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MICROEISMICITY TRENDS IN N-W HIMALAYA USING RADON SIGNALS

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Microseismicity trends in N-W Himalaya using radon signals

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Radon monitoring work in soil-gas and groundwater was started during 1989 at Palampur in Kangra valley, Himachal Pradesh in N-W Himalaya using emanometry and track-etch techniques. It was observed that the time series radon data in both the media show a similar trend. Radon anomalies are correlatable with some of the microseismic events that occurred in the region (31-33°N, 75-77°E). Under Himalayan Seismicity Programme of Department of Science and Technology (DST), Govt of India, five more stations were set up during 1992 in Kangra and Chamba valleys (H.P) using alpha logger probes for real time continuous monitoring of radon in soil-gas. Radon emanometry data in soil gas and groundwater were also collected at Palampur and Dalhousie stations uptil July 1995. The analysis of radon data over the past six years has revealed some interesting trends in microseismicity pattern of N-W Himalaya.

Introduction

Before occurrence of earthquakes, radon anomalies were observed quite often in soil and groundwater or spring water (e.g., Tashkent earthquake, *Ulomov* and *Mavashev*, 1967). These anomalous changes have been considered to be one of the plausible precursory earthquake phenomenon and can be used for earthquake prediction research. However, the way to do so is still not very clear because of a number of unsolved problems. It is not always that an earthquake is preceded by a radon anomaly and not every radon anomaly is followed by an earthquake. Sometimes the distance between the place of manifestation of radon anomaly and the future epicentre can reach several hundreds of kms. It is evident that radon with its relatively short half life of 3.83 days can not migrate over hundreds of kms. Therefore a forthcoming earthquake must influence the area of the observed aquifer even upto such distances. Only small changes in stress distribution can be assumed to occur so far away from a future epicentre. Thus anomalies can only be recorded in areas which are extremely sensitive to very small changes in stress and therefore they may not be very specific for forthcoming earthquakes. Any other tectonic or non-tectonic effect may also influence the very unstable situation which is responsible for radon anomalies. Especially every phenomenon which causes even tiny changes in the stress may produce anomalies or atleast fluctuations in the observed radon anomalies. These fluctuations are critically analysed as a function of both meteorological variables and subsoil changes (*Steele et al.*,1982;*Singh et al.*,1988a). Recent reports dealing with the measurement of radon concentration in soil-gas and groundwater indicate that anomalous radon emanations occurred prior to several moderate to large earthquakes (*Birchard* and *Libby*, 1980; *Fleischer* and *Mogro- Campero*, 1979; *King* 1978, 1980, 1984/85; *Steele*, 1984/85; *Liu et al.*,1984/85; *Teng et al.*,1981; *Singh et al.*,1988b; *Ramola et al.*,1990; *Papastefanou et al.*,1989; *Virk* and *Singh* 1992, 1993). Laboratory studies have shown that in rocks undergoing stress, microfracture occurs, radon can be exhaled through these channels giving rise to an anomalous behaviour in exhalation pattern (*Group of Hydrochemistry*, 1977).

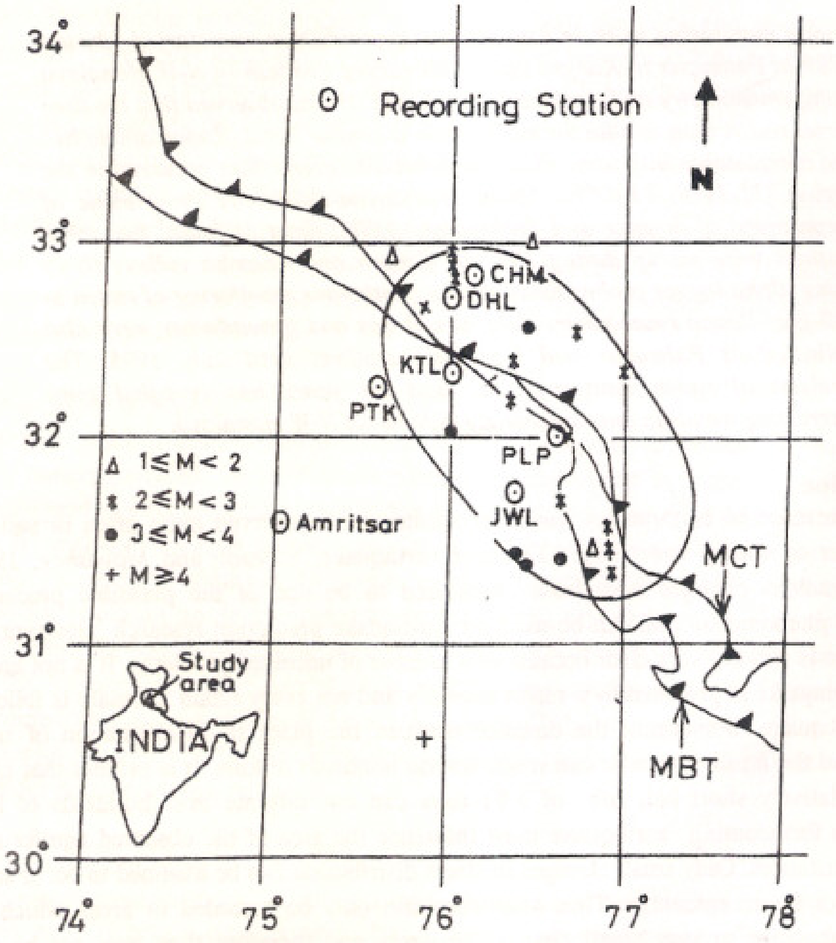


Fig.1 Map showing radon recording stations, tectonic features and the location of the epicentres of earthquakes of magnitude 1.7 to 4.5 recorded by IMD correlated with the radon anomalies occurring at Palampur.

