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Radon anomaly in soil gas as an earthquake precursor

I. Miklavčić, V. Radolić, B. Vuković, M. Poje, M. Varga, D. Stanić, J. Planinić*

Department of Physics, University of Osijek, Trg Ljudevita Gaja 6, POB 125, 31000 Osijek, Croatia

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Abstract

The mechanical processes of earthquake preparation are always accompanied by deformations; afterwards, the complex short- or long-term precursory phenomena can appear. Anomalies of radon concentrations in soil gas are registered a few weeks or months before many earthquakes.

Radon concentrations in soil gas were continuously measured by the LR-115 nuclear track detectors at site A (Osijek) during a 4-year period, as well as by the Barasol semiconductor detector at site B (Kašina) during 2 years.

We investigated the influence of the meteorological parameters on the temporal radon variations, and we determined the equation of the multiple regression that enabled the reduction (deconvolution) of the radon variation caused by the barometric pressure, rainfall and temperature.

The pre-earthquake radon anomalies at site A indicated 46% of the seismic events, on criterion $M \geqslant 3$, $R < 200$ km, and 21% at site B.

Empirical equations between earthquake magnitude, epicenter distance and precursor time enabled estimation or prediction of an earthquake that will rise at the epicenter distance R from the monitoring site in expecting precursor time T.

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Keywords: Radon anomaly in soil; Meteorological parameters; Earthquake precursor

1. Introduction

Variation of radon emanation from soil and water can give early evidence on tectonic disturbances in the Earth's crust (King, 1993). Radon is an alpha-emitting radioactive gas produced from uranium–radium found in rock grains or soil. Although the changes of radon emanation are also influenced by meteorological parameters such as atmospheric pressure, rainfall and soil temperature, soil gas observation and radon anomalies can be used for the earthquake prediction (Wattananikorn et al., 1998). The mechanical processes of earthquake preparation are always accompanied by deformations; afterwards short- or long-term precursory phenomena can appear. Anomalies of radon concentrations in soil gas were registered a few weeks or months before several earthquakes (King, 1993; Igarashi et al., 1995). The precursory phenomena can be observed beyond the distance R_e (km), which is roughly the radius of the effective precursory manifestation zone. The size of this zone can be approximately estimated by using the following formula (Martinelli, 1993; Dobrovolsky et al., 1979):

$$R_e = ae^M, \tag{1}$$

where M is the magnitude of the earthquake, and a is a parameter with value $\geqslant 1$ depending on the crust structure of the area considered. Between the precursor time T (day), the epicentral distance R (km) and magnitude M, the following empirical relationship is derived (King, 1993; Sultankhodhaev, 1984):

$$\log(RT) = 0.63\,M + b, \tag{2}$$

where the parameter b is proposed as the value of 0.15 for gaseous geoseismic precursors of earthquakes. Based on the published data on pre-earthquake radon anomalies, it

*Corresponding author. Fax: +385 31 232 701.
E-mail address: planinic@ffos.hr (J. Planinić).

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is recognized that the shape of the peak (and not only the amplitude) could be used as a diagnostic parameter for the forthcoming seismic events (Martinelli, 1993). The relation between the amplitude and duration of the gaseous anomaly and the magnitude of the expected earthquake has the following form:

$$M = k\sqrt{S}, \quad (3)$$

where k is a correction factor and S the area of the detected peak anomaly.

In order to express the potential to detect a seismic event at a measurement site, one may use the parameter ε (called the earthquake effectiveness) as follows (Dobrovolsky et al., 1979; Bella et al., 1998):

$$\varepsilon = 10^{(1.3M-8.19)}\,R^{-3}, \quad (4)$$

where R is the epicenter distance (km).

Also, we proposed and introduced the representative parameter q of an earthquake in the following form:

$$q = \frac{M^2 \times 100}{R} \quad (5)$$

that was suitable for graphical presentation too.

