A brief description on radon monitoring in India in some seismically sensitive areas (*)(**)

P. MUKHERJI
CA 17, Sector I - Salt Lake, Calcutta 700 064, India

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Summary. — Radon anomalies in both groundwater as well as soil gas prior to a major earthquake were first observed in the Tashkent region (1966) of USSR. Since then, scientists have taken note of geochemical changes in seismically active areas on a regular basis. Emanation of radon gases and associated anomalies in spring and well waters have been observed in various seismically active regions in the Himalayan belt — both in the north-eastern as well as in the western part of the mountain chain. An attempt has been made in this paper to give a brief review of the radon monitoring work done in the Indian subcontinent in some seismically active regions.

PACS 91.40 – Volcanology.
PACS 29.40 – Radiation detectors.
PACS 51.20 – Viscosity, diffusion, and thermal conductivity.

1. – Introduction

Predicting an earthquake is certainly a matter of deep concern for scientists as well as for the general public. Among the various natural hazards, earthquakes are very destructive in nature, causing colossal damages to property, loss of human and animal lives. Major earthquakes often make substantial damage to a country's ecology and economy. Thus, to successfully foretell an earthquake is very desirable. A probable long-term or even a short-term earthquake prediction would go a long way in mitigating disasters associated with major or medium-intensity natural earthquakes.

Measurements of various types of physical parameters, such as strain, tilt, fore shocks, seismic-wave velocity, fault creep, earth resistivity, geomagnetic effects etc., have been carried out for the past two decades or more. Various physical anomalies of

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(**) The Editors apologize to the readers for the bad quality of figures which is due to difficulties in contacting the author.

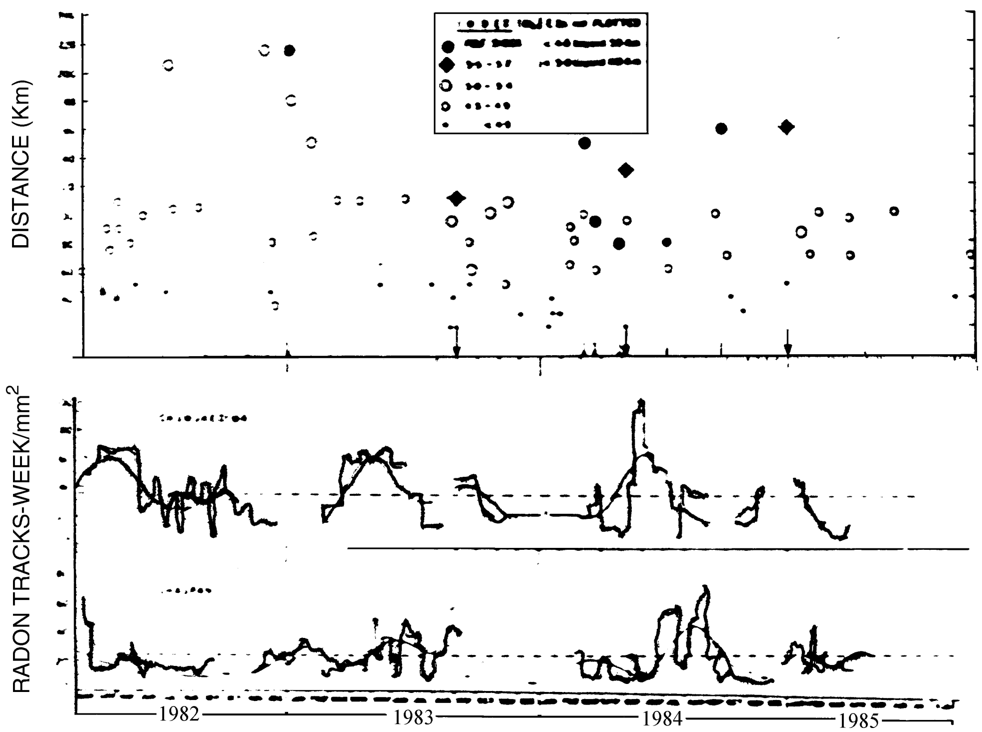

Fig. 1. – The radon concentration as measured at Chumukedima and Ghaspani in Nagaland from 1982 to 1985 (actual = histogram, average = broken line, low-pass filter = solid line). The epicentral distances with magnitude symbols are shown in the upper part of the figure.

the Earth have also been studied carefully but, unfortunately, correct prediction of earthquakes is still a distant dream.

The variation of radon concentration in the groundwater of a deep well in Tashkent, prior to the magnitude 5.2 earthquake of 1966, lent credence to treat variation in radon concentrations as a possible earthquake precursor. Although there is still no reason for excessive jubilation, radon monitoring can be treated as a promising method worth investigating. For this reason, long-term detailed study is carried out in many countries like USA, USSR, France, Japan, China, Mexico and India, to ascertain potential premonitory signals and to eliminate artifacts. In India, various projects on radon monitoring have been carried out for more than a decade, specially in the Himalayan region which is seismically very active.

