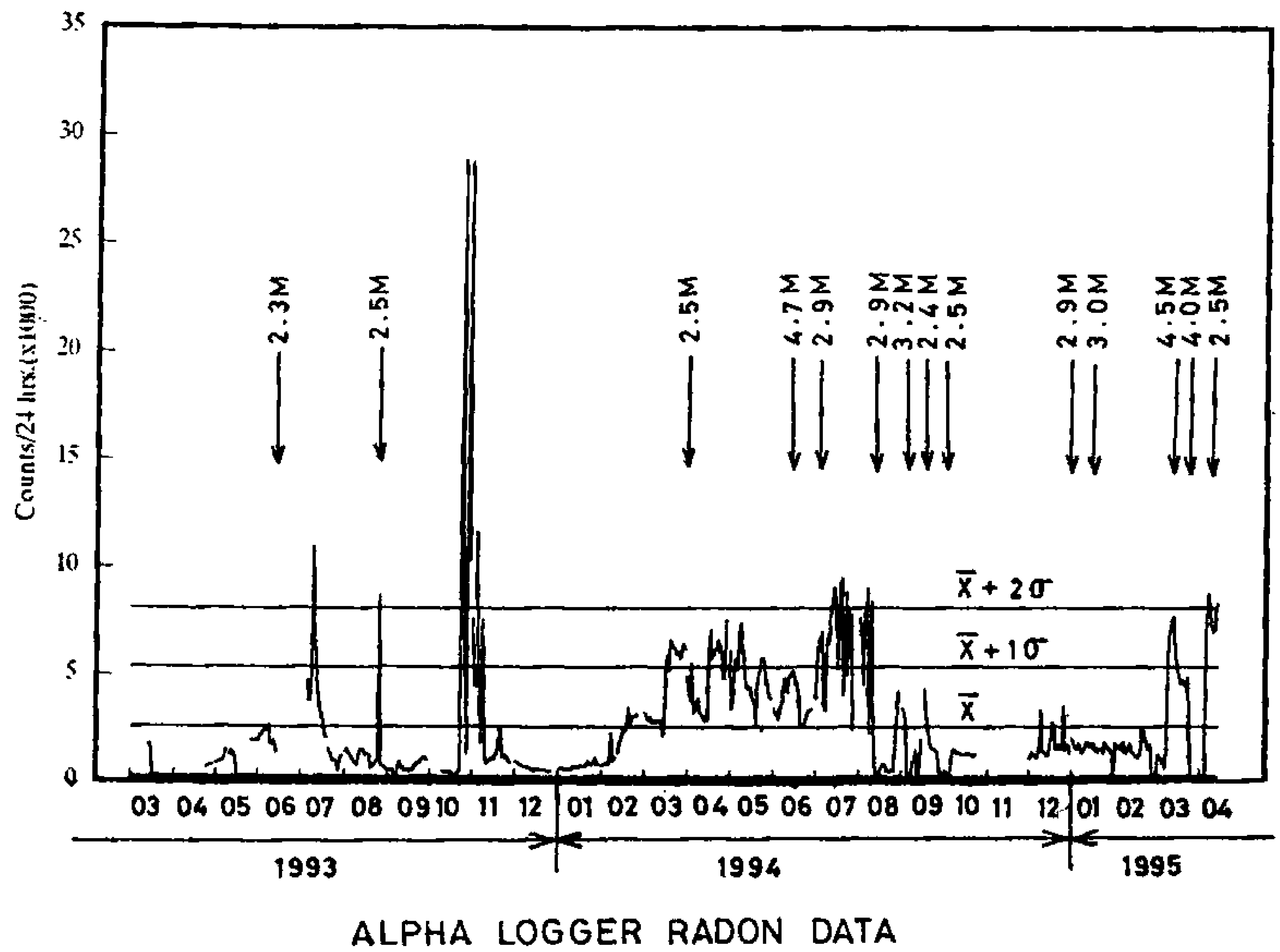



**Figure 6.** Alpha-logger radon data for Chamba station (arrows represent the seismic events recorded by IMD network).

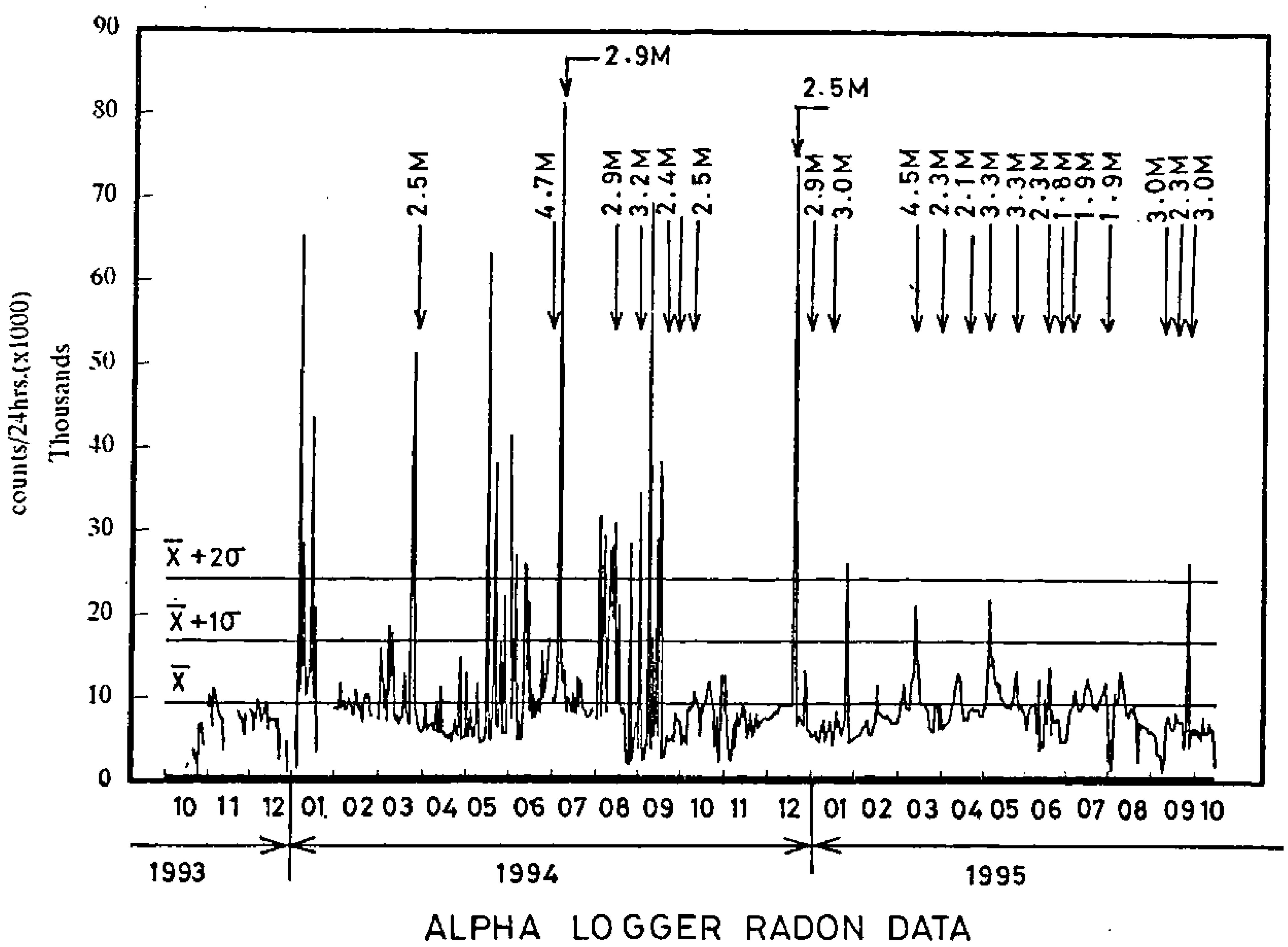



**Figure 7.** Alpha-logger radon data for Jawalamukhi station (arrows represent the seismic events recorded by IMD network).

site in November 1993 due to logistic problem after which it started recording radon data faithfully. Radon peaks at Dalhausie and Palampur show some matching with emanometry data reported elsewhere[11]. Jawalamukhi station is quite sensitive to seismic events occurring in the Kangra valley as shown by large-scale fluctuations in radon emission (Figure 7). Being in close proximity to a fault, it has recorded the highest average value of radon emanation. The Chamba earthquake which occurred on 24 March recorded its signature as a radon anomaly on 21 March. It is one of the unique events[13] that strongly supports radon as an earthquake precursor. The events which are correlated with alpha-logger radon data from these stations are summarized in Tables 4–8. Since there are some peaks which do not correspond to any event, a meteorological analysis of alpha-logger radon data has been carried out at Palampur station. Results of this statistical analysis are given in Table 9.