Radon concentration in soil-gas and groundwater has been monitored at Palampur and Dalhousie stations using emanometry and alphalogger technique is used for monitoring radon continuously in soil-gas at Palampur, Jawalamukhi, Kotla, Pathankot, Dalhousie and Chamba stations (Fig. 1) along the Main Boundary Fault. As a result, various radon anomalies associated with earthquakes have been observed (*Virk*, 1995; *Virk et al.*, 1995, 1997). These observations show a definite yearly pattern .

The origin and mechanism of observed radon anomalies and their relationship to earthquakes is yet poorly understood, although several constraints from laboratory experiments have been described (*Thorsteinsson*, 1973; *Andrews*, 1977; *Dobrovolsky et al.*,1979; *Anderson* and *Grew*, 1977; and *King*, 1978,1980). The origin of radon anomalies is the most uncertain phenomenon. Laboratory studies of radon emanation from rocks, as a function of particle size of the rock, have been carried out by Andrews (1977). He reported that the radon release is inversely proportional to the square root of the particle diameter. Recoil of radon into crystal imperfections or grain boundaries which allow fast diffusion into water filled cracks and pores, can account for this result.The ratio of the radon emanated into the water to the radon generated in the rock is a complicated function of the radium distribution, crystal imperfections, grain boundaries, rock structure and the applied stress field *Anderson* and *Grew* (1977) 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.

King (1978) proposed the 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. We may expect to see influences on the radon concentration from vadose water, from environmental parameters like precipitation and temperature, from artificial disturbances of the aquifer like drilling or pumping, and of course from tectonic and tidal effects which will not culminate in earthquakes. This explains why sometimes anomalies are observed which are not followed by earthquakes.

Radon monitoring techniques

(a) Radon emanometry

The radon concentration in soil-gas and groundwater is monitored by using instantaneous and continuous monitoring techniques. An emanometer (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 (*Ghosh* and *Bhalla*, 1966). This technique gives us instant value of alpha particles emitted by radon and is highly suitable for quick radon survey.

In radon emanometry, the augur 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 augur hole and forms an air-tight compartment. The rubber pump, soil-gas probe and alpha detector are connected in a close-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 the 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 scaler-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 sample bottle (250 ml). 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 equilibrium between radon and its daughters is established.

(b) 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 fluctuations 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 minute increments over a period of 40 days non-stop. The detector 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 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.

Radon monitoring results

Diurnal radon concentrations in soil-gas and groundwater were monitored regularly at Palampur and Dalhousie stations since 1992 using radon emanometry. Results from the analysis of emanometry data from February 1992 to July 1995 are summarized in Tables 1 and 2. The trends of radon concentration variations at Palampur and Dalhousie are shown

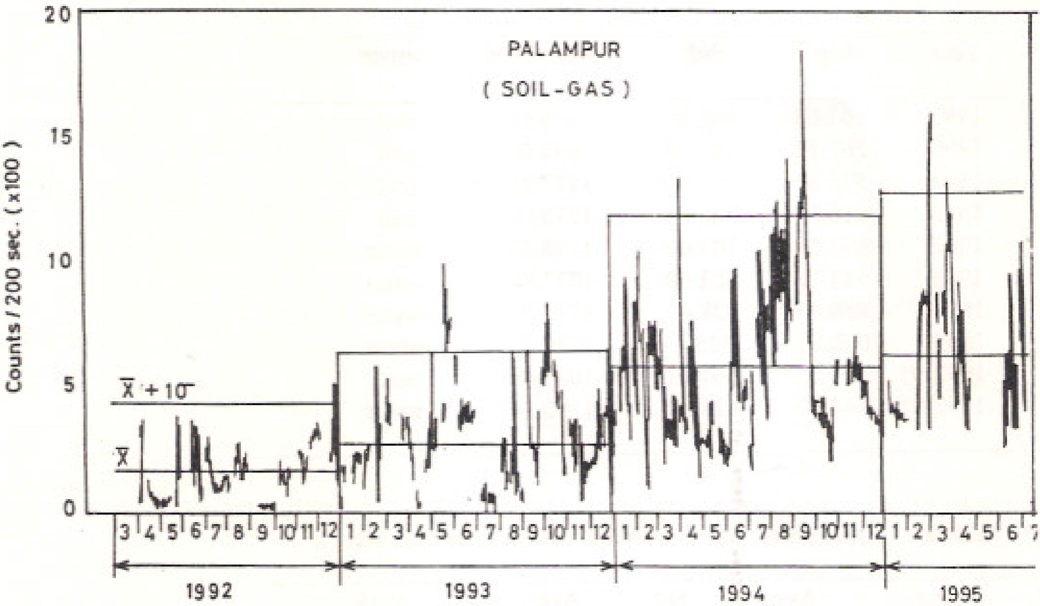
Table 1. Emanometry data reported from Palampur station

Year	Avg	Std	Avg+2Std	mode
1992	163.08	102.85	429.01	soil
1993	267.18	185.54	638.26	soil
1994	572.91	302.69	1177.29	soil
1995	616.88	326.64	1270.16	soil
1992	632.38	283.00	1198.38	water
1993	913.72	482.08	1877.88	water
1994	858.45	428.47	1715.39	water
1995	1070.07	328.10	1726.27	water
1992-95	415.24	301.02	1017.48	soil
1992-95	844.60	428.87	1702.34	water

Table 2. Emanometry data reported from Dalhousie station

Year	Avg	Std	Avg+2Std	mode
1992	207.43	174.73	556.89	soil
1993	195.38	113.18	421.74	soil
1994	55.98	29.72	85.70	soil
1995	70.34	44.43	159.20	soil
1992	88.08	60.87	209.82	water
1993	158.21	83.50	325.21	water
1994	77.79	33.30	144.39	water
1995	72.38	44.70	161.78	water
1992-95	121.08	115.97	353.02	soil
1992-95	104.7	64.10	232.97	water

in Figures 2 and 3, respectively. The yearly average radon concentrations in terms of alpha counts/200s in soil at Palampur from 1992-95 were 163.08, 267.18, 572.91 and 616.88, with standard deviations of 102.85, 185.54, 302.69 and 326.64, respectively. The corresponding values in water were 632.38, 913.72, 858.45 and 1070.07, with standard deviations of 283, 482, 428.47 and 328.10, respectively for the same period. The overall average values of radon concentration for the period under investigation in soil and groundwater have been found to be 415.24 and 844.60 with standard deviations of 301 and 428.87, respectively. Similarly for Dalhousie station average values of radon concentration in soil were 207.43, 195.38. 55.98 and 70.34 with standard deviations of 174.73, 113.38,



