Research Highlights in Earth System Science.
DST's Spl. Vol.2 on "Seismicity" (*Ed.* O.P. Varma).
Published by Ind. Geol. Cong., 2001, pp. 277-288.

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Radon/Helium Studies for Earthquake Prediction and Fault Delineation in NW Himalaya

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INTRODUCTION

The rare gas emanations, especially radon and helium, have received considerable attention as geochemical precursors of impending earthquakes (Areshidze et al.,1992; Bella et al.,1995; Ranguelov et al.,1991; Mamyrin et al.,1979; UNESCO 1984; Virk 1986,95,96; Virk and Sharma, 1997; Virk and Singh, 1992, 93, 94 Virk et al., 1995; 97; Wakita 1996). The monitoring sites are generally the fault zones or any suitable area free from U/Th mineralisation to keep the noise to signal ratio low. Radon/Helium monitoring studies are quite useful for earthquake prediction research and delineation of faults. Several groups in Europe, Mexico, China and Japan are engaged in this area of research. This geochemical method may prove useful for short-term prediction of earthquakes and fault delineation in N-W Himalaya, which is seismically active zone in H.P.

Radon monitoring work was started in May 1996 using Emanometry in soil-gas and groundwater at Palampur and Dalhousie stations. Alpha logger probes were installed at four other stations, viz., Palampur (32.10°N, 76.51°E), Dalhousie (32.60°N, 76.00°E), Chamba (32.55°N, 76.10°E) and Jawalamukhi (31.87°N, 76.33°E) (Fig.1) for continuous monitoring of radon in soil gas. Under the revised project, multisensor probes for radon and helium mass spectrometers were installed in May 1997. Helium stations were set at Palampur and Manikaran to monitor helium in the thermal springs of Parbati valley and other areas of H.P. state. Discrete helium sampling at these stations yields some interesting results.

EXPERIMENTAL TECHNIQUES

The radon concentrations in soil-gas and groundwater are measured at Palampur and Dalhousie stations using emanometry based on scintillation technique. Time-series radon data is being recorded continuously at all the four stations using alpha-logger technique. Helium monitoring in soil-gas was carried out using helium leak detector at Palampur station. The detailed description of techniques used for radon and helium surveys is given below.

Radon Emanometry

An emanometry (Model RMS-10) manufactured by Atomic Minerals Division, 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 scintillation chamber using a closed - circuit technique.

In radon emanometry, the auger holes, each 60 cm in depth and 6 cm in dia., are left covered for 24 hours so that 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

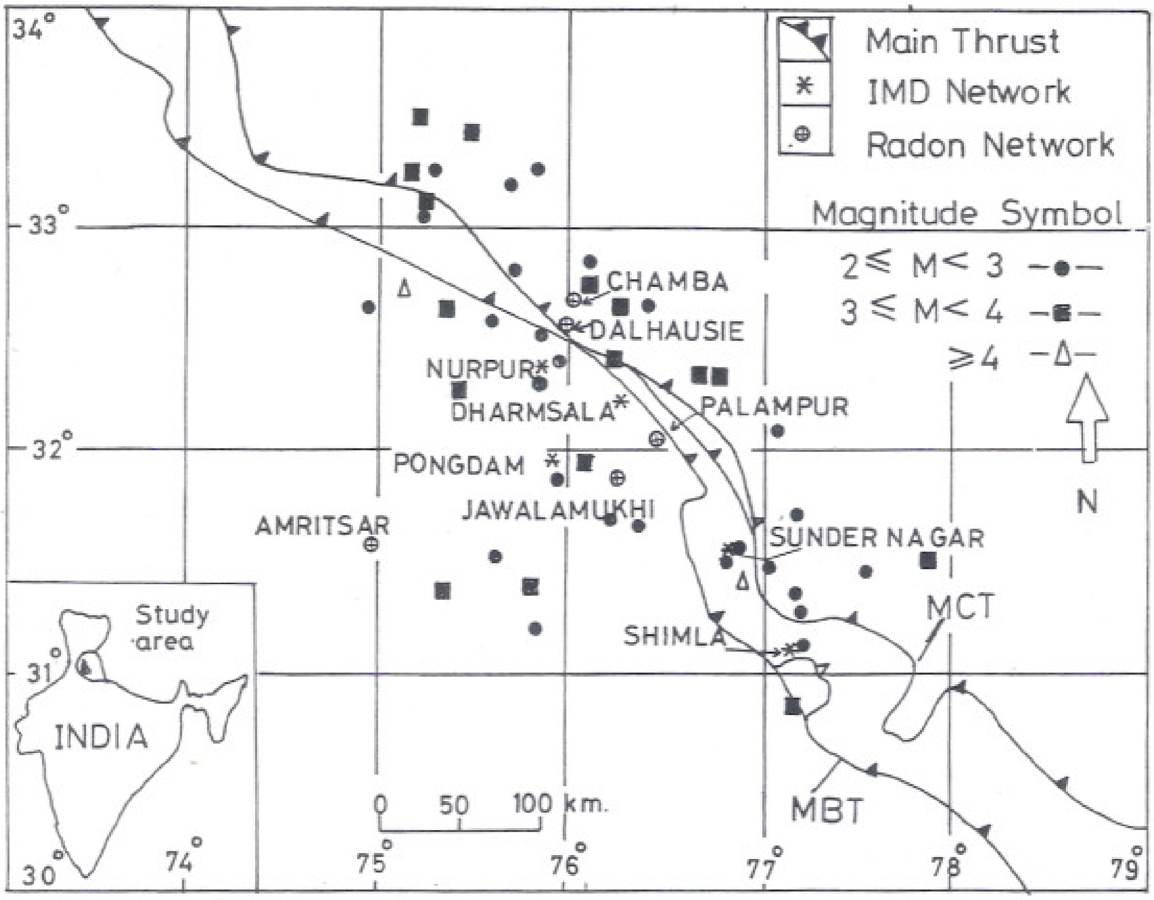

Fig.1. Map showing monitoring sites along with tectonic feature and microseismic activity in N-W Himalaya.

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.