The origin and mechanism of observed radon anomalies and their relationship to earthquakes is yet poorly understood, although several constraints from laboratory experiments, mathematical modelling and *in situ* hydraulic experiments have been described[14–16]. Anderson and Grew[17] proposed the mechanism based on the stress corrosion theory. This attributes the radon anomalies to slow crack growth controlled by stress corrosion in a rock matrix saturated by groundwater. The mechanism of stress corrosion suggests that the occurrence of radon anomalies may depend on strain rate and local conditions such as rock type, elastic moduli, the pattern of microearthquakes, the degree of saturation, temperature, stress intensity factors and hydraulic properties.

**Table 4.** Events correlated with radon anomalies occurring at Kotl

| Date of Rn anomaly | Date of event | Lat°N | Long°E | Depth (km) | M |
|---|---|---|---|---|---|
| 16–06–93 | 24–06–93 | 32.86 | 76.02 | 06.1 | 2.3 |
| 27–08–93 | 28–08–93 | 32.54 | 76.76 | 15.0 | 2.5 |
| 10–04–94 | 10–04–94 | 31.55 | 76.76 | 15.0 | 2.5 |
| 24–06–94 | 02–07–94 | 32.72 | 76.05 | 15.0 | 4.7 |
| 15–08–94 | 19–08–94 | 31.72 | 76.63 | 19.0 | 2.9 |
| 08–09–94 | 08–09–94 | 32.54 | 76.43 | 15.0 | 3.2 |
| 18–09–94 | 25–09–94 | 32.22 | 76.47 | 15.0 | 2.4 |
| 28–09–94 | 02–10–94 | 32.64 | 75.86 | 57.0 | 2.2 |
| 13–10–94 | 15–10–94 | 32.05 | 76.66 | 15.0 | 2.5 |
| 09–12–94 | 20–12–94 | 32.18 | 76.35 | 15.0 | 2.5 |
| 24–12–94 | 05–01–95 | 32.33 | 77.06 | 36.0 | 2.9 |
| 19–01–95 | 19–01–95 | 32.95 | 76.05 | 15.0 | 3.0 |
| 25–01–95 | 04–02–95 | 32.50 | 76.00 | 04.0 | 1.3 |

King[18] proposed a compression mechanism for radon release. According to this mechanism the anomalous high-radon release may be due to an increase in crustal compression before an impending earthquake that squeezes out the soil gas into the atmosphere at an increasing rate. An increased outgassing rate may perturb the vertical subsurface radon concentration profile such that the deeper soil gas containing more radon is brought up to the detection level.

The Kangra valley and its environs did not experience a major seismic event in the time window, March 1993 to August 1995, except for Chamba earthquake of 24 March 1995 of magnitude 4.5 as reported by IMD network in the grid (31–33°N, 75–77°E).

Radon peaks are correlated with seismic events recorded in N-W Himalaya for all the stations using alpha-logger probes. Kotla (Table 4) shows a similar trend to Palampur station, lying in the immediate vicinity of main boundary thrust (MBT). Surprisingly, all alpha-logger sites are unique in character in response to radon fluctuations but most of the seismic events which occurred in the grid (31–33°N, 75–77°E) are reflected in the radon data. The background radon values are generally found high at Palampur, Kotla and Jawalamukhi stations which indicate the presence of radioactive minerals in this area.

Migration of radon from the source which lies between 300 and 800 m beneath the surface is only possible by groundwater flow and pressure gradient. This strain field model[16] explains the behaviour of radon migration to some extent. The variation in the sensitivity of stations towards radon emanation is due to variation in the porosity and permeability of the underlying rock strata. Seasonal variations affect the radon emanation up to 10–20% of the average value. A rise in radon value does not always mean an event. Generally in 60 to 70% of the cases, a rise between $\bar{x}+1\sigma$ and $\bar{x}+2\sigma$ corresponds to an event. The mean values of radon emanation differ widely over monitoring sites, with Chamba recording the lowest value of 2536 counts/day and Jawalamukhi, the highest radon value of 9300 counts/day. King[3] reported similar results: the average level at four sites separated only by tens of meters, differed by as much as a factor of 5. The rising trend of radon at Palampur and Jawalamukhi indicates the increase in microseismic activity in the Kangra valley (Tables 3 and 7). The low background value of radon at Chamba may be attributed to the presence of granitic rocks in the area. The other cause of its low value may be collapse of pore spaces during the process of strain field development.