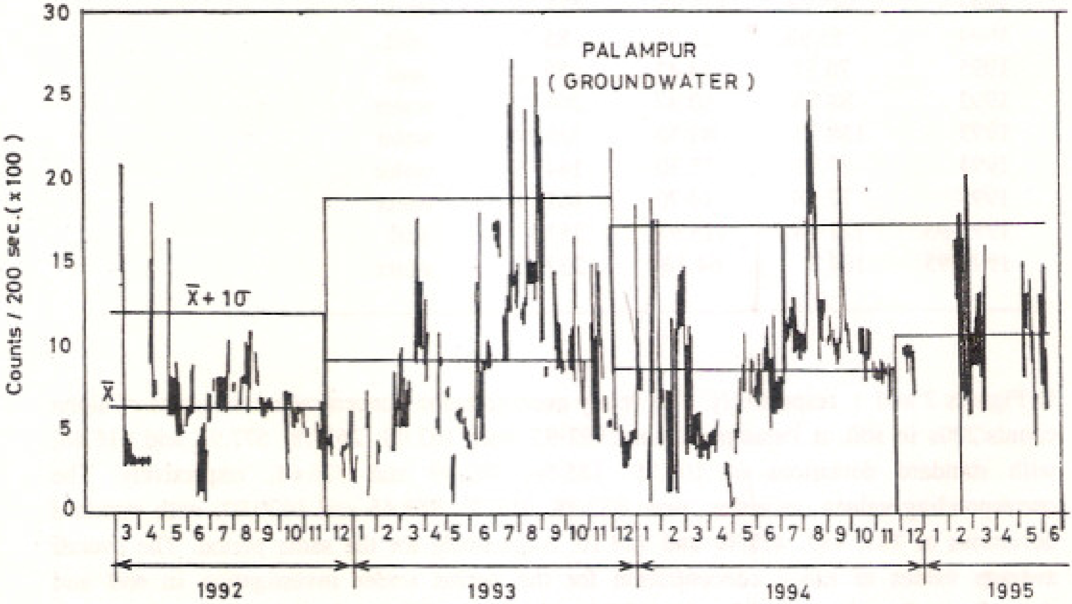
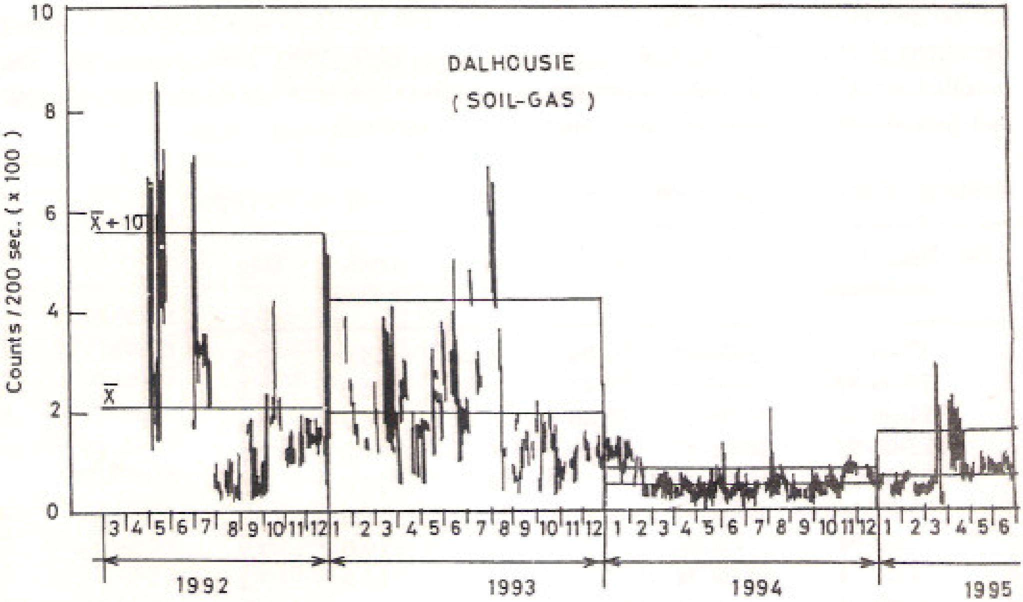


Fig.2 The yearly trends of radon fluctuation in Soil-gas and groundwater at Palampur station using emanometry technique.



