PERGAMON

Radiation Measurements 34 (2001) 379–384

Radiation Measurements

www.elsevier.com/locate/radmeas

Helium/radon precursory signals of Chamoli Earthquake, India

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Received 28 August 2000; received in revised form 23 November 2000; accepted 31 January 2001

Abstract

The Bhagirthi and Alaknanda valleys of Garhwal Himalaya, were rocked, respectively, by two major earthquakes: the Uttarkashi earthquake of magnitude $m_b = 6.5$, $M_s = 7.0$ on October 20, 1991 and the Chamoli earthquake of $m_b = 6.8$, $M_s = 6.5$ on March 29, 1999, during this decade. Both these seismic events are associated with ongoing deformation along the main central thrust of the Himalayas. Helium and radon anomalies on March 24 and March 27, 1999, respectively, were recorded at Palampur which is about 393 km from the Chamoli earthquake epicentre. A He/Rn ratio anomaly was recorded on March 20, 9 days before the Chamoli earthquake. The precursory nature of radon and helium anomalies is a strong indicator of the physical basis of earthquake prediction and a preliminary test for the proposed conceptual He/Rn ratio model.

Keywords: Helium; Radon; Chamoli; Earthquake

1. Introduction

The Bhagirthi and Alaknanda valleys of Garhwal Himalaya around main central thrust (MCT) in NW Himalayas are good examples of tectonically active areas. The region has suffered several major and minor earthquakes of magnitude 5–7, including the Badrinath earthquake (1803), Gangotri earthquake (1816) and the Mussoorie earthquake (1865) (Oldham, 1883). During this decade two major earthquakes have occurred in the Garhwal Himalaya: the Uttarkashi earthquake of magnitude $M_s = 7.0$ occurred on October 20, 1991 and the Chamoli earthquake of $M_s = 6.5$ on March 29, 1999. Both earthquakes (Fig. 1) were followed by severe aftershocks for many days.

Studies of geochemical and hydrological anomalies preceding significant earthquakes had been reported from China, Japan, Uzbekistan (Tashkent), Mexico, Italy, India and Germany (Liu et al., 1984/85; Igarashi and Wakita, 1990; Segovia et al., 1995; Heinicke et al., 1995; Virk, 1996). However, studies of these pre-seismic 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 the NW Himalaya have been reported (Virk, 1995; Virk and Singh, 1994; Virk et al., 1997). Radon monitoring started in 1989 at Palampur in the Kangra valley using plastic detectors and emanometry. Radon anomalies in soil-gas and groundwater were correlated with seismic events in NW Himalaya. The apparent postdiction of the Uttarkashi earthquake (Virk, 1998) at our radon network in Kangra valley encouraged us to set up five more stations using alpha-logger probes for continuous monitoring of radon in real time.Time series radon data in soil-gas and groundwater during 1992–1998 have established that more than 50% of radon anomalies are correlatable with microseismic events of 2–4*M* (Virk and Sharma, 1997).

Helium monitoring was started at Palampur during 1997. The global value of helium concentration in soil-gas is 5 ppm only. In general, helium is emanated from deeper layers of the crust than radon in the earthquake active zone during the strain build up. Hence helium is a better precursor than radon and the conceptual He/Rn ratio model

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1350-4487/01/$ - see front matter
PII: S1350-4487(01)00190-1

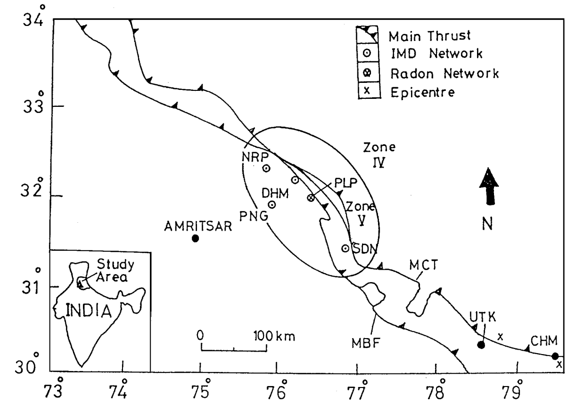

Fig. 1. Radon monitoring station Palampur (PLP) together with IMD network stations viz. Nurpur (NRP), Dharamsla (DHM), Pong Dam (PNG) and Sundernagar (SDN) and Epicentres of Uttarkashi (UTK) and Chamoli (CHM) Earthquakes.