Critical analysis of alpha-logger radon data (Tables 1 and 2) strongly supports the fact that radon rise does not always lead to an event, but in most of the cases

**Table 5.** Events correlated with radon anomalies occurring at Chamba

| Date of Rn anomaly | Date of event | Lat°N | Long°E | Depth (km) | M |
|---|---|---|---|---|---|
| 15–06–93 | 24–06–93 | 32.86 | 76.02 | 06.1 | 2.3 |
| 26–08–93 | 28–08–93 | 32.54 | 76.76 | 15.0 | 2.5 |
| 31–03–94 | 10–04–94 | 31.55 | 76.90 | 15.0 | 2.5 |
| 22–06–94 | 02–07–94 | 32.72 | 76.05 | 15.0 | 4.7 |
| 05–07–94 | 07–07–94 | 31.42 | 76.90 | 15.0 | 2.9 |
| 14–08–94 | 19–08–94 | 31.72 | 76.63 | 19.0 | 2.9 |
| 07–09–94 | 08–09–94 | 32.54 | 76.43 | 15.0 | 3.2 |
| 17–09–94 | 25–09–94 | 32.23 | 76.47 | 15.0 | 2.5 |
| 08–10–94 | 15–10–94 | 32.05 | 76.66 | 15.0 | 2.5 |
| 01–01–95 | 05–01–95 | 32.33 | 77.06 | 36.0 | 2.9 |
| 12–01–95 | 19–01–95 | 32.95 | 76.05 | 15.0 | 3.0 |
| 13–03–95 | 24–03–95 | 32.60 | 75.91 | 18.0 | 4.5 |
| 25–03–95 | 30–03–95 | 33.23 | 75.96 | 24.0 | 4.0 |
| 06–04–95 | 06–04–95 | 33.23 | 75.07 | 15.0 | 2.5 |

**Table 6.** Events correlated with radon anomalies occurring at Pathankot

| Date of Rn anomaly | Date of event | Lat°N | Long°E | Depth (km) | M |
|---|---|---|---|---|---|
| 19–03–93 | 22–03–93 | 32.04 | 76.06 | 15.0 | 3.5 |
| 09–08–93 | 28–08–93 | 32.54 | 76.76 | 15.0 | 2.5 |
| 05–04–94 | 10–04–94 | 31.55 | 76.90 | 15.0 | 2.5 |
| 20–05–94 | 02–07–94 | 32.72 | 76.05 | 15.0 | 4.7 |
| 03–07–94 | 07–07–94 | 31.42 | 76.90 | 15.0 | 2.9 |
| 11–08–94 | 19–08–94 | 31.72 | 76.63 | 19.0 | 2.9 |
| 05–09–94 | 08–09–94 | 32.54 | 76.43 | 15.0 | 3.2 |
| 15–09–94 | 25–09–94 | 32.23 | 76.47 | 15.0 | 2.4 |
| 17–12–94 | 20–12–94 | 32.18 | 76.35 | 15.0 | 2.5 |
| 26–12–94 | 05–01–95 | 32.33 | 77.06 | 36.0 | 2.9 |
| 19–01–95 | 19–01–95 | 32.95 | 76.05 | 15.0 | 3.0 |
| 29–01–95 | 04–02–95 | 32.50 | 76.00 | 04.0 | 1.3 |