Alpha-Logger Technique

Alpha-logger probe (manufactured by Alpha Nuclear Company in Toronto, Canada) is a portable, battery-powered, microprocessor based data acquisition and control system. The unit is designed to measure near surface radon gas fluctuation over relatively short intervals of time. It consists of a silicon-diffused junction diode for the detection of alpha particles and can record radon alpha counts in 15 minutes increments over a period of 40 days non-stop. The detector is placed inside a covered auger hole about 60 cm in depth. The detector is separated from the soil surface at the bottom of the hole by a 6.4 cm gap and the air in the gap shields the detector from the impact of the alpha particles emanated by radon and their isotopes. 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 minute counting intervals for better counting statistics.

Helium Monitoring

Helium leak detector ASM 100 HDS (Alcatel, France) using sniffing technique is used for hêlium analysis in soil-gas at Palampur and in thermal springs at Manikaran. It comprises of a helium gas analyser with a pumping system.

The main component of helium leak detector is a spectro-cell which acts as a mass spectrometer. The helium ion analysis is based on the partial pressure of helium in the system which is calibrated to yield helium concentration in ppm. The helium is estimated in soil-gas by sniffing techniqu. Thermal spring water samples were collected in air tight bottles (100cm3) and kept indoor for a period of one month to get helium accumulation. A closed circuit technique is followed to estimate helium in the collected samples using two hypodermic syringes, air tight bottle containing silica gel and the helium leak detector. The test value of helium is displayed on the calibrated logarithmic scale showing the value in ppm as well as in terms of voltage. The whole operation is fully automatic and it can measure the helium concentration from 0.1 ppm to 100% helium.

Alpha Scintillometry Technique

Water samples were collected from the thermal springs along the Parbati river at Manikaran and Kasol. Alpha Scintillometer GBH 2002 (GBH Electronic) with Lucas cell assembly was used to record alpha counts from one litre of spring water over an interval of 10 minutes. Radon gas emanated from radium present in the thermal waters was sucked by a pump connected to a radon bubbler. The electronic digital counter records the alpha counts and the radon activity is measured by using the calibration constant (10 counts = 1Bq/L).

Alpha Guard Technique

Alpha Guard PQ-2000 PRO (Genitron Instruments, Germany) based on pulse ionisation technique was employed for radon activity measurements in soil - gas. The special soil-gas unit consists of an Alpha Guard, Alpha pump and a modified STITZ soil-gas probe connected in series. The main advantage of the Alpha Guard are its fast response, higher sensitivity and a wide dynamic range which is linear over the interval 2-2 x 106 Bq/m3. It is a multi-sensor unit which can measure temperature, pressure and humidity simultaneoûsly along with radon.

RESULTS AND DISCUSSION

The results of radon monitoring in soil-gas and groundwater at Palampur & Dalhousie as well as alpha logger radon data in soil-gas for four stations are summarized in Table 1. Some of the radon anomalies are correlated with microseismic events recorded by network in the time window June 1996 and Sept.1997 (Fig.2-9). Helium monitoring at Palampur in soil-gas is used for interpretation of Sundernagar event of 4.2 M which occurred on 29th July,1997 in Himachal Pradesh at a distance of about 100 km.

Helium/Radon ratio in the soil gas and groundwater can be used as a predictive tool for earthquake monitoring. This hypothesis was tested during the occurrence of Sundernagar earthquake of 4.2M and two aftershocks of 2.2M and 3.2M as shown in Fig.10. The curve shows that helium/radon ratio first rises sharply and then has an equally sharp fall on 28th July, a day before the occurrence of main shock at Sundernagar.

In general, the micro-seismicity is showing a rising trend as evidenced from a comparative study of seismic and radon data monitored in Kangra and Chamba valleys (Fig.11). The total number of events recorded by IMD network during 1996 and 1997 in the grid (30-34^{0}N, 74 - 78^{0}E) is 83 and 85, respectively, with almost a three fold increase in the microseismic events (27) recorded during 1992. Hence, the Kangra and Chamba valleys in N-W Himalaya are experiencing build up of strain along the major thrust faults during the recent years. It is imperative to monitor radon, helium and other geochemical precursors in the region over a wider network to investigate further the micro-seismicity trends in N-W Himalaya.

Table 1. Microseismic Eventsw correlated with Radon Anomalies in soil-gas and groundwater at different stations.

