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Structure and Tectonics of the Indian Plate

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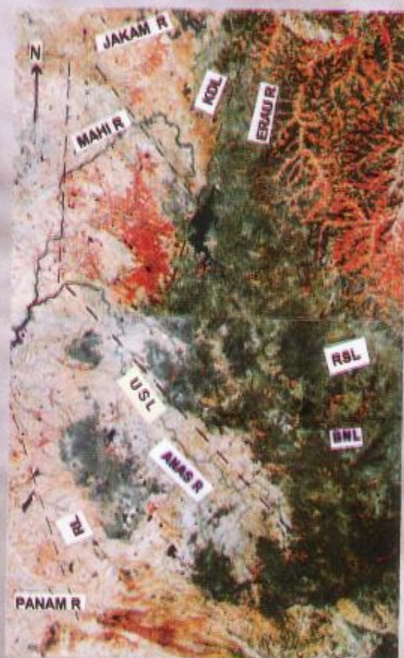

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A critical analysis of radon emanometry data recorded at Palampur and Dalhousie for earthquake prediction studies in NW Himalaya

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Abstract

Radon monitoring has been carried out using emanometry technique at Palampur and Dalhousie stations in the Kangra valley of Himachal Pradesh in the time window, June 1996 to Sept. 1999. Discrete radon concentrations are recorded in soil-gas and groundwater at both the stations. Radon anomalies are correlated with microseismic events recorded along the main boundary fault (MBF) of NW Himalaya in the grid (30-34°N, 74-78°E). The influence of meteorological parameters viz. temperature, rainfall, relative humidity and wind velocity on radon concentration is qualitatively evaluated. The radon emanation shows positive correlation with temperature, rainfall, relative humidity and negative correlation with wind velocity. Both positive and negative radon anomalies are recorded. The study reveals the precursory nature of radon anomalies and their correlation with microseismic events in 62% of the cases but prediction of earthquakes is yet a remote possibility.

Introduction

The Himalayan orogeny is believed to be a product of ongoing collision of the Indian plate with the Eurasian plate. Some of the largest earthquakes in history occurred in the vicinity of Himalaya as a consequence of under-thrusting of the Indian plate. The seismicity and tectonics of the Himalaya have been subjects of special investigation under the coordinated Himalayan Seismicity Programme of Department of Science & Technology (DST), Govt. of India since 1980. Earthquake prediction studies using radon emanometry, track-etch technique and alpha logger probes were undertaken under the seismicity programme in N-W Himalaya in a project mode after 1988 (Virk and Singh, 1992, 1993, 1994; Virk et al., 1995, 1997).

Srivastava et al. (1979) studied earthquake occurrence during the years 1965-75 in the epicentral region of the great Kangra earthquake of 1905 with the help of a closely spaced network of seismic stations. Most of the seismic activity of the region was found to be related to the main boundary fault (MBF) of the NW Himalaya. They also identified a seismic gap in the eastern part of Himachal Pradesh and suggested that this gap may be the locale of a future major earthquake in the region. Bhattacharya et al. (1986) have carried out micro-earthquake survey around Thein Dam during 1983 in the vicinity of Kangra valley. Indian Meteorological Department (IMD) is operating a seismic network to monitor micro-earthquake activity around major hydroelectric dam sites in N-W Himalaya and yearly bulletins are published (IMD, 1992-99).

The geochemical and hydrological anomalies preceding strong earthquakes had been reported by various authors (Umolov and Mavashev, 1967; Talwani et al., 1980; Fleischer, 1981; Liu et al., 1984/85; Segovia et al., 1989; Heinicke et al., 1995; Virk 1986, 1990; Virk and Singh, 1994; Virk et al., 1995;

Singh et al., 1999). Hydrogeo-chemical phenomena and radon are strain indicators in the preparation stage of an earthquake and can be exploited as earthquake precursors for prediction studies (Barsukov et al., 1984/85). However, the physical mechanism and their relationship with the strain build up are not yet fully understood to propose a comprehensive theoretical model for earthquake prediction. Dilatancy-diffusion model proposed by Dobrovolsky et al. (1979) had been used by Fleischer (1981) to interpret the radon data and establish a relationship between the earthquake magnitude and the maximum distance for detection of precursory radon signals. The aim of the present study is to investigate the correlation of radon anomalies recorded in soil-gas and groundwater at Palampur (32.06°N, 76.51°E) and Dalhousie (32.54°N, 75.97°E) stations with the microseismic activity along the MBF recorded by the IMD seismic network.

