CORRELATION OF RADON ANOMALIES WITH MICRO- EARTHQUAKES IN KANGRA AND CHAMBA VALLEYS OF N-W HIMALAYA

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Abstract

Seismicity in the Himalaya : 100 years since the Kangra earthquake is a welcome initiative by Geological Survey of India to celebrate the event and to focus on the future plan of action in earthquake prediction and hazard evaluation in the Kangra valley. A detailed study of the Kangra earthquake of 4th April, 1905 was published as Memoirs of GSI by C S Middlemiss.

The seismicity and tectonics of the Himalaya have been subjects of special investigation under the coordinated Himalayan Seismicity Program of DST, Govt of India since 1980s. Earthquake prediction studies using radon emanometry, track-etch technique and alpha-logger probes were undertaken under the DST program in N-W Himalaya in a project mode during 1989-2002. Radon monitoring was carried out at Palampur in the Kangra valley and Dalhousie and Chamba in the Chamba valley of Himachal Pradesh in the grid (30-34°N, 74-78°E). Radon anomalies were recorded in both soil-gas and groundwater using two different techniques across the main boundary fault (MBF) of Himalaya.

The study reveals the precursory nature of radon anomalies and the total correlation index with micro-earthquakes is found to be 62% for the radon network. Signal to noise ratio is different for Palampur and Dalhousie stations and so is the radon emanation pattern across the MBF. Most of the seismic events are preceded by positive radon anomalies but some are followed by negative anomalies. Empirical scaling relationships between earthquake magnitudes, epicentral distances and amplitudes of radon anomalies in N-W Himalaya have been worked out for the first time. The correlation of radon data with micro-earthquakes recorded by IMD network in Kangra valley, during the time window 1992-1998, shows a rising trend in both radon emanation and micro-seismicity in Kangra and Chamba valleys of N-W Himalaya. The need for a multiparametric station network in Kangra valley is the need of the hour to promote earthquake prediction research in N-W Himalaya.

Introduction

The death and destruction caused by the great Kangra earthquake is vividly described by C.S.Middlemiss: “Such is the scene now presented at Kangra, but one’s imagination cannot picture the horrors of the actual calamity on the morning of the earthquake. There was no one left alive who could direct operations for rescuing the people burried in the ruins. All the subordinate officials were killed and the people fled panic-stricken fearing that worst terrors would envelope them.”

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 Indian plate collides with the Eurasian plate and has thus been the scene of major earthquakes in India. The Kagra earthquake of 8.5 M took an estimated toll of 20,000 human lives and damaged most of the buildings in the epicentral tract. During the last three decades, N-W Himalaya has recorded half a dozen seismic events of 5 M. The Kangra and Chamba valleys are considered to be a highly seismic zone in the N-W Himalayan belt and its seismic activity has been monitored by Wadia Institute of Himalayan Geology (WIHG), Dehradun and Guru Nanak Dev University (GNDU), Amritsar during 1989-2002, using radon and helium as earthquake precursors. The purpose of this study was to monitor micro-seismicity in N-W Himalaya and to establish Radon as an earthquake precursor.

Radon Anomalies and Earthquakes

Radon anomalies depend to a large extent on the tectonic disturbance of the host minerals, whereby surface areas of the micro fracture are altered. According to the dilatancy mechanism for earthquake occurrance (Scholz et al., 1973), when regional stress increases, dilation of rock masses could cause an increase either in the surface area of rocks due to cracking, or in the flow rate of pore fluids as they are forced out of the interstitial space. Both of these processes will enhance the transport of radon from its original enclosures into the groundwater or spring waters.

Natural water always contains radon in detectable quantities. The tremor due to an earthquake is instrumental in dislodging the suspended radon in the water and creating an anomaly. The suspended radon which gets de-emanated due to agitation tends to migrate upwards along with some other dissolved gases in the medium, and shows a higher concentration of radon in water or soil-gas at shallower depths. Since radon has a half-life of 3.83 days, which effectively means that an anomaly can spend at the most 20 days travelling from a source to a monitoring well (Hauksson & Goddard, 1981). If the travel time is longer, the anomaly will be totally attenuated since radon decays to its daughter isotopes. The flow velocity of groundwater is determined by the rock permeability and regional hydraulic gradient which in some cases can be modified by localized withdrawal of water, for example, at geothermal wells.