S. No.	Radon Station	Date of Event	Latitude (°N)	Longitude (°E)	Magnitude	Depth (km)	Distance (km)	Date of Anomalies
1.	P^s	12-06-96	31.28	77.17	2.8	22	112	10th June, 1996
2.	P^s	19-06-96	33.02	75.25	2.2	24	174	15th June, 1996
3.	P^s	23-06-96	31.12	77.17	2.1	15	126	23rd June, 1996
4.	P^sD^w	14-07-96	32.67	76.24	3.8	17	73,33	13th & 14th July, 1996
5.	D^s	03-08-96	33.23	75.28	2.4	15	107	Ist Aug., 1996
6.	C	14-08-96	32.06	77.06	2.6	15	134	12th Aug., 1996
7.	D^s, C,J	17-08-96	33.52	75.22	3.5	06	136,124,219	14th, 17th & 18th Aug., 1996
8.	D^s	04-09-96	31.51	75.62	2.3	34	119	31st Aug., 1996
9.	P^s,D^s,D^w	05-09-96	32.54	75.97	3.4	15	80, 00	7th, 6th & 7th Sept., 1996
10.	D^s	13-09-96	33.11	75.28	3.3	03	98	10th Sept., 1996
11.	P^w	18-09-96	31.55	75.90	2.1	15	71	19th Sept., 1996
12.	P^w,C	23-09-96	31.12	77.17	2.2	15	126, 170	22nd & 22nd Sept., 1996
13.	C	03-10-96	32.8	74.98	2.6	04	125	29th Sept., 1996
14.	P^w,D^w,J	09-10-96	31.20	75.38	2.7	04	121, 40, 92	8th, 5th & 5th Oct., 1996
15.	P^s,P^w	13-10-96	32.32	76.78	3.0	03	41	9th & 11th Oct., 1996
16.	P^w	08-11-96	32.55	75.61	2.7	42	113	8th Nov., 1996
17.	P^w	19-11-96	32.69	75.42	3.2	03	123	18th Nov., 1996
18.	D	28-11-96	31.79	75.86	3.1	15	83	28th Nov., 1996
19.	P^w,D^w,D,J	09-12-96	32.63	75.34	3.2	54	143, 17, 137	7th, 9th, 10th, & 10th Dec., 1996
20.	D	16-12-96	33.25	75.84	3.1	15	79	17th Dec., 1996
21.	J	30-12-96	32.30	76.68	3.6	19	61	20th Dec., 1996
22.	J	02-01-97	30.83	77.17	3.0	15	147	31st Dec., 1996
23.	P^s	07-02-97	31.09	76.64	7.2	03	100	6th Feb., 1997
24.	C	14-02-97	32.77	76.11	3.0	39	05	11th Feb., 1997
25.	C	20-02-97	32.54	75.87	2.5	49	39	18th Feb., 1997
26.	D^w,D	08-03-97	31.36	76.27	3.7	02	133	5th & 6th Mar., 1997
27.	D	14-03-97	31.40	75.86	3.1	15	126	12th Mar., 1997
28.	P^s	22-03-97	31.46	76.97	2.6	11	84	20th Mar., 1997
29.	P^s	28-03-97	31.95	76.12	2.8	15	44	26th Mar., 1997
30.	P^s,C	03-04-97	32.80	75.72	2.8	53.	119	5th Apr. & 31st Mar., 1997
31.	D^w	12-04-97	33.44	75.49	3.4	01	112	19th Apr., 1997
32.	D^w,D	17-04-97	31.33	77.17	2.4	25	187	16th & 16th Apr., 1997
33.	C	01-05-97	32.61	76.42	2.1	44	42	1st May, 1997
34.	C	26-05-97	31.67	76.38	2.1	19	129	26th May, 1997
35.	D^s,D^w,P	07-06-97	33.23	75.24	3.4	15	111, 189	7th, 3rd & 7th June. 1997
36.	D^s,D^w,J	14-06-97	32.76	75.25	4.2	15	83, 154	13th June, 1997*
37.	P^s,P^w,D^s,D^w,D	26-06-97	32.77	76.10	2.2	20	90, 29	28th, 27th, 25th, 25th, & 27th June, 1997
38.	D^s	19-07-97	31.39	75.34	3.2	40	144	18th July, 1997
39.	P^s,P^w,D^s,P,J	29-07-97	31.53	76.90	4.2	09	72, 151, 73	29th, 28th, 28th, 29th & 25th July, 1997
40.	P^w,J	31-07-97	31.55	77.02	2.2	15	79, 84	30th July & 1st Aug., 1997
41.	J	10-08-97	31.48	77.02	2.7	11	138	6th Aug., 1997
42.	P^s,P^w,J	13-08-97	31.55	76.94	3.2	11	73, 76	13th, 12th & 12th Aug., 1997
43.	D^w,D	14-08-97	33.18	75.70	2.2	01	76	12th & 11th Aug., 1997
44.	P^s,P^w	07-09-97	32.30	75.87	2.8	15	75	15th & 3rd Sept., 1997
45.	J	10-09-97	32.40	75.97	2.3	15	70	10th Sept., 1997
46.	P^s,D^s,P,J	13-09-97	31.70	76.20	2.5	15	52, 96, 24	12th, 12th, 11th & 13th Sept., 1997
47.	P^s,P	17-09-97	31.53	76.90	2.1	11	72	17th & 15th Sept., 1997
48.	P^s,P^w,D^w,P,J	23-09-97	31.84	75.97	2.2	15	64, 77, 40	24th, 19th, 25th 20th & 21st Sept., 1997

P^s,P^w,D^s, & D^w stand for emanometry data recorded at Palampur and Dalhousie stations (s for soil-gas and w for groundwater)
P,D,C & J stand for alpha-logger data recorded at Palampur, Dalhausie, Chamba and Jawalamukhi
* Anomalies on same date at all station.

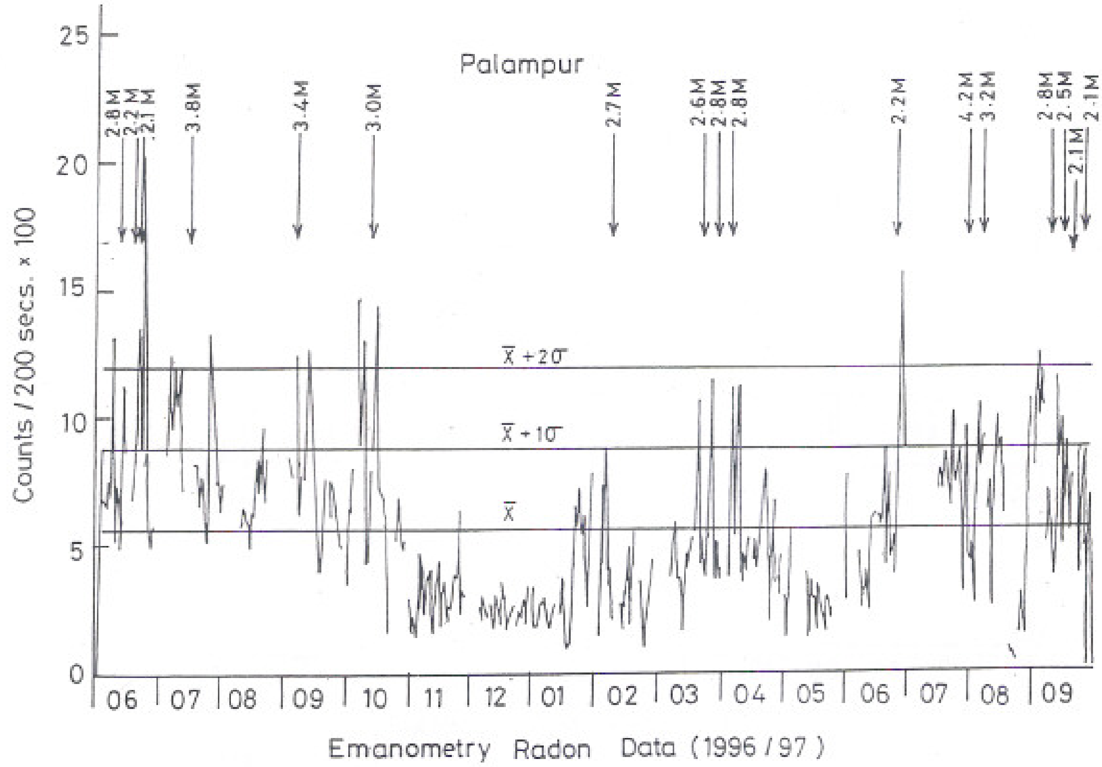

Fig.2. Radon activity recorded in soil-gas at Palampur using emanometer.