Experimental Technique

Radon Emanometry

The radon concentrations in soil-gas and groundwater were measured at Palampur and Dalhousie stations along the MBF using emanometry based on scintillation technique of recording alpha particles.

An emanometer (Model RMS-10) manufactured by Atomic Minerals Division (AMD) of Department of Atomic Energy, Hyderabad is used to measure the alpha emanation rate from radon in the gas fraction of a soil or water sample by pumping the gas into a scintillation chamber using a closed-circuit technique (Ghosh and Bhalla, 1966). This technique gives us instant value of radon concentration and is highly suitable for a radon quick survey.

In radon emanometry, the auger holes, each 60 cm in depth and 6 cm in diameter, are left covered for 24 hours so that the soil-gas radon and thoron become stable. The soil-gas probe is fixed in the auger hole and forms an air-tight compartment. The rubber pump, soil-gas probe and alpha detector are connected in a closed-circuit. The soil-gas is circulated through a ZnS-coated chamber (110 ml) for a period of 15 min. till the radon forms a uniform mixture with air. The detector is then isolated by clamping both the ends and observations are recorded after four hours when equilibrium is established between radon and its daughters. Alpha particles emitted by radon and its daughters are recorded by the scintillation assembly consisting of photomultiplier tube (PMT) and a scalar-counter unit.

Radon monitoring in water is also carried out by using closed-circuit technique. Groundwater samples are collected daily from a 'bauli' (natural spring) in a 250 ml sample bottle. The air is circulated in the closed-circuit containing a hand-operated rubber pump, the water sample bottle, a drying chamber and a ZnS(Ag) detector cell for 10 minutes. The alpha counts are recorded after four hours during which the secular equilibrium between radon and its daughters is established.

Radon Monitoring Results

Radon concentrations in soil-gas and groundwater (baulis/natural springs) have been monitored daily at same time at Palampur and Dalhousie stations since 1992 using radon emanometry. Radon concentration is monitored in a discrete mode at mid-day along with meteorological variables in the campus of Himachal Pradesh Krishi Vishavidalya (HPKV) at Palampur while this facility is restricted to only radon measurements at Dalhousie station. It is assumed that the

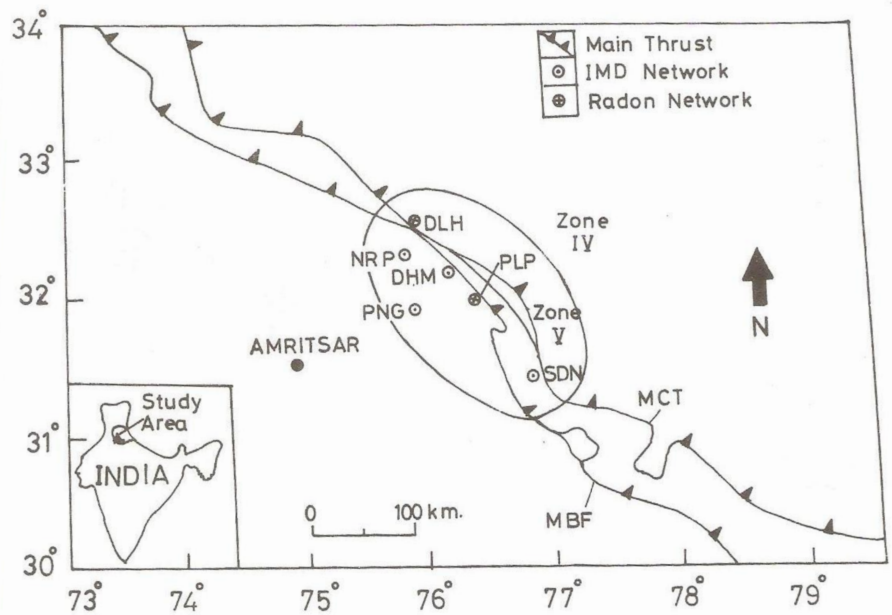

Fig. 1: Map showing radon monitoring sites, Palampur(PLP) and Dalhousie (DLH) along with IMD network stations viz. Nurpur (NRP), Dharamsala (DHM), Pong Dam (PNG) and Sundernagar (SDN) in N-W Himalaya.

weather conditions are almost identical in the environs of radon monitoring stations except for their locations, Palampur being situated in the south of MBF while Dalhousie being on the north side (Fig. 1).

