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A RADON MEASURING NETWORK TO STUDY RADON ANOMALIES AS PRECURSORS OF STRONG EARTHQUAKES IN THE GUERRERO SEISMIC GAP

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ABSTRACT

The subduction of the Cocos plate under the North-America plate defines a high risk seismic zone along the Pacific coast of Mexico. Soil radon determinations, with passive and active detectors, have been performed in the area. The results indicate that the response of the passive detectors, due to their long exposure time in the field, can mask possible radon anomalies related to single earthquakes. Since the zone is characterized by a high seismicity, active detectors that record information in a short term basis are expected to eliminate this specific problem. A telemetric transfer of the radon signal recorded by the active detectors is proposed using a cellular telephone system.

KEYWORDS

Soil radon; passive and active detector; seismicity; telemetric transfer.

INTRODUCTION.

Over the last three decades a large number of geophysical and geochemical surveys have been carried out in many countries with high seismic activity in order to predict earthquakes. The behaviour of ground and water gases has been studied. Among them, ^{222}Rn has been the most intensively investigated because its variations in concentration appear to be a good indicator of a forthcoming earthquake, after a long or short delay.

^{222}Rn is a member of the Uranium decay series. Uranium is present in all rocks of the Earth's crust and so consequently is ^{222}Rn. Due to its alpha radioactivity and half-life (3.8 days), ^{222}Rn can easily be detected and measured even when present in minute amounts, down to 10^{-20} atom/atom. One must say in addition that the two other isotopes of Rn, ^{220}Rn (thoron) and ^{219}Rn (actinon) are of no geochemical interest up to now because of their very short life times (55 sec and 4.0 sec respectively). Experimental studies of seismo-chemical precursor mechanisms have shown that the geochemical anomalies are related to elastic and plastic deformation of the rocks when they are submitted to heavy stress and to the motion of the plates before the seismic events. Similarly it has been observed that before a seismic event the average ^{222}Rn content changes (Monnin and Seidel, 1992). The occurrence of short and long term ^{222}Rn anomalies in soil and ground water related to large geophysical events have been observed and sustained by theoretical models. However it is neither a mutually exclusive nor a biunivocal relationship. In other words, ^{222}Rn anomalies that were not followed by earthquakes have been observed, as well as earthquakes not preceded by ^{222}Rn anomalies.

Nevertheless it must be said that the occurrence of a ^{222}Rn anomaly with an earthquake is more frequent than non-correlated events. In addition, the number of correlated events recorded increases with the improvement of measurement techniques at both field and equipment levels. Similarly, correlations are found to be more common in fault zones where the fluid transport towards the surface is facilitated, and when the ^{222}Rn monitors are located at a distance from the epicentre which is comparable to the rupture area of the seism (Segovia et al., 1989). However, the variation of the environmental parameters has to be recorded in order to screen out possible non-tectonic factors (Segovia et al., 1995a) that may affect ^{222}Rn readings (*e.g.* rainfall, atmospheric pressure, temperature, moisture,...).

The subduction of the Cocos Plate under the North America Plate defines a high risk zone along the Pacific coast of Mexico. A seismic gap has been identified at the Guerrero state, where a large earthquake (up to Ms=8.2) is likely to occur within the next years (Singh and Mortera, 1991). During several years, an in-soil ^{222}Rn network has been operated with passive detectors along the Pacific coast (Segovia et al., 1995b). However, since the monitoring is performed with an exposure time of one month, the integrated results do not show possible anomalies of shorter duration that have possibly occurred in the meantime. Also, one of the main problems related to the monitoring of such an extended zone is that the passive detectors have to be picked up periodically before the information being analysed. Accordingly, continuous radon probes have been installed at the Acapulco station.

It is intended to report here some recent results of soil ^{222}Rn obtained at the Guerrero seismic zone and the possibility of telemetrically transfer the radon signal measurements from the continuous radon probes to the main laboratory, in order to analyse the possible anomalous ^{222}Rn behaviour on a quasi-real time basis.

METHODS.