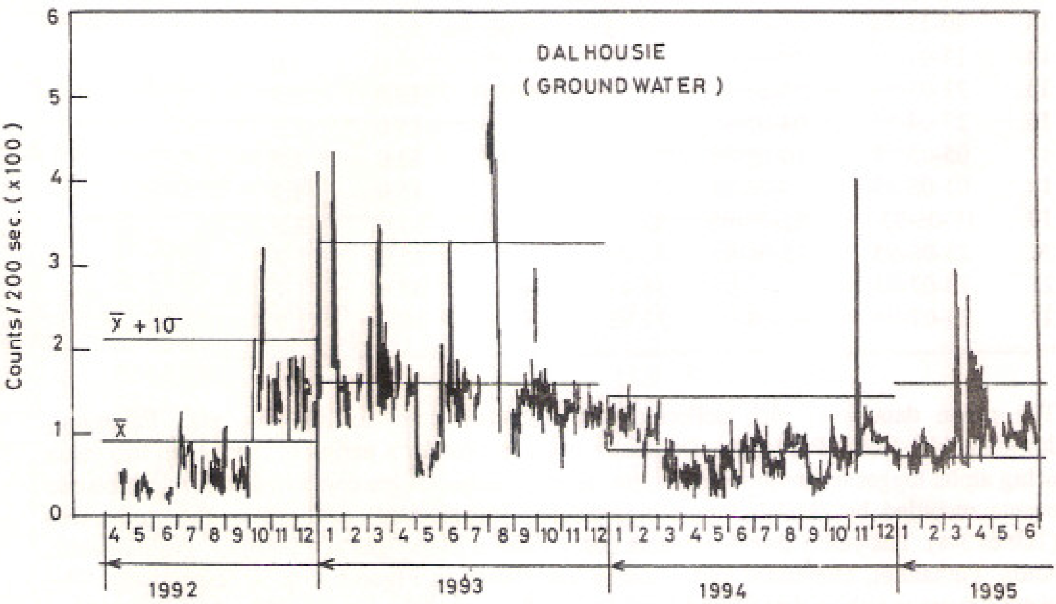


Fig.3 The yearly trends of radon fluctuation in Soil-gas and groundwater at Dalhousie station using emanometry technique.

29.72, and 44.43; and in groundwater were 88.08, 158.21, 77.79 and 72.38 with standard deviations of 60.87, 83.5, 33.3, 44.7, for years 1992, 1993, 1994, 1995, respectively. The overall average values of radon concentration for this period were 121.08 and 104.7 for soil and groundwater with standard deviations of 115.97 and 64.10, respectively.

Table 3. Events correlated with radon anomalies occurring at Palampur

S.No	Date of Rn anomaly	Date of event	Lat°N	Long°E	Depth in Kms	Mag
1.	17-03-93	22-03-93	32.04	76.06	15.0	3.5
2.	23-03-93	23-03-93	32.41	76.35	10.5	2.8
3.	21-06-93	24-06-93	32.86	76.02	06.0	2.3
4.	23-08-93	28-08-93	32.54	76.76	15.0	2.5
5.	02-04-94	10-04-94	31.55	76.90	15.0	2.5
6.	05-07-94	07-07-94	31.42	76.90	15.0	2.9
7.	19-08-94	19-08-94	31.72	76.63	19.0	2.9
8.	31-08-94	08-09-94	32.54	76.43	15.0	3.2
9.	20-09-94	25-09-94	32.23	76.47	15.0	2.4
10.	28-09-94	02-10-94	32.64	75.86	57.0	2.2
11.	09-10-94	15-10-94	32.05	76.66	15.0	2.5
12.	12-12-94	20-12-94	32.18	76.35	15.0	2.5
13.	30-12-94	05-01-95	32.33	77.06	36.0	2.9
14.	13-01-95	19-01-95	32.95	76.05	15.0	3.0
15.	21-03-95	24-03-95	32.60	75.91	18.0	4.5
16.	27-04-95	04-05-95	31.43	76.95	15.0	2.3
17.	05-05-95	10-05-95	32.83	76.02	12.0	2.0
18.	01-06-95	07-06-95	31.42	76.58	15.0	3.3
19.	19-06-95	22-06-95	32.55	76.38	01.0	2.3
20.	25-06-95	28-06-93	33.00	76.42	15.0	1.8
21.	15-07-95	21-07-95	31.47	76.81	65.0	1.7
22.	23-07-95	05-08-95	32.92	75.60	19.0	1.9

The radon data were also collected and analysed from six stations, viz., Palampur, Jawalamukhi, Kotla, Pathankot, Dalhousie and Chamba for a period of more than two years using alpha logger technique for soil-gas. Radon anomalies are correlated with microseismic events recorded by IMD(Indian Meteorological Department) network in the study area (Tables 3-8). The yearly trends of radon concentration in soil-gas at Palampur, Jawalamukhi, Kotla, Pathankot, Dalhousie and Chamba are shown in Figures 4 to 9, respectively. The overall average values determined from the analysis of alpha-logger radon data from 1993-95 at Palampur, Jawalamukhi, Kotla, Pathankot, Dalhousie and Chamba stations were 5728, 9300, 7015, 2355, 6646, and 2536 with standard deviations of 4802,7443, 3036, 1583, 5158 and 2766, respectively. The statistical analysis of alpha logger radon data collected from these stations is given in Table 9.

Table 4. Events correlated with radon anomalies occurring at Kotla

S.No	Date of Rn anomaly	Date of event	Lat°N	Long°E	Depth in Kms	Mag
1.	16-06-93	24-06-93	32.86	76.02	06.1	2.3
2.	27-08-93	28-08-93	32.54	76.76	15.0	2.5
3.	10-04-94	10-04-94	31.55	76.76	15.0	2.5
4.	24-06-94	02-07-94	32.72	76.05	15.0	4.7
5.	15-08-94	19-08-94	31.72	76.63	19.0	2.9
6	08-09-94	08-09-94	32.54	76.43	15.0	3.2
7.	18-09-94	25-09-94	32.23	76.47	15.0	2.4
8.	28-09-94	02-10-94	32.64	75.86	57.0	2.2
9.	13-10-94	15-10-94	32.05	76.66	15.0	2.5
10.	09-12-94	20-12-94	32.18	76.35	15.0	2.5
11.	24-12-94	05-01-95	32.33	77.06	36.0	2.9
12.	19-01-95	19-01-95	32.95	76.05	15.0	3.0
13.	25-01-95	04-02-95	32.50	76.00	04.0	1.3

