GEOPHYSICAL RESEARCH LETTERS, VOL. 21, NO. 8, PAGES 737-740, APRIL 15, 1994

197

201

# Radon recording of Uttarkashi earthquake

**H.S. Virk and Baljinder Singh**
Department of Physics, Guru Nanak Dev University, Amritsar.

**Abstract.** Spatial and temporal distribution of radon is recorded in both soil-gas and groundwater using two different techniques, viz. track etch method and emanometry. Radon recording stations have been set up at one site in Amritsar and four sites in the Kangra valley (Himachal Pradesh) under the Himalayan seismicity project. The track-etch method gives integrated measurement of radon over a week or a fortnight whereas emanometry is used for daily recording of radon activity in soil-gas and groundwater.

The Uttarkashi earthquake ($m_b$ = 6.5, $M_S$ = 7.0) occurred on October 20, 1991 (Oct. 19 U.T.) in the Garhwal Himalayas (30.78°N, 78.77°E) about 330 km from our recording stations in the Kangra valley and about 450 km from Amritsar, respectively. Radon anomalies were recorded at all sites in Kangra valley and Amritsar about a week before the Uttarkashi earthquake, which clearly establishes that radon changes can be effective for forecasting some earthquakes.

## Introduction

Since the first observation of changes in the radon concentration of groundwater prior to 1966 Tashkent earthquake (*Ulomov and Mavashev*, 1967), these changes have been considered to be a plausible precursory earthquake phenomenon. Observations of radon in soil-gas and groundwater generally show some fluctuations. These have been widely studied and interpreted as a function of meteorological variables, sub- soil changes or both (Steele et al., 1982; Singh et al., 1988a).

Recent reports dealing with the measurement of radon concentrationin 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*, 1986; 1990; *Virk and Singh*, 1992). Anomalous changes in sub-surface radon concentration may be expected at a distance of a few hundred kilometers from the hypocenter according to the two models (*Dobrovolsky et al.*, 1979; *Fleischer*, 1981) that, interestingly, lead to the similar prediction of the relation between earthquake magnitude and maximum distance for detection of premonitory signals.

In this paper results of radon measurements in soil-gas and groundwater using two different techniques are reported for correlation with the Uttarkashi earthquake of 6.6 $m_b$ which occurred on October 20, 1991 in India. Anomalous changes in radon concentration were observed at recording stations at Palampur, Andretta, Chamunda Devi and Dharamsala (Fig. 1) in Kangra valley of Himachal Pradesh and at Amritsar (Punjab).



Paper number 94GL00310
0094-8534/94/94GL-00310$03.00

## Radon Measurement Techniques

The radon concentration in soil gas and groundwater was measured using instantaneous and time-integrated techniques. The detectors used for radon emanation employed ZnS(Ag) scintillator and plastic track detectors, respectively.

## Radon Monitoring in Soil-gas

For measuring radon in soil-gas auger produced holes are left covered for 24 hours; the same holes being used daily for radon monitoring. An emanometer is used to measure the alpha emission from radon in the gas fraction of a sample by pumping the gas into a scintillation chamber using a closed-circuit technique (Fig. 2) (*Ghosh and Bhalla*, 1966). The alpha particles emitted from the decay of radon impact the scintillator ZnS(Ag) creating an energy pulse in the form of photons and these photons are recorded by scintillation assembly consisting of PMT and scaler unit.

An integrated soil-gas radon concentration over weekly time intervals is inferred from alpha particle tracks determined through the use of a commercially manufactured nitro-cellulose plastic film (LR-115 Type II). Radon-Thoron discriminator (Fig.3) (*Singh et al.*, 1984; *Ghosh and Soundrarajan*, 1984) containing strips of film is placed into the shallow holes 60 cm in depth which are then covered tightly for protection against surface water etc. The films are replaced at weekly intervals and are chemically processed to enlarge the damage zone caused by alpha particle interaction. The tracks are counted within an area of 1cm$^2$ for density measurements. The measured track density is assumed to be proportional to the average radon concentration of the soil-gas during the period of measurement.

## Radon Monitoring in Groundwater

The groundwater sample is collected daily from a 'bauli' (natural spring) in a sample bottle. A closed-circuit technique is used to collect the gas that has passed through the water sample in the ZnS(Ag) detector cell (*Ghosh and Bhalla*, 1966) as follows : The air is circulated in the closed-circuit containing a hand-operated rubber pump, a water sample bottle, a drying chamber and a ZnS(Ag) detector cell for 10 minutes (Fig. 2). The counts are recorded