Solid State Nuclear Track Detectors

The easiest way to record the alpha-radioactivity from ^{222}Rn is by means of solid state nuclear track detectors (SSNTD). The SSNTD that was used in this work is a sheet of cellulose nitrate polymer. When a charged particle enters such a material it produces a damage trail which may last for several months under normal conditions. When etched in a suitable manner a preferential etching occurs along the damage trail. It produces at last an empty channel, often referred to as a "track" that may be viewed under an optical microscope. Each charged particle produces one single track. Therefore the counting of the tracks provides a way to measure the number of particles that have actually impinged onto the surface of the detector. SSNTD are not sensitive either to light charged particles or to electromagnetic radiations, which could otherwise induce an unwanted background . The experimental set-up used to lay such type of detectors has been described by Seidel and Monnin (1982). It consists of a 1 m long pipe vertically placed into the ground. A 30 cm long smaller inner tube is inserted into the previous one. It is closed at its upper orifice by a stopper holding the detector itself, facing down. The reason of the 30cm inner tube is to get rid of any influence from the thoron, which is quite abundant. Due to its short life time thoron decays away completely while moving by mere diffusion towards the detector; while ^{222}Rn decays only by a negligible amount. The SSNTD actually used in the study is LR-115 type II, produced by Dosirad Co., France. It consists of a 12 micrometer thick cellulose nitrate sheet backed with a 100 micrometer thick polyester support. After field exposure, the detectors are chemically etched. The processing is carried out with a 2.5 N NaOH etching bath at 60 °C for a period of 110 min. Track counting using an optical microscope is particularly tedious. However, in the case of the LR-115 and after separation from the polyester backing, the etching process reduces the original thickness down to 6.5 micrometers; each track is not only a channel but a true hole, because the particle may cross through the entire sensitive medium. Therefore it is possible to use an automatic jumping spark counter to determine the number of tracks on the detector. Typically, track densities in the range 10 to 5 000 tracks. cm^{-2} can be determined, with a natural background of 2 to 3 tracks.cm^{-2}. The properties of the LR-115 enabling the use of the spark counter make the technique particularly well suited for routine measurements.

Clipperton active detectors

The automatic electronic CLIPPERTON II radon probe is based on a silicon diode detector associated with electronic data processing and storage units of low energy consumption. The probe appears as a 5 cm in diameter and 50 cm long tube opened at one of its ends. This encasing tube is made out of a particularly strong glass fiber-epoxy alloy and it can withstand severe environmental conditions. The upper part of the tube contains the electronics and it is separated from the bottom part by a water and gas tight wall. The active part of the probe is a silicon photodiode-type detector (Hamamatsu S 3590-02) which has a good energy resolution (2 to 3 % at 5.5 MeV) without polarization. It is located in the 30 cm bottom part of the tube. The detector is surrounded by a metallic shielding cup for protection against electromagnetic noise; it is also protected against humidity by a special treatment. The probe is provided with a diffusion membrane which can be placed at will, over its open end to avoid the thoron contribution and water condensation on the diode when the Clipperton is operated in the ground. When operated in ground water there is no need for the protecting membrane.

When the probe is placed vertically in the ground or in ground water the radon gas enters the bottom part of it and move by diffusion towards the detector. It produces alpha particles in the volume in front of the detector. Pulses generated by impinging alphas are preamplified and amplified with an overall multiplication factor of 550. A discriminator with a window, whose lower threshold is set at 0.4 V corresponding to 0.8 MeV a-particles and its upper threshold set at 2.7 V corresponding to 5.5 MeV ^{222}Rn a-particles, works as a pulse shaper for those pulses that are accepted within the above limits. While recording the alpha activity the Clipperton probe carries out a real-time discriminating data analysis which precludes the wrong recording of countings due to anything else but alpha particles impinging the detector. Operated with regular alkaline batteries the probe has an autonomy of 3 months at least. It has been already successfully operated over longer periods of time. The sensitivity of the probe is : 1 count.h^{-1} = 140 Bq.m^{-3}. The time monitoring period is fixed by the operator, ranging from 1 minute to 48 hours. Depending on the duration of this grab sampling time, the available memory space allows up to a maximum of 1 600 individual countings to be recorded safely. The data extraction is directly achieved in the field with a tiny palm "PSION Organiser II" microcomputer by means of an EPROM memory. The advantage of the EPROM memory is that it ensures full safety for the data even in the case of errors committed in the operation process. From the EPROM, data are then transferred easily into a PC computer. Alternatively, data can be retrieved directly into a lap-top computer in the field without passing via the EPROM memory. Data are transferred under such a format that eventual data processing can then be realized in the PC by using a software like Excel, Quattro Pro or Lotus 1-2-3.

RESULTS

Long term measurements

Figures 1 and 2 indicate example behaviour of radon in soil signals as obtained with SSNTD. The records correspond to the Acapulco and Marquelia, Guerrero state, stations. The last one located 150 km south-east of Acapulco along the Pacific coast of Mexico. At first sight we can see what is the main disadvantage of this technique. It is a cheap technique but it requires regular trips to the field. In this particular case, the laboratory is some 450 km from the field. It would be advisable to retrieve the detectors every 10 days but for practical and cost related reasons this is not possible. Additionally the zone has shown extremely high seismicity during the monitoring period (Zuñiga, 1996), therefore, the data lack details and they also sometimes consist of interrupted series, as can be seen on the Marquelia diagram. In addition, it can be seen that large fluctuations are observed. Some earthquakes are preceded by radon increases but it should also be pointed out that some anomalies are not related to any obvious seism. The question remains whether one has to deal with radon peaks that occur randomly or whether they are produced by a non-seismic relaxation of the stress that has been building up in the area under survey.