(Virk, 1999) is proposed to be tested in NW Himalaya. To date, we have only two events, the Sundarnagar earthquake of $M_s = 5.1$ on July 29, 1997 (Virk, 1999) and the Chamoli earthquake of $M_s = 6.5$ on March 29, 1999, where both helium and radon anomalies were precursory. This suggests that helium responds to seismic events of $M \geqslant 5$ but its signatures are not visible for microseismic events of 2–4M. In fact, this is a preliminary study to test the novel idea for forecasting of earthquakes.

2. Experimental techniques

Radon is monitored in soil-gas and groundwater by using an emanometry technique. An emanometer (Model RMS-10) manufactured by the Atomic Minerals Division, Department of Atomic Energy, 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 a scintillation chamber using a closed-circuit technique (Ghosh and Bhalla, 1966). This technique gives instant values of radon concentration and is therefore highly suitable for quick radon surveys.

In this method, the auger holes, each 60 cm in depth and 6 cm in diameter, are left covered during 24 h 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, the soil-gas probe and the 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 min, allowing the radon to uniformly mix with air. The detector is then isolated by clamping both ends, and observations are recorded after 4 h 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 250 ml sample bottle. The air is circulated in the closed-circuit containing a hand-operated rubber pump, the water sampling bottle, a drying chamber and a ZnS(Ag) detector cell for 10 min. The alpha counts are recorded after 4 h during which the equilibrium between radon and its daughters is established.

A helium leak detector ASM 100 HDS (Alcatel, France) based on a sniffing technique has been used for helium analysis in soil-gas at Palampur using discrete sampling at a fixed site daily. The detector 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. In soil-gas, helium is estimated directly by a sniffing probe from an auger hole. The helium ion analysis is based on the partial pressure of helium in the system which is calibrated to yield the helium concentration in ppm. The whole operation is fully automatic and helium values from 0.1 ppm to 100% helium can be measured.

3. He/Rn ratio model

It is felt that radon abundance alone may not be relied upon as an earthquake precursor but should be correlated with a deep origin gas like helium. Radon coming from deep layers of the crust (>500 m) may not be detectable at the surface due to its short half life of 3.8 days. Helium, on the other hand consists of two stable isotopes, ^{3}He and ^{4}He with a ratio (11–14) $\times 10^{-6}$, 2×10^{-8} and 1.4×10^{-6} in the mantle, crust and air, respectively (Zhignan, 1997). ^{3}He is primordial in origin and occurs in traces in mantle-derived magma. ^{4}He is a highly mobile gas and originates at deeper layers of the crust ($\geqslant 5$ km) from the decay of U/Th series. The presence of radon and helium anomalies in geothermal springs of NW Himalaya indicates the depth distribution of radioactive elements in the deep crustal layer (Virk et al., 1998). 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 useful in earthquake prediction studies. Groundwater helium content has been used as pathfinder of fault systems and as a precursor to some of the earthquakes (Quattrocchi et al., 1999; Biagi et al., 1999). However the idea of He/Rn ratio as an earthquake precursor has never been tried before.

The various stages of the conceptual model of the mobility of He/Rn gases prior to an earthquake (Sharma, 1997) shown in Fig. 2, are as follows:

(i) Under normal stress/strain conditions, the helium to radon ratio may have some constant value depending on the geology and meteorological conditions at the monitoring site (segment AB).

(ii) Stress build up around the hypocentre, eventually causing an earthquake. During this phase, helium is affected at deeper layers and its emanation rate increases. As a result, the He/Rn ratio rises sharply (segment BC).