Radon anomaly is defined, as a matter of convention, any sudden change in radon concentration crossing the average of that season by $\pm 2s$, where s represents the standard deviation from the mean value'X. Radon anomalies crossing'X + 2s are called positive anomalies and those crossing'2000 X-2s are called negative anomalies. Generally, radon anomalies precede the seismic events and are called pre-seismic or precursory anomalies. Sometimes these occur simultaneously with seismic events and are classified as co-seismic. However, it is also observed that some anomalies follow the seismic events, which seems a bit strange, as these are not helpful in earthquake prediction studies. In case of major earthquakes, several anomalies precede the seismic event but in case of microearthquakes only one or two anomalies are recorded. Precursor time is generally defined as the interval between the time of recording of radon anomaly and the occurrence of the seismic event in the grid under reference. For major events, it can vary from a week to several months but in case

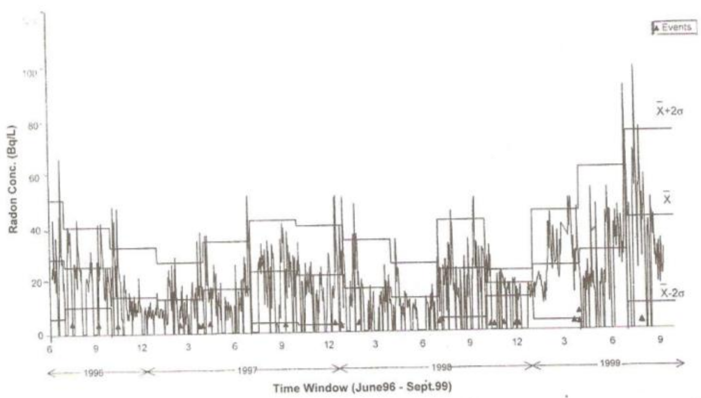

Fig. 2: Radon activity recorded in soil-gas at Palampur along with seismic events (shown by arrowheads correlated with radon anomalies.

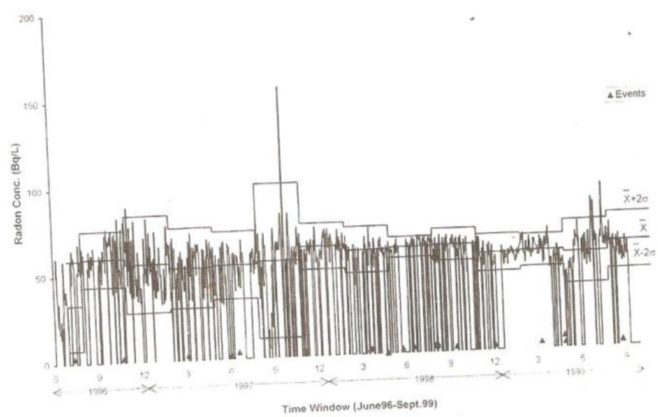

Fig. 3: Radon activity recorded in groundwater at Palampur along with seismic events (shown by arrowheads) correlated with radon anomalies.

of microearthquakes it may vary from a few minutes to a few days. All other parameters, viz. magnitude, depth, epicentral distance, latitude and longitude of the seismic events are calculated following the standard procedure laid down in seismology.

Radon emanometry data in the grid (30-34°N, 74-78°E) for the time-window June 1996 to September 1999 for Palampur and Dalhousie stations are plotted (Figs. 2-5). There are large scale fluctuations in the time-series radon data but the general trend is similar to the previous years (Virk and Sharma, 1997). Radon emanation in soil-gas is enhanced generally during summer months after heavy rainfall in the months of July and August (Monsoon season in N-W Himalaya). This trend is not observed in groundwater because meteorological variables do not influence radon concentration to the same extent as in the soil-gas. However, during December 1997-January 1998, unusual radon behaviour was observed in the soil-gas both at Palampur and Dalhousie stations during winter months. Five radon anomalies were observed during December 1997 showing a rise in seismic activity and the occurrence of five microearthquakes along the MBF. This anomalous behaviour is not reflected in groundwater radon. The highest radon concentration was observed in soil-gas at Palampur during July-August, 1999 during and after the Monsoon rains. This behaviour is absent at Dalhousie station. On the contrary, radon highs are observed in groundwater during rainy season and afterwards at Dalhousie.