Radon anomalies can also occur in soil-gas prior to an earthquake when measurements are carried out in an auger hole. It must be remembered that meteorological variations and seasonal changes affect the radon emanation in the soil-gas resulting in a low signal to noise ratio as compared to the measurements carried out in deep bore wells. Radon anomalies in groundwater must be reflected in soil-gas, if radon monitoring is carried out under similar environmental conditions.

Radon Anomalies and Earthquake Prediction Models

The origin and mechanism of observed radon anomalies and their relationship to earthquakes is poorly understood, although several constraints from laboratory experiments, mathematical modelling, and hydraulic experiments have been described (Thorsteinsson, 1973; Andrews, 1977; Dobrovolsky et al., 1979). Initially, the dilatancy diffusion model (Fleischer,1981) and its versions, suggested that radon anomalies were related to mechanical crack growth rate in the volume of dilatancy, or to change in flow rate of groundwater (Ulomov & Mavashev, 1967; Scholz et al., 1973). The dilatancy model provides a framework within which a long-term precursor can be fitted in the general sense. The time scale for such divergent parameters as the ratio of seismic velocities, changes in local magnetic field strength, change in the earth's electrical resistivity, and change in the radon content of subsurface water can be accounted for by the dilatancy model. The drawback with this explanation is that it often requires an unreasonably large change in stress or strain far away, from the subsequent epicentre. Dilatancy related phenomena might not provide a recognizable short-term precursor, particularly for a large earthquake. Although all precursor signals are necessarily related to the changing stresses in the earthquake zone, one might expect the short term precursors to constitute a less consistent set than long term precursors. In summarizing various precursor phenomena, Scholz et al. (1973) found that the time of appearance and/or duration of a precursor are roughly proportional to the Richter magnitude of the subsequent earthquake.

King (1978) proposed a compression mechanism for radon release. According to this mechanism the anomalous high radon concentration 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.

It is observed that radon anomalies frequently, but not always, precede earthquakes. While a radon anomaly may be associated with an earthquake shock, the exact time when the shock will appear can not be predicted. The earthquake shock may appear while the radon is in an increasing or decreasing mode. This behaviour may be due to the position of the monitoring site with respect to the epicentre of earthquake. One Chinese study (Liu et al., 1975) suggests that radon monitors located in zones of compressional strain record anomalous increases, whereas those in dilatant zones record abnormal decreases. The delay in receiving the signal at the monitoring site from the epicentre is one of the factors which determines whether the earthquake will occur while the radon is in a rising or falling trend (Ghosh et al., 1987). However, the subsequent shock may not be equally spaced so that the radon anomaly may be used only as an indication of a possible earthquake.

Radon Monitoring Techniques

For earthquake prediction using radon monitoring, both spatial and sequential measurements are probably needed. Recording stations were set up at Guru Nanak Dev University, Amritsar in 1984, and at H.P. Krishi Vishav Vidyalya, Palampur in Kangra valley of Himachal Pradesh in 1989. The radon monitoring was carried out at sites free from uranium mineralization to reduce background effects. Radon monitoring stations fall in the North-Western seismic zone of India, in close proximity to the Main Boundary Thrust (MBT) in the Himalayan foot-hills (Fig. 1).

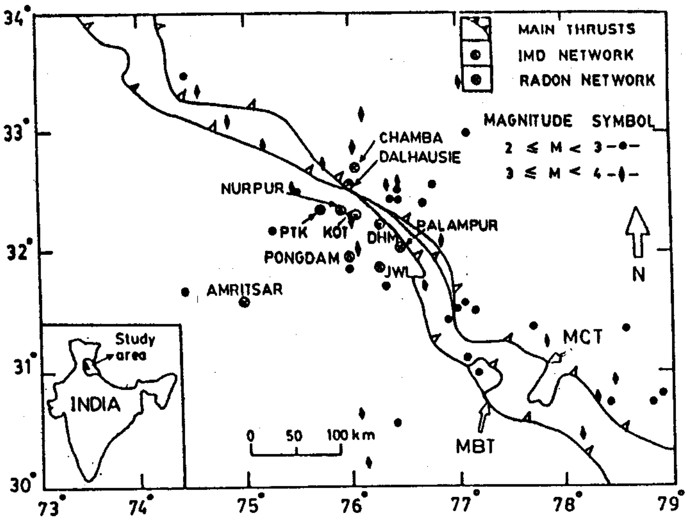

Fig. 1 Microseismic activity recorded by IMD and Radon network in Himachal Pradesh along the Himalayan thrusts (MBT = main boundary thrust, MCT = main central thrust, PTK = Pathankot, KOT = Kotla, JWL = Jawalamukhi and DHM = Dharamsala).