2. – Radon monitoring techniques used in India

In India, solid-state nuclear track detectors (SSNTDs) have usually been used for measuring radon concentration in soil gas and groundwater. An emanometer devised by the Atomic Minerals Division, Hyderabad, has been used for measuring the emanation rate of alpha-particles from radon [1, 2]. *This technique is very suitable for quick radon survey.* Groups of research scientists of the Atomic Minerals Division have

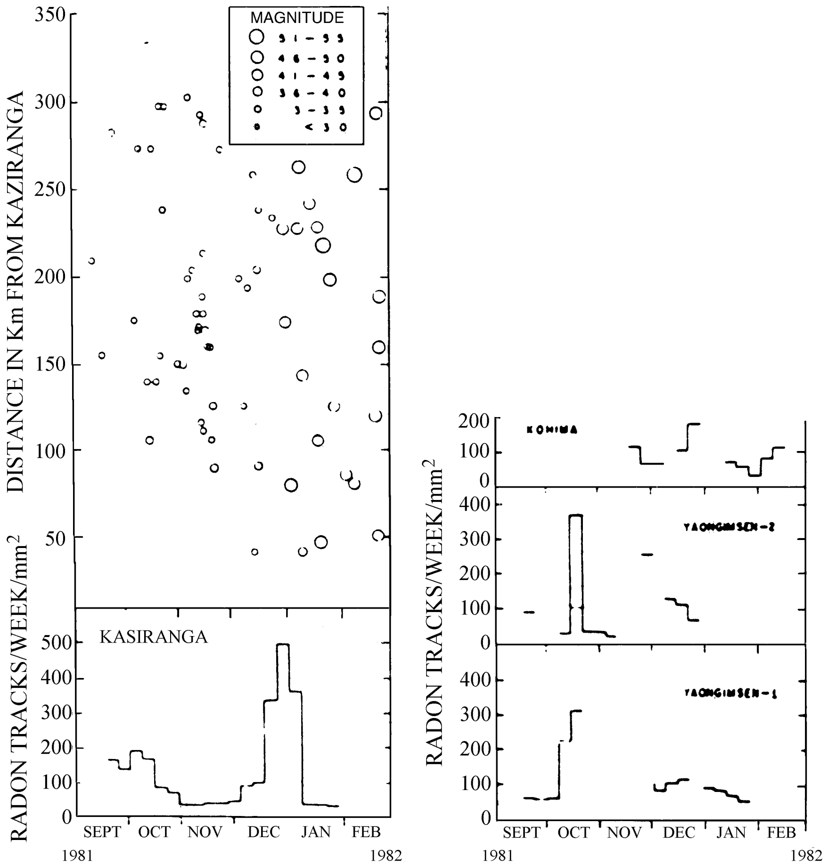

Fig. 2. – Radon concentration as measured at Kaziranga, Kohima and Yaongimsen from September 1981 to February 1982. Epicentral distances from Kaziranga for all the earthquakes are also shown.

applied this technique for measuring radon concentration in bore well water in the Shillong *plateau* in North-East India.

In 1981, scientists from the National Geophysical Research Institute (NGRI), Hyderabad, used a technique similar to the track-tech method [3], and started measuring radon concentrations of soil gas in shallow bore holes at sites along the Naga thrust belt in North-East India. For measuring radon concentration in water samples, they used Radon RDU-200 Detector of EDA Instruments, Canada.

The other method in vogue in radon emanation measurements in India in recent times is the "Alpha Card" method. This alpha card system is a passive radon detection method. This method provides a means for sensitive measurements of radon in soil gas. A lot of radon measurements in soil gas as well as groundwater in the Palampur-Dalhousie region in the Kangra Valley of the North-West Himalayas have been carried out by research groups working in rare-gas geochemistry in the GND University of Punjab [4].