Table 5. Events correlated with radon anomalies occurring at Chamba

S.No	Date of Rn anomaly	Date of event	Lat°N	Long°E	Depth in Kms	Mag
1.	15-06-93	24-06-93	32.86	76.02	06.1	2.3
2.	26-08-93	28-08-93	32.54	76.76	15.0	2.5
3.	31-03-94	10-04-94	31.55	76.90	15.0	2.5
4.	22-06-94	02-07-94	32.72	76.05	15.0	4.7
5.	05-07-94	07-07-94	31.42	76.90	15.0	2.9
6.	14-08-94	19-08-94	31.72	76.63	19.0	2.9
7.	07-09-94	08-09-94	32.54	76.43	15.0	3.2
8.	17-09-94	25-09-94	32.23	76.47	15.0	2.5
9.	08-10-94	15-10-94	32.05	76.66	15.0	2.5
10.	01-01-95	05-01-95	32.33	77.06	36.0	2.9
11.	12-01-95	19-01-95	32.95	76.05	15.0	3.0
12.	13-03-95	24-03-95	32.60	75.91	18.0	4.5
13	25-03-95	30-03-95	33.23	75.96	24.0	4.0
14.	06-04-95	06-04-95	33.23	75.07	15.0	2.5

Table 6. Events correlated with radon anomalies occurring at Pathankot

S.No	Date of Rn anomaly	Date of event	Lat°N	Long°E	Depth in Kms	Mag
1.	19-03-93	22-03-93	32.04	76.06	15.0	3.5
2.	09-08-93	28-08-93	32.54	76.76	15.0	2.5
3.	05-04-94	10-04-94	31.55	76.90	15.0	2.5
4.	20-05-94	02-07-94	32.72	76.05	15.0	4.7
5.	03-07-94	07-07-94	31.42	76.90	15.0	2.9
6.	11-08-94	19-08-94	31.72	76.63	19.0	2.9
7.	05-09-94	08-09-94	32.54	76.43	15.0	3.2
8.	15-09-94	25-09-94	32.23	76.47	15.0	2.4
9.	17-12-94	20-12-94	32.18	76.35	15.0	2.5
10.	26-12-94	05-01-95	32.33	77.06	36.0	2.9
11.	19-01-95	19-01-95	32.95	76.05	15.0	3.0
12.	29-01-95	04-02-95	32.50	76.00	04.0	1.3

Table 7. Events correlated with radon anomalies occurring at Jawalamukhi

S.No	Date of Rn anomaly	Date of event	Lat°N	Long°E	Depth in Kms	Mag
1.	25-03-94	10-04-94	31.55	76.90	15.0	2.5
2.	30-06-94	02-07-94	32.72	76.05	15.0	4.7
3.	05-07-94	07-07-94	31.42	76.90	15.0	2.9
4.	15-08-94	19-08-94	31.72	76.63	19.0	2.9
5.	02-09-94	08-09-94	32.54	76.43	15.0	3.2
6.	17-09-94	25-09-94	32.23	76.47	15.0	2.4
7.	28-09-94	02-10-94	32.64	75.86	57.0	2.2
8.	11-10-94	15-10-94	32.05	76.66	15.0	2.5
9.	20-12-94	20-12-94	32.18	76.35	15.0	2.5
10.	29-12-94	05-01-95	32.33	77.06	36.0	2.9
11.	15-01-95	19-01-95	32.95	76.05	15.0	3.0
12.	15-03-95	24 -03-95	30.60	75.91	18.0	4.5
13.	01-04-95	04-04-95	31.43	76.95	15.0	2.3
14.	24-04-95	01-05-95	32.33	76.61	53.0	2.1
15.	06-05-95	12-05-95	32.40	76.43	02.0	3.3
16.	26-05-95	07-06-95	31.42	76.58	15.0	3.3
17.	18-06-95	22-06-95	32 91	76.38	01.0	2.3
18.	26-06-95	28-06-95	33.00	76.42	15.0	1.8
19.	07-07-95	08-07-95	33.61	76.54	15.0	1.9
20.	01-08-95	05-08-95	32.92	75.60	19.0	1.9
21.	10-09-95	15-09-95	32.62	76.73	03.0	3.0
22.	17-09-95	20-09-95	32.81	76.28	05.0	2.3
23.	28-09-95	29-09-95	32.61	76.56	06.0	3.0

Table 8. Events correlated with radon anomalies occurring at Dalhousie

S.No.	Date of Rn anomaly	Date of event	Lat°N	Long°E	Depth in Kms	Mag
1.	26-08-93	28-08-93	32.54	76.76	15.0	2.5
2.	06-04-94	10-04-94	31.55	76.90	15.0	2.5
3.	21-06-94	02-07-94	32.72	76.05	15.0	4.7
4.	18-08-94	19-08-94	31.72	76.63	19.0	2.9
5.	05-09-94	08-09-94	32.54	76.43	15.0	3.2
6.	22-09-94	25-09-94	32.23	76.47	15.0	2.5
7.	05-10-94	15-10-94	32.05	76.66	15.0	2.5
8.	06-12-94	20-12-94	32.18	76.35	15.0	2.5
9.	24-12-95	05-01-95	32.33	77.06	36.0	2.9
10.	09-01-95	19-01-95	32.95	76.05	15.0	3.0
11.	02-02-95	04-02-95	32.50	76.00	04.0	1.3
12.	17-03-95	24-03-95	32.60	75.91	18.0	4.5
13.	28-03-95	30-03-95	33.23	75.96	24.0	4.0
14.	06-04-95	06-04-95	33.23	75.07	15.0	2.5

Discussion of results

Both the base stations Palampur and Dalhousie respond differently to radon emanation from soil gas and groundwater. A continuous rising trend was observed in soil-gas radon at Palampur, whereas in water, there was a step increase and then a slight decrease in groundwater radon emanation. In case of Dalhousie station, a continuous decreasing trend was observed in soil-gas radon with a slight hike in the last year. However, the groundwater radon was almost showing the similar trend to that at Palampur. Radon anomalies were identified in the time series radon data shown in Figs. 2 to 9 by applying the following method. For each data set that covered a period of one year, a mean value of radon concentration and a corresponding standard deviation were calculated. If one or more measured radon values deviated from the yearly mean 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 that satisfied the above criteria. The event was identified as a false alarm, i.e. noise if it was not followed by an earthquake.

