Radon/helium studies for earthquake prediction in N-W Himalaya (*)(**)

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Summary. — The great Himalayan orogenic belt is one of the most active intra-continental regions in the world where a dozen earthquakes exceeding 7.5 M occurred in the past from 1897 through 1950. Radon monitoring started in the Kangra valley, Himachal Pradesh in 1989 under the Himalayan Seismicity Programme of the Goverment of India. Six stations were set up along the main boundary fault (MBF) of N-W Himalaya. Radon monitoring is carried out using three techniques, *viz.*, track etch technique, emanometry and alpha-logger system in both soil-gas and groundwater. Radon anomalies are correlated with microseismic activity in the N-W Himalaya. The correlation index varies for different stations and there is no one-to-one correspondence between radon anomalies and seismic events. The Uttarkashi ($M_s = 7.0$) and Chamba earthquakes ($M_s = 5.1$) are postdicted using radon anomalies which occurred in soil-gas and groundwater, simultaneously. Currently, we are using multisensor probes for monitoring of radon and meteorological parameters simultaneously in the study area. Helium is being monitored along with radon at Palampur in soil-gas and in thermal springs in the Kullu and Parbati valleys of Himachal Pradesh. The He/Rn ratio will be used as a predictive tool for earthquakes.

PACS 91.30.Px – Phenomena related to earthquake prediction.
PACS 91.25.Ey – Interactions between exterior sources and interior properties.
PACS 01.30.Cc – Conference proceedings.

1. – Introduction

Earthquakes constitute one of the worst natural calamities on Earth. In India, where more than 55% of the land area falls under active seismic zones, considerable destruction was caused by the earthquakes of Shillong (1897), Kangra (1905), Bihar-Nepal (1934), Assam (1950), Koyna (1991), Bihar-Nepal (1988), Uttarkashi (1991) and Latur (1993). With a population growing towards one billion by the end of this century, damage to life and property is likely to increase remarkably, unless success in

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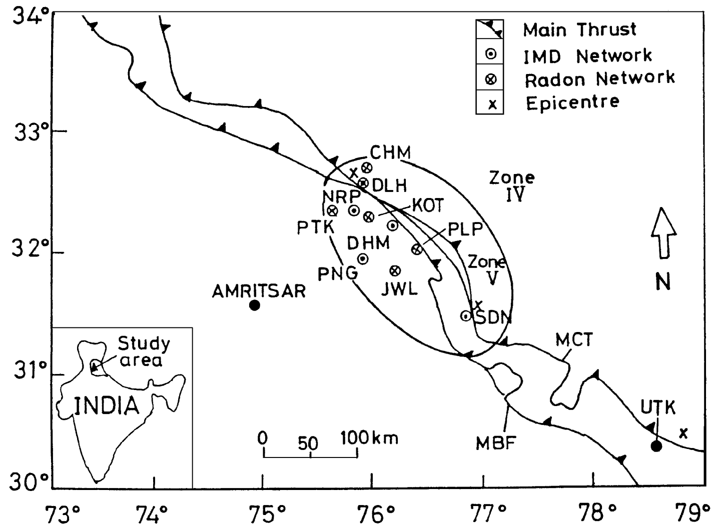

Fig. 1. – Map showing the radon recording stations, IMD network, main boundary fault (MBF), main central thrust (MCT) and high-seismicity zone V in N-W Himalaya. The symbol PTK stands for Pathankot, JWL for Jawalamukhi, KOT for Kotla, PNG for Pongdam, UTK for Uttarkashi, CHB for Chamba, SDN for Sundernagar and DLH for Dalhousie.

earthquake prediction is achieved, which seems to be a remote possibility in the near future.

Over the past three decades a number of earthquake precursors have been identified. Radon and helium have received considerable attention as geochemical precursors of impending earthquakes [1-6]. The great Himalayan orogenic belt is one of the most active intra-continental regions of the world where a dozen earthquakes exceeding 7.5*M* occurred in the past from 1897 through 1950. Bilham *et al.* [7] have predicted strain build-up along the Indo-Tibetan collision zone based on the GPS data.

