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Soil radon as a possible earthquake precursor: Preliminary results from Ileia (Greece)

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Radon (^{222}Rn) is a naturally occurring radioactive gas which is directly produced by the decay of the ^{238}U series. It is significant for the studies of Earth, in hydrogeology and atmosphere. Radon is used as a trace gas due to the long half-life (3.82-days) which allows migration at long distances. In addition, it is an alpha emitter, fact which enables detection of low levels of radon. Anomalies of radon impending earthquakes of a variety of magnitudes have been observed in soil gas, ground- and thermal-waters and in underground tunnels. Increasing is the scientific interest in this field during the last two years. However, the majority of the published papers refer to data of rather long time intervals between sequential measurements (~2-4 weeks).On the other hand, it is justified, both on laboratory and geophysical scale, that when a heterogeneous material is strained acoustic and electromagnetic (EM) emissions occur in a wide frequency spectrum, ranging from very low to very high frequencies. These emissions are considered as precursors of general fracture.

In the search of soil radon as a possible earthquake precursor, a station for quick and continuous monitoring of soil radon has been installed in a very active tectonic site in Greece (Ileia, Peloponnese, SW Greece). The monitoring site is Kardamas Ileias, located 3 km south from Amaliada which is the second highly populated city. The instrumental and felt seismicity of Ileia is dominated by extensional active seismicity structures (e.g. Alfeios, Neda, Melpeia, Kiparissia-Aetos) and has shown more than 600 earthquakes of magnitude greater than 4.0 R in the last 100 years. Two earthquakes were very destructive (5.8 R on 26/3/93 and 6.8 R on 8/6/08 respectively). The station consists of a high precision active instrument (Alpha Guard-AG, Genitron Ltd.), equipped with an appropriate unit designed for pumping and measurement of radon in soil gas (Soil gas Unit, Genitron Ltd.). Soil radon is continuously pumped into AG at a rate of 1 L/min. Pumping is performed via a 1-m soil probe to minimize meteorological influences and a 25-m radon proof 25-mm tube to avoid simultaneous measurement of soil ^{220}Rn. Proper dust and moisture filters are employed. Radon is monitored every 10 minutes. This interval can be reduced to 1 minute, however with lower accuracy and data storage capacity. For comparison purposes, calibrated passive radon dosimeters based on CR-39 Solid State Nuclear Track Detectors (SSNTD's) were periodically installed and exposed to soil radon in 50 cm holes were dug near the 1-m probe. The exposures lasted 1-2 weeks. Afterwards, the SSNTD's were removed, etched and measured via standard methods (optical microscopy track counting). The period of comparison measurements was 6 months.

Continuous monitoring and passive measurements were cross-calibrated and found to provide similar estimates of mean soil radon concentration. Active techniques are much more precise and quick, however, they indicated the necessity of periodical checks for the pumping and measurement status, especially after strong rainfalls.The mean soil radon concentration was found fairly constant ($\sim$ 25-30 kBq m^{-3}). Numerous soil radon concentration anomalies were detected. These were arbitrarily corresponded in terms of magnitude and duration to seismic events of the near area. All detected anomalies were sudden, significantly ($p<0.001$) deviating from the average values and, for the majority of the cases, consisted of transient concentration increase followed by consequent decrease. Two very high anomalies (~500-600 kBq m^{-3}) were detected three and two months prior to the 6.8 R earthquake on 8/6/08. These anomalies consisted of a continuous decrease of 1 day duration, a sudden increase of approximately 1 hour and a gradual increase up to baseline values. A series of seven anomalies have been detected during the last 3 months. Five were at the range of 500-800 kBq m^{-3} and two of 100-150 kBq m^{-3}. All these anomalies were sudden and not preceded or followed by gradual deviations. These anomalies could be precursors of an earthquake in the near area within the next weeks. In the search of EM precursors, EM background measurements are conducted in the KHz-MHz range for the installation of an EM station.

Active techniques were quicker providing the opportunity of more precise monitoring of precursory seismic phenomena. Both methods were correlated to electromagnetic (EM) precursory data provided by the near Station (installed at Zante Island). Anomalies of soil radon concentration can give evidence about tectonic disturbances in the Earth's crust, though the radon changes are also influenced by meteorological parameters. Further studies are needed to differentiate the changes that are due to tectonic disturbances from other causes, and to reduce the effect of the meteorological parameters on the measured radon concentration. However, probable explanations for these anomalies may be given through the dilatancy-diffusion (DD) model and crack-avalanche (CA) model. According to the DD model, a porous cracked saturated rock constitutes the initial medium. With the increase of the tectonic stresses the cracks extended as well and disengagement cracks appear near the pores, the favourably oriented cracks being opened. This results in a decrease of pore pressure in the total preparation zone and water flows into the zone from the surrounding medium. The return of pore pressure and crack increase brings about a main rupture at the end of the diffusion period. According to the CA model, the process is as follows: a cracked focal rock zone is formed by the increasing tectonic stresses. The shape and volume of this focal zone change slowly with time. After comparing both models, one can recognize a common principle: at a certain preparation stage a region with many cracks is formed. The mechanical processes of earthquake preparation are always accompanied by deformations, afterwards complex short- or long-term precursory phenomena can appear. Additional explanations may be provided by microcrack propagation theory and the self-asperity model of two rough and rigid fractional-Brownian-motion-type profiles slipping one over the other, with a roughness which is consistent with field and laboratory studies. According to these, significant quantities of radon may be released and migrated during either the crack-formation or the Brownian slipping.