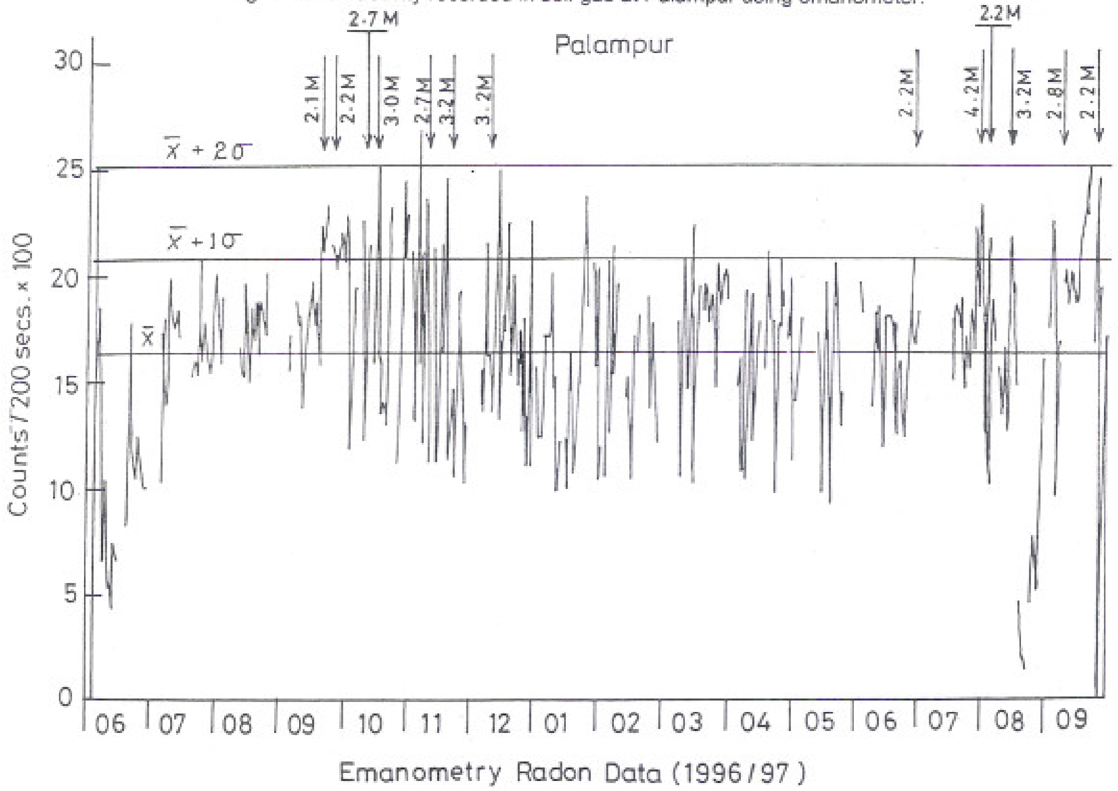

Fig.3. Radon activity recorded in groundwater at Palampur using emanometer.

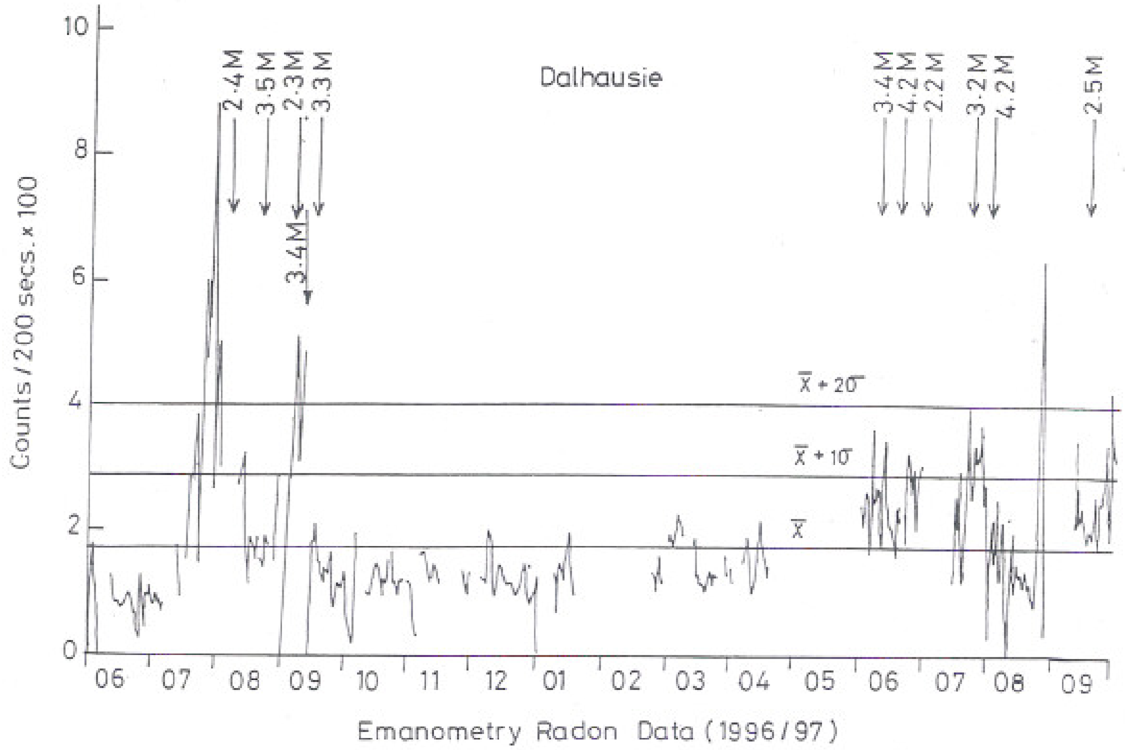

Fig.4. Radon activity recorded in soil-gas at Dalhousie using emanometer.