On the basis of seismological data reported by IMD, it has been found that some of the microearthquakes recorded in the consecutive time window chosen for analysis in the grid 31-33° N and 75- 77° E, were preceded by radon anomalies prior to their occurrence. The time period of precursory radon anomaly occurrence varies from 3-10 days. An analysis of radon anomalies following earthquakes, earthquakes not following radon anomalies and anomalies not following earthquakes, has been made (Tables 10,11).

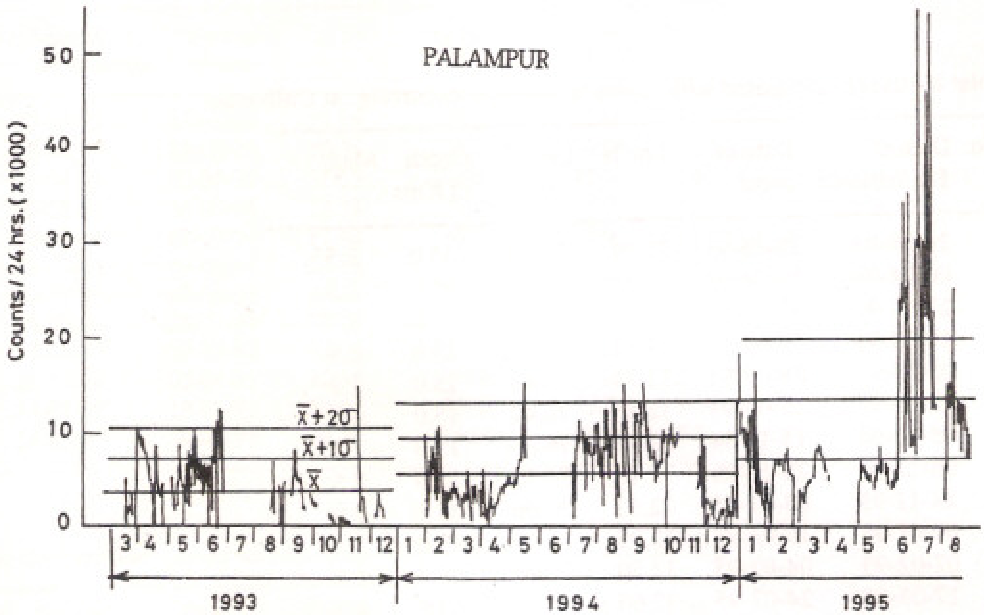


Fig.4 The yearly trends of radon fluctuation in Soil-gas at Palampur station using alpha logger technique.

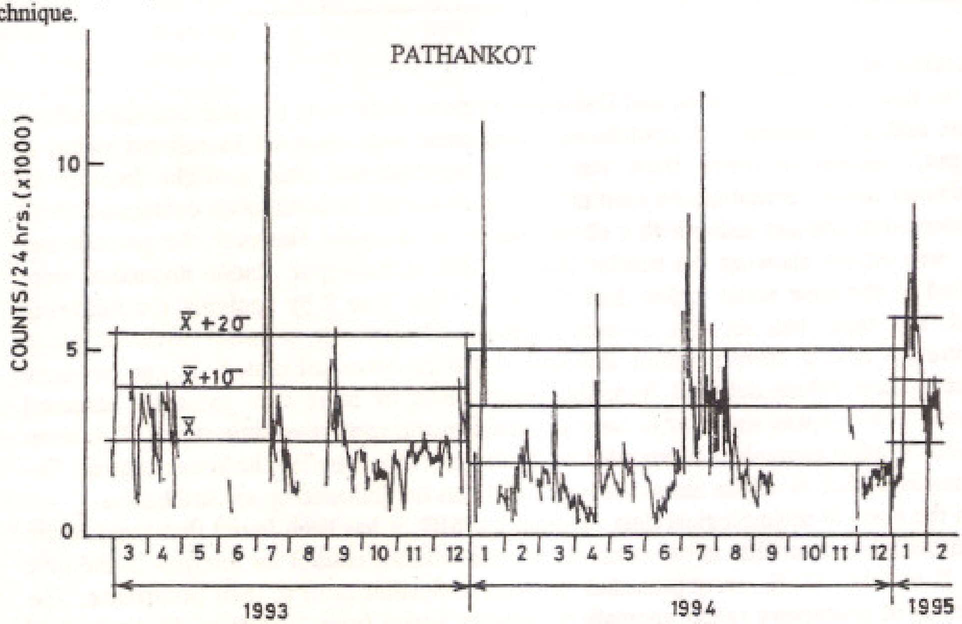


Fig.5 The yearly trends of radon fluctuation in Soil-gas at Pathankot station using alpha logger technique

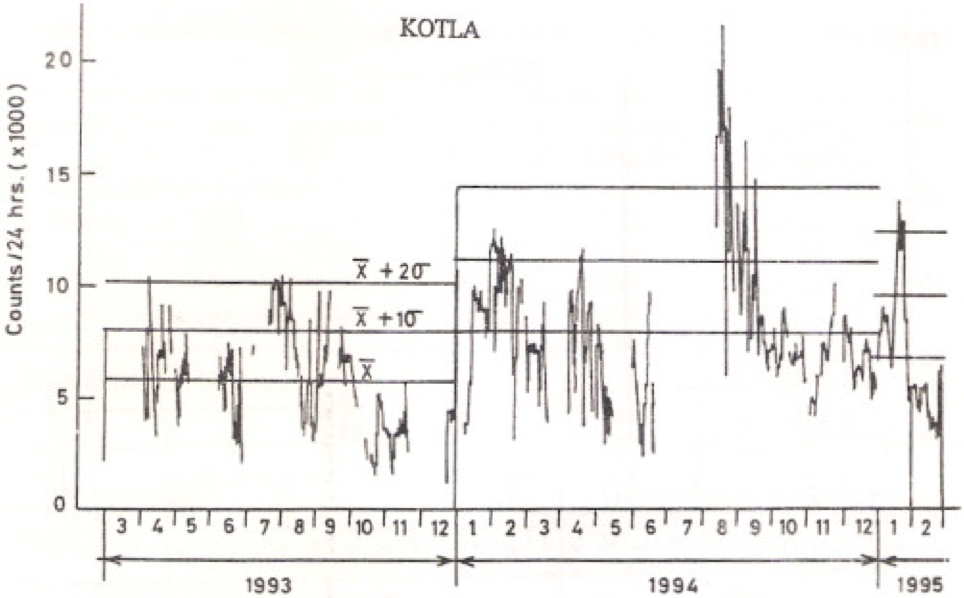


Fig.6 The yearly trends of radon fluctuation in Soil-gas at Kotla station using alpha logger technique