(iii) When the stress reaches the elastic limits before the rupture, radon emanation is enhanced from upper crustal rocks under excessive strain and hence He/Rn ratio falls suddenly (segment CD); this is an alarm signal for the impending earthquake.

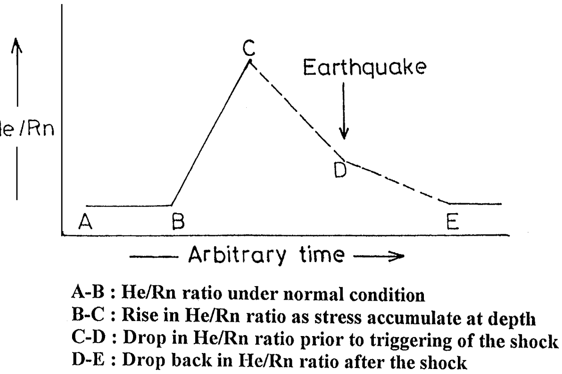

Fig. 2. A conceptual model of He/Rn ratio as a predictive tool for earthquakes in a seismic area.

(iv) After the earthquake, both Rn and He drop down to normal values after relaxation of strain as the ground conditions stabilizes (segment DE).

4. Results and discussion

The Chamoli earthquake of magnitude $6.5M_s$ occurred at 00:35.50 (IST) on March 29, 1999 with epicentre at 30.2°N, 79.5°E. The epicentre was situated about 13 km northwest of Chamoli town in the Garhwal Lesser Himalaya, with a focal depth of 15–21 km as reported by USGS/IMD (Indian Meteorological Department, New Delhi). A radon anomaly (defined as radon concentration spike crossing $\bar{X} + 2\sigma$, where $\bar{X}$ is the average value and σ, the standard deviation) was recorded simultaneously in both soil-gas and groundwater on March 27 at Palampur (32.10°N, 76.51°E) which is about 393 km from the Chamoli earthquake epicentre, with radon activity crossing the 2σ level above the average value. Temporal variations of radon in soil-gas and in groundwater recorded during March 1999 at Palampur are shown in Figs. 3 and 4. The average radon values recorded during 1999 at Palampur in soil-gas and groundwater were 24.31 and 56.69 Bq/l with a standard deviation of 10.4 and 4.66 Bq/l, respectively. The radon anomalies were recorded in both the media on March 27 with the peak values of 46.63 and 69.66 Bq/l, crossing the $\bar{X} + 2\sigma$ level (Figs. 3 and 4). In