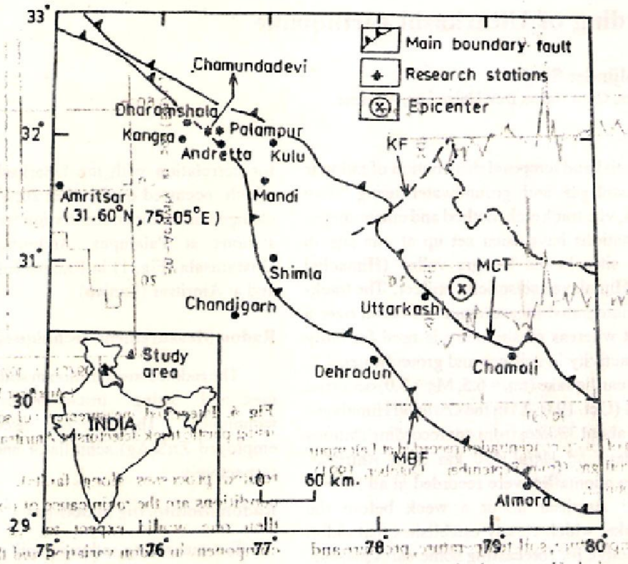


**Fig. 1.** Map showing recording stations, earthquake epicentre, major thrusts (MCT) and faults (MBF) in the Himalayas. Inset shows the study area in Kangra valley of Himachal Pradesh.

after four hours during which the equilibrium between radon and its daughters is established (*Singh et al.*, 1986).

**Results and Discussion**

Daily measurements of radon in soil-gas and groundwater have been recorded at Palampur since 1989 using the ZnS(Ag) detector. The average value from daily measurement of radon concentration from soil- gas and groundwater is 27,500.25 and 48,860.30 Bq/L with standard deviations of 11.49 and 14.89 Bq/L, respectively. The weekly measurements since January 1991 at Dharamsala, Chamunda Devi, Palampur, Andretta and Amritsar give average values 55.290.30, 13.700.30, 28.480.30, 9.250.30 and 23.500.30 Bq/L with standard deviation 38.17, 11.87, 25.81, 12.14 and 17.21 Bq/L, respectively. The large variation may be due to different radon sensitivities of the monitoring sites.

An empirical criterion is here adopted to define the radon anomaly as the positive deviation that exceeds the mean radon level by more than twice the standard deviation measured over a given interval of time.

Temporal variations in soil-gas and groundwater at Palampur from September to October 1991 are shown in Fig. 4. A radon anomaly was recorded simultaneously in both soil-gas and groundwater on October 15, 1991 with radon concentration about 154 % and 68 % above the mean that was measured by emanometry. Weekly integrated data also showed abnormal behaviour during first week of October, 1991 at recording stations of Palampur, Andretta and Chamunda Devi; while at other stations, viz. Dharamsala and Amritsar, the abnormal behaviour was recorded during second week of October, 1991 (Figs. 5 & 6). Except for high wind velocity and low humidity no unusual behaviour was noticed in other meteorological parameters, viz. maximum

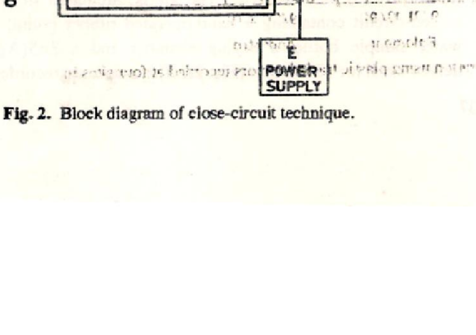


**Fig. 2.** Block diagram of close-circuit technique.

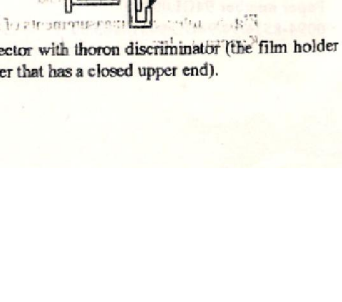


**Fig. 3.** Radon detector with thoron discriminator (the film holder slides into a cylinder that has a closed upper end).

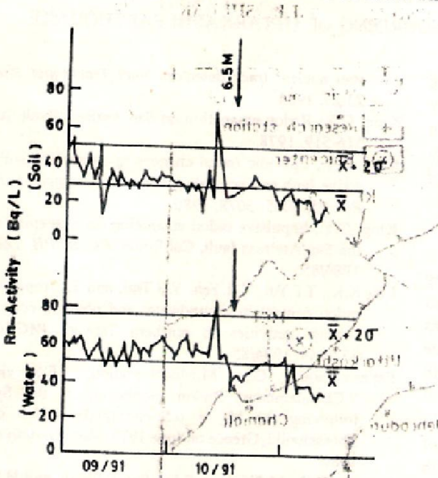


Fig. 4. Daily variation of radon concentration recorded at Palampur in groundwater and soil-gas (from September - October, 1991), using a scintillation counter.

