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Radon Precursory Signals for Some Earthquakes of Magnitude > 5 Occurred in N-W Himalaya: An Overview

Vivek Walia,[1,2] Hardev Singh Virk,[3] and Bikramjit Singh Bajwa[4]

Abstract—The N-W Himalaya was rocked by a few major and many minor earthquakes. Two major earthquakes in Garhwal Himalaya: Uttarkashi earthquake of magnitude $M_s = 7.0$ ($m_b = 6.6$) on October 20, 1991 in Bhagirthi valley and Chamoli earthquake of $M_s = 6.5$ ($m_b = 6.8$) on March 29, 1999 in the Alaknanda valley and one in Himachal Himalaya: Chamba earthquake of magnitude 5.1 on March 24, 1995 in Chamba region, were recorded during the last decade and correlated with radon anomalies. The helium anomaly for Chamoli earthquake was also recorded and the Helium/Radon ratio model was tested on it. The precursory nature of radon and helium anomalies is a strong indicator in favor of geochemical precursors for earthquake prediction and a preliminary test for the Helium/Radon ratio model.

Key words: Radon, helium, precursor, uttarkashi, chamba, chamoli.

1. Introduction

The Himalayan orogeny is believed to be a product of the on-going 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 underthrusting of the Indian plate. The seismicity and tectonics of the Himalaya have been subjects of special investigation. 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 N-W 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) carried out a micro-earthquake survey around the Thein Dam during 1983 in the vicinity of the Kangra valley.

[1]National Center for Research on Earthquake Engineering, Taipei-106, Taiwan
[2]Department of Geosciences, National Taiwan University, Taipei-106, Taiwan
[3]360, Sector 71, SAS Nagar, (Mohali)-160071, India
[4]Department of Physics, Guru Nanak Dev University, Amritsar-143005, India

The Kangra valley of Himachal Himalaya and Bhagirthi & Alaknanda valleys of Garhwal Himalaya are good examples of tectonically active areas in N-W Himalaya. The region has suffered several major and minor earthquakes. Each of these earthquakes have created their own unforgettable histories (OLDHAM, 1883). During the last decade two major earthquakes have occurred in the Garhwal Himalaya; Uttarkashi earthquake of magnitude Ms = 7.0 occurred on October 19, 1991 and the Chamoli earthquake of Ms = 6.5 on March 29, 1999. In the Chamba region of Kangra valley, Chamba earthquake of magnitude 5.1 occurred on March 24, 1995. The epicentral zones of major earthquakes are located within the lesser Himalaya close to the Main Central Thrust (MCT) (Fig. 1), which is dominated by north-south compressive tectonics resulting from the continent-continent collision between Indian and Eurasian plates (LE FORT, 1975).

Radon is established as a useful geochemical precursor. Studies of geochemical and hydrological anomalies preceding significant earthquakes had been reported in China, Japan, Uzbekistan, Mexico, Italy, Taiwan, India and Germany (LIU *et al.*, 1984/85; IGARASHI and WAKITA, 1990; ULOMOV and MAVASHEV, 1967; SEGOVIA *et al.*, 1995; HEINICKE *et al.*, 1995; CHYI *et al.*, 2005; YANG *et al.*,