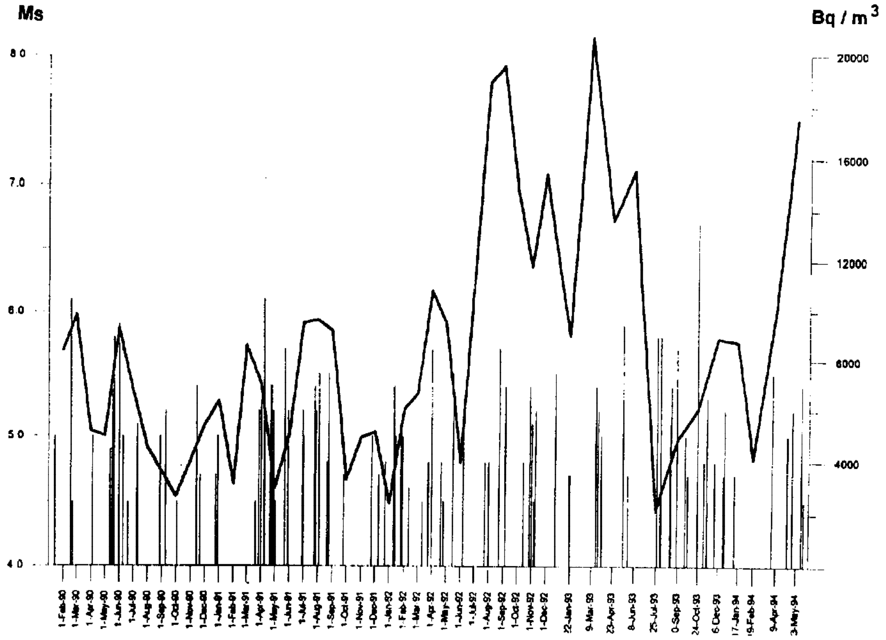

Fig. 1.- Soil radon response with SSNTD at Acapulco station. The seismicity (higher than Ms = 4.4) is indicated with vertical lines.

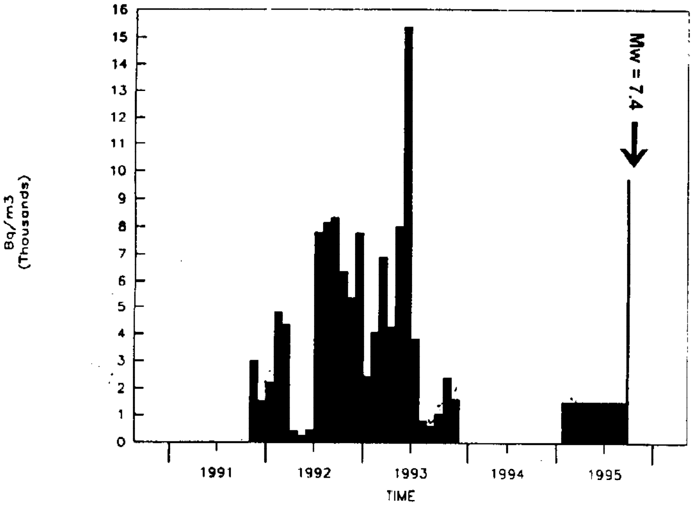

Fig 2.- Soil radon response with SSNTD at Marquelia, 150 km south-east from Acapulco. The occurrence of the Mw = 7.4 earthquake on September 14, 1995, at Guerrero state is also shown.

An indication that shorty term measurement are probably more likely to carry pertinent information is shown on Figure 2. The ultimate radon peak corresponds to a detector that has been retrieved from the field 10 days only after the Mw = 7.4 earthquake occurred on September 14, 1995 (Singh, 1996) at the south-eastern part of Guerrero state. It shows a sharp peak-like signal. In other words the signal has not been shadowed as it would have been if the detector had stayed on the spot for a much longer time.

Short term measurements

Figure 3 shows the radon in soil behaviour obtained with the Clipperton probe located at Acapulco in a period that includes the Mw = 7.4 earthquake occurred on September 14, 1995. The radon signal suffers a sudden perturbation from August 10 till September 16, then reaches its original value and a needle-like signal occurs on September 21 after the earthquake, reaching the original values again.

