Systematic radon survey over active volcanoes (*)

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Summary. — In-soil radon-222 monitoring has been conducted on active volcanoes, in particular on the Arenal, Irazu and Poas volcanoes in Costa Rica and on the Piton de la Fournaise volcano, La Réunion island. Automatic electronic probes buried in soil at one meter depth were used to study the short- and long-term fluctuations of radon related to the external parameters and/or related with the volcanic activity. Three radon stations are in operation on each Costa Rican volcano and a network of 24 stations (with 3 teletransmitted) is operated on the Piton de la Fournaise.

Data obtained since 1993 on Costa Rica volcanoes are presented and radon anomalies recorded before the December 8, 1994 eruption of the Irazu volcano are discussed. The Piton de la Fournaise volcano is inactive since mid 1992. We could intensively study the influence of the external parameters on the radon behavior and individuate the type of perturbations induced on short-term measurements. One seismic crisis occurred on November 27, 1996. Radon anomalies appear on most of 50% of the stations 36 hours before the occurrence of the crisis.

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1. – Introduction

As radon-222 is now recognized as one of the possible geochemical tracers of the volcanic activity (Seidel *et al.*, 1988; Thomas, 1989), we carry out large radon surveys over active volcanoes, principally in North and Central America (Mexico and Costa Rica) and on the French active volcanoes (La Soufrière de la Guadeloupe and Le Piton

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de la Fournaise volcanoes). The first aim of this study is to figure out in various types of volcanoes the basic relationship between the variation of the in-soil radon concentrations and fluxes with the volcanic activity. The advantage of the new operated techniques lies upon the fact that real-time and high-time-resolution probes are now available. The collected data have to be correlated with geophysical and geochemical data obtained by others groups working on the volcanoes in the same time. The atmospherical parameters also have to be monitored on the same place for determining their influence on in-soil radon behavior and for discriminating anomalies due to exogenous factors to those originating from endogenous ones.

2. – Technique

Since 1993, we substitute the real-time detection technique to the Solid State Nuclear Tracks Detectors (SSNTD) technique using laboratory-made probes called Clipperton probes. This electronic automatic probe is based on an alpha silicon diode detector associated with electronic, data processing and storage units of low consumption (4 alkaline batteries LR20). The detecting area is 1 cm^2. The detector is protected from moisture effects by means of a waterproof polymeric epoxy-layer deposited at the edges of it. The pulse processing electronics includes integrated pre-amplification and amplification and discrimination sub-units. The recorded countings are stored in a RAM memory. The memory can store up to 3250 data value and their identification labels. Both the α-particle sensor and the above-described electronics are installed in the body of the probe which is a cylinder fabricated from carbonfiber-polyester composite having a diameter of 5 cm and an overall length of 50 cm. A humidity and rain proof external box contains the 4 batteries and is placed at a location easily reached by the operator. With such batteries, the probe can be safely operated in the field for two months. The external box allows instructions to be given to the device and the retrieval of data and operating information from it. This plug can be connected either to a PSION Organizer II (or any other type of the PSION series) palm computer, or to a PC laptop. For the sensitivity, the conversion factor has been found to be: 0.007 ± 10^{-4} count $\cdot\, h^{-1}/Bq \cdot m^{-3}$.

3. – Field experiments

3·1. *Irazu volcano* (*Costa Rica*). – Since 1993 we substitute the Clipperton probes to the SSNTD technique. The Arenal, Irazu and Poas volcanoes were respectively equipped with 3 probes, generally located on structural features as faults or cones or small craters alignments). The stations are actually operated by the staff of the Volcanological and Seismological Observatory of Costa Rica and the data are monthly retrieved.

The Irazu volcano is localized on the Central Volcanic Cordillera of Costa Rica. Its last eruptive cycle began in 1962 and finished in 1965. It was characterized by small eruptions with some of Strombolian type. Since January 1991, the seismic activity increased with numerous seisms of tectonic origin, whose epicenters are mainly concentrated on the South-East part of the volcano. On December 93, we installed the Clipperton probes on the volcano. Station 1 is located on an E-W pyroclastic cones alignment, station 3 is located on the N10-20W regional fault which crosses the volcano and station 5 is located over the western rift of the volcano, on a pyroclastic cones