Radon concentration at a station depends upon various geological, geophysical and meteorological factors. It also depends upon the nature of the soil, its porosity and permeability and presence of radioactive minerals. The site selection is a major problem in N-W Himalaya. The tectonic uplift and the relative motion of crustal blocks along the MBF influences radon emanation under seismic strain build up uniquely at Palampur and Dalhousie stations. Hence there is no one to one correspondence between radon anomalies recorded at both the stations and in both the media. Average radon concentration during the time-window June1996 to Sept.1999, in groundwater at Palampur is 57 Bq/L which is more than its double average value in the soil-gas (22 Bq/L). Dalhousie station shows the reciprocal behaviour with average value of radon concentration in soil-gas which is nearly double its average value in groundwater. It clearly shows the influence of radioactive minerals on the transport and diffusion of radon at Palampur station vis-a-vis Dalhousie station.

Correlation of radon anomalies recorded in soil-gas and groundwater with seismic events recorded (Fig.6) in the grid under reference (30-34°N, 74-78°E) are summarized in Table1. The total number of microseismic events correlated are 63 and their magnitudes vary from 2.1-4.8 on Richter scale, with the exception of Chamoli earthquake (6.8m) which occurred outside the grid but recorded its signature at Palampur station. The Himalayan earthquakes have shallow depths of foci and are confined to the (MBF).

The effect of meteorological variables on radon concentration in soil-gas at Palampur is represented by Figs. 7-8. As already established (Virk and Singh 1992; Sharma et. al., 2000) for NW Himalaya, the temperature, rainfall and relative humidity have positive correlation with radon concentration while wind velocity shows a negative correlation with radon as in case of high pressure which suppresses radon emanation from the soil. Correlation coefficients of radon emanation

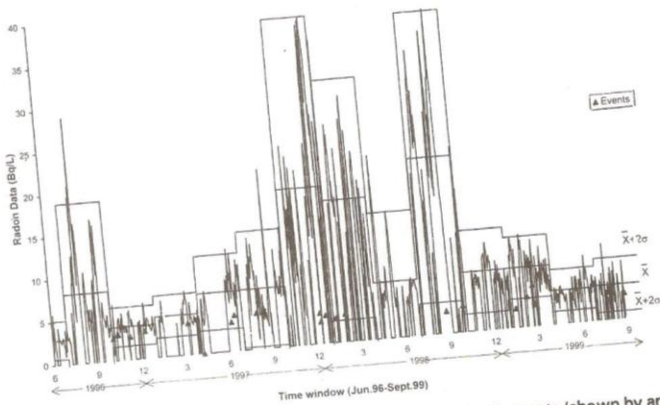

Fig. 4: Radon activity recorded in soil-gas at Dalhousie along with seismic events (shown by arrowheads) correlated with radon anomalies.

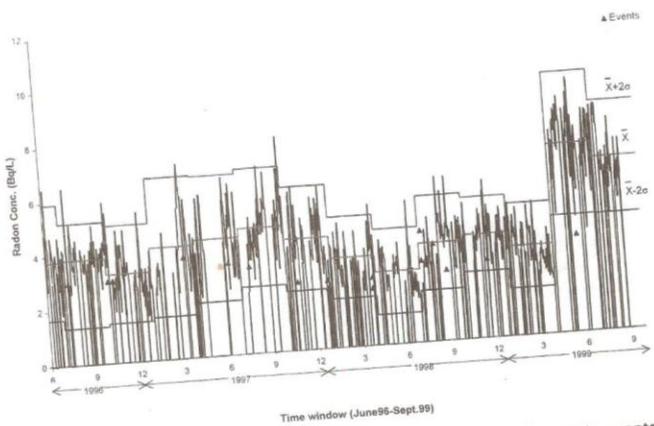

Fig. 5: Radon activity recorded in groundwater at Dalhousie along with seismic events (shown by arrowheads) correlated with radon anomalies.