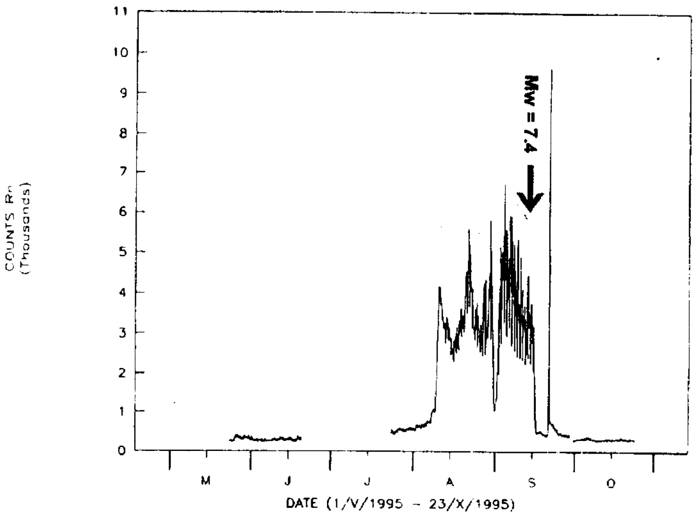

Fig 3.- Records of soil radon as obtained with the Clipperton probe at Acapulco station. The occurrence of the Mw = 7.4 earthquake on September 14, 1995, at Guerrero state is also shown.

The radon behaviour shown in the preceding examples can be summarized as follows: the passive detectors response will not show details in the short term since the information is recorded during one month or one month and a half, they are additionally picked up and then analysed, with the corresponding time lack. At the Guerrero coast, due to the extremely high seismicity, this method has the additional disadvantage that signals due to single seisms will overlap during the long exposure period. The use of continuously recording devices will permit to eliminate this problem and to identify the radon signals, if any, of single earthquakes in this zone. A proposal in this way is the telemetric transfer of the radon signal in order to start analyzing the response in a quasi-real time basis.

Radon Measurements Telemetry

The Seismic Alert System for Mexico City (SAS) has deployed a set of 12 seismic detecting field stations along the Guerrero coast. The stations are separated from each other by 25 km average, and they cover an extension of about 350 km of the coast line. The stations are located over the seismic gaps which have the highest probability of generating an up to 8.2 Ms earthquake (Singh and Mortera, 1991). Due to this seismic sensors distribution it was considered that the installation of Clipperton active detectors in the same locations used by the SAS would be suited to correlate the seismic information with the radon measurements, besides the advantages of operation and data transmission over the SAS telecommunication infrastructure. However, the telemetry links used by the SAS once the system started operating as a public service on Aug. 1, 1993 it became unavailable to accept data from other sources. The alternate way to transmit the information captured by the Clipperton radon detectors is based on the cellular telephone system which at present is undergoing a remarkable expansion in Mexico. The first approach was to test the functionality installing three Clipperton radon detectors two at both ends of the SAS field station array and one in Acapulco, approximately at the centre of the SAS array, because these points have good cellular telephone coverage, as it was found during the communication test done to verify the availability of this facility. The equipment required to implement this first stage in each selected point is merely in addition to the Clipperton radon detector, a cellular telephone, a modem, solar panel with regulator and a rechargeable battery. All these components are installed inside a metallic protection box with a mast to support the solar panel and an external cellular telephone antenna. In this stage, the matching equipment at the laboratory is any PC with modem and software suitable to handle the Clipperton sensor protocol. This configuration has been tested using the cellular telephone facilities in Mexico city and it was found to be satisfactory when only one laboratory ask for the measurements. As another objective of the radon telemetric measurements is to allow researchers access to radon measurements using the internet, this first approach required some changes. Among them is the central storage of radon data by means of an intelligent communication controller. It will have a circular buffer with enough memory to store about 7 days of radon data sampled at 20 minutes intervals from a set of up to 24 Clipperton radon detectors. This communications controller will periodically interrogate each radon detector using packet radio modems. Additionally, personnel from different laboratories will access the stored radon data via cellular telephone. As an option the data may automatically be sent to an internet access node to make them accessible to the interested researches all over the world. In an advanced stage of this project, each Clipperton radon detector will be complemented with a small meteorological station interfaced to the telemetric system.

From the results shown, the transmission of the radon signal through telemetry transfer is expected to avoid sampling effects related to the data recuperation and analysis. The fact that the telemetric stations can also support the meteorological gauges at the specific radon measurement stations, will also provide the environmental parameters that influence the soil radon fluctuations.

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