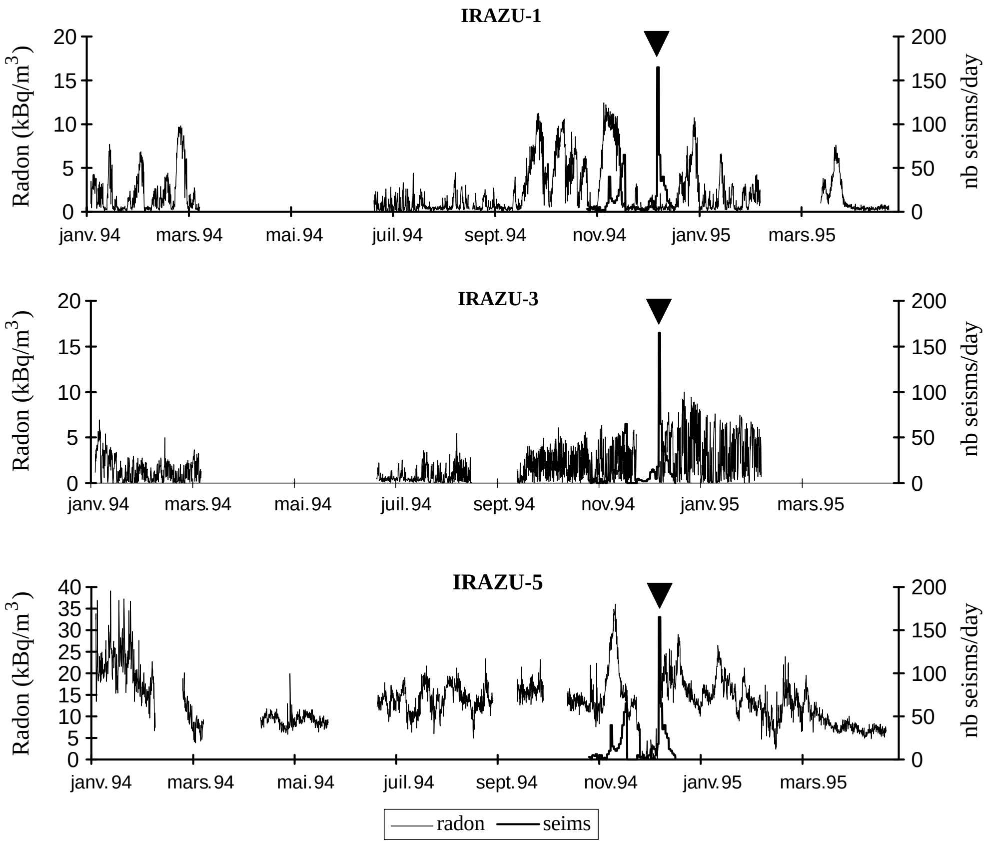

Fig. 1. – Irazu (Costa Rica); radon time series of stations 1, 3 and 5 and seismicity (number of events/day). The phreatic eruption is indicated by the arrow.

alignment where the last lava flow was emitted. The volcano is also equipped with several seismic stations and one meteorological station. Hourly radon time series of the three stations are reported in fig. 1 together with the recorded seismic activity (number of seisms per day) from January 94 to April 95. During this period, a phreatic eruption occurred on December 8, 1994, indicated by an arrow on the figure.

Stations 1 and 3 radon concentration averages (2.11 ± 0.17 and 1.90 ± 0.12 $kBq \cdot m^3$, respectively) are quite similar but much lower than station 5 average (13.59 ± 0.37 $kBq \cdot m^3$). The uranium content of the soils, 1 ppm for stations 1 and 5 and 2 ppm for station 3, cannot explain the higher concentration of station 5. The difference can be attributed to the structural environment of each monitored site. Even if stations 1 and 3 are located on faults, their radon behavior (fig. 2) appears to be principally influenced by the precipitations and the resulting permeability changes of the soil and indicates a diffusive gas flux conditions (Baubron, 1995). Station 5 is located on the main western rift of the Irazu volcano. The radon behavior of this site (fig. 2) does not show any correlation with rainfalls. The radon increase beginning on November 7 is correlated with the seismic activity (see fig. 2) which precedes the phreatic eruption of December 94.

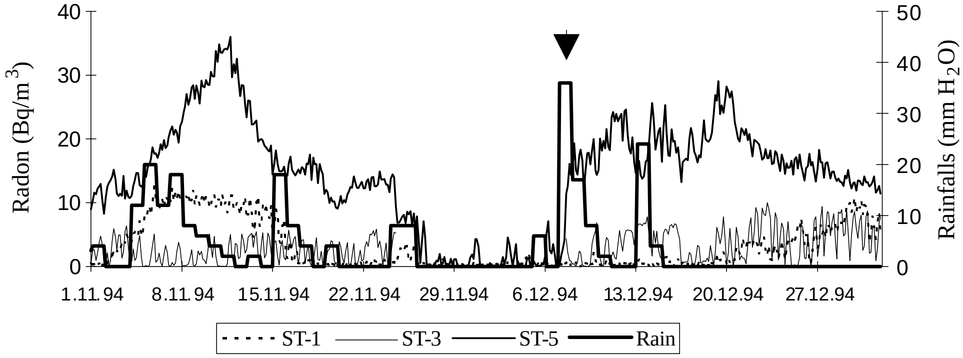

Fig. 2. – Irazu (Costa Rica); radon time series of stations 1, 3 and 5 and daily rainfalls from November 94 to January 95.

