

MEASUREMENTS OF RADON EXHALATION FROM THE GROUND
FOR EARTHQUAKE PREDICTION STUDIES

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A B S T R A C T

A network of radon stations has been established in the Thessalian plain, Central Greece. Specially made devices (an improved model) are in operation with alpha track detectors (ATD) in registering alphas from radon exhaled from the ground and its progeny, by using cellulose nitrate films type CN-85 (Kodak) for about 7 months. The radon exhalation rates were not influenced by the radium content of the soil surrounding the devices. High radon exhalation rates as high as $1440 \text{ tracks} \cdot \text{cm}^{-2} \cdot \text{day}^{-1}$ were recorded on the great Fault which had caused a large $M_L = 7.0$ earthquake on April 30, 1954 and an earthquake of $M_L = 6.5$ on July 9, 1980.

ΜΕΤΡΗΣΕΙΣ ΤΗΣ ΡΟΗΣ ΤΟΥ ΡΑΔΟΝΙΟΥ ΑΠΟ ΤΟ ΕΔΑΦΟΣ ΣΤΗΝ ΠΡΟΒΛΕΨΗ
ΤΩΝ ΣΕΙΣΜΩΝ

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Π Ε Ρ Ι Λ Η Ψ Η

Δίκτυο σταθμών ελέγχου και καταγραφής της ροής ^{222}Rn από το έδαφος εγκαταστάθηκε και λειτουργεί στην Θεσσαλική Πεδιάδα. Συσκευές ειδικής κατασκευής περιλαμβάνουν πλαστικούς ανιχνευτές ιχνών για την καταγραφή των σωματιδίων άλφα από το Ραδόνιο που απορρέει από το έδαφος ως και τα θυγατρικά αυτού. Οι ανιχνευτές είναι τύπου CN85 της Kodak. Το δίκτυο λειτουργεί για περισσότερο από 6 μήνες. Τα πρώτα αποτελέσματα έδειξαν ότι η στάθμη της ροής του ραδονίου από το έδαφος δεν εξαρτάται από την συγκέντρωση ^{222}Ra , πατρικού του Ραδονίου, στο έδαφος που περιβάλλει την συσκευή μέτρησης. Υψηλές τιμές της ροής του Ραδονίου της στάθμης των $1440 \text{ tracks} \cdot \text{cm}^{-2} \cdot \text{day}^{-1}$ έχουν καταγραφεί στο μεγάλο ρήγμα που προκάλεσε ο σεισμός μεγέθους $M_L = 7.0$ της 20 Απριλίου 1954 και έτερος σεισμός μεγέθους $M_L = 6.5$ την 9 Ιουλίου 1980.

INTRODUCTION

There have been many reports dealing with the measurements of radon concentration in soil gas emanating from the ground along active faults which may provide useful signals before seismic events (Smith et al., 1975; King, 1976, 1977, 1978a,

1978b, 1980; Birchard and Libby, 1976, 1978, 1980; Birchard, 1977; Moore et al., 1977; Shapiro et al., 1980a, 1980b, 1981; Talwani et al., 1980). Anomalous changes in subsurface radon concentrations may be expected prior to large earthquakes according to the dilatancy-diffusion model for earthquake occurrence (Scholz et al., 1973). Several investigators currently monitor radon by using a variety of techniques such as charcoal trap technique (Megumi and Mamuro, 1972), track etch technique (Fleischer, 1975), aerosol filtration technique (Melvin et al., 1978) etc.

This paper reports data obtained from field measurements of 7 months (from August 1992 to March 1993) using an improved model of a special device developed in the Nuclear Physics Laboratory, University of Thessaloniki for continuous monitoring of radon emanating from the ground by using solid state nuclear track detectors (SSNTD) (Savvides et al., 1985) as probe in order to explore the possible relation between radon changes and earthquakes.