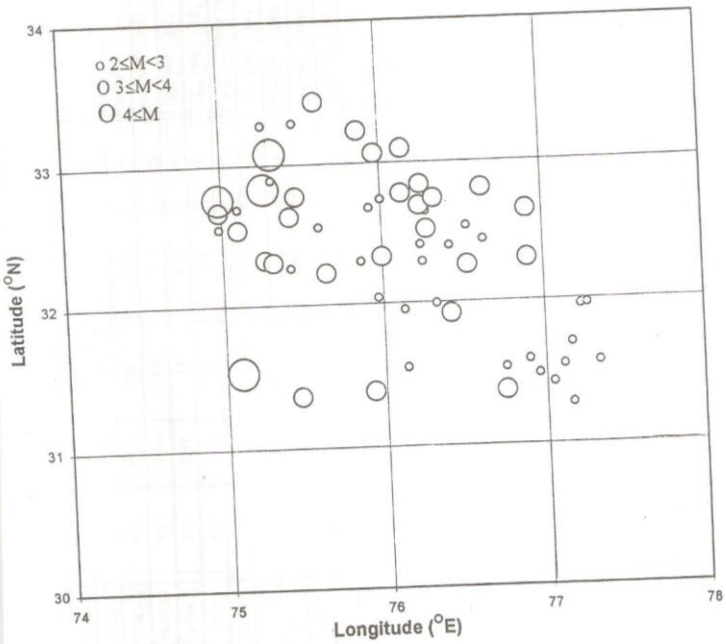

Fig. 6: Map showing seismic events correlated with radon anomalies in grid under reference (30-34°N, 74-78°E).

in soil with different meteorological parameters are summarized in Table 2. A detailed discussion about influence of meteorological variables on radon concentration is given elsewhere (Virk et al., 2000). Here our interest lies in filtering noise from the signal. The eight radon anomalies observed during December 1997-January 1998 in soil-gas at Palampur clearly established the correlation of radon with microseimic activity in NW Himalaya. These anomalies occurred when temperatures were lowest in winter, wind velocity was normal, rainfall was scanty and relative humidity was normal. The influence of meteorological variables is obvious during July-August 1999 when radon spikes are caused due to a heavy rainfall, high relative humidity, high temperatures and low wind velocity. It is estimated that the integrated effect of meteorological variables is less than 2s. As a consequence, radon anomalies due to

Table 1 : Correlation of radon anomlies recorded at Palampur(P) and Dalhousie (D) in Soil-gas(S) and Groundwater (W) with Seismic events.