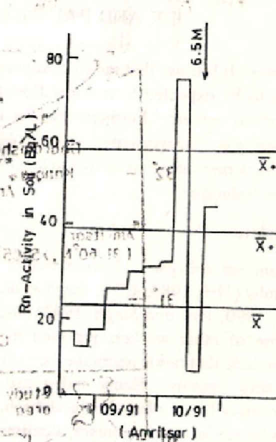


Fig. 6. Integrated measurements of soil-gas radon concentration using plastic track detectors at Amritsar.

and minimum air temperature, soil-temperature, pressure and rain-fall during that period. However, in the past the over-all increase in radon concentration due to these parameters is always less than x1σ . This recorded anomaly may be correlated with a severe earthquake of 6.5mb in Uttarakashi area (30.78°N, 78.77°E) of Garhwal Himalayas in Uttar Pradesh, India. The focal depth of this earthquake was around 19 km.

The research stations in Kangra valley are located within 10 km of main boundary fault(MBF) in the Himalayas, and the research station at Amritsar about 150 km away from MBF. The variations in radon emanation may depend on changes in atmospheric (meteorological) and sub-crustal conditions (geological conditions and some earthquake related processes along faults). If changes in weather conditions are the main cause of observed radon anomalies, then one would expect to see a significant seasonal component in radon variation and this component would be synchronous throughout the study area because the climatic conditions of the area are nearly uniform.

The increase in radon content is connected with the amount of porosity of rock and therefore is sharply increased and then decreased before the earthquake due to closure of small pores. The observed radon anomalies in soil-gas and groundwater are similar and may be explained by dislocation model proposed by *Fleischer* (1981). Near the surface of the Earth, compression will force upward flow of the radon in the pore spaces and tension will produce downward flow. Because of its short half life, transferral of radon over long distances is not possible. But stress in an elastic body will produce strains everywhere, the maximum being at the

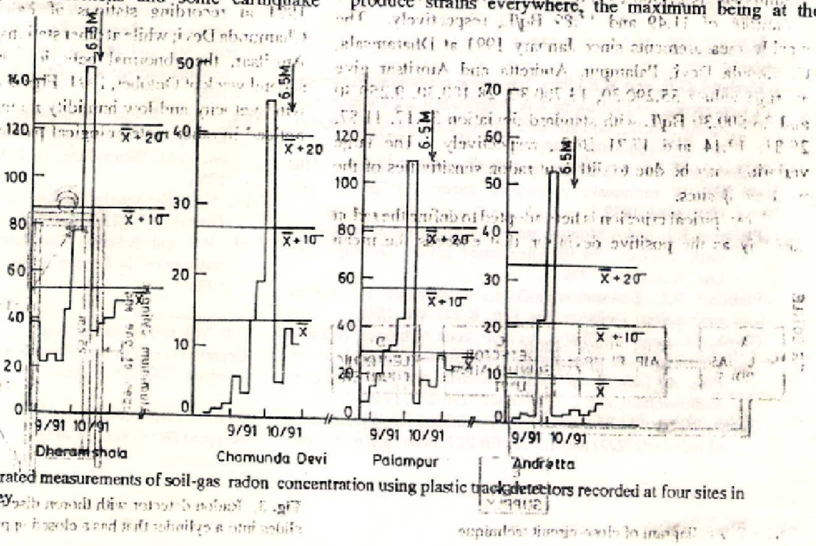


Fig. 5. Integrated measurements of soil-gas radon concentration using plastic track detectors recorded at four sites in Kangra valley.

hypocenter. It follows that radon changes at the monitoring sites are to be expected from local flow that is caused by distant stress centers. Furthermore, the large variation in daily soil-gas emanometry radon data and weekly etched-track measurements is due to the integrating nature of the latter technique.

## Conclusions

1. From our soil-gas and groundwater radon monitoring results (*Virk*, 1986, 1990; *Singh et al.*, 1988; *Ramola et al.*, 1990; *Virk and Singh*, 1992) since 1984 as well as those of other workers reported in the literature, we conclude that radon anomalies are often associated with seismic activity. Hence radon can serve as a useful precursor for earthquake prediction.
2. To be useful as a precursor, continuous monitoring of radon both in soil-gas and in groundwater, along with other environmental factors at several monitoring sites in a grid pattern along the Main Boundary Fault is useful, as faults are the paths of least resistance along which terrestrial gases generated or stored in the Earth can escape into the atmosphere.
3. Simultaneous occurrence of radon anomalies in both soil-gas and groundwater augers well for accepting radon as an earthquake precursor even though peak radon concentrations are widely different in both media. Another positive point of our study is that radon anomalies are recorded using two different monitoring techniques and that the two methods agree.
4. The simultaneous recording of radon anomalies at different recording stations is a strong indicator of the physical basis of earthquake prediction. The radon recording of the Uttarkashi earthquake a few days before the occurrence of the event is a unique achievement in our efforts to establish the efficacy of radon as a useful precursor.