INSTRUMENTATION AND SITING

The criteria for selection of places where the devices were installed, were as follows:

1. ^{222}Rn is a radioactive inert gas, in the natural radioactive series of ^{238}U with a half-life of 3.82 days. Due to its relatively small half-life its diffusion length in the soil is also small. For instance, from a 2 m soil column only 10% of the underlying radon can penetrate up to the ground surface (King, 1978b). So, the measuring places had to be pretty close to the surface cracks. In that way, there was a large possibility for ^{222}Rn to be able to diffuse at large distances through the disintegrated underlying rocks.

2. The need of electrical power supply was an important point in choosing the measuring places. Heating systems were installed in the specially made devices in order to control the temperature in the radon counting chamber.

3. Another criterion was that the measurements of radon flux from the soil had to cover the maximum possible length of the cracks in order to increase the possibility of observing ^{222}Rn fluctuations prior to the seismic events.

The locations chosen for installing the devices under the above considerations were as follows:

Station A: Ekkara
Station B: Leontario
Station C: N.Anchialos
Station D: Mikrothives

The stations A and B covered the western part of the Fault, while the other two stations, C and D, covered the eastern part of the Fault (Fig.1).

The radon flux measurement systems consisted of two measuring devices and a heating unit, as shown in Fig.2. The devices which were used in the present study are the same ones as those had been used in earlier measurements at Stivos Fault

(Papastefanou et al., 1989), with some improvements. The ^{222}Rn penetrates in the device from the conical base and diffuses up to its upper part, where the alpha-particles from ^{222}Rn and its decay products are measured by using solid state nuclear track detectors (SSNTD) cellulose nitrate films type CN-85 (Kodak). The device has the appropriate length, so that ^{220}Rn (from ^{232}Th -series) is not able to reach the detector and hence influencing the measurement of ^{222}Rn flux from the ground (Savvides et al., 1985).

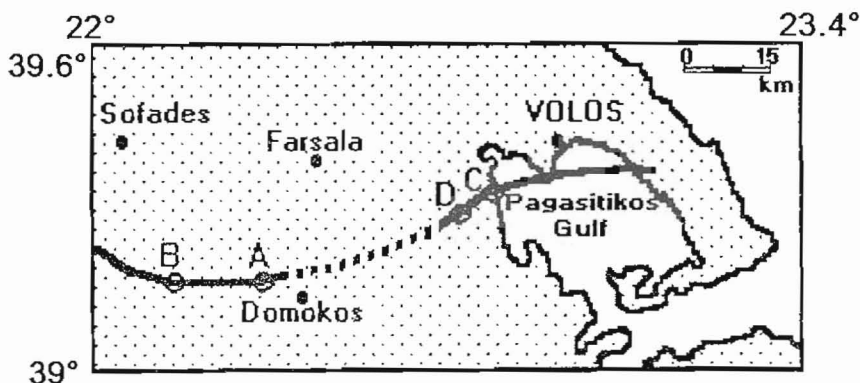


Fig.1. A map of Thessalian plain showing the locations of radon stations.