S.No.	Station	Date of Event	Lat ° N	Long.° E	Magnitude of Seismic Event(M)	Depth (Kms)	Epicentral Distance (Kms)	% Variation from (Avg ± 2s)	Precursor time (Days)	Date of anomalies
1.	P_w	12-06-96	31.28	77.17	2.8	22	113	2.8	5	7th June 1996
2.	P_s, D_w	14-07-96	32.67	76.25	3.8	17	74, 33	1.1, 24.1	6 , Co	8th ,&14 thJuly 1996
3.	P_s	05-09-96	32.54	75.97	3.4	15	81	2.7	-2	7th Sept., 1996
4.	P_w	22-09-96	31.70	77.17	2.1	37	84	18.8	Co	22nd Sept., 1996
5.	$^*D_s$,D_w	03-10-96	32.55	74.98	2.6	04	110	62.9, 23.2	-1,1	4th & 2nd Oct.,1996
6.	P_s, D_s, D_w	13-10-96	32.32	76.78	3.0	03	42,93	30.7,5.4, 21.6	4, 7, 8	9th ,6th , 5th Oct., 1996
7.	D_s, D_w	13-10-96	32.30	74.85	3.0	15	127	5.4, 21.6	7, 8	6th & 5th Oct., 1996
8.	P_w, $^*D_s$	08-11-96	32.55	75.61	2.7	41.57	114,100	5.7, 36.0	4, 3	4th & 5th Nov., 1996
9.	D_s, D_w	09-12-96	32.63	75.34	3.2	53.74	71	4.8, 8.6	Co, Co	9th & 9th Dec., 1996
10.	P_w	03-02-97	31.55	77.12	2.4	23.25	88	1.7	10	24th Jan., 1997
11.	P_s	14-02-97	32.77	76.11	3.0	38.51	90	7.2	8	6th Feb., 1997
12.	D_s, D_w	08-03-97	31.36	76.27	3.7	01.88	135	3.8, 16	3, 3	5th Mar., 1997
13.	P_s	21-03-97	32.40	76.42	2.6	03.61	39	30.3	1	20th Mar., 1997
14.	P_s	28-03-97	31.95	76.13	2.8	15.00	44	43.1	2	26th Mar., 1997
15.	P_s	12-04-97	33.44	75.49	3.4	15.00	191	7.6	4	8th Apr., 1997
16.	$^*P_w$	01-05-97	31.99	76.33	2.2	15.00	21	4.6	9	22nd Apr., 1997
17.	$^*P_w$	19-05-97	32.22	74.99	3.6	39.64	169	9.2	1	18th May, 1997
18.	D_s, D_w	07-06-97	33.23	75.25	3.4	15.00	111	4.8,1.6	Co, 5	7th & 2nd June 1997
19.	D_s	14-06-97	32.76	75.25	4.2	15.00	84	0.5	1	13th June , 1997
20.	$^*D_w$	19-0797	31.39	75.34	3.2	39.85	146	8.2	4	15th July, 1997
21.	D_s	29-07-97	31.53	76.90	4.2	09.14	153	-5.8	7	22nd July, 1997
22.	P_s	07-09-97	32.30	75.87	2.8	15.00	76	-2.8	4	3rd Sept., 1997
23.	P_w	06-10-97	31.43	77.05	2.3	03.02	93	60.0	2	4th Oct., 1997
24.	D_w	25-10-97	32.68	75.93	2.5	15.00	61	0.3	3	22ndOct., 1997

25.	D_s	07-12-97 07-12-97	33.07 32.69	75.83 75.10	3.6 2.6	01.84 15.00	61 98	-7.8	-2	9th Dec., 1997
26.	P_s, D_s	19-12-97	32.33	76.33	3.3	19.11	36, 47	28.4, 1.6	3, 4	16th & 15th Dec., 1997
27.	P_s, D_w	24-12-97 25-12-97	32.41 32.04	76.24 75.97	2.5 2.2	21.83 15.00	49,61 60,33	0.2, 3.4	Co,-1 Co, 1	24th & 25th Dec., 1997
28.	D_s	08-01-98	32.29	76.25	2.8	23.29	31	15.4	6	2nd Jan.,1998
29.	P_s, D_s	29-01-98	32.78	75.77	3.3	36.45	115, 35	6.6, 6.3	3, 6	26th & 23 Jan.,1998
30.	$^*P_w$	17-02-98 18-02-98	31.57 32.75	77.34 75.47	2.4 2.5	15.00 06.00	104 139	15.2	-1 Co	18th Feb., 1998
31.	$^*P_w$	21-02-98	33.29	75.47	2.8	15.00	180	1	-2	23rd Feb., 1998
32.	D_w	24-03-98 24-03-98	32.74 32.65	76.00 76.28	2.1 2.5	29.35 33.03	23 14	7.8	1	24th Mar., 1998
33.	$^*P_w$	25-04-98	31.54	76.75	2.3	30.40	64	1	4	21st Apr., 1998
34.	$^*P_w$	18-05-98	33.10	75.73	3.0	00.65	67	-1.7	10	8th May, 1998
35.	P_s, P_w	01-07-98	32.69	75.32	3.5	19.43	150	7.8,0.6	1	30th &30th June, 1998
36.	$P_s, P_w\ ^*D_w$	05-07-98 06-07-98	32.84 32.83	75.60 75.60	3.0 4.1	12.04 13.46	133, 53 133,53	7.8,0.6, 7.0	5,5, -1 6,6, Co	30th ,30th June & 6th July, 1998
37.	D_w	31-07-98	32.52	75.37	3.6	06.19	137	8.5	4	27th July 1998
38.	$^*P_w$	15-08-98	32.44	76.63	2.4	37.15	81	4.6	4	11th Aug., 1998
39.	D_s, D_w	25-08-98	32.54	76.53	2.6	15.00	63	-2.3, 2.5	9	16th Aug., 1998
40.	$^*P_w, ^*D_s$	28-09-98	32.74	75.95	3.1	15.00	98, 22	0.5, 38.7	6, 2	22nd & 26th Sept., 1998
41.	P_s	09-10-98	31.96	77.23	2.3	15.00	80	42.4	1	8th Oct., 1998
42.	P_s	16-10-98	31.97	77.27	2.3	30.12	85	24.6	6	10th Oct., 1998
43.	$P_s, ^*P_w$	04-11-98	31.49	76.96	2.6	02.40	.81	0.1, 2.15	4,4	30th , 30th Oct , 1998
44.	D_w	18-11-98	33.26	75.65	2.9	23.19	88	11.5	1	17th Nov., 1998
45.	$^*P_s$	27-11-98	32.30	76.90	2.3	23.22	49	11.6	-1	28th Nov., 1998
46.	$^*P_s$	03-12-98	31.55	76.14	2.3	26.85	78	15.3	1	2nd Dec., 1998
47.	D_s	16-01-99	31.59	76.90	2.2	15.00	148	0.2	2	14th Jan.,1999