**Table 7.** Events correlated with radon anomalies occurring at Jawalamukhi

| Date of Rn anomaly | Date of event | Lat°N | Long°E | Depth (km) | M |
|---|---|---|---|---|---|
| 25–03–94 | 10–04–94 | 31.55 | 76.90 | 15.0 | 2.5 |
| 30–06–94 | 02–07–94 | 32.72 | 76.05 | 15.0 | 4.7 |
| 05–07–94 | 07–07–94 | 31.42 | 76.90 | 15.0 | 2.9 |
| 15–08–94 | 19–08–94 | 31.72 | 76.63 | 19.0 | 2.9 |
| 02–09–94 | 08–09–94 | 32.54 | 76.43 | 15.0 | 3.2 |
| 17–09–94 | 25–09–94 | 32.23 | 76.47 | 15.0 | 2.4 |
| 25–09–94 | 02–10–94 | 32.64 | 75.86 | 57.0 | 2.2 |
| 11–10–94 | 15–10–94 | 32.05 | 76.66 | 15.0 | 2.5 |
| 20–12–94 | 20–12–94 | 32.18 | 76.35 | 15.0 | 2.5 |
| 29–12–94 | 05–01–95 | 32.33 | 77.06 | 36.0 | 2.9 |
| 15–01–95 | 19–01–95 | 32.95 | 76.05 | 15.0 | 3.0 |
| 15–03–95 | 24–03–95 | 30.60 | 75.91 | 18.0 | 4.5 |
| 01–04–95 | 04–04–95 | 31.43 | 76.95 | 15.0 | 2.3 |
| 24–04–95 | 01–05–95 | 32.33 | 76.61 | 53.0 | 2.1 |
| 06–05–95 | 12–05–95 | 32.40 | 76.43 | 02.0 | 3.3 |
| 26–05–95 | 07–06–95 | 31.42 | 76.58 | 15.0 | 3.3 |
| 18–06–95 | 22–06–95 | 32.91 | 76.38 | 01.0 | 2.3 |
| 26–06–95 | 28–06–95 | 33.00 | 76.42 | 15.0 | 1.8 |
| 07–07–95 | 08–07–95 | 33.61 | 76.54 | 15.0 | 1.9 |
| 01–08–95 | 05–08–95 | 32.92 | 75.60 | 19.0 | 1.9 |
| 10–09–95 | 15–09–95 | 32.62 | 76.73 | 03.0 | 3.0 |
| 17–09–95 | 20–09–95 | 32.81 | 76.28 | 05.0 | 2.3 |
| 28–09–95 | 29–09–95 | 32.61 | 76.56 | 06.0 | 3.0 |

**Table 8.** Events correlated with radon anomalies occurring at Dalhausie

| Date of Rn anomaly | Date of event | Lat°N | Long°E | Depth (km) | M |
|---|---|---|---|---|---|
| 26–08–93 | 28–08–93 | 32.54 | 76.76 | 15.0 | 2.5 |
| 06–04–94 | 10–04–94 | 31.55 | 76.90 | 15.0 | 2.5 |
| 21–06–94 | 02–07–94 | 32.72 | 76.05 | 15.0 | 4.7 |
| 18–08–94 | 19–08–94 | 31.72 | 76.63 | 19.0 | 2.9 |
| 05–09–94 | 08–09–94 | 32.54 | 76.43 | 15.0 | 3.2 |
| 22–09–94 | 25–09–94 | 32.23 | 76.47 | 15.0 | 2.5 |
| 05–10–94 | 15–10–94 | 32.05 | 76.66 | 15.0 | 2.5 |
| 06–12–94 | 20–12–94 | 32.18 | 76.35 | 15.0 | 2.5 |
| 24–12–95 | 05–01–95 | 32.33 | 77.06 | 36.0 | 2.9 |
| 09–01–95 | 19–01–95 | 32.95 | 76.05 | 15.0 | 3.0 |
| 02–02–95 | 04–02–95 | 32.50 | 76.00 | 04.0 | 1.3 |
| 17–03–95 | 24–03–95 | 32.60 | 75.91 | 18.0 | 4.5 |
| 28–03–95 | 30–03–95 | 33.23 | 75.96 | 24.0 | 4.0 |
| 06–04–95 | 06–04–95 | 33.23 | 75.07 | 15.0 | 2.5 |

Table 9. Statistics of radon-monitoring site and its correlation with meteorological parameters

| Parameter | Avg. | Std.dev. | Avg + std | Percentage vari. coefficient (C%) Std./Avg. | Correlation coefficient |
|---|---|---|---|---|---|
| Radon (Counts/24 h) | 5728 | 4802 | 15330 | 83 | – |
| Evaporation (mm) | 2.65 | 2.53 | 7.71 | 95 | – 0.08 |
| Temperature (°C) | 22.01 | 12.17 | 46.35 | 55 | 0.10 |
| Relative humidity (%) | 47.56 | 20.19 | 87.94 | 42 | 0.12 |
| Wind velocity (km/h) | 5.53 | 1.76 | 9.05 | 32 | – 0.14 |
| Rainfall (mm) | 40.57 | 56.38 | 153.33 | 138 | 0.08 |

it precedes the occurrence of earthquakes. Although the concept of negative peak is there, there is no exact demarcation, from where and to what level the value will decrease. A low or high value in radon emanation may be due to meteorological variations too. The results reveal that radon emanation is directly correlated with temperature, relative humidity and rainfall, and inversely with evaporation and wind velocity (Table 9).