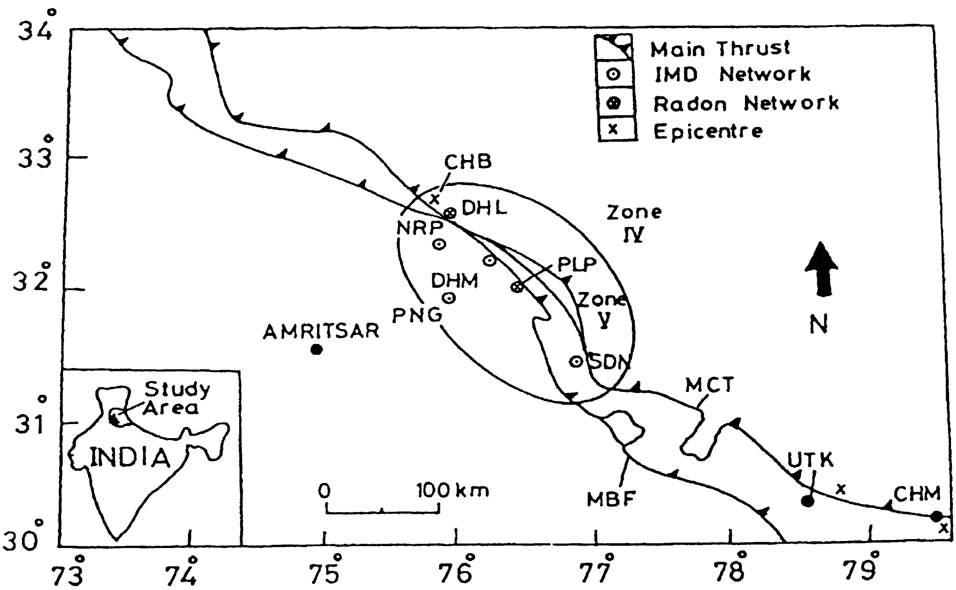

Figure 1
Radon monitoring station Palampur (PLP) and Dalhousie (DHL) together with IMD network stations, viz. Nurpur (NRP), Dharamsala (DHM), Pong Dam (PNG) and Sundernagar (SDN) and Epicenters of Uttarkashi (UTK), Chamba (CHB) and Chamoli (CHM) earthquakes.

2005,06; VIRK, 1996, 1999). However, studies of these preseismic phenomena have been controversial for several reasons (SILVER and WAKITA, 1996; WAKITA, 1996). During the last decade some highly useful data on the correlation of radon anomalies with seismic events which occurred in N-W Himalaya have been reported (VIRK, 1986, 1990, 1995; VIRK and SINGH, 1992, 1993, 1994; VIRK *et al.*, 1995,97; VIRK and SHARMA, 1997; WALIA *et al.*, 2005; RAMOLA *et al.*, 1990). Radon monitoring started in 1989 at Palampur in Kangra valley (Fig. 1) using plastic track detectors and emanometry. Radon anomalies in soil-gas and groundwater were correlated with seismic events in N-W Himalaya. The postdiction of Uttarkashi earthquake at radon network in Kangra valley encouraged us to set up 5 more stations using alpha-logger probes for continuous monitoring of radon in real time.

Helium monitoring was started at Palampur during 1997. In general helium emanates from deeper layers of the crust than radon. Hence helium is a better precursor than radon and the He/Rn ratio model is proposed to be tested in N-W Himalaya for the Chamoli earthquake.

2. Experimental Techniques

2.1 Radon Emanometry

Radon is monitored in soil-gas and groundwater by using the emanometry technique. An emanometer (Model RMS-10) manufactured by the Atomic Minerals Division, Department of Atomic Energy, India 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 instant values of radon concentration and is highly suitable for a quick radon survey.

In this method, 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 forming 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 minutes, allowing the radon to form 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 a photomultiplier tube and a scaler-counter unit.

Radon monitoring in water is also carried out by using the 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. Meteorological effects on radon emanation at Palampur have been reported elsewhere (SHARMA *et al.*, 2000). It is observed that radon emanation in water is not influenced by meteorological effects, whereas the net effect is less than 1σ in the case of soil-gas.

2.2 Helium Monitoring

A helium detector ASM 100 HDS (Alcatel, France) is a complete leak detection system. It uses a sniffing technique and comprises a helium gas analyzer with a pumping system: Molecular Drag Pump (MDP) and a set of dry pumps connected to the MDP exhaust. The main component of a helium leak detector is a spectro-cell (with sensitivity 3.10^{-4} A/mbar) which acts as a mass spectrometer. The helium ion analysis is based on the partial pressure of helium in the system; its magnitude indicates the flow rate of the helium that has been detected. It is calibrated and the logarithmic scale used to display the helium concentration in ppm. The whole operation is fully automatic and helium values from 0.1 to 10^6 ppm (100%) can be measured (Walia *et al.*, 2005). This sniffing probe technique is used for helium analysis in soil-gas from an auger hole at Palampur, using discrete sampling at a fixed site daily.