48.	P_w, D_s	10-02-99	31.92	75.92	3.5	15.00	67, 65	0.9, 2.0	5, 8	5th & 2nd Feb., 1999
49.	*D_s	23-02-99 24-02-99 28-02-99 28-02-99	33.08 33.28 32.26 32.89	75.57 75.27 75.43 75.32	4.8 2.8 2.5 2.5	22.48 15.00 15.00 12.37	75 113 67 81	15.7	-1 Co 4 4	24th Feb., 1999
50.	P_s	19-03-99	32.26	75.75	3.2	23.33	87	10.8	4	15th Mar., 1999
51.	P_s,P_w	29-03-99 30-03-99	30.2 32.18	79.5 76.41	6.8 3.0	15-21 15.00	393 17	2.9, 5.6	2,2 3,3	27th & 27th Mar., 1999
52.	D_w	21-05-99	31.38	76.90	3.6	06.26	165	1.5	Co	21st May, 1999
53.	P_s,P_w,D_s	27-07-99 28-07-99	32.65 32.30	76.33 76.21	3.2 3.0	46.05 23.77	68,46 42,24	2.7, 22.0, 23.4	Co,8,8 1, 9, 9	27th, 19th & 19th July 1999

P, D, S,W stands for Palampur , Dalhousie, Soil-gas , Groundwater whereas * stands for negative anomaly (i.e. radon values less than Avg-2s) and Co stands for Co-seismic event.

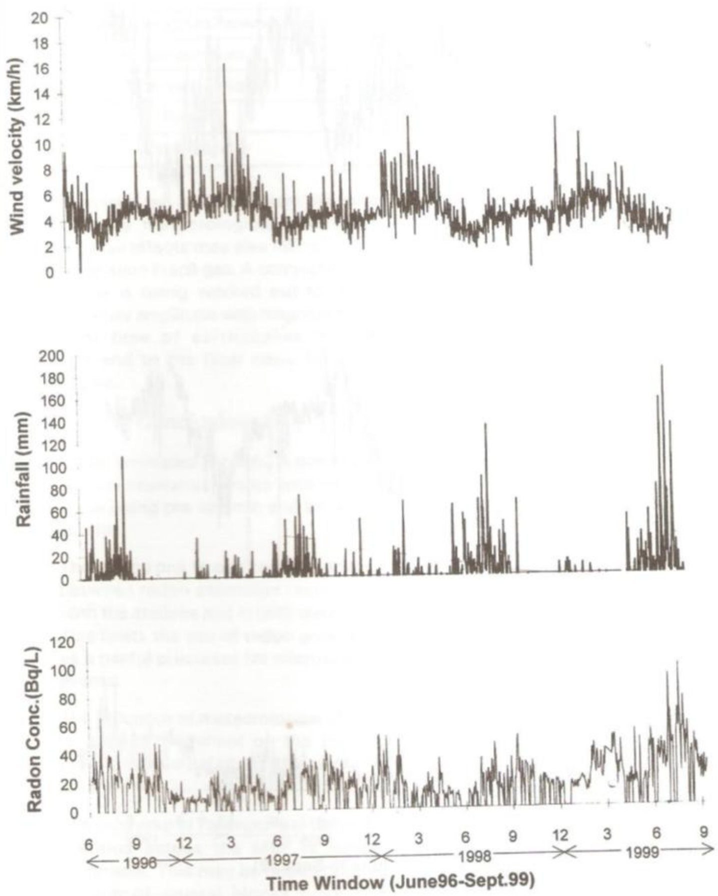

Fig. 7: Radon data plotted against Soil temperature and Relative humidity during June 1996 to Sept 1999 at Palampur.