Radon monitoring started in the Kangra valley of the Himachal Pradesh state lying at the foothills of the Dhauladhar range of N-W Himalaya under the Coordinated Himalayan Seismicity Programme of the Government of India. In 1989 the central radon monitoring station was set up at Palampur in the Kangra valley. Radon monitoring was based on track-etch technique, emanometry and alpha-logger technique. During 1992-1995, six stations were made operational in the Kangra and Chamba valleys, *viz.* Palampur, Jawalamukhi, Kotla Pathankot, Chamba and Dalhousie (fig. 1). Some of these stations are situated in close proximity to the two major thrust faults traversing along the Himalayan orogeny known as MBF (Main Boundary Fault) and MCT (Main Central Thrust).

2. – Experimental techniques

Radon monitoring in soil-gas and groundwater was carried out using emanometry at the Palampur and Dalhousie stations and alpha-logger probes in soil-gas at all the six stations. The detailed description of techniques is given elsewhere [8-10].

2·1. *Helium monitoring.* – A helium leak detector ASM 100 HDS (Alcatel, France) using sniffing technique is used for helium analysis in thermal springs at Manikaran and in soil-gas at Palampur. It comprises a helium gas analyser with a pumping system.

The main component of the 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. A closed circuit technique is used to estimate helium in thermal-spring samples using two hypodermic syringes, an air-tight bottle containing silica gel and the helium leak detector. Helium is estimated in soil-gas by sniffing technique. The calibrated logarithmic scale displays the helium concentration in ppm. The whole operation is fully automatic and helium values from 0.1 ppm to 100% helium can be measured. In soil-gas, helium is estimated directly by a sniffing probe from an Auger hole.

3. – Results and discussion

During the last decade, radon time-series data were recorded using both discrete and continuous measurement techniques. A number of anomalies were correlated with micro-seismic events which occurred in the grid (30-34 °N, 73-79 °E).

The physical basis of radon anomalies is yet to be fully understood in terms of a comprehensive theoretical model. However, it is understood that the build-up of stresses prior to an impending earthquake induces strain fields over vast areas and a change in the strain field of the order of 10^{-6}–10^{-8} can generate radon anomalies in the time-series data. On the whole only 50% of the micro-seismic events are correlatable with radon anomalies. Most of the radon anomalies precede the seismic events, some of them are co-seismic and others follow the event. We are interested in those anomalies which precede the events as they can establish radon as a precursor. Radon anomalies in soil-gas during 1989-91 by track-etch technique are correlated with seismic events at Palampur (fig. 2). The results of radon monitoring using alpha-logger and emanometry techniques for the time-window 1993-97 are reported elsewhere [8-12].

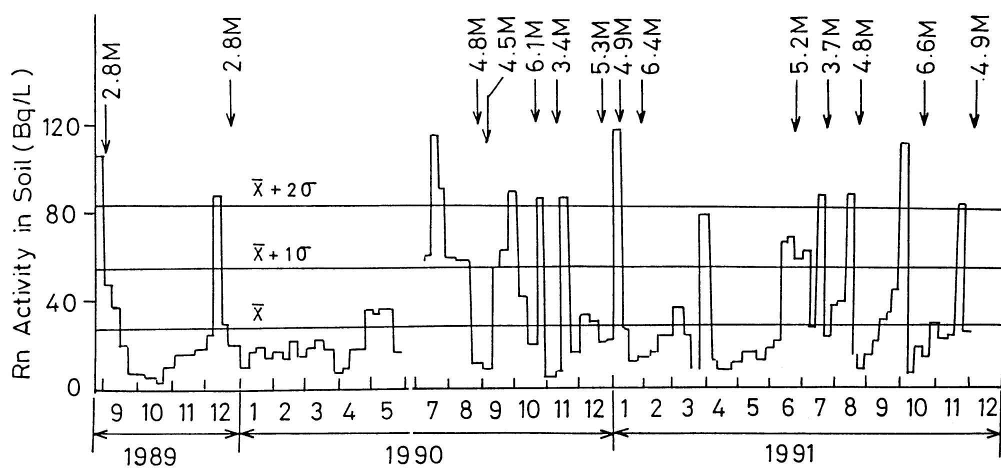

Fig. 2. – Weekly radon data in soil-gas at Palampur (Sept. 1989-Dec. 1991) using track-etch technique. The arrows represent seismic events correlated with radon anomalies.