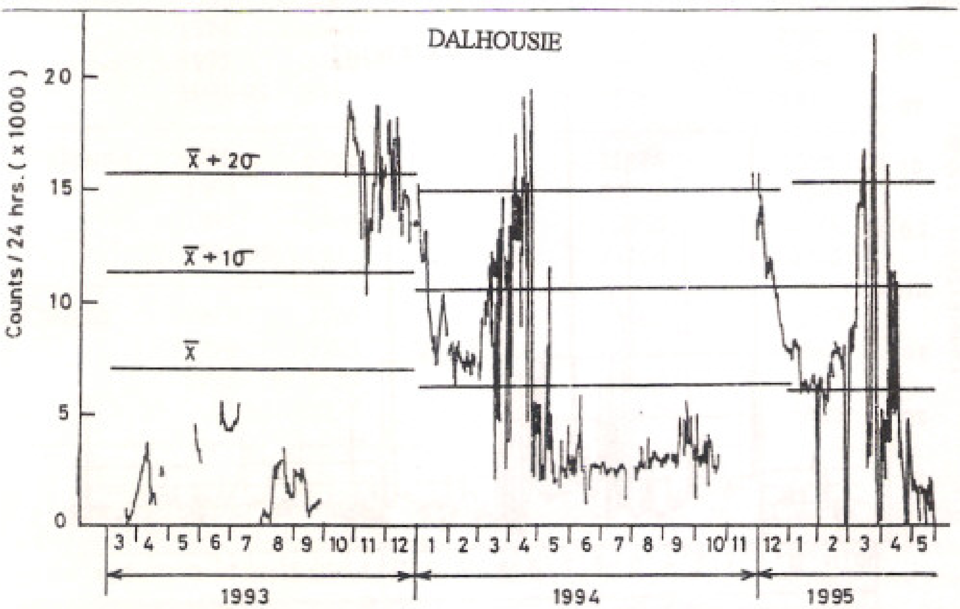


Fig.7 The yearly trends of radon fluctuation in Soil-gas at Dalhousie Station using alpha logger technique

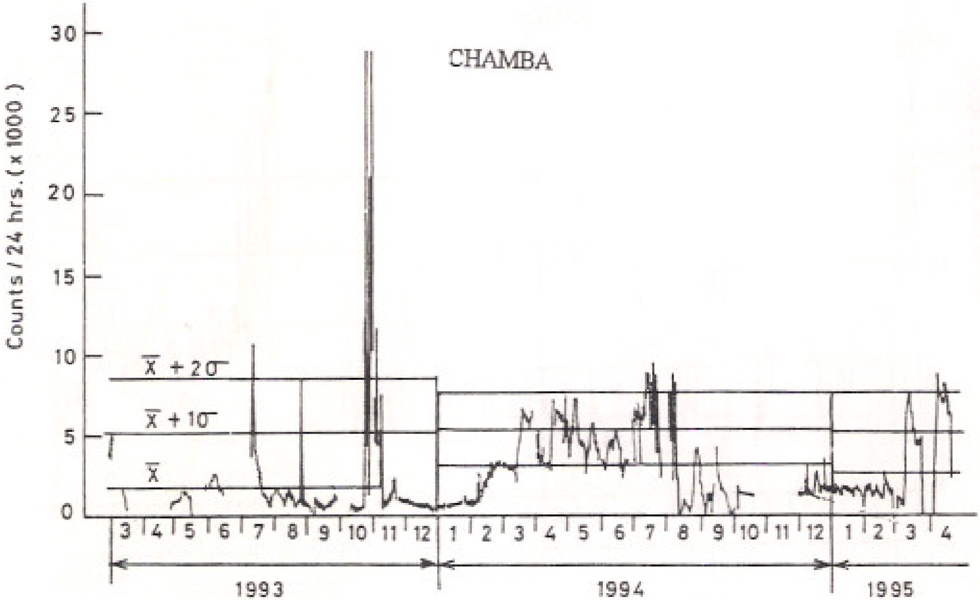


Fig.8 The yearly trends of radon fluctuation in Soil-gas at Chamba Station using alpha logger technique