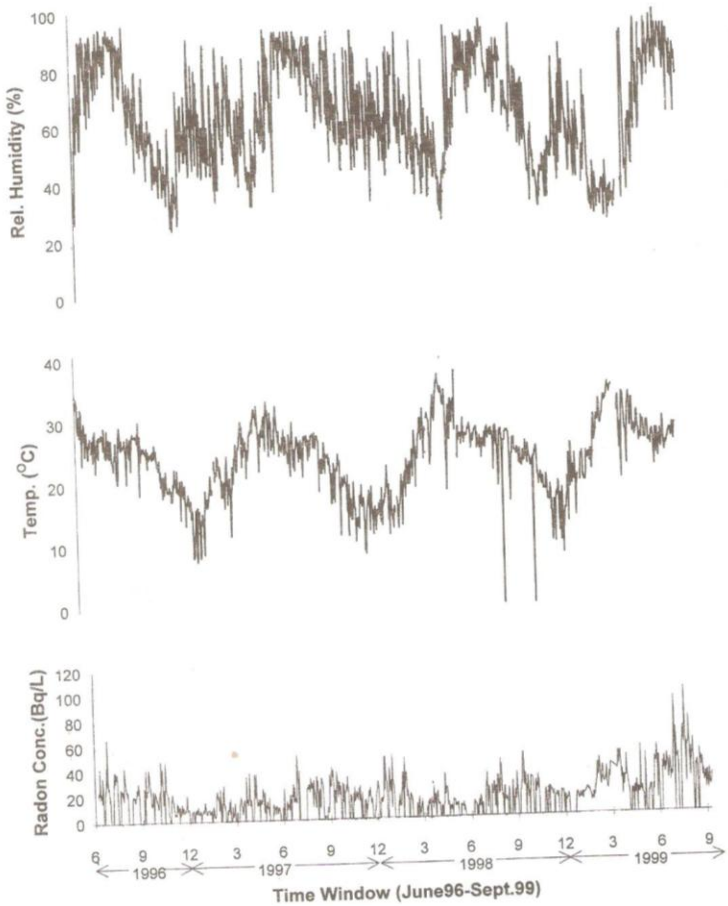

Fig. 8: Radon data plotted against Rainfall and Wind velocity during June 1996 to Sept 1999 at Palampur.

Table 2 : Correlation coefficient of radon concentration in soil-gas with different meteorological parameters at Palampur .

Meteorological Parameter	Correlation Coefficient
Temperature	0.18
Relative Humidity	0.31
Rainfall	0.19
Wind Velocity	- 0.27

microseismicity can be filtered from the noise generated by meteorological effects. In addition, tidal effects may also influence the radon emanation in soil-gas. A comprehensive programme is being worked out to relate radon anomaly amplitude with magnitude and precursor time of earthquakes in N-W Himalaya and to the filter noise from the radon signal.

Conclusions

(i) Radon anomalies show 62% correlation with microseismic events with most of these being pre-seismic and some co-seismic.

(ii) There is no one to one correspondence between radon anomalies recorded at both the stations and in both the media. This limits the use of radon anomalies as a useful precursor for microseismic events.

(iii) The Influence of meteorological effects is more predominant on the soil-gas radon as compared to the radon in groundwater.

(iv) The behaviour of Palampur and Dalhousie stations across the MBF is almost reciprocal. This may be due to relative motion of crustal blocks producing compressional strain on one side and dilatation strain on the other.

(v) The soil temperature, relative humidity and rainfall have positive correlation while wind velocity has a negative correlation with radon concentration in the soil-gas.

(vi) The high microseismicity is confined to areas along the MBT in Kangra valley, which witnessed the highest magnitude (M >8.6) earthquake recorded in India in April, 1905.

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