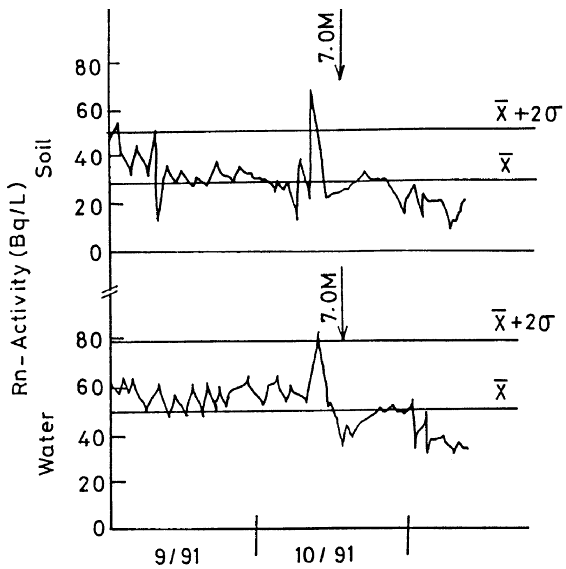

Fig. 3. – Radon emanometry data in soil-gas and groundwater at Palampur (Sept.-Oct. 1991). The arrows represent the Uttarkashi earthquake of 7.0 M_s on 20 October 1991.

3·1. *Postdiction of Uttarkashi and Chamba earthquakes.* – The best representative events recorded at the Palampur and Dalhousie stations pertain to the postdiction of Uttarkashi and Chamba earthquakes [13, 14]. The Uttarkashi earthquake of 7.0 M_s with epicentre (33.75 °N, 78.80 °E) occurred on 20 October 1991 in the Garhwal Himalaya about 330 km from the Palampur station in the Kangra valley. Temporal variations of radon in soil-gas and groundwater recorded by emanometry from September to October 1991 at Palampur are shown in fig. 3. A radon anomaly was

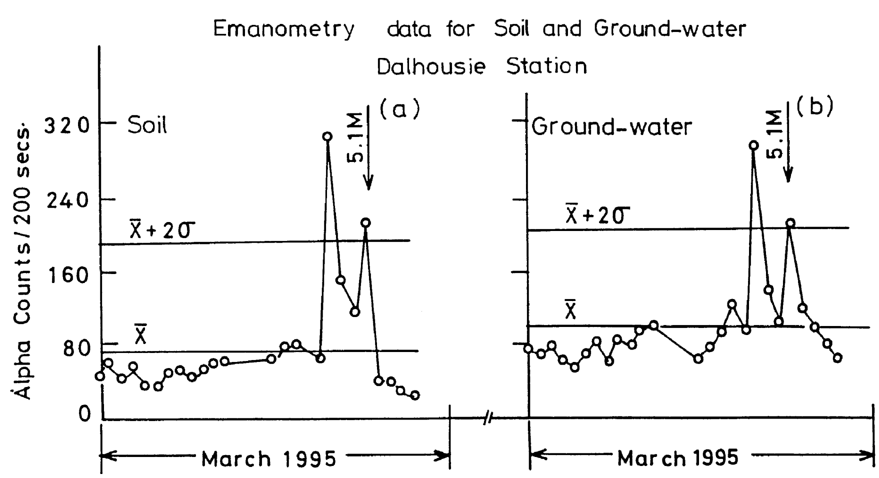

Fig. 4. – Radon emanometry data in soil-gas and groundwater at Dalhousie (March 1995). The arrows represent the Chamba earthquake of 5.1 M_s on 24 March 1991.

recorded simultaneously in both the media on October 15 with radon activity crossing the 2σ level above the average value. The track-etch technique also recorded a radon anomaly at Palampur crossing the $\overline{X} + 2\sigma$ level, a week before the Uttarkashi event ($m_b = 6.6$, $M_s = 7.0$) as shown in fig. 2. The effect of meteorological parameters on radon emanation was also studied during this period. Except for high wind velocity and low humidity, no unusual behaviour was noticed for other parameters. Hence the chances for a non-tectonic origin of this radon anomaly are negligible.