The fluctuations in near surface, and groundwater radon concentration are monitored using both instantaneous, and time- integrated techniques. Track-etch, alpha-logger, and emanometry techniques have been exploited for long term, short term, and instantaneous radon recording, respectively. Physical principles involved in all three techniques are different but the most important common feature is the detection, and recording of alpha particles emitted by radon and its daughters. It is imperative to calibrate all types of radon detectors, namely, plastic track detector (LR-115 type II), ZnS(Ag) scintillation detector, and silicon-diffused junction detector using 5.4 micro-curie (200 kBq) $RaC1_2$ standard solution preferably under similar ambient conditions as prevailing at radon monitoring sites. To reduce the length of this paper, experimental details are omitted and may be found elsewhere (Virk, 1996).

Correlation of Radon Data with Seismic Events

There is no general definition of an anomaly for time-series data of geochemical, and/or geophysical observations. Hence, we must set a criterion for an anomaly appropriate to our radon monitoring. We define the radon anomaly as the positive deviation that exceeds the mean radon level by more than twice the standard deviation.

Several impuslive radon increases with amplitudes much larger than the background level may be recorded under different weather conditions. It is imperative to correct the data for the influence of meteorological variables by using the correlation matrix. The fact that an impulsive radon increase is recorded under a variety of weather conditions suggests that the radon anomaly is more likely to be caused by some crustal disturbance rather than by the atmospheric disturbance.

Radon Data at Palampur

Daily, and weekly measurements of radon in soil-gas, and groundwater have been recorded at Palampur since August 1989 using radon emanometry, and track-etch techniques. The mean values of radon concentration from daily, and weekly monitoring in soil-gas are 27.50 ± 2.5, and 28.48 ± 3.0 Bq/L with standard deviation of 11.49, and 25.81 Bq/L, respectively. The daily measurements in groundwater using radon emanometry give an average value of 48.86 ± 3.0 Bq/L with a standard deviation of 14.89 Bq/L.

The first observable radon anomaly (Fig. 2a) was recorded on August 30, 1989 with radon concentration about 70 % above the mean value. This anomaly also occurred in groundwater with radon rise of 60% above the mean. Both the soil-gas, and the groundwater radon anomalies were followed by an earthquake of magnitude 2.8 which occurred on August 31, 1989 with an epicentre in Dharamsala area about 30 km. from the recording station.

In all sixteen radon peaks are observed in soil-gas and groundwater radon data (Fig. 2a & b), and most of these peaks satisfy the criteria set for a radon anomaly after the signal is corrected for the noise. Surprisingly, all these anomalies are correlatable with seismic events that occurred in the North-West Himalayas (Table 1). Weekly radon data recorded by Track-Etch technique is also plotted (Fig. 3a & b). Radon anomalies are more pronounced but follow a different pattern due to integrating nature of the technique. However, plausible correlations can be established with the earthquakes occurring in the region in an identical manner as for daily data.

Microseismicity Data from Palampur and Dalhausie

Under Himalayan Coordinated Seismicity programme of Department of Science and Technology (DST), New Delhi, we extended our range of activity, and set up six radon recording stations along the MBT in Kangra and Chamba valleys of Himachal Pradesh in 1992. Radon emanometry data in soil-gas and groundwater has been

Fig. 2a. Radon activity in soil-gas and groundwater at Palampur (from Aug. 1989 to Jan. 1991)