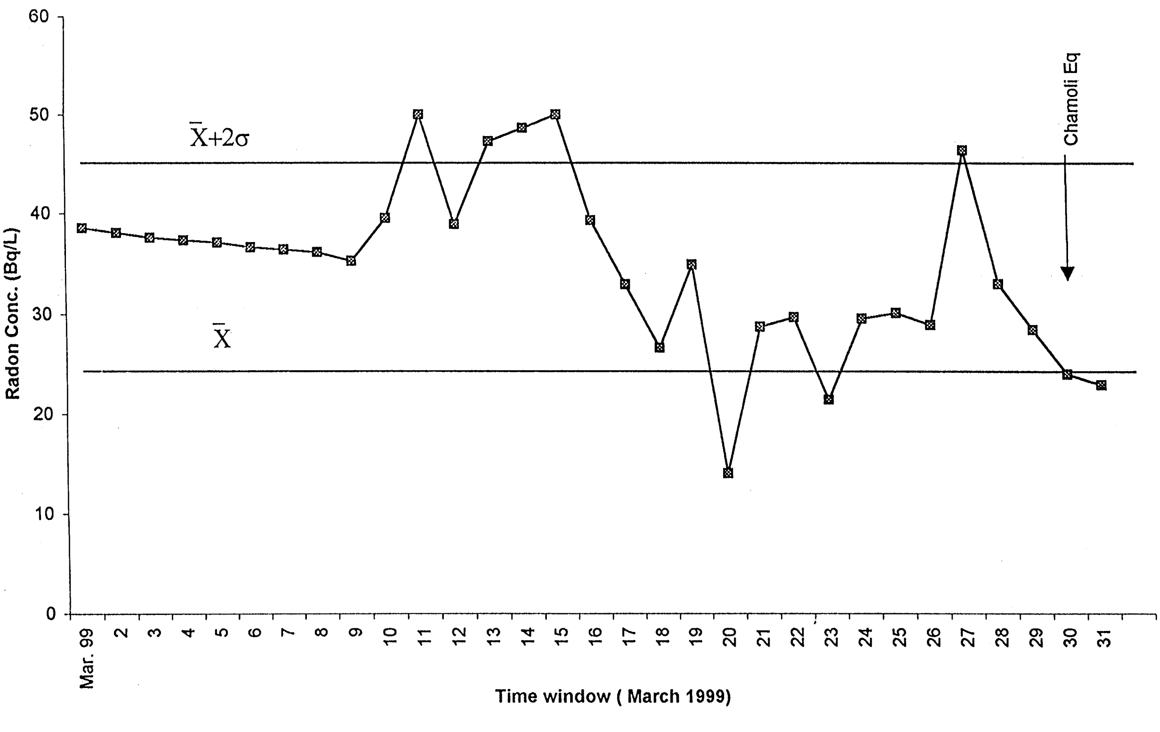

Fig. 3. Radon anomaly in soil-gas at Palampur as a precursor to Chamoli earthquake.