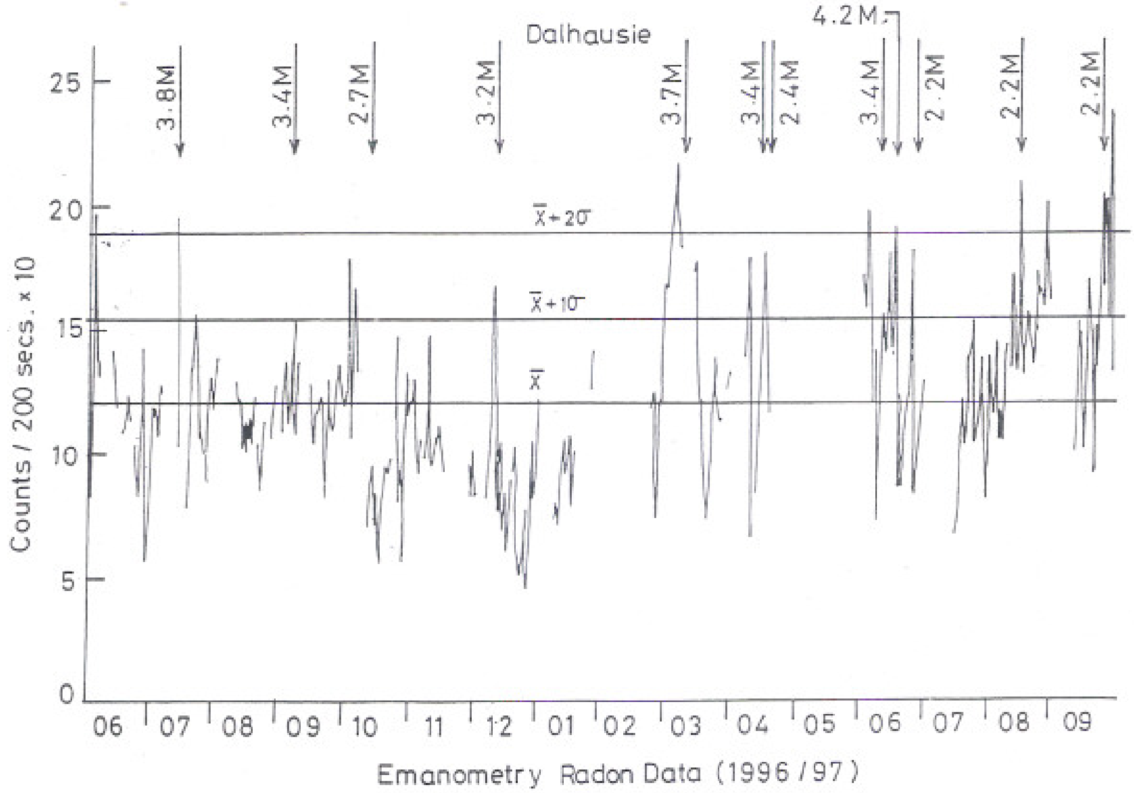

Fig.5. Radon activity recorded in groundwater at Dalhousie using emanometer.

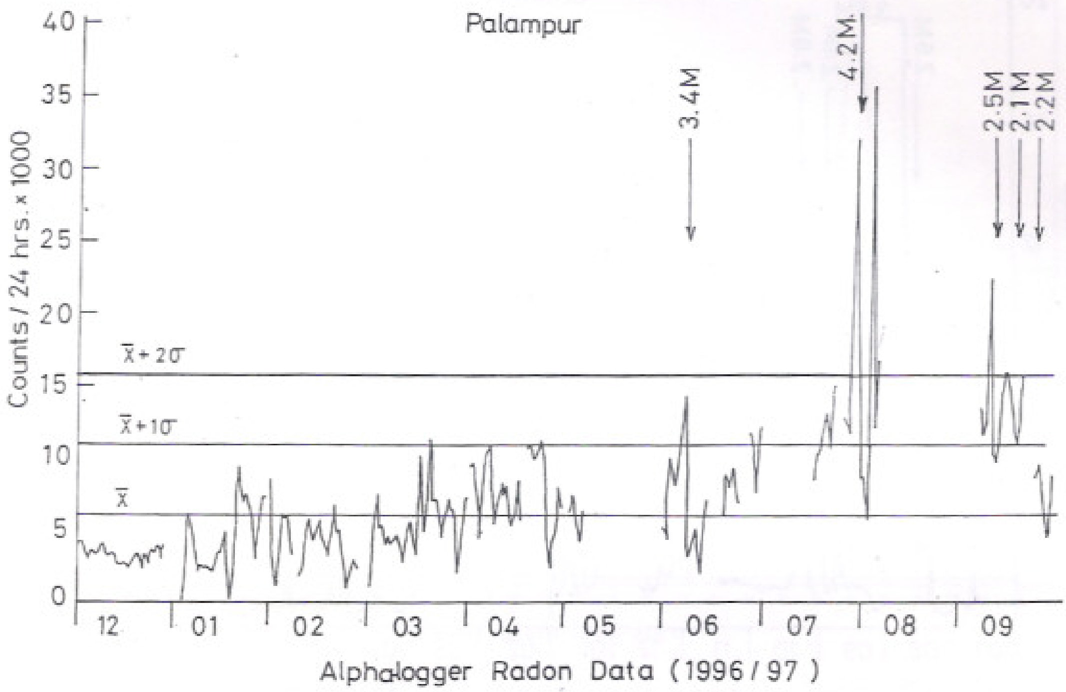

Fig.6. Radon activity recorded in soil-gas at Palampur using Alpha-logger.