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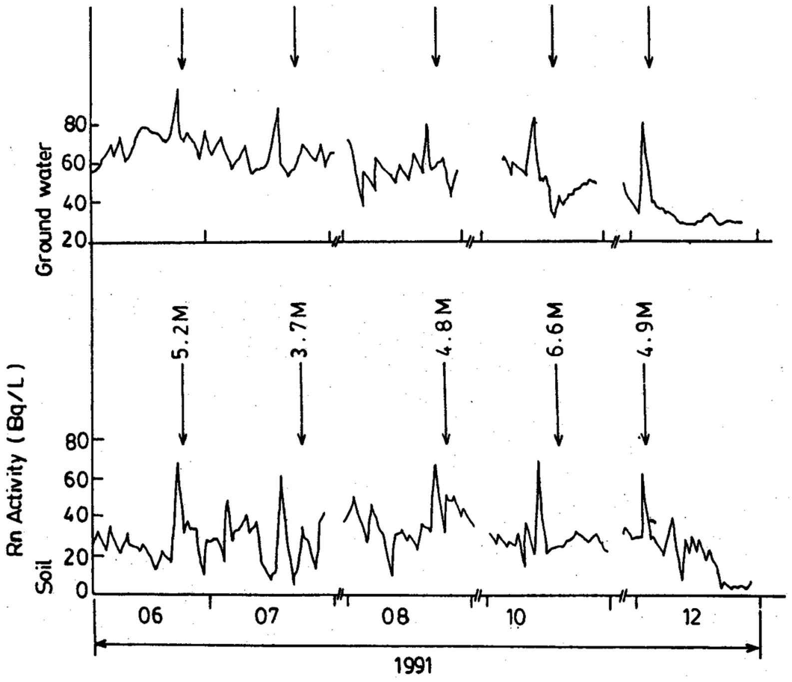


Fig. 2b. Radon activity in soil-gas and groundwater at Palampur (from June to December 1991)

Table 1. Radon emanometry data from Palampur (Aug. 1989 to Dec. 1991)

Occurrence of Rn anomaly	Latitude (λ)	Longitude (Ø)	Depth (km)	Magnitude (M)	Correlatable seismic event
Aug.30, 1989	In Chamba area		-	2.8	Aug.31, 1989
Dec.23, 1989	In Dharamsala area		-	2.8	Dec.24, 1989
Sep.02, 1990	36.40°N	70.63°E	33	4.8	Sep.03, 1990
Sep.07, 1990	37.73°N	69.70°E	33	4.5	Sep.08, 1990
Oct.24, 1990	35.19°N	70.63°E	15	6.1	Oct.25, 1990
Nov.14, 1990	30.51°N	72.12°E	33	5.3	Nov.16, 1990
Dec.23, 1990	33.30°N	75.65°E	30	5.3	Dec.24, 1990
Jan. 08, 1991	33.61°N	76.01°E	15	4.7	Jan.10, 1991
Jan. 18, 1991	37.08°N	77.53°E	33	4.8	Jan.20, 1991
Jan. 24, 1991	37.08°N	70.69°E	32	4.9	Jan.26, 1991
Jan. 30, 1991	36.30°N	70.20°E	15	6.6	Feb.01, 1991
Jun. 22, 1991	32.32°N	76.69°E	33	5.2	Jun.23, 1991
Jul. 23, 1991	32.21°N	76.42°E	17	3.7	Jul.24, 1991
Aug. 22, 1991	36.36°N	68.80°E	33	4.8	Aug.23, 1991
Oct. 15, 1991	30.73°N	78.80°E	19	6.6	Oct.20, 1991
Dec. 03, 1991	36.39°N	69.30°E	42	4.9	Dec.04, 1991

recorded at both Palampur, and Dalhousie stations. Alpha-logger data has been collected continuously at several stations as shown in figure 1. Palampur station started functioning in April 1992 while at Dalhausie, it became operational in July 1992.

There has been no major seismic event in the study area during the time window April 1992 to September 1993. However, the area is showing enhanced microseismicity as recorded by seismic network being operated by IMD. For example, Pong Dam station recorded 16 seismic events with magnitude between 2-4, and with epicentres lying within a range of 100 km. The total number of events recorded in the grid (30-34°N, 73-77°E) having magnitudes in the range of 2-4 is reported to be more than 50 in the given interval. Most of these seismic events have epicentres along the MBT trend line (Fig. 1). It is interesting to note that radon emanometry data recorded at Palampur (Fig. 4), and Dalhausie (Fig. 5) show anomalies corresponding to nearly 62% of these events. A correlation of radon anomalies with microseismic events is given in table 2.