Radon monitoring at Chamba started in July 1993. Radon emanometry data (fig. 4) in soil-gas and groundwater at the Dalhousie station recorded the Chamba earthquake of magnitude $5.1M$ quite faithfully. The radon anomalies were recorded in both the media simultaneously on 21 March, three days before the Chamba earthquake which occurred on 24 March 1995. In fact there are two radon anomalies, *viz.* 21 March and 24 March, which seem to be triggered by the Chamba earthquake of 24 March. There is a sudden fall in the radon emanation rate in both soil-gas and groundwater after the strain was released. In March 1995, weather conditions were stable (normal). Hence the Chamba earthquake is postdicted by detection of radon anomalies. In fact, the radon spike was so sharp on 21 March that we could foresee the coming event on 24 March. It established the precursory nature of radon anomalies.

3·2. *The results of helium monitoring.* – Helium concentration in soil-gas has been monitored at Palampur since 20 July 1997. Surprisingly, the value recorded was below the global average of 5 ppm (fig. 5). On 23 July, helium recorded its lowest value and then it started rising. There was a slight fall before the occurrence of Sundernagar earthquake of magnitude $4.2\,M$ on 29 July 1997. The helium activity started rising during the first week of August and crossed the mean level. It again dropped below the average a day before the occurrence of the seismic event of $3.2\,M$ on 13 August, 1997. In fact, there was a swarm of seismic events of magnitude between $1\,M$ and $3.2\,M$ following the Sundernagar earthquake which is the only event of some consequence recorded during the time-window.

Helium activity in thermal springs is recorded in N-W Himalay. Most of these springs, are related to tectonic belts, grabens and fault zones in India and their major

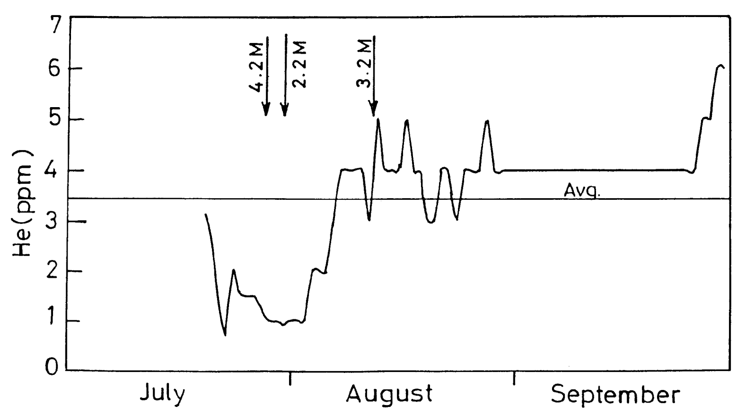

Fig. 5. – A profile of helium activity in soil-gas at Palampur (July-Sept. 1997). The arrows represent the Sundernagar earthquake of $4.2\,M$ on 29 July 1997 and two aftershocks of $2.2\,M$ and $3.2\,M$ on 31 July and 13 August, respectively.

TABLE I. – *Helium content in thermal springs of N-W Himalaya (Himachal Pradesh).*

Sr. No.	Place	Spring code	Spring temp. (°C)	^{4}He content (ppm)
1	Manikaran	MK1	94.4	50
2	Brahamganga	MK2	94.4	30
3	Tegri	MK3	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	Tattapani	TP1	96.4	20

concentration is in the Parbati and Kullu valleys of Himachal Pradesh. Helium contents of eight thermal springs are reported in table I. A maximum value of 90 ppm is recorded in the thermal spring (KL3) at Kasol near Manikaran, a famous pilgrimage centre since historical times. It is planned to measure the He/Rn ratio in thermal springs to use it as a predictive tool for earthquakes in N-W Himalaya.

4. – Conclusions

a) On the whole, about 50% events are correlatable with radon anomalies recorded by track-etch, alpha-logger and emanometry techniques.

b) The precursory nature of radon anomalies is established for two major seismic events which occurred in N-W Himalaya.

c) Radon anomalies are recorded in both soil-gas and groundwater almost simultaneously.

d) Helium content of thermal springs can be correlatable with radon and radium content in water.

e) The statistics for helium data is quite poor. More radon and helium data need to be recorded over a wider network in N-W Himalaya to study the confidence level and sensitivity of radon monitoring stations.

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