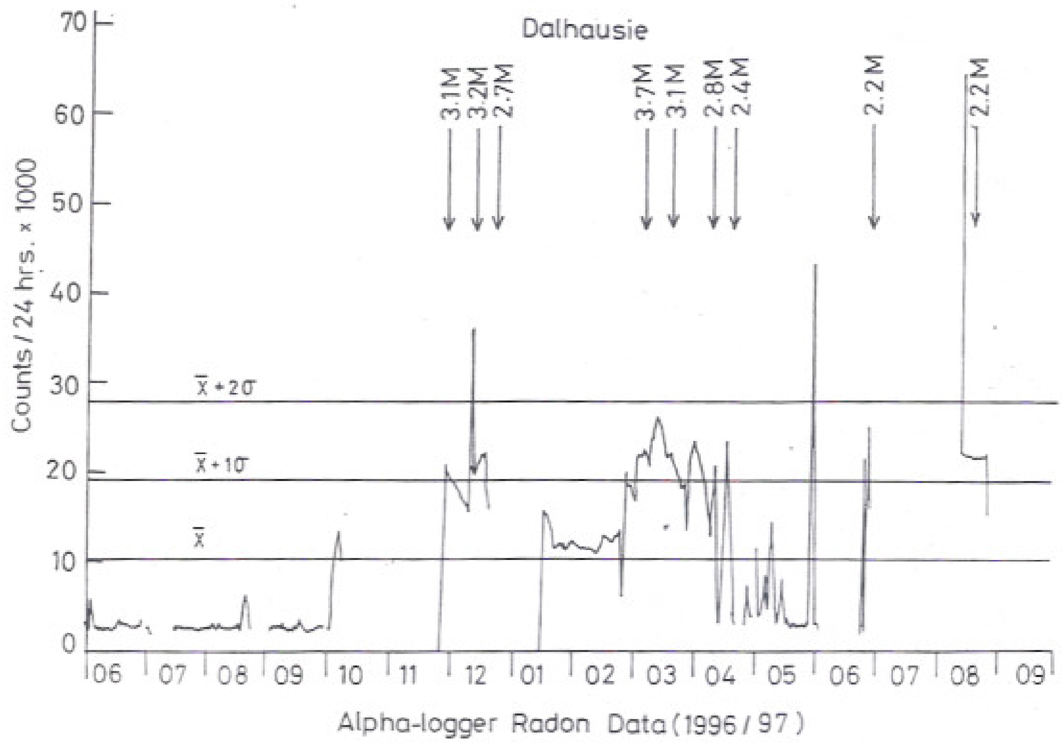

Fig.7. Radon activity recorded in soil-gas at Dalhousie using Alpha-logger.

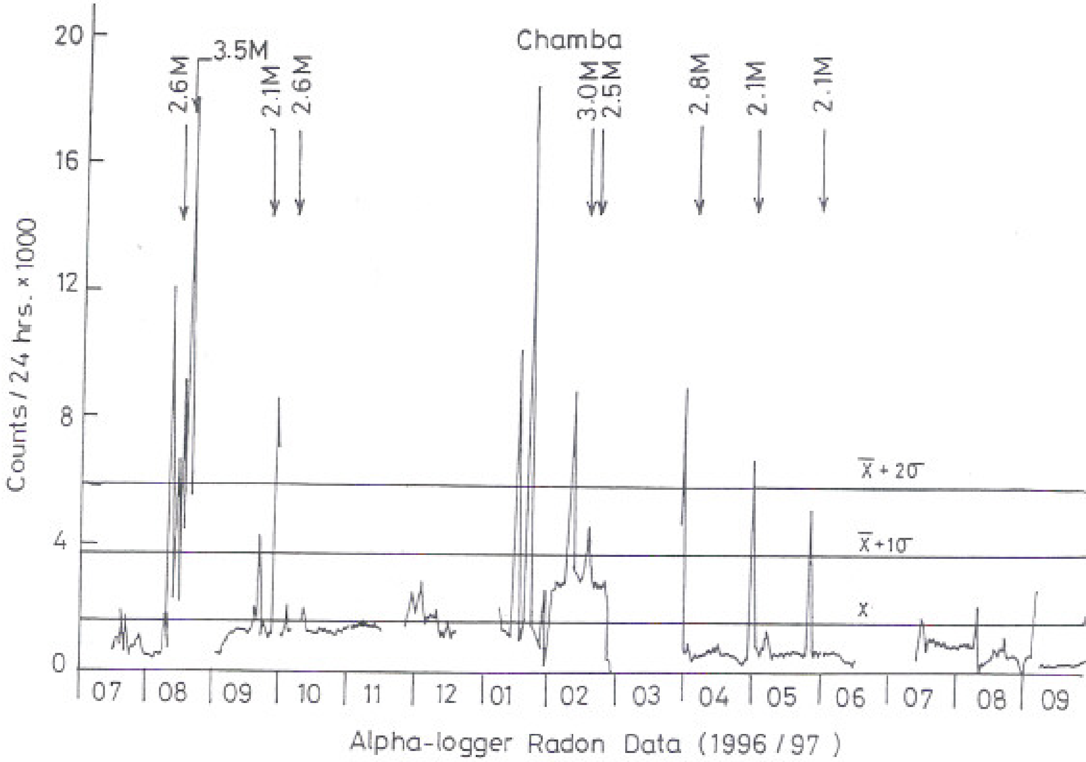

Fig.8. Radon activity recorded in soil-gas at Chamba using Alpha-logger.