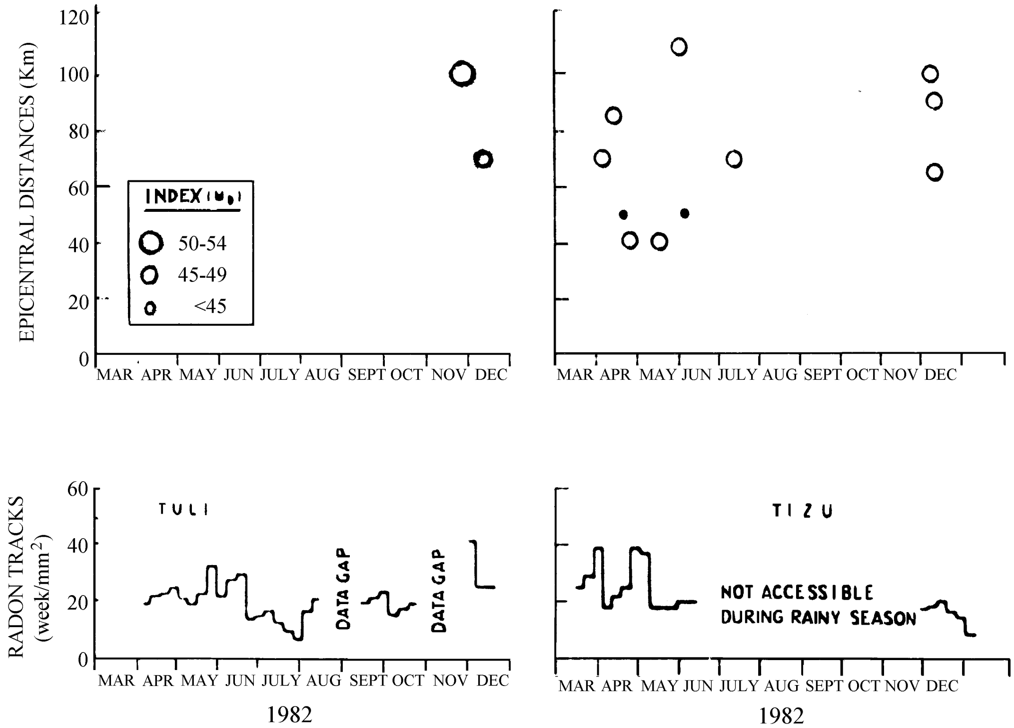

Fig. 3. – Radon concentration and epicentral distances at Tuli and Tizu in the Nagaland state during 1982.

3. – Radon monitoring in India

North-East India being one of the most seismically active areas of the world, the seismicity of this region was closely monitored since 1979 and several new seismic stations were set up to this purpose.

Along with standard measurements of physical precursors for earthquake prediction, in 1981-85, radon concentration of soil gas in shallow bore holes was measured at two sites in Nagaland for more than two years. At eight other sites also situated in Nagaland, these measurements were carried out for nearly a year. At sites along the Naga *thrust belt*, the radon concentration was found to have increased before three earthquakes of magnitude $M = 5.5$ (Richter), which occurred at distances of more than 100 km from radon stations [5]. In general, radon levels were found to be higher before and sometimes during earthquakes of magnitude $M > 4.5$ (Richter). Variation of radon concentration was also noted for earthquakes of magnitude $M > 2.0$ (Richter). As mentioned earlier, all these radon measurement sites were close to surface trace of important thrusts or faults.

Ghosh *et al.* [6] measured radon in water samples collected from bore wells in Shillong between May 1982 and June 1984. The Shillong *plateau* is situated in the north-eastern region of India, which is a highly seismically active area. After analyzing the collected radon counts, they found an increase in the number of earthquakes

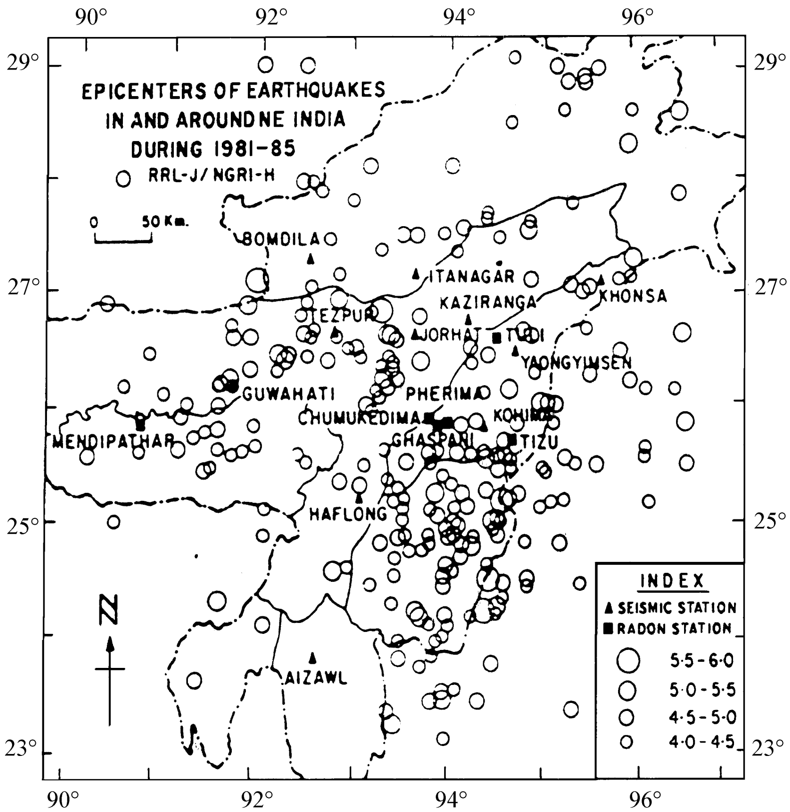

Fig. 4. – Seismicity of North-East India during 1981-1985 from the Annual Data Bulletin of NGRI (H) and the Regional Research Laboratory (Jorhat).

TABLE I. – *Sites for measurement of radon concentration in North-East India* (*table reproduced from: Rastogi and Chadha*, [5]).

Sl. No.	Radon stations	Duration	
		from	to
1	Kaziranga	18.9.81	18.2.83
2	Yaongimsen (I) (Nagaland)	16.9.81	30.1.82
3	Yaongimsen (II) (Nagaland)	16.9.81	30.1.82
4	Kohima (Nagaland)	17.11.81	17.2.82
5	Chumukedima (Nagaland)	7.3.82	29.5.85
6	Ghaspani (Nagaland)	7.3.82	19.7.85
7	Pherima (Nagaland)	7.3.82	28.12.82
8	Tuli (Nagaland)	4.4.82	21.12.82
9	Tizu (Nagaland)	14.3.82	9.1.83
10	Mendipathar (Meghalaya)	4.4.82	7.12.82