3. Helium/Radon Ratio Model

It is felt that radon alone may not be relied upon as an earthquake precursor but should be correlated with a deep origin gas-like helium. Radon coming from deeper layers of the crust may not be detectable at the surface due to its half life of 3.8 days and displays a poor intrinsic mobility with diffusion coefficient of 0.12 cm^2/s. Helium, on the other hand, is a highly mobile gas with diffusion coefficient of 1.68 cm^2/s and originates at deeper layers of the crust. It is highly stable and diffuses through interstitial spaces in rocks during strain build up prior to an earthquake. A hypothesis based on the mobility of radon and helium gases in crustal layers may prove to be more useful in earthquake prediction studies.

The various stages of the conceptual model (SHARMA, 1997) shown in Figure 2, are as follows:

(i) Under normal conditions, helium to radon ratio may have some constant value depending on the geology and meteorological conditions at the monitoring site (Segment AB).
(ii) The stresses causing an earthquake buildup around the hypocenter. During this phase, first helium is affected at deeper layers and its emanation rate increases, hence He/Rn ratio rises sharply (Segment BC.)

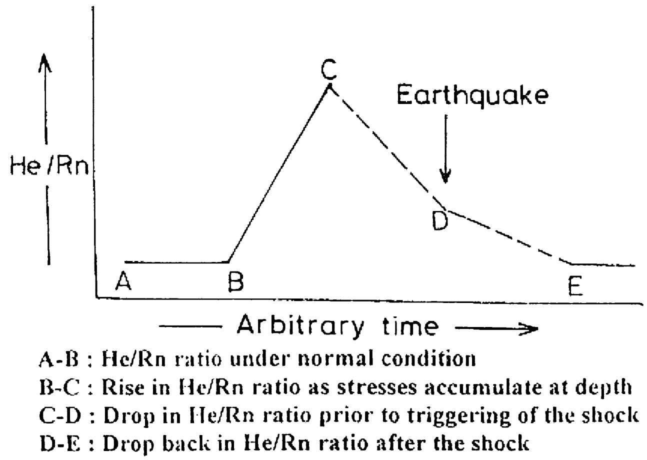

Figure 2
A conceptual model of He/Rn ratio as a predictive tool of earthquake prediction in a seismic area.

(iii) When the stress reaches upper crustal layers, radon emanation is enhanced from rocks under excessive strain and hence He/Rn ratio falls suddenly (Segment CD); this is an alarm signal for the impending earthquake.
(iv) After the quake, both Rn and He drop down to normal values (Segment DE) as the ground conditions stabilise.

After plotting helium and radon gas concentrations in soil-gas during March, 1999, a plot of helium/radon ratio (Fig. 7) is prepared after normalizing both helium and radon for the sake of comparison. As predicted, the anomaly in gas ratio, He/Rn, precedes anomalies represented by radon and helium plots (Figs. 5,6).

4. Results and Discussion

The Uttarkashi earthquake of 7.0 M_s (m_b = 6.6) with epicenter at 30.78°N, 78.80°E occurred on 20th October, 1991. A radon anomaly was recorded simultaneously in both the media on October 15 at Palampur (31.10°N, 76.51°E) which is about 293 km from the Uttarkashi earthquake epicenter, with radon activity crossing the 2σ level above the average value (VIRK and SINGH, 1994). Temporal variations of radon in soil-gas and groundwater recorded from September to October 1991 at Palampur are shown in Figure 3. The average radon values recorded by emanometry were 27.55 Bq/L and 48.86 Bq/L with standard deviations of 11.49 Bq/L and 14.89 Bq/L in soil-gas and groundwater, respectively.

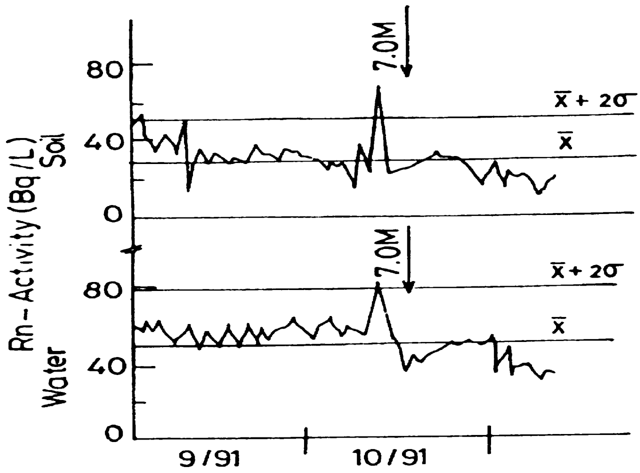

Figure 3
Radon anomalies in soil-gas and groundwater earthquake at Palampur as a precursor to the Uttarkashi earthquake.