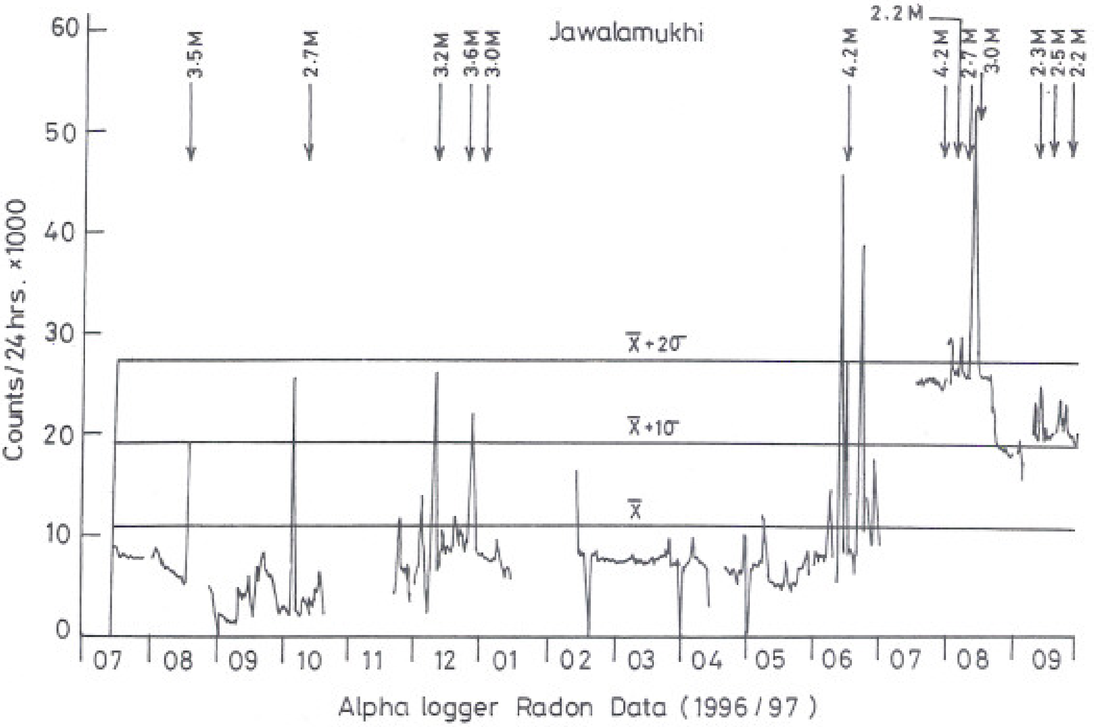

Fig.9. Radon activity recorded in soil-gas at Jawalamukhi using Alpha-logger.

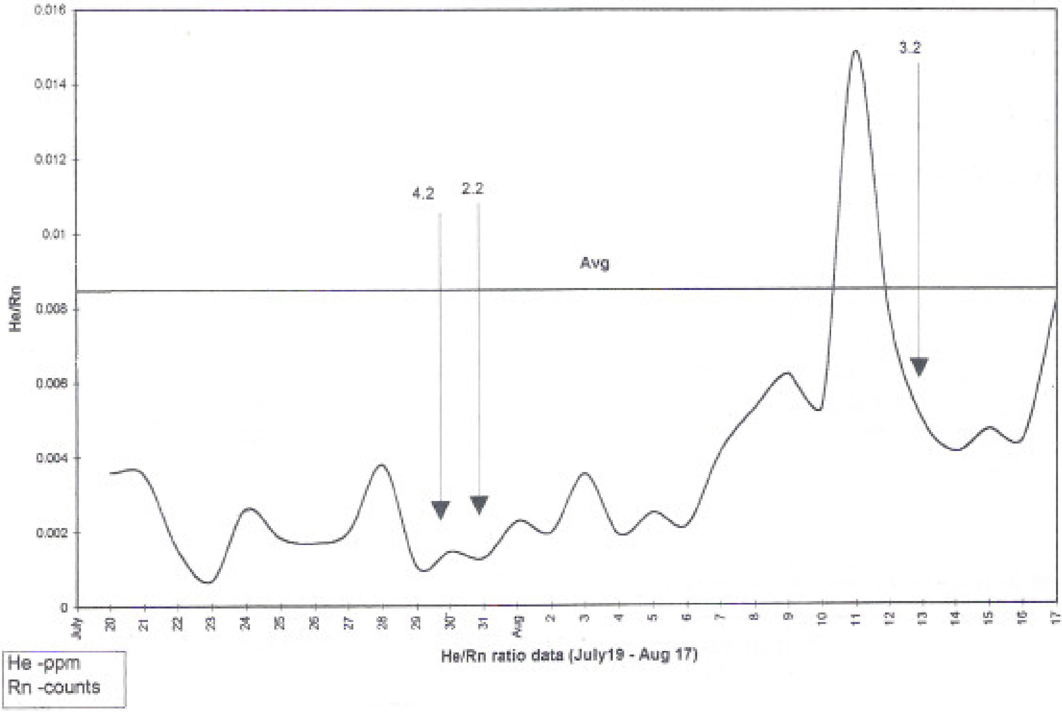

Fig.10. A profile of helium/radon ratio in soil-gas at Palampur (July 19 - Aug. 17, 1997).