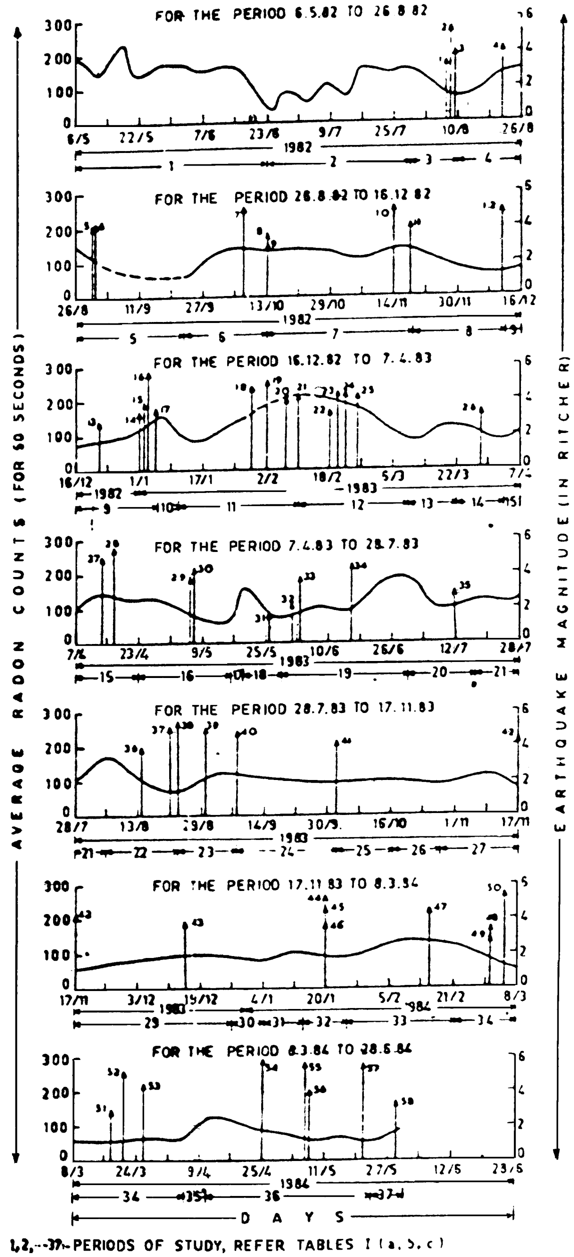

Fig. 5. – Radon monitoring at Pyntheromukrah Polo Ground, Shillong for the period 6.5.1982 to 31.5.1984.

following periods of higher radon counts. Ghosh *et al.* [1, 6] correlated periods of high radon concentration with high seismicity.