Fig. 3a Weekly radon activity at Palampur (Sept. 1989 to Dec. 1990) using track-etch technique

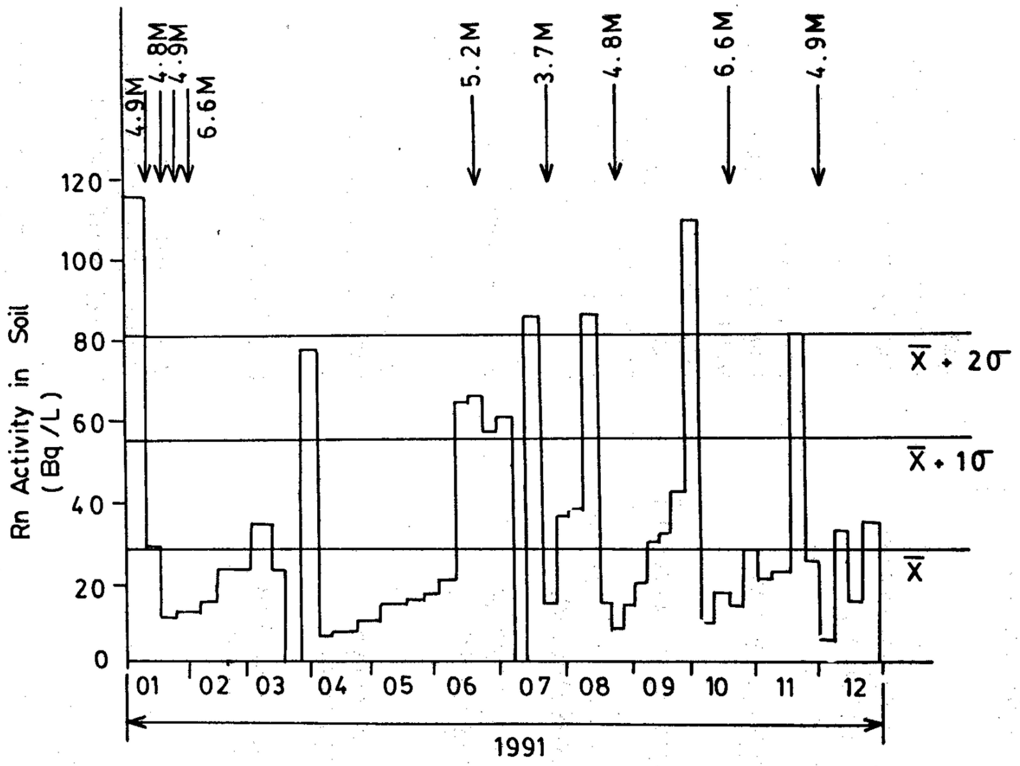


Fig 3b. Weekly radon activity at Palampur (Jan. to Dec 1991) using track-etch technique

Table 2. Correlation of Radon anomalies recorded at Palampur and Dalhousie with microseismic activity in Himachal Pardesh

Date of Radon Anomaly	% change above mean	Magnitude (M)	Latitude (°N)	Longitude (°E)	Date of Earthquake
(a) Radon Emanometry Data at Palampur.					
April 14, 1992	195*	2.2	31.36	77.67	April 11, 1992
May 23, 1992	165*	2.7	31.51	77.17	May 26, 1992
July 21, 1992	-83	3.6	31.25	77.82	July 21, 1992
April 30, 1993	152	1.9	30.67	78.44	May 1, 1993
July 25, 1993	99*	3.1	30.23	76.13	July 30, 1993
Aug 11, 1993	152*	3.7	30.73	78.79	Aug 15, 1993
Aug 28, 1993	252*	2.5	32.54	76.76	Aug 28, 1993
Sept 17, 1993	247	3.0	32.84	73.24	Sept 9, 1993
Sept 28, 1993.	273	3.2	33.43	74.59	Sept 28, 1993
(b) Radon Emanometry data at Dalhousie					
July 7, 1992	250	2.4	31.08	77.06	July 14, 1992
July 9, 1992	250	3.6	31.25	77.82	July 21, 1992
Oct 23, 1992	109	3.1	31.73	76.68	Oct 24, 1992
	117*				
Jan 3, 1993	153	4.4	30.02	73.48	Jan 12, 1993
	183				
Jan 23, 1993	205	3.8	32.73	75.75	Jan 24, 1993
Jan 28, 1993	93	2.7	31.37	76.90	Jan 29, 1993
Mar 17, 1993	93	3.5	32.04	76.06	mar 22, 1993
	128*				
Mar 20, 1993	161*	2.8	32.41	76.35	Mar 23, 1993
Mar 30, 1993	94	3.0	32.52	75.43	Mar 31, 1993
June 17, 1993	109	3.2	32.86	76.02	June 24, 1993
June 18, 1993	140*				
July 9, 1993	138	3.5	33.14	76.14	July 12, 1993
Aug 5, 1993	242	3.7	30.73	78.79	Aug 15, 1993
	227*				