The Chamba region was rocked by an earthquake of magnitude 5.1 M on 24 March, 1995 with its epicenter at Pliure (32.60°N, 75.91°E) nearly 7 km away from Chamba Town. The radon anomaly was recoded simultaneously in both media on 21 March, three days before the event at Dalhousie station (32.60°N, 76.00°E) which is only about 10 km from the Chamba earthquake epicenter, with peak values crossing the 2σ level above the average value of 4.52 Bq/L in soil-gas and 4.73 Bq/L in groundwater respectively (Fig. 4) (Virk *et al.*, 1995). There was another anomaly peak on March 24 followed by a sudden fall in the emanation rate after the strain was released. The simultaneous recording of radon peaks in both soil-gas and groundwater at the same site and under similar meteorological conditions before the occurrence of Chamba earthquake on 24 March established the efficacy of radon as an earthquake precursor. Further, a total of 36 microseismic events were correlated with radon anomalies at the Dalhousie station in both the media during the time window of June 1996 to September 1999 (Walia, 2001).

The Chamoli earthquake of magnitude $M_s = 6.5$ (6.8 m_b) occurred at 00:50 (IST) on March 29, 1999, with epicenter at 30.2°N, 79.5°E. The epicenters of both the Uttarkashi and Chamoli earthquakes lie along MCT (Fig. 1). The radon and helium anomalies were recorded at Palampur which is about 393 km from the Chamoli earthquake epicenter (Virk *et al.*, 2001). The average radon values recorded during 1999 at Palampur in soil-gas and groundwater were 24.31 Bq/L and 56.69 Bq/L with a standard deviation of 10.4 Bq/L and 4.66 Bq/L, respectively. Although the radon

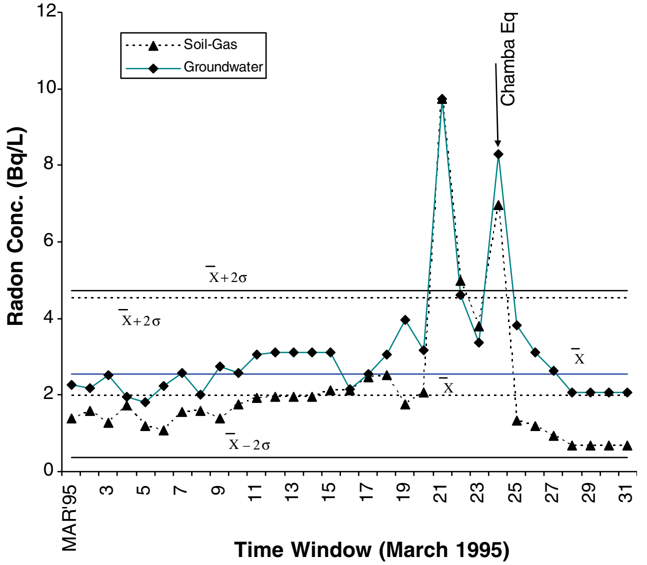

Figure 4
Radon anomalies in soil-gas and groundwater earthquake at Dalhousie as a precursor to the Chamba earthquake.

monitoring station operating during 1989–1991 is about 1 km from the present monitoring station nevertheless the average values and standard deviation do not show sizable difference i.e., only about 12% and 14%, respectively, which is reasonably good keeping in mind the considerable time difference, seasonal and

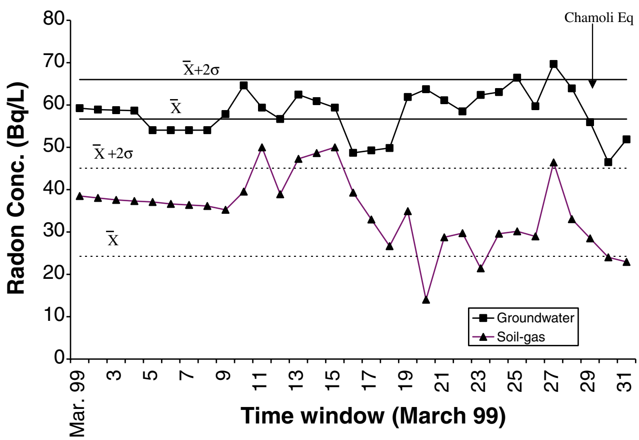

Figure 5
Radon anomaly in soil-gas and groundwater at Palampur as a precursor to the Chamoli earthquake.