Finally, we may conclude that there is a high microseismic activity in the region and the stations in close proximity of MBT record impulsive values of radon before an impending seismic event. Sensitivity of a radon-monitoring station also depends upon the geological conditions of the region, nature of the soil and the meteorological variations.


1. Birchard, G. F. and Libby, W. F., *J. Geophys. Res.*, 1980, **85**, 3100–3106.
2. King, C. Y., *J. Geophys. Res.*, 1980, **85**, 3065–3078.
3. King, C. Y., *Earthquake Prediction Res.*, 1984, **3**, 13–34.
4. Teng, T., *J. Geophys. Res.*, 1980, **85**, 3989–3099.
5. Teng, T., Sun, L. and Mcraney, J. K., *Geophys. Res. Lett.*, 1981, **8**, 441–444.
6. Hauksson, E. and Goddard, J. G., *J. Geophys. Res.*, 1981, **86**, 7037–7054.
7. Wakita, H., Narkamura, Y., Notsu, K., Noguchi, M. and Asada, T., *Science*, 1980, **207**, 882–883.
8. Virk, H. S. and Singh, B., *Nucl. Geophys.*, 1992, **6**, 287–291.
9. Virk, H. S. and Singh, B., *Tectonophysics.*, 1993, **227**, 215–224.
10. Ulomov, V. I. and Mavashev, B. Z., *Dokl. Akad. Sci. USSR Earth Sci. Sect.*, 1967, **176**, 9–11.
11. Virk, H. S., *Nucl. Geophys.*, 1995, **9**, 141–146.
12. Wedpohl, K. H., *Handbook of Geochemistry*, Springer, Berlin, 1978.
13. Virk, H. S., Walia, V. and Sharma, A. K., *Curr. Sci.*, 1995, **69**, 452–454.
14. Thorsteinsson, T., Proceedings of 2nd U.N. Symposium on Development and use of Geothermal Resources, US Govt. Printing Office, Washington DC, 1973, pp. 2173–2180.
15. Andrews, J. N., Proceedings of 2nd International Symposium on Water-Rock Interaction, 1977, pp. 334–342.
16. Dobrovolsky, I. P., Zubkov, S. I. and Miachkin, V. I., *Pure Appl. Geophys.*, 1979, **117**, 1025–1044.
17. Anderson, O. L. and Grew, P. C., *Rev. Geophys. Space Phys.*, 1977, **15**, 77–104.
18. King, C. Y., *Nature*, 1978, **271**, 516–519.



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# A feasibility study towards absolute dating of Indo-Gangetic alluvium using thermoluminescence and infrared-stimulated luminescence techniques


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**Results of a successful maiden attempt to date the Indo-Gangetic alluvium using the luminescence dating technique are presented. The low equivalent dose for the surface sample indicates that these samples had experienced a solar resetting of geologically acquired luminescence. The infrared stimulated luminescence ages on other terraces range from ~2 to 15 ka and are stratigraphically consistent.**


THE 0.25 million sq km Gangetic plain is a foreland basin, extending from Delhi ridge in the west to Rajmahal hills in the east and from Siwaliks in the north to Bundelkhand–Vindhyan high-lands in the south. Major rivers on this plain, viz. Ganga, Yamuna, Ramganga, Ghaghra, Gandak, etc. originate in the Himalaya and carry a large sediment load towards Bay of Bengal. The alluvial fill shows a south-eastward decrease in thickness[1] and this varies from 1000 m in the north near Himalaya to < 10 m in the south adjoining peninsular shield. The basement of the Ganga basin is segmented by a number of transversely occurring geofractures, giving a horst and graben topography[2]. This structural fabric of the basin was responsible for the creation of a number of sub-basins such as the Western UP Shelf, Faizabad