* Anomaly in water

Fig. 4. Time-series radon emanometry Data in Soil-gar and groundwater at Palampur (April 1992 to Sept. 1993)

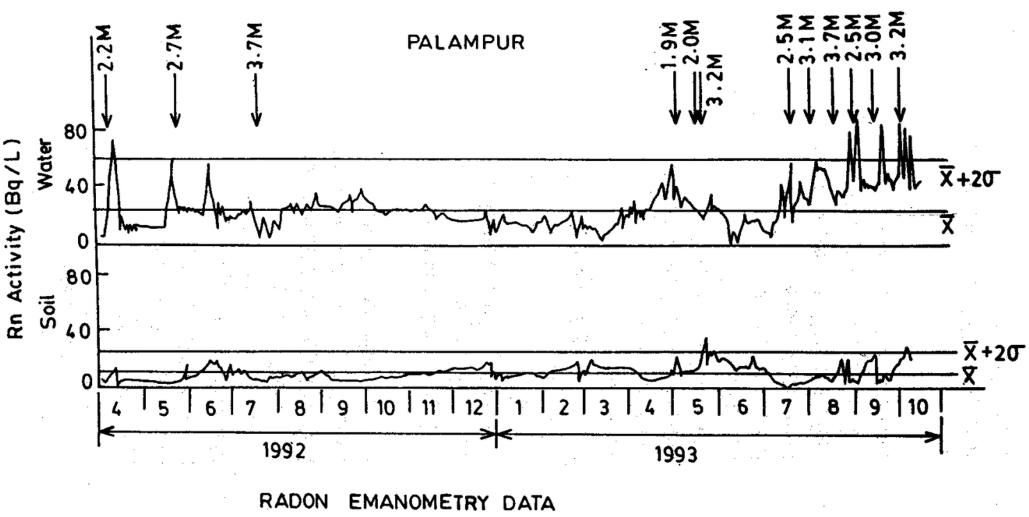
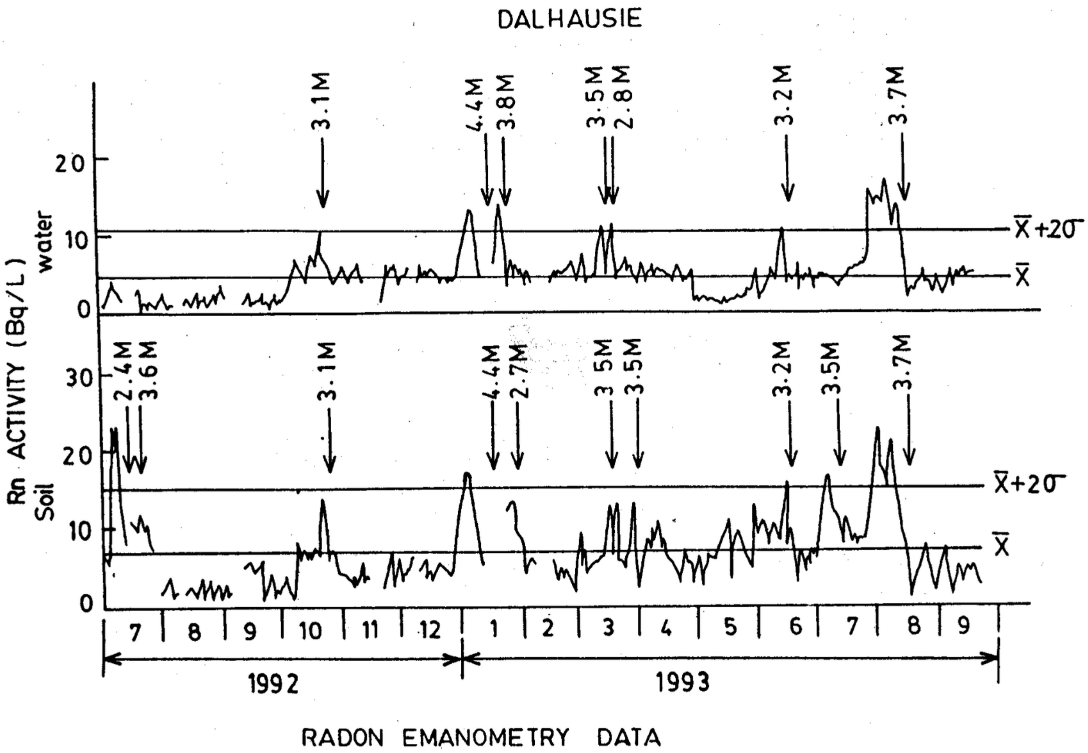