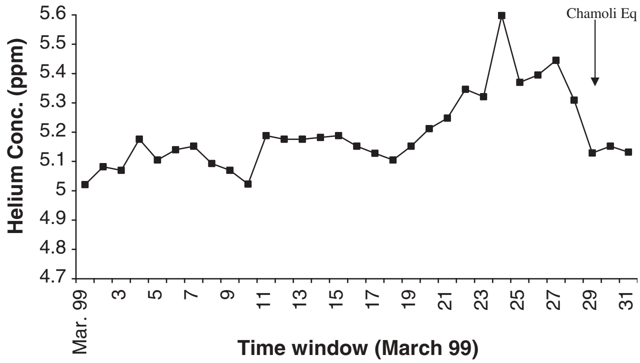

Figure 6
Helium anomaly in soil-gas at Palampur as a precursor to the Chamoli earthquake.

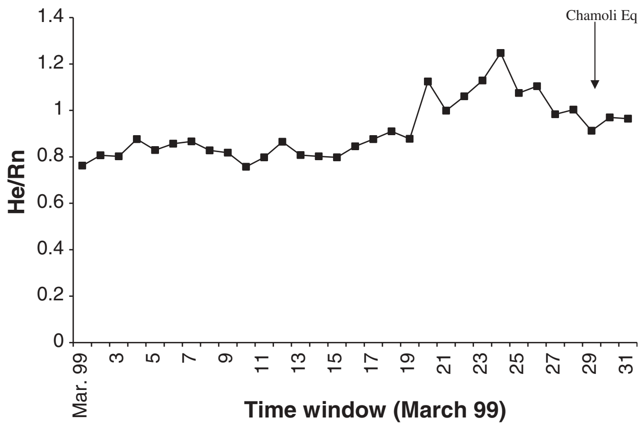

Figure 7
Helium/radon ratio anomaly in soil-gas at Palampur as a precursor to the Chamoli earthquake.

annual variations and variations due to other geodynamic activities in the area. The radon anomalies were recorded in both the media on 27 March, 1999 with the peak values of 46.63 Bq/L and 69.66 Bq/L, crossing $\bar{X} + 2\sigma$ level as shown in Figure 5, respectively. In fact, radon fluctuations in soil-gas started on 10th March with some highs and lows (Fig. 5) attaining the minimum value on 20th March and the final peak on 27th March. There are two positive and one negative radon anomalies before the main shock anomaly. These may be reflecting the stress behavior of crustal rocks before the main event.

Helium variations in soil-gas during March, 1999 are shown in Figure 6. The helium anomaly was recorded on March 24, i.e., three days before the radon anomaly and five days before the Chamoli earthquake. It clearly shows that helium is influenced by strain buildup prior to radon and due to its high mobility reaches the surface earlier than radon. The same trend is observed in He/Rn ratio (Fig. 7) which is plotted after normalizing both radon and helium data. Normalization is needed to nullify the big fluctuations i.e., about 200% in radon as compared to helium which is about 12%. As helium varies in ppm, a sizable percentage variation could not be expected from it. On March 20th there was a sharp rise in He/Rn ratio, with a peak value on March 24th, followed by a fall with minima recorded on March 29 on the day of the event. This sudden rise and then fall in the He/Rn ratio is a precursory signal for the impending earthquake which occurred near Chamoli, and a meteorological variation has not been recorded during that period. The observed trend follows the He/Rn ratio model and may be considered as a preliminary test of this time predictive tool.

In all the above three events, anomalous values were recorded in both soil-gas and groundwater almost simultaneously, which clearly indicate that the degassing system is only disturbed by the ongoing stress before the major event. Further, during the time window of June 1992 to August 1995 and June 1996 to September 1999, about 142 microseismic events with magnitudes ranging between 2.1 to 4.8 were correlated with radon anomalies at both Dalhousie and Palampur stations in both the media (WALIA *et al.*, 2003). The above study related to major events clearly indicates the efficiency of both radon and helium as precursors.

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