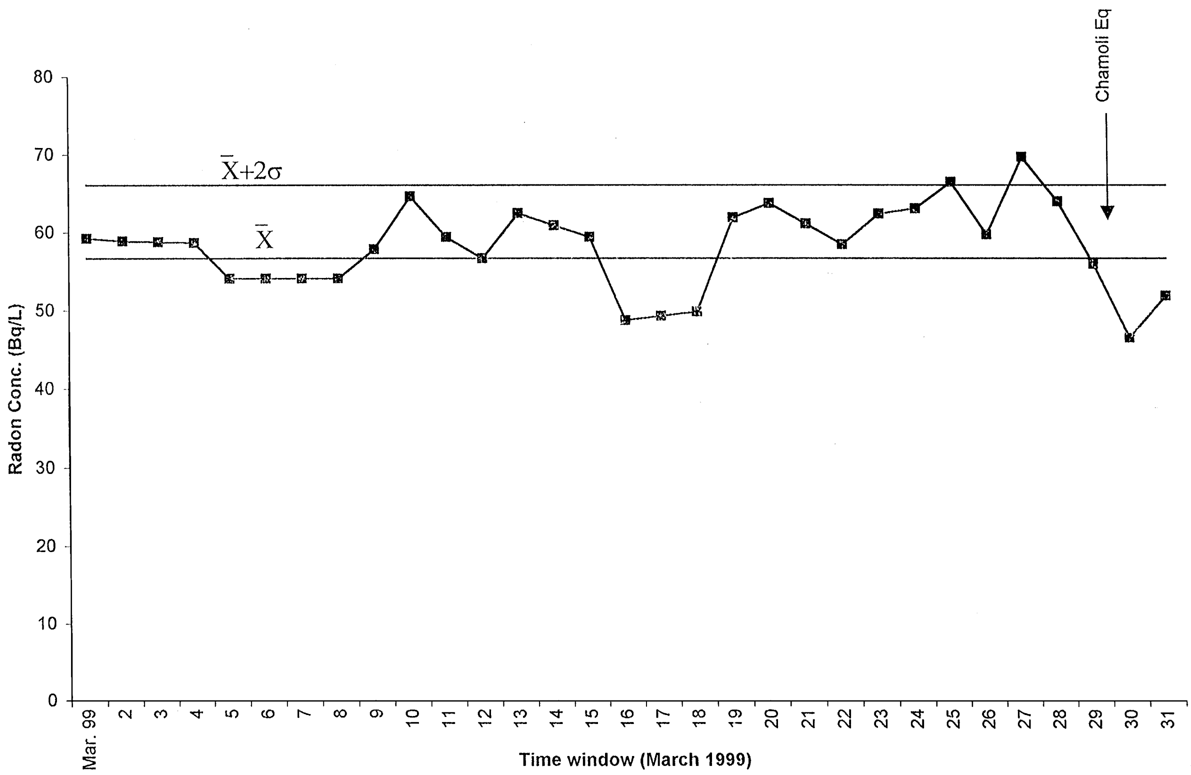

Fig. 4. Radon anomaly in groundwater at Palampur as a precursor to Chamoli earthquake.

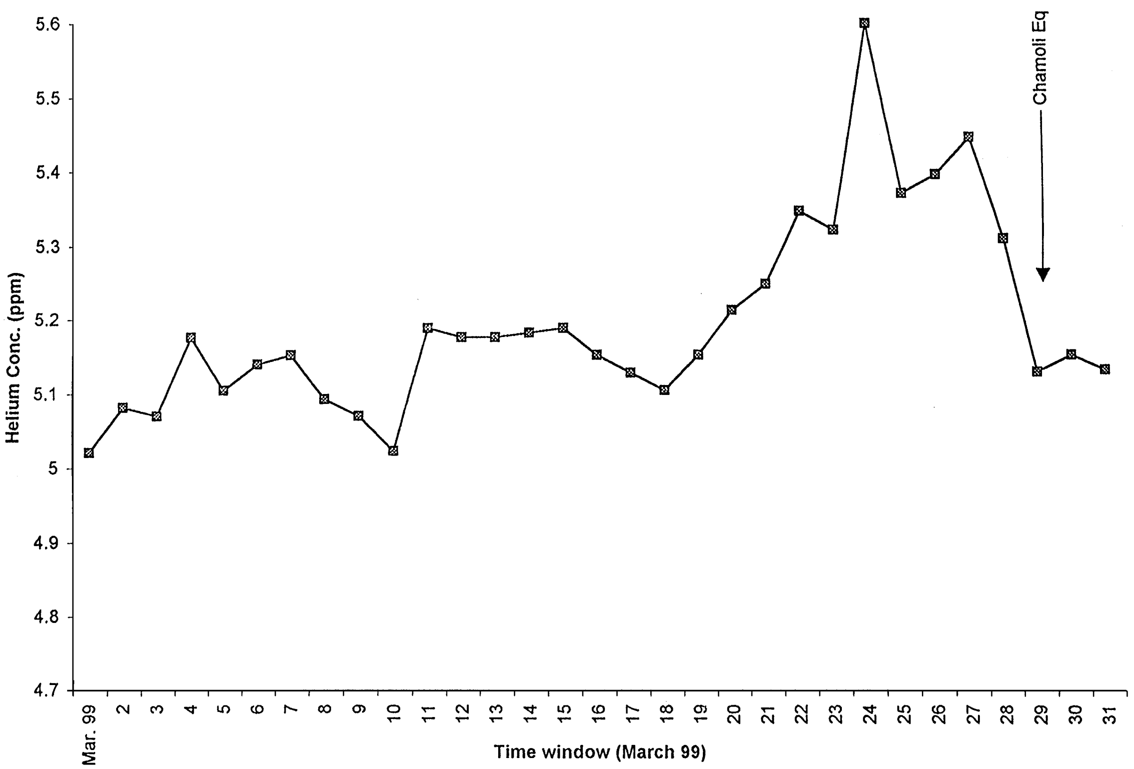

Fig. 5. Helium anomaly in soil-gas at Palampur as a precursor to Chamoli earthquake.