2. Methods

The radon concentrations in soil gas were continuously measured in Osijek with nuclear track detectors, which were placed 0.5 m deep in the soil. The radon detector was constructed with an exterior metallic cylinder and a plastic vessel (cup) closed by filter paper, presented in Fig. 1 (Planinić et al., 2000, 2001); a film ($2 \times 3\,\text{cm}^2$) of LR-115 nuclear track detector (produced by Kodak-Pathe) was placed inside the cup.

The detectors were exposed for 1 week; subsequently, the detector films were etched in 10% NaOH aqueous solution at 60 °C (333 K) for 120 min and counted visually using an optical microscope with the 10×16 magnification. The calibration factor of the detector was $20.8\,\text{Bq}\,\text{m}^{-3}\,\text{d/tr}\,\text{cm}^{-2}$, the background track density $70\,\text{tr}\,\text{cm}^{-2}$, and the low-level detection was $3.2\,\text{Bq}\,\text{m}^{-3}$. The earthquake data were collected from the Earthquake Data Base of the National Earthquake Information Center—US Geological Survey (NEIC, 2007). The meteorological parameters were obtained from the Meteorological Centre at the Osijek Airport (15 km far from the measuring site A); the barometric pressure at 88 m altitude, precipitation and temperature of air 2 m above the soil were measured daily.

We also used the Barasol semiconductor Rn detector (produced by Algade, France) for the continuous radon measurement in soil gas at depth of 0.8 m at the site B (location Kašina, near Zagreb).

3. Results and discussion

3.1. Radon concentration measurement in soil gas at site A (Osijek)

The radon concentrations in soil gas at site A (Osijek) at the depth of 0.5 m (c_s) have been measured continuously from May 1998 together with the barometric pressure (p), rainfall (h) and temperature (t), with the intention to reduce the dependence of radon variations on them, particularly on the barometric pressure. The radon measurements, as well as the values of the meteorological parameters for the 4-year period (2003–2006), are presented in Fig. 2.

For the first time, we used the parameter q from Eq. (5) by quantization of the registered earthquake; it was especially suitable in graphical presentation (except for very short epicenter distances).

The earthquakes of magnitude $M > 3$ at the epicenter distance $R < 200$ km from the monitoring site in Osijek were considered (Wattananikorn et al., 1998). The earthquakes, which we recognized by radon variations in the Rn temporal curve in Fig. 1, are denoted as e_i ($i = 1, \ldots, 19$) and described by the earthquake parameter q; all the earthquakes registered by the US Geological Survey, by $M > 3$ and $R < 200$ km, are given in Table 1.

A common approach to testing (whether a radon increase was an anomaly and as such a precursor of a forthcoming earthquake) could be to examine the difference between the radon peak and the mean value of the radon concentration for a few months or a year. When the difference mentioned is greater than two standard deviations, $2s$ the radon peak can be observed as the radon anomaly with the confidence of 95.5%. In cases when the radon maximum increases by $1s$ from the mean, a possible influence of the meteorological parameters should be

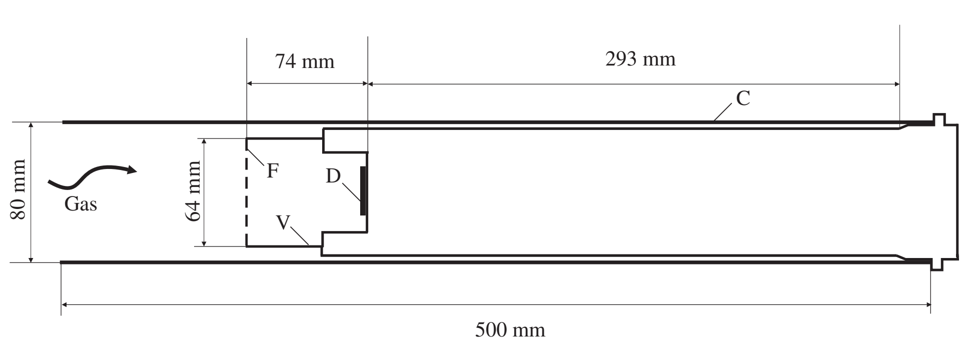

Fig. 1. Nuclear track detector for Rn measurement in soil; C—cylinder, D—detector film, V—cup and F—filter.