3·2. *Piton de la Fournaise volcano* (*La Réunion Island*). – The Piton de la Fournaise volcano is an active basaltic shield volcano located in an intra-plate environment. It is considered as one of the most active volcanoes in the world (Bachelery *et al.*, 1982). Radon monitoring was initiated on 1983 using the SSNTD technique and we correlated in-soil radon anomalies with the volcanic activity in 1984 and 1985 (Seidel *et al.*, 1988). In the frame of the European Volcanological Project the opportunity was given us to substitute the real-time measurement technique to the SSNTD one for the monitoring of gas emanations from the soils. A network of 24 Clipperton stations was set up on the summit area. The sampling time is chosen to one hour and to one minute for the three teletransmitted ones. As the volcano was in a

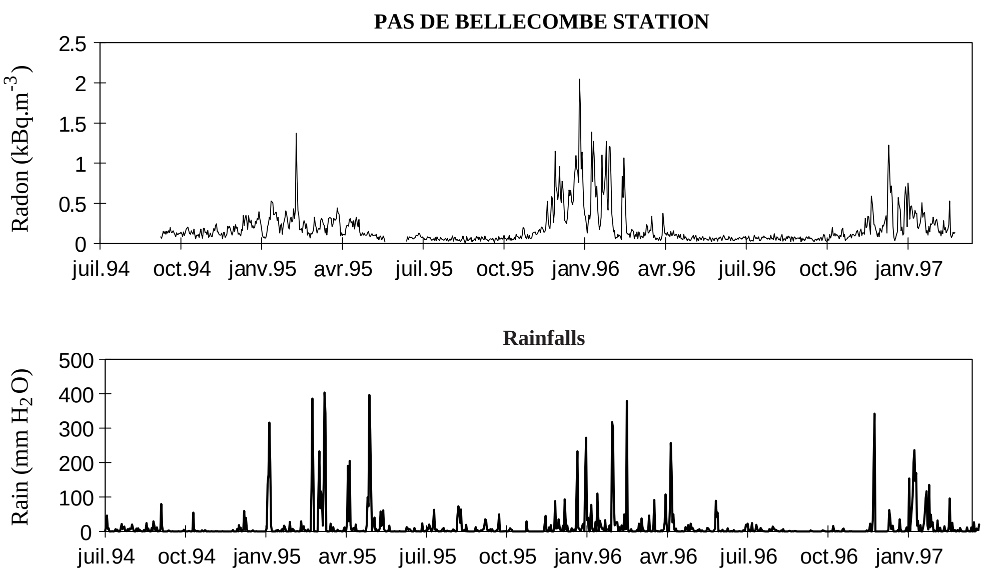

Fig. 3. – Piton de la Fournaise (La Réunion Island); radon time series of station Pas de Bellecombe and daily rainsfalls from July 94 to January 97.

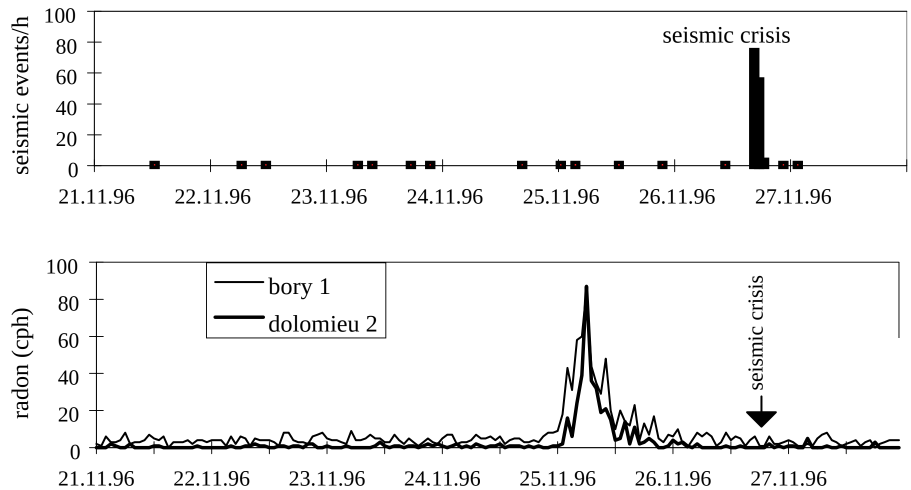

Fig. 4. – Piton de la Fournaise (La Réunion Island); radon anomaly preceding the November 26, 1996 crisis.

quiescence phase since 1992, we were able to determine the natural variability of the Rn-222 activity (background) and to characterize the influence of the external factors (barometric pressure, atmospheric temperature and rainfalls) with a predominant influence of the precipitations (fig. 3). Even if the volcano remains in a quiet phase, a seismic crisis has occurred on November 26, 1996 and was preceded by positive radon anomalies which appeared 36 hours before the crisis on more than 30% of the stations (fig. 4). No rain was registered during the considered period and the radon increase can be induced by a deeper gas flow forecasting the seismic crisis (Ricard *et al.*, 1997).

4. – Conclusion

Radon studies performed in the field of volcanic surveillance have demonstrated the need for continuous measurement in the field over rather large periods of time. In-soil radon time series obtained in zones of volcanic gas circulation give useful information concerning the evolution of volcanic activity. Even if in-soil radon variations are influenced by exogenous factors, radon gas monitoring achieved in convective zones can be considered as a geochemical forerunner of volcanic activity.

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