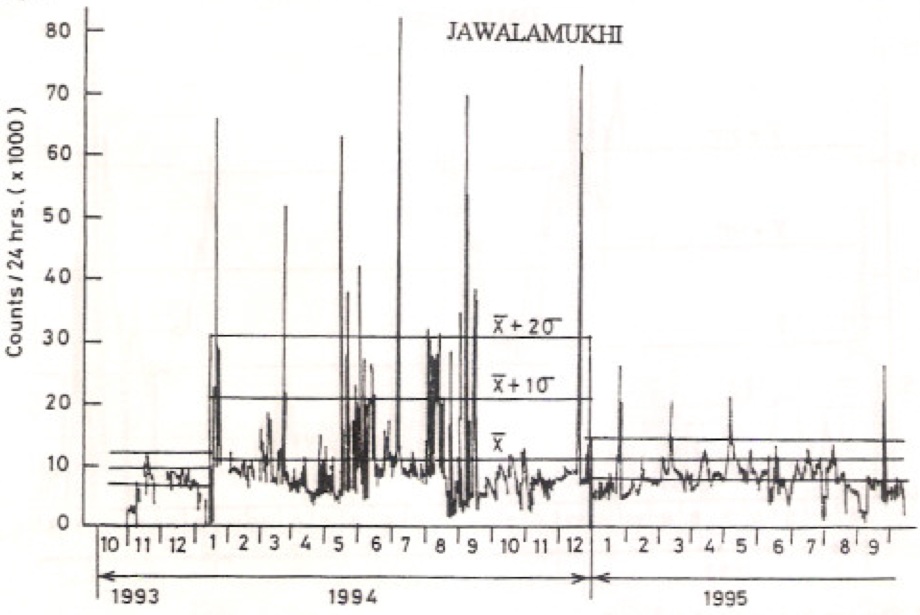


Fig.9 The yearly trends of radon fluctuation in Soil-gas at Jawalamukhi Station using alpha logger technique

Table 9. Statistical analysis of alpha logger radon data pertaining to various stations

Station	Year	Average	Standard deviation	Average + Std.Dev.	Average +2 Std.Dev.
Palampur	1993	3938	3264	7202	10465
	1994	5712	3658	9370	13028
	1995	7216	6285	13501	19786
	1993-95	5728	4802	10530	15330
Jawalamukhi	1993	6870	2469	9339	11808
	1994	10739	9889	20628	30520
	1995	8066	3105	11171	14276
	1993-95	9300	7443	16743	24186
Kotla	1993	5738	2175	7913	10088
	1994	7879	3242	11121	14363
	1995	6785	2820	9605	12430
	1993-95	7015	3036	10051	13087
Pathankot	1993	2505	1461	3966	5427
	1994	1931	1535	3466	5001
	1995	2488	1676	4164	5840
	1993-95	2355	1583	3938	5521
Dalhousie	1993	6963	4313	11276	15588
	1994	6216	4312	10528	14840
	1995	5965	4605	10570	15174
	1993-95	6646	5158	11804	16963
Chamba	1993	1789	1573	3362	8513
	1994	3101	2223	5324	7606
	1995	2654	2602	5156	7657
	1993-95	2536	2766	5302	8068

For each radon monitoring station, confidence level i.e. signal to noise ratio is calculated. Signal is defined as the ratio of the number of anomalies preceding earthquakes to the total number of events and noise is defined as the ratio of the anomalies not preceding an earthquake to the total number of anomalies observed in the consecutive time series. The results are presented in table 12.

Table 10. Critical analysis of radon emanometry data in soil-gas and groundwater

Station	Total events	Total Rn anomalies		Rn anomalies preceding events		Rn anomalies not preceding events		Events not preceding anomalies	
		soil	water	soil	water	soil	water	soil	water
Palampur	25	16	19	12	14	04	05	09	06
Dalhousie	17	28	16	11	10	17	06	06	07

Table 11. Critical 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
Dhalhousie	14	10	04	06	10
Chamba	14	12	08	04	06
Pathankot	12	11	07	04	05

Table 12. Signal to noise ratio for various stations in the grid (31-33°N, 75-77°E)

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
Dalhousie	29.0	60.0	0.48
Chamba	57.0	34.0	1.70
Pathankot	60.0	36.0	1.70
Palampur* (s)	48.0	25.0	1.92
Palampur* (w)	56.0	26.0	2.10
Dalhousie* (s)	65.C	60.0	1.08
Dalhousie* (w)	59.0	37.5	1.56

* stands for emanometry data and s, w stand for soil and water, respectively

The correlation of radon anomalies with microseismic events that occurred in the grid under investigation is shown in Table 12. It is observed that signal to noise ratio varies depending upon the statistics of radon monitoring station. By statistics of the station we mean-type of geological formation, epicentral distance of an event from the monitoring site, and radon response towards occurrence of an event.The confidence level for alpha-logger soil gas radon data varies from 0.48 (Dalhousie) to 2.1(Palampur).The greater the confidence level, the more reliable is the correlation between an event and the radon anomaly.

Conclusions

All the six radon monitoring stations can be grouped into two categories: Palampur, Kotla and Jawalamukhi in the first category and Dalhousie, Chamba and Pathankot in the second category. There is a rising trend in the radon concentration of first category, and there is a decreasing trend in the second category. This may be due to different geological settings of radon monitoring stations around the Main Boundary Fault. The microseismicity in the region plays a major role in radon fluctuations as confirmed by the radon anomalies occurring prior to some of the microseismic events.

The radon data (emanometry and alpha logger) reveals an interesting pattern of radon anomalies and leads to the following conclusions :

1. The radon values obtained from different stations follow a specific trend, continuous rise or fall which is a clear-cut signal of squeezing by compaction or attenuation by long distance migration . The squeezing or attenuation is only possible if there were some porosity changes.
2. The radon anomalies observed at Palampur, Kotla, Chamba and Pathankot respond appreciably to the microseismic events that occurred in the selected time-window from 1992-95.
3. There is no exact formulation that completely fits the radon data to correlate it with the microseismicity in the region. The confidence level (signal/noise) varies from 0.4 for Dalhousie to 2.10 for Palampur station which is found to be most suitable for radon emanometry. Sometimes the radon rise is followed by a microseismic event and othertimes there is an event but no radon rise.
4. The radon transport phenomenon in soil-gas and groundwater is entirely different. This fact can be understood by the radon behaviour observed in soil-gas and groundwater. Sometimes we have large rise in radon value in groundwater and at the same time no rise in soil-gas and vice versa.If the transport mechanism were the same there should be one to one correspondence between soil-gas and groundwater radon rise.
5. Radon monitoring carried out for earthquake prediction seems to be quit a promising technique; however a lot of more data is required and we need better models for understanding the earhquake preparation process. The final goal of earthquake prediction will be achieved in future only by the judicious combination of othei precursory parameters among which, radon measurements will certainly play an important role.

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