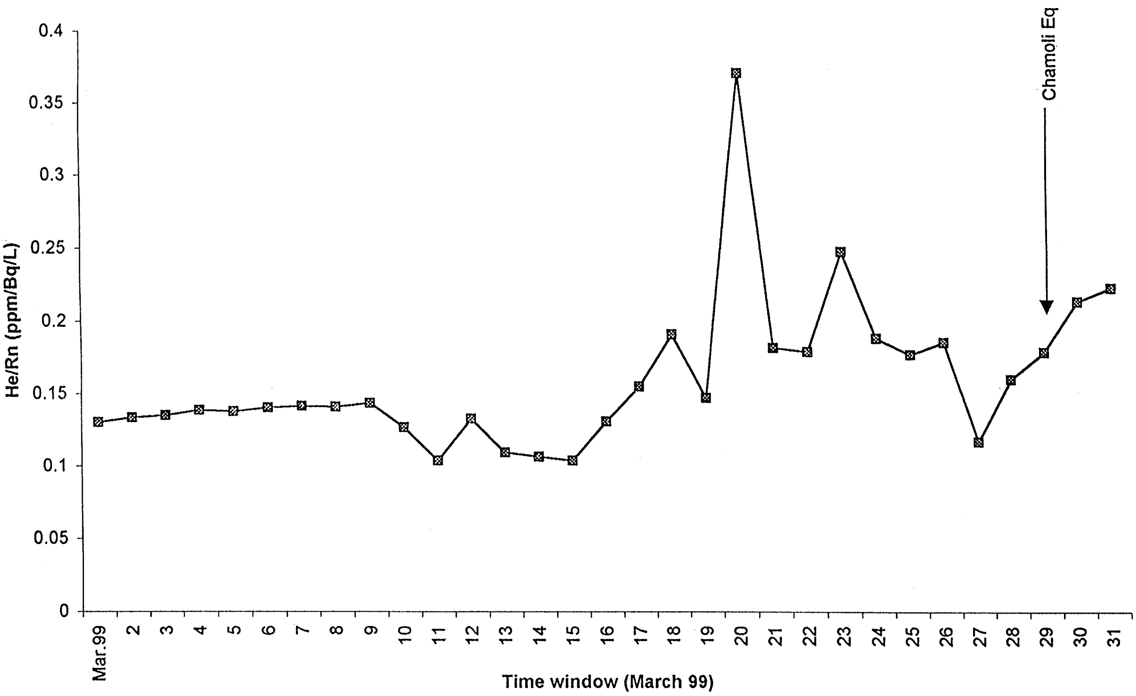

Fig. 6. He/Rn ratio anomaly in soil-gas at Palampur as a precursor to Chamoli earthquake.

fact, radon fluctuations started on March 10 with some highs and lows (Fig. 3) attaining its minimum value on March 20 and the final peak on March 27. This appears to show the stress behaviour of crustal rocks.

The epicentres of both the Uttarkashi and Chamoli earthquakes lie along MCT (Fig. 1). Helium variations in soil-gas during March, 1999 at Palampur are shown in Fig. 5. Helium concentration starts rising on March 18 and an anomaly was recorded on March 24, 3 days before the radon anomaly and 5 days before the Chamoli earthquake. This clearly shows that helium is influenced by strain build-up prior to radon. The same trend is observed in He/Rn ratio (Fig. 6). On March 19, there was a sharp rise in He/Rn ratio, with a peak value on March 20, followed by a sudden fall with a minima recorded on March 27. This sudden rise and then fall in the He/Rn ratio seems to be a precursory signal for the impending earthquake which occurred near Chamoli in Garhwal Himalaya.

The stresses causing an earthquake develop closer to the focal depth would affect the upper layers of the crust at a later phase (Fig. 2). This would increase the emanation of helium from depth while the radon emanation from the upper crust may remain unchanged. Thus a rise in He/Rn ratio is a natural consequence, which would increase progressively as the stresses build up. The continuous rise in He/Rn ratio is thus a precursory signal of an earthquake event. During the next phase when strain reaches closer to the surface, the radon emanation would also increase and He/Rn ratio would drop, which would be the alarm signal. The observed trend (Fig. 6) follows the He/Rn ratio model and may be considered as a preliminary test of this time predictive tool for future earthquake prediction.

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