Durrah *et al.* [7] measured radon concentration in water-dissolved gases in the

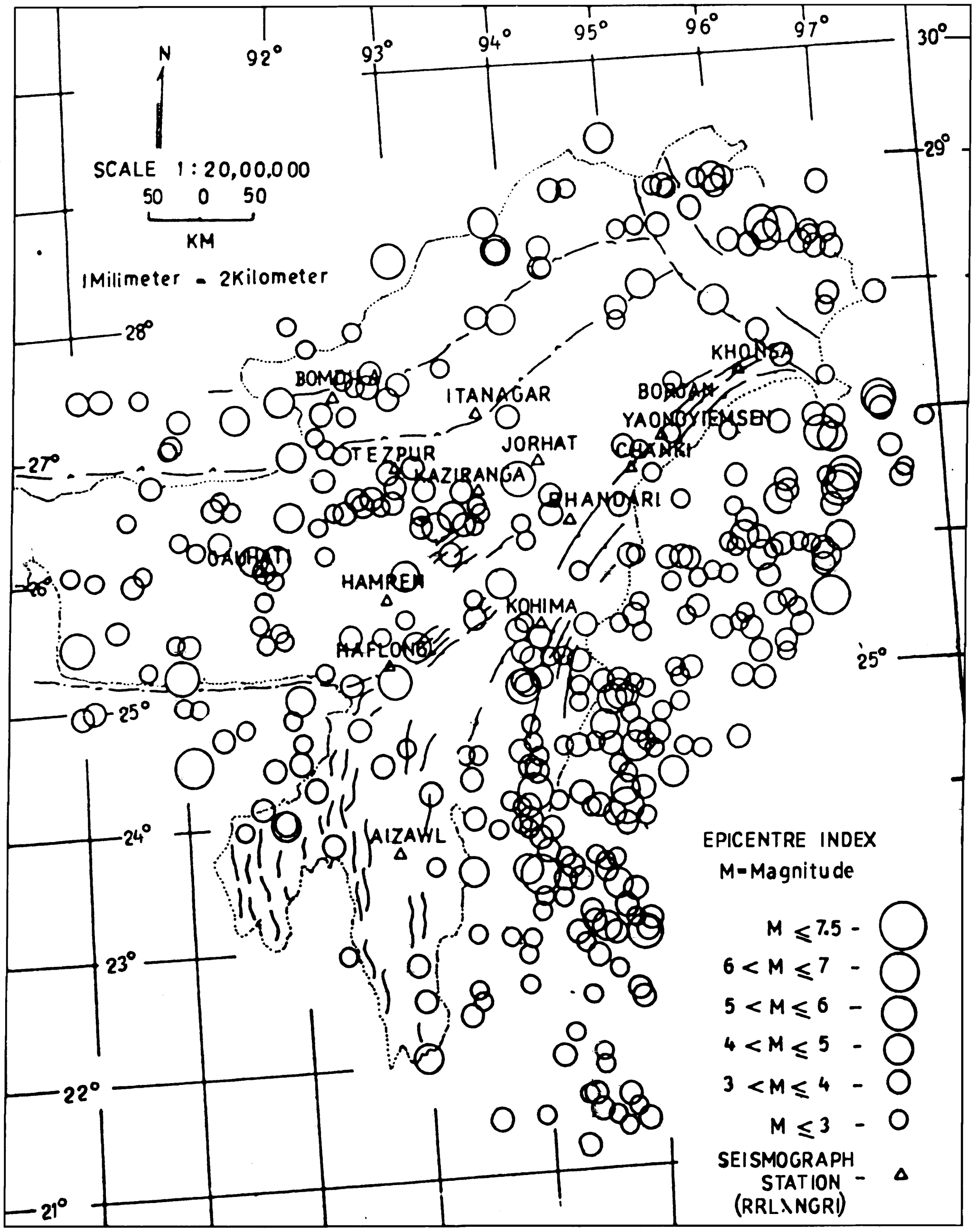

Fig. 6. – Epicentral map of the north-eastern region, India, 1980-1993 (data from RRL (J), NGRI (H)).

Mikir *plateau*, again in the north-eastern region of India. The Mikir *plateau* has been identified as an area of great importance in earthquake research as this plateau, along with the Upper Assam platform basin, has been considered as a seismic gap because

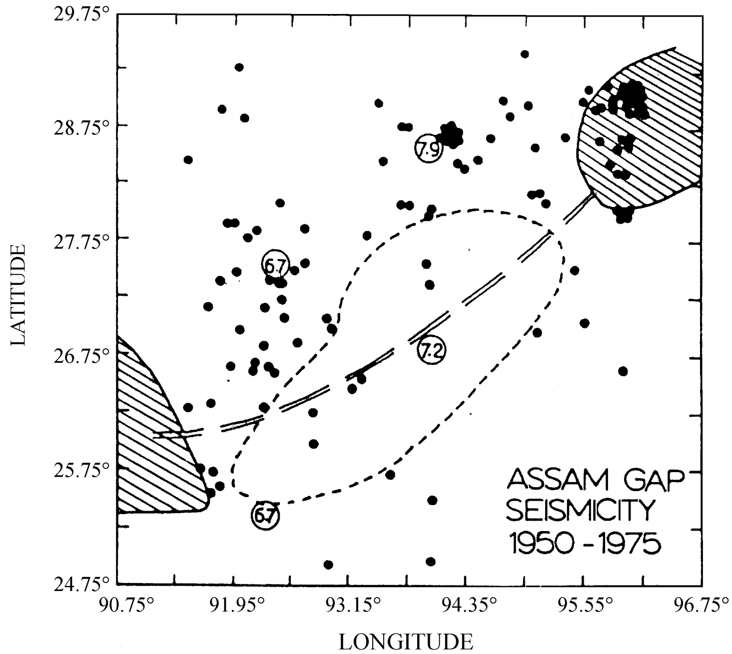

Fig. 7. – The seismicity gap (Assam Gap) after Khattri and Wyss, 1978. Epicentres in the gap from 1950-1975. The double-dashed line marks the zone of likely locations of future great earthquakes; the aftershock areas of past great earthquakes are shaded.

there have been no major earthquakes in this region after the two great earthquakes of magnitude $M = 8.7$ (Richter), in 1897 and 1950. The presence of numerous hot springs confirm high tectonically active deformation. Thus, the area is of great importance from the geophysical point of view and radon emanation studies in this area could be an important precursor to any major seismic activity in the future. Durrah *et al.* [7] analyzed the radon data of this region for April 1989 to March 1993 and tried to establish a correlation with the seismic activity of the region. The radon anomalies were remarkable in the case of moderate-intensity earthquakes, $M < 5.5$ (Richter), occurring within epicentral distances of 250 km. Soil gas and groundwater-dissolved radon gave similar anomaly patterns. However, for earthquakes of magnitude $M < 4.0$ (Richter), no proper correlation could be established between the radon emanations and the events. The authors concluded that the radon studies could be useful for short-term predictions of seismic events in the region.

Around the same time, radon emanation studies in soil gas and groundwater were taken up by Virk *et al.* [4] in some areas of the Kangra Valley, Himachal Pradesh. The confidence level (signal/noise) varied from 0.4 for Dalhousie to 2.10 for Palampur stations in the North-West Himalayas. After analyzing the data collected between 1989 to 1995 in the Palampur and Dalhousie stations of the Kangra Valley, the authors noted some interesting trends in the micro-seismicity pattern of the North-West Himalayas. They found that sometimes there was a rise in the radon concentration prior to a micro-seismic event but this was not always true.