## References


Birchard, G.F., and W.E.Libby, Soil radon concentration changes preceding and following four magnitude 4.2-4.7 earthquakes on the San Jacinto Fault in Southern California. *J. Geophys. Res. 85*, 3100-3106, 1980.

Dobrovolsky, I.P., S.O.Zubkov, and V.I.Miachkin, Estimation of the size of earthquake preparation zones. *PAGEOPH, 117*, 1025-1044, 1979.

Fleischer, R.L. and A.Mogro-Campero, Radon enhancement in the earth: Evidence for the intermittant upflow. *Geophys. Res. Lett., 6*, 361-364, 1979.

Fleischer, R.L., Dislocation model for radon response to distant earthquakes. *Geophys. Res. Lett., 8*, 477-480, 1981.

Ghosh, P.C., and N.S.Bhalla, A close-circuit technique for radon measurement in water and soil, with some of its applications. *Proc. All India Symp. on Radioactivity and Meteorology of Radionuclides*, A.E.E.T., Bombay, 226-239, 1966.

Ghosh, P.C., and M.Soundararajan, A technique for discrimination of radon (Rn-222) and thoron (Rn-220) in soil gas using solid state nuclear track detectors. *Nucl. Tracks and Rad. Meas. 9*, 23-27, 1984.

King, C.Y., Radon emanation on San Andreas Fault. *Nature 271*, 516-519, 1978.

King, C.Y., Episodic radon changes in subsurface soil-gas along active fault and possible relation to earthquakes. *J. Geophys. Res. 85*, 3065-3078, 1980.

King, C.Y., Impulsive radon emanation on a creeping segment of the San Andreas fault, California. *PAGEOPH, 122*, 340-352, 1984/85.

Liu, K.K., T.F.Yui, Y.H.Yeh, Y.B.Tsai, and T.L.Teng, Variation of radon content in groundwater and possible correlation with seismic activities in northern Taiwan. *PAGEOPH, 122*, 231-244, 1984/85.

Papastefanou, C., M.Manolopoulou, E.Savvides, and S.Charalambous, Radon monitoring at the Syivos fault following the $M_L$ = 6.5 earthquake which occurred at Thessaloniki, Greece on June 1978. *Nucl. Geophys., 3*, 49-56, 1989.

Ramola, R.C., M.Singh, A.S.Sandhu, S.Singh, and H.S.Virk, The use of radon as an earthquake precursor. *Nucl. Geophys. 4*, 275-287, 1990.

Singh, M., N.P.Singh, S.Singh, and H.S.Virk, Radon-thoron estimation in soil using LR-115 plastic track detector. *Nucl. Tracks and Radiat. Meas. 8*, 415-418, 1984.

Singh, M., R.C.Ramola, S.Singh, and H.S.Virk, Influence of meteorological parameters on soil gas radon. *J. Assoc. Expol. Geophys., 9*, 85-90, 1988a.

Singh, M., R.C.Ramola, N.P.Singh, S.Singh, and H.S.Virk, Measurement of soil gas radon at Amritsar. *Geophys. Res. Bull., 26*, 8-12, 1988b.

Steele, S.R., Anomalous radon emanation at local and regional distances preceding earthquakes in the New Madrid seismic zone and adjacent areas of the Central Mid Continent of North America, 1981-84. *PAGEOPH, 122*, 353-368, 1984/85.

Steele, S.R., W.C.Hood, and J.L.Sexton, Radon emanations in the New Madrid seismic zone, Investigations of New Madrid, Missouri, earthquake region, edited by. F.A.McKeown, and L.C.Pakiser, *U.S. Geol. Surv. Prof. Paper 236*, 191-201, 1982.

Teng, T., L.Sun, and J.L.McRaney, Correlation of groundwater radon anomalies with earthquakes in the Greater Palmdale Bulge area. *Geophys. Res. Lett., 8*, 441-444, 1981.

Ulomov, V.I. and B.Z.Mavashev, On fore-runners of a strong tectonic earthquakes. *Dokl. Acad. Sci. USSR, 176*, 319-322, 1967.

Virk, H.S., Radon monitoring and earthquake prediction. Earthquake Prediction - Present Status, edited by S.K. Guha and A.M. Patwardhan, pp.157- 162, Univ. of Puna, Pune, 1986.

Virk, H.S., Earthquake forecasting using radon signals. *Physics Education 7*, 221-228, 1990.

Virk, H.S and B.Singh, Correlation of radon anomalies with earthquakes in Kangra valley. *Nucl. Geophys. 6*, 293-300, 1992.


---

H.S. Virk and Baljinder Singh,
Department of Physics, Guru Nanak Dev University,
Amritsar - 143 005, India.

(Received November 3, 1993;
accepted December 3, 1993)