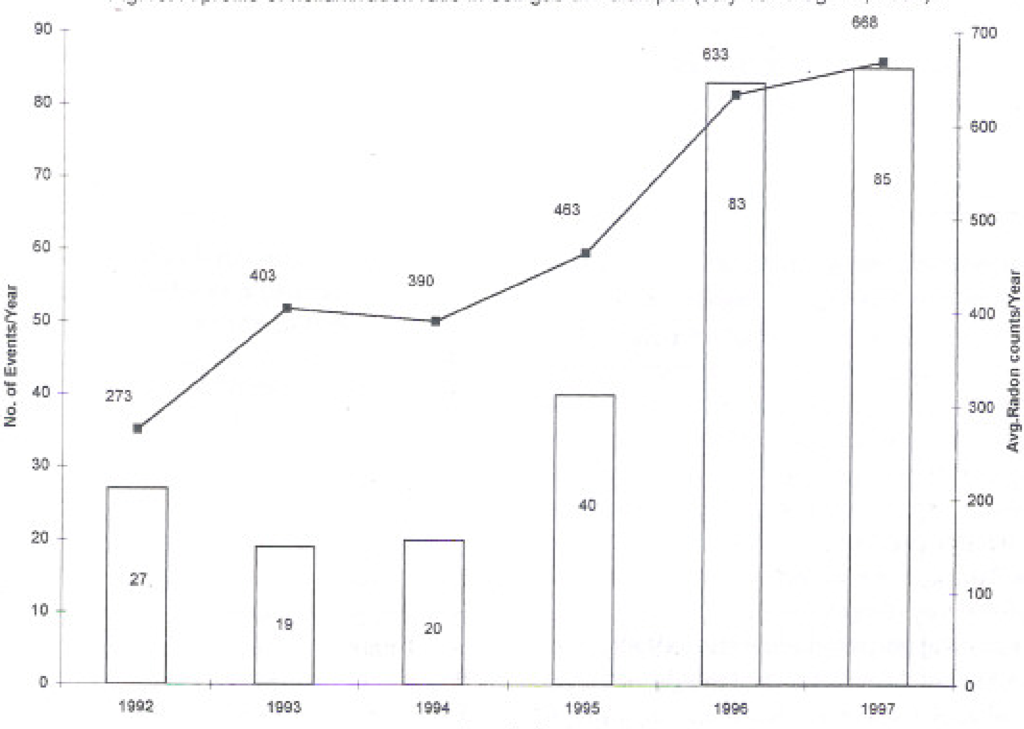

Fig.11. Microseismic trend in the grid (30-34°N, 74-78°E) during 1992-1997 based on Radon and IMD network data.

Radon survey results of spring water and soil-gas in the Parbati valley are reported in Tables 2&3, respectively. High radon content is correlatable to high radium and uranium concentration in the environs of Parabati valley as reported by Virk (1997). Helium contents of eight thermal springs are reported in Table 4. A maximum value of 90 ppm is recorded in thermal spring (No.3) at Kasol near Manikaran. The helium concentration varies from 15ppm to 90 ppm in thermal springs. Helium content of Manikaran springs in the vapour phase was estimated to be 100ppm and the highest value in the Rampur borehole was reported to be 2.1% by GSI survey (Singh, 1989).

Meteorological parameters like temperature, pressure, wind velocity, rainfall and humidity also affect the radon emanation rate from the soil-gas to some extent. However, their effect is observed to be negligible in water media. Correlation co-efficients of radon emanation in soil with different meteorological parameters for both the techniques are summarized in Tables 5 & 6.

Table 2. Radon survey of spring water in the Parbati valley using Scintillometry.

Sr. No.	Place	Spring	Radon value (Bq/L)	Temperature (°C)	Pressure (mbar)	Rel. Humidity (%)
1.	Kasol	Thermal 1	371.9	90	846	46
2.	Kasol	Thermal 2	518.1	91	846	53
3.	Kasol	Thermal 3	716.3	91	846	68
4.	Kasol	River water	52.4	12	846	53
5.	Baradha	Bauli 1	34.2	24	835	52
6.	Takrer	Bauli 2	15.9	19	838	85

Table 3. Radon survey using Alpha Guard in the soil-gas in the environs of Parbati.

Sr. No.	Place	Radon value (Bq/m^3)	Temperature (°C)	Presure (mbar)	Rel. Humidity (%)
1.	Chhinjra	2230 ± 430	31	864	67
2.	Jaan	13300 ± 695	29	875	54
3.	Bradha	19600 ± 481	18	838	84
4.	Kasol	19500 ± 950	29	845	46
5.	Takrer	19400 ± 1060	19	838	85
6.	Dharmaur	57700 ± 2050	17	834	91

Table 4. Helium analysis in the thermal springs of Parbati, Beas and Sutlej valleys.

Sr. No.	Place	Spring code	Spring Temp. (°C)	^4H content (ppm)
1.	Manikaran	MK1	94.4	50
2.	Brahm Ganga	MK2	94.4	30
3.	Tegri	MK4	40.4	15
4.	Kasol	KL1	92.2	60
5.	Kasol	KL2	92.3	70
6.	Kasol	KL3	91.2	90
7.	Tauk	TK1	60.5	50
8.	Tatta Pani	TP1	96.4	20

Table 5. Statistical analysis of Correlation coefficient of radon data (emanometry soil gas) with different meteorological parameters of Palampur.

Parameter	Avg.	Std. dev.	Percentage variation. coefficient (C%) Std/Avg.	Correlation coefficient
Radon (counts/200secs)	563	315	1.79	--
Temperature (^{0}C)	24.43	4.90	4.99	0.37
Rainfall (mm)	4.95	11.32	0.44	0.20
Relative humidity (%)	64.72	18.79	3.44	0.45
Wind velocity (km/h)	4.75	1.57	3.02	-0.21

Table 6. Statistical analysis of correlation coefficient of radon data (alphalogger) with different meteorological parameters at Palampur.

Parameter	Avg.	Std. dev.	Percentage variation. coefficient (C%) Std/Avg.	Correlation coefficient
Radon (counts/24h)	6104	1865	3.28	--
Temperature (^{0}C)	24.43	4.90	4.99	0.47
Rainfall (mm)	4.95	11.32	0.44	0.15
Relative humidity (%)	64.72	18.79	3.44	0.52
Wind velocity (km/h)	4.75	1.57	3.02	-0.12

CONCLUSIONS

(1) Most of the radon anomalies correlatable with seismic events are precursory or co-seismic but some of them follow the events.

(2) The total number of 48 seismic events out of 78 are correlated with the observed radon anomalies recorded using both emanometry and alpha-logger techniques during the time window June 1996 to Sept. 1997 in the grid (30-34^{0}N, 74-78^{0}E).

(3) The radon transport phenomenon in soil-gas and groundwater is entirely different, as observed by the radon emanation in both the media. There is no one to one correspondence in radon anomalies recorded in groundwater and soil-gas.

(4) The helium concentration varies from 15ppm to 90ppm in thermal springs of Parbati valley. Helium/Radon ratio may be used as a precursor for future investigations as indicated by the correlation with an isolated event recorded at Sundernagar on 29th July, 1997.

(5) Micro-seismicity shows a rising trend in the grid under reference (30-34^{0}N, 74-78^{0}E) during the time window 1992-1997 as evidenced from seismic data recorded by IMD network in Kangra and Chamba valleys. This correlates with radon emanation.

(6) The net effect of meteorological changes on radon emanation from the soil is of the order of 10-20% only. However, the meteorological effect on radon emanation from water is negligible.

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