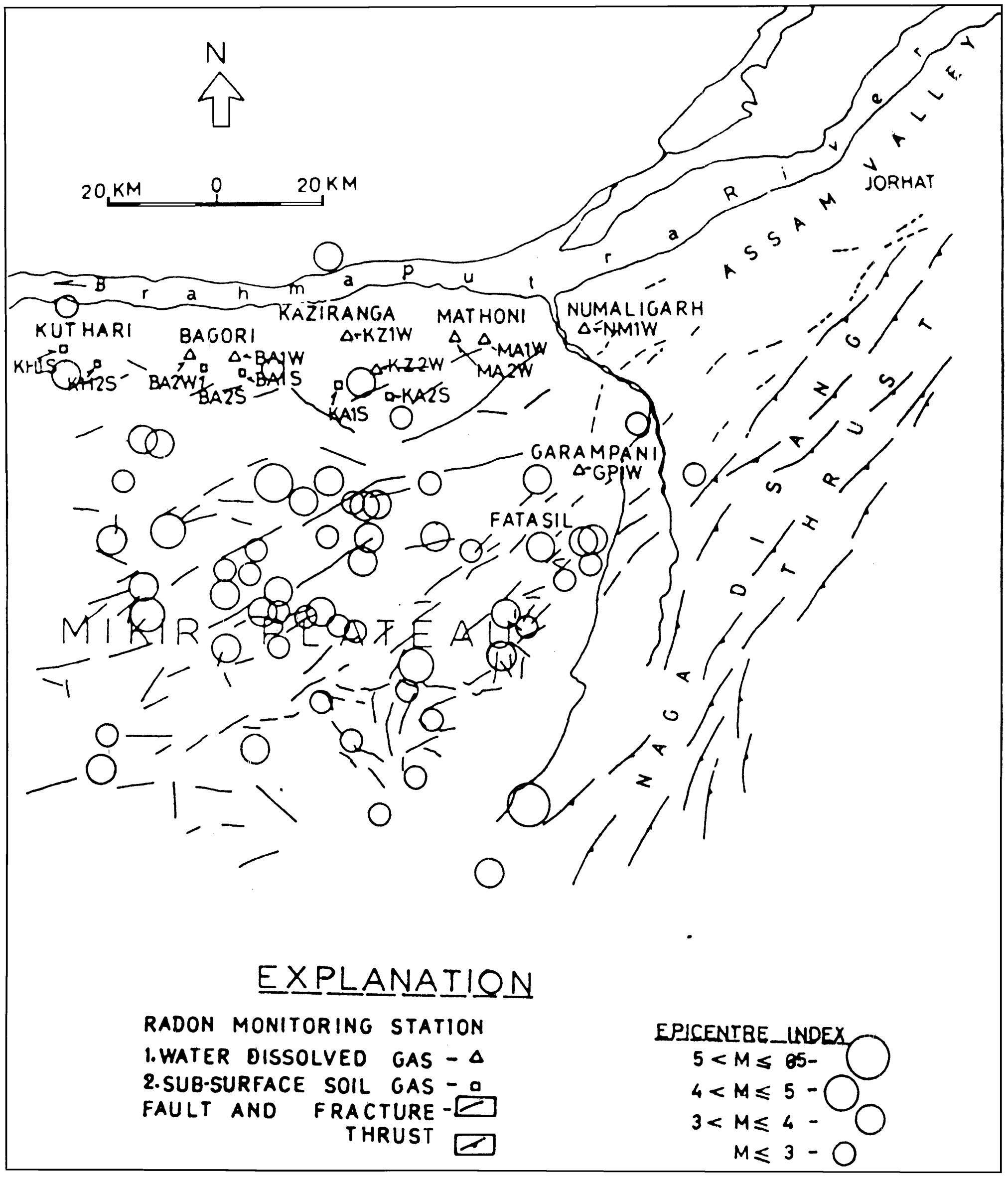

Fig. 8. – Location of radon monitoring stations, epicentres (1980-1993) and tectonic lineaments in the Mikir plateau, north-eastern region, India.

After all the detailed discussions that have been done on the radon emanometric studies in the seismically active regions of India, *viz.* the regions in the North-East and the North-West Himalayas, I would like to draw attention to *peninsular India*, which till recently was supposed to be largely seismically inactive. But the occurrence of the Killari earthquake of September 1993 definitely contradicts this theory.

Radon monitoring in this area started only after the earthquake had already taken