Fig 5 Time-series radon emanometry data in soil-gas and groundwater at Dalhousie (from July 1992 to Oct. 1993)



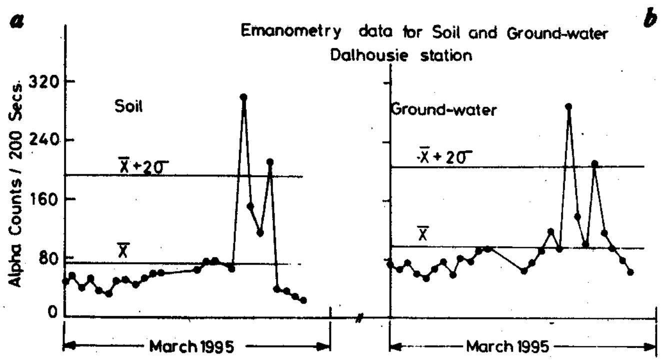


Fig. 6 a. Radon emanometry data in soil-gas at Dalhousie during March 1995.

b. Radon emanometry data in groundwater at Dalhousie during March 1995.

The most interesting feature of radon monitoring in Chamba valley was postdiction of Chamba earthquake (Virk et al., 1995). The Chamba region was rocked by earthquake of magnitude 5.1 M on 24 March, 1995 with its epicentre at Pliure (32.60°N, 75.91°E) nearly 7 km away from Chamba town. The radon anomaly was recoded simultaneously in both media on 21 March three days before the event at Dalhousie station (32.60°N, 76.00°E) which is only about 10 km from Chamba earthquake epicentre with peak values crossing the 2σ level above the average value of 4.52 Bq/L in soil-gas and 4.73 Bq/L in groundwater respectively (Fig. 6). There was another anomaly peak on March 24 and then sudden fall in the emanation rate after the strain was released. The simultaneous recording of radon peaks in both soil-gas and groundwater at the same site and under similar meteorological conditions before the occurrance of Chamba earthquake on 24 March establishes the efficacy of radon as an earthquake precursor.

Radon data comparison of two stations reveals some interesting features of this study. While at Palampur radon emanation is more pronounced in groundwater compared with soil-gas, the Dalhausie station shows the reciprocal trend. This may be due to the different geological conditions of the region. Moreover, meteorological conditions do not affect radon emanation in groundwater appreciably while these variations affect the soil-gas radon significantly.

Concluding Remarks

From our soil-gas, and groundwater radon monitoring results (Virk, 1986, 1990; Virk & Singh, 1992, 1993, 1994; Singh et al., 1988; Ramola et al., 1990) of over ten years as well as those of other workers reported in the literature, we conclude that radon anomalies are generally associated with seismic activity. Hence radon can serve as a useful precursor for earthquake prediction in India. To be useful as a precursor, continuous monitoring of radon both in soil-gas, and in groundwater, along with other environmental factors, at several monitoring sites along the MBT in a grid pattern, is necessary.

Most of the radon anomalies in both soil-gas and groundwater show perfect correspondence, and are recorded simultaneously. This augurs well for accepting radon as an earthquake precursor even though peak radon concentrations are widely different in both the media. Another plus point of our study is that radon anomalies are recorded using three different monitoring techniques.

Recording station at Amritsar is not sensitive to seismic events of magnitude 3.5 or lower occurring in Kangra valley, Himachal Pradesh. Since Palampur and Dalhausie stations are located on the main boundary thrust (MBT) of the Himalaya, they are even sensitive to microseismic events of magnitude 2 which occurred within a range of 50 km of radon monitoring station. However, seismic events of magnitude 5 or more can be correlated with radon anomalies even when they occur at 500 km or still farther away from recording station.

Radon precursory signals of 5.1 M Chamba earthquake, which occurred on 24 March, 1995, were recorded at Chamba and Dalhousie stations using two different techniques. Radon was used to anticipate some hidden fault in the Chamba valley which has been confirmed recently (Joshi, 2004).

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