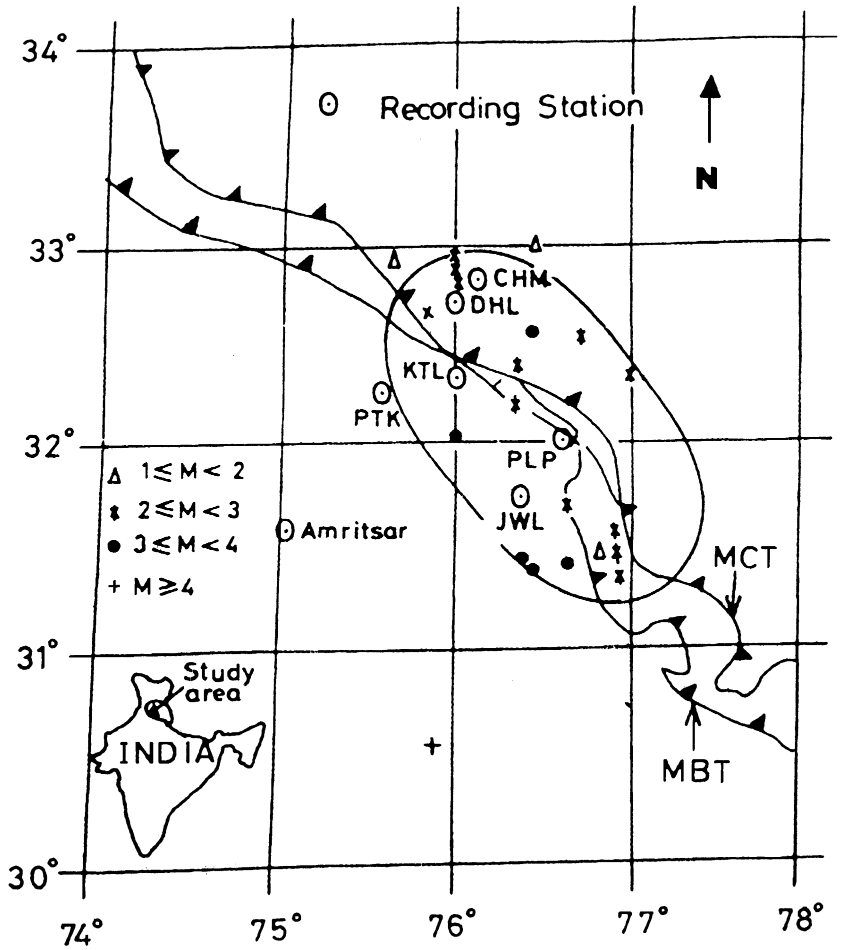

Fig. 9. – Map showing radon recording stations, tectonic features and the location of the epicentres of earthquakes of magnitude 1.7 to 4.5 recorded by the India Meteorological Department, correlated with the radon anomalies occurring at Palampur.

place on September 30, 1993. Taking into account all relevant facts, like adequate soil thickness for drilling Auger bore holes up to 1 m; comparatively dry soil conditions and other geological and geotechnical characteristics, twelve sites were selected for setting up radon monitoring stations. Of these twelve stations, some stations were in the badly damaged zone, while some were in the extreme ends of the damaged zones. Some stations were located away from the earthquake-affected zone but in a seismically active fault system. A schematic diagram showing the location of the radon monitoring stations has been reproduced in fig. 9.

Continuous radon monitoring in the area around Killari indicated very good correlations between radon emanations and micro-seismic activities. It was observed that radon values increased prior to small- and medium-sized earthquakes and there was a decrease in radon concentrations after the shock and the radon values got back to the pre-earthquake level. However, during the post-earthquake period (8-19

TABLE II. – *Signal-to-noise ratio for various stations in the grid* 31-33 °N, 75-77 °E (*reproduced from Virk et al.* [4], *Proceedings of 3rd ICRGG*).

Station	Signal (%)	Noise (%)	Confidence level (signal/noise)
Palampur	45.4	38	1.2
Jwalamukhi	43.5	50	0.87
Kotla	46.1	25	1.84
Dalhousie	29	60	0.48
Chamba	57	34	1.7
Pathankot	60	36	1.7
Palampur* (S)	48	25	1.92
Palampur* (W)	56	26	2.1
Dalhousie* (S)	65	60	1.08
Dalhousie* (W)	59	37	1.56

November, 1993), an overall fall in radon emanation was observed. This is a common phenomenon during post-earthquake periods and has been observed in many places.

4. – Radon data

To substantiate the comments made about the general scenario of radon monitoring in India and related observations on earthquakes, some relevant pieces of information from the highly seismic NE India, including the Mikir *plateau* in the North-East Himalayas are given. Table I indicates the chosen sites in Nagaland, where monitoring was done by Rastogi and Chadha between 1981 and 1985. Figures 1, 2, 3 and 4 indicate the radon concentrations measured at different sites, mentioned in table I. Figure 5 indicates the radon monitoring carried out by Ghosh *et al.* [1, 6] in Shillong.

Following Durrah *et al.* [7], figs. 6, 7 and 8 indicate interesting radon anomalies in the Mikir plateau in the North-East Himalayas. The seismic gap and predictions about future great earthquakes are also shown in fig. 8.

Finally, following Virk *et al.* [4] fig. 9 indicates the correlation between radon anomalies and earthquake occurrences in the Palampur region of the North-West Himalayas. Quoting from the above-mentioned work, I would like to draw the attention of scientists from all over the world to the fact that the correlation between radon anomalies and micro-seismic events in the North-West Himalayas is quite noteworthy. A table (table II) to that effect is given above.

Unfortunately, no data was available from the Killari earthquake in *peninsular* India. So only a radon map (fig. 10) of the area is enclosed in this review paper.

5. – Discussions and conclusions

After going through the results of radon monitoring by various research groups in the Indian subcontinent, the following conclusions can be drawn:

1) Interpretation of changes in radon concentrations in shallow depth are often complicated by the presence of various atmospheric parameters as has been noticed in the north-eastern regions of India, radon concentration in the groundwater of wells and springs increases during summer months but diminishes during monsoons. As the

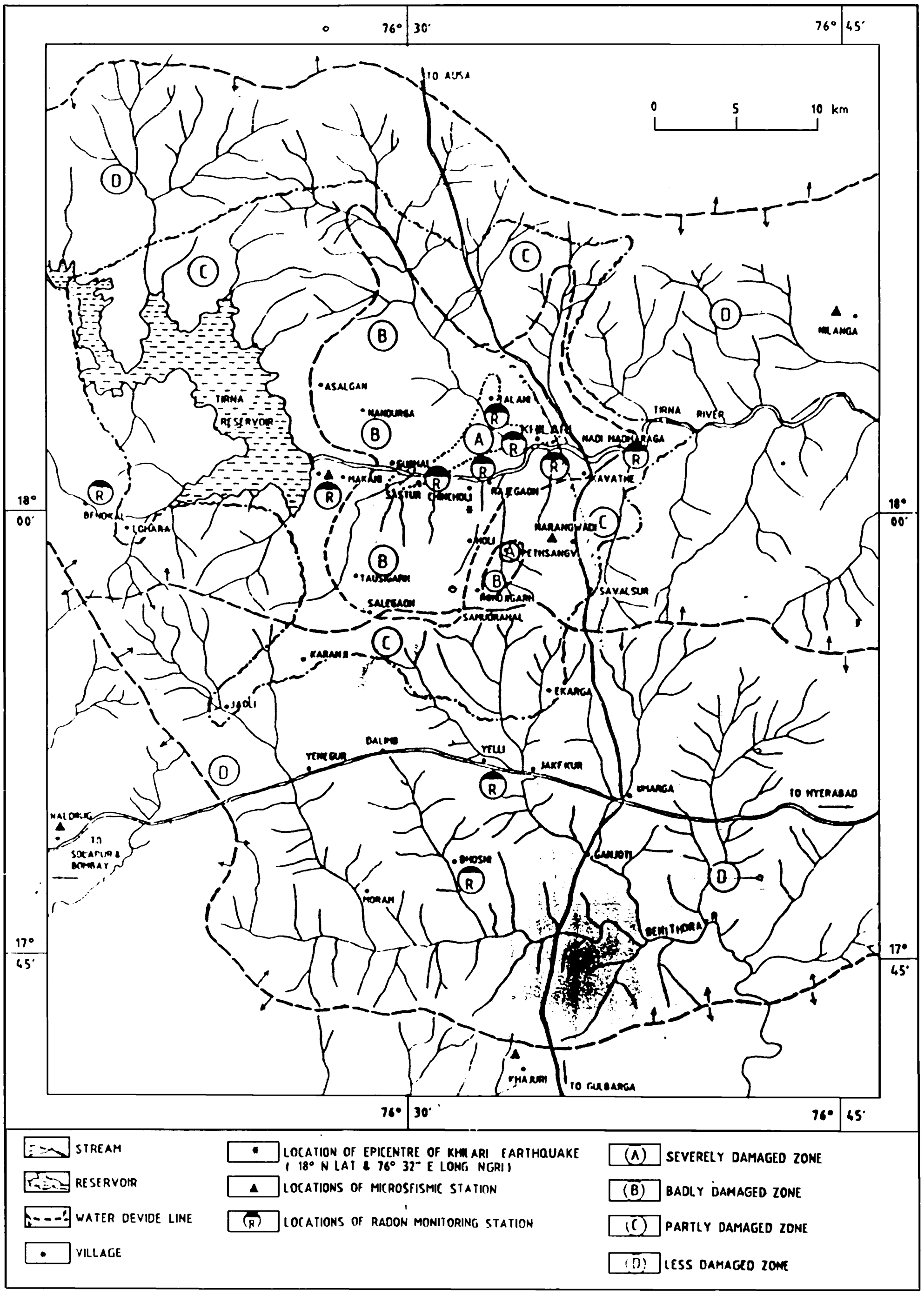

Fig. 10. – Map showing damaged zones and locations of radon monitoring stations in parts of the Latur and Osmanabad districts of Maharashtra, peninsular India.

north-eastern regions of India have very heavy rains during the monsoons (July-September), the radon concentration gets diluted during this period.

However, changes in radon concentrations due to climatic changes are of low amplitude. If high-amplitude changes are detected, they may be interpreted as earthquake induced.

2) An increase in radon concentration and the subsequent decrease may be considered as a possible signal for an impending earthquake. From dilatancy principle of earthquake occurrence, it is well known that micro-cracks, fissures and fractures develop as a result of dilatancy of rocks before an earthquake. Because of these tectonic disturbances, a large amount of radon is released in the crustal rocks due to the decay of radium. This increases the radon concentration in water outflow from mineral spring exits which is recorded in the monitoring stations.

3) From various data collected in different parts of seismically active areas of India, it is noteworthy that when the monitoring sites are situated in the epicentral area, stress changes responsible for earthquakes may cause detectable long-period precursory radon anomalies. However, if the monitoring sites are situated far away from the epicentral area, short-period changes have been observed both before and after the event (*e.g.*, Killari and Lattur earthquakes).

4) The incidence of radon anomaly is probably controlled both by the distance to the source and the geological conditions prevailing in the monitoring site.

5) For meaningful correlation between radon emanation and earthquake prediction, long-term and continuous radon monitoring surveillance should be undertaken in seismically sensitive areas of India.

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I am grateful to the authors of all the research papers cited in the references: I have used their data and figures freely in my paper.

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