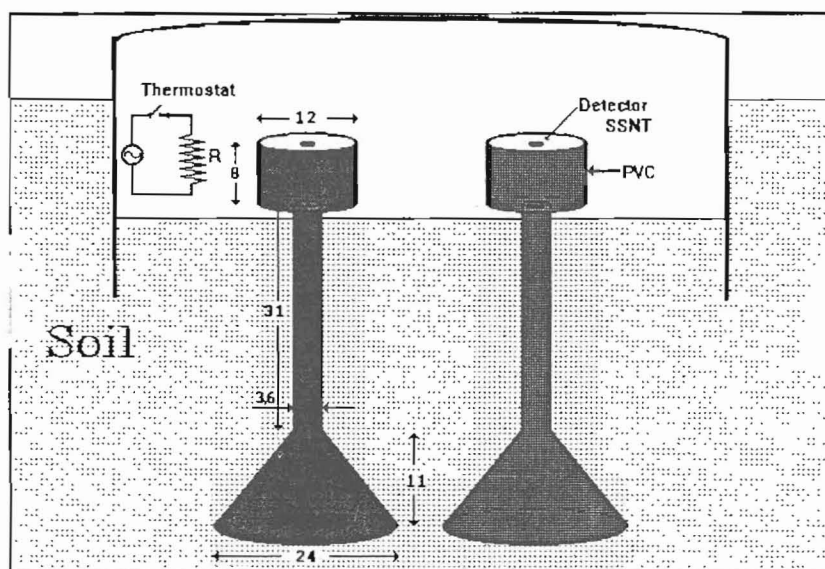


Fig.2. A vertical cut of the measuring device of the ^{222}Rn flux from the soil (dimensions in cm).

Exposure times of the detectors were at least 14 days, enough to minimize any influence of the short-time meteorological effects. The chemical etching of the detectors (4N NaOH, 50°C, 3.5h) was followed and the tracks measurement from the alpha-particles of ^{222}Rn and its daughters was obtained by an optical microscope.

RESULTS AND DISCUSSION

The ^{222}Rn flux measurements at the Thessalian Fault from 20 August 1992 up to 17 March 1993 are illustrated in Fig. 3. In this figure, simultaneous ^{222}Rn flux measurements carried out in Thessaloniki (at the University area) are also shown. The latter was made for comparison purposes by using the corresponding measurements as a reference level (background level).

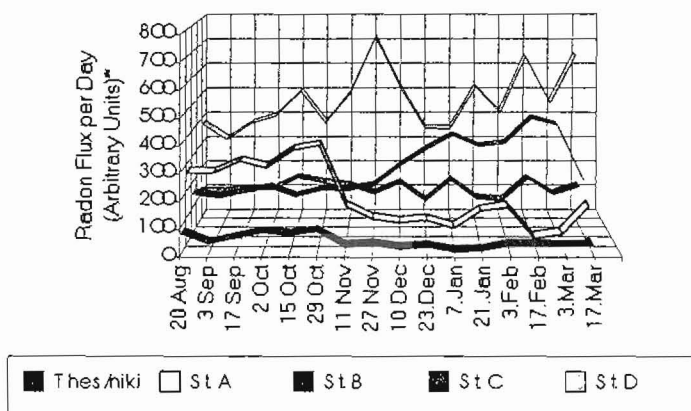


Fig.3. Dual parameter histogram of ^{222}Rn flux measurements from the soil at radon stations versus time.

Comparing the obtained results, it was observed that ^{222}Rn flux from the ground in Thessalian Fault was much higher than the background level as determined by the ^{222}Rn flux measured at the station installed in the city of Thessaloniki. This could be attributed either to the cracks, or to the higher ^{226}Ra concentration of the station area subsoil, or to the higher ^{222}Rn emanation factor.

*Arbitrary unit was determined as the number of radon nuclei exhaled from the ground per day and per cm^2 multiplied by the efficiency of the device (tracks $\cdot \text{cm}^{-2}$ / $\text{Bq} \cdot \text{cm}^{-3} \cdot \text{day}$)

In order to clarify that point, measurements of concentrations of the natural radionuclides as well as the ^{222}Rn emanation factor have been carried out in soil collected from the stations area. The results of these measurements are presented in Table 1. Also, in Figure 4 the seismic events in the same period and in the same area (Fig.1) are shown.

Table 1. Activity concentrations of the natural radionuclides and ^{222}Rn emanation factor at radon stations.

Station area	K-40 Bq/kg	Ra-228 Bq/kg	Ra-226 Bq/kg	Emanation Factor (%)
Ekkara	404±3	16±0.1	13 ±0.1	23 ± 3
Leontario	330±2	22±0.2	15±0.1	14 ± 3
N.Anchialos	373±2	21±0.1	20±0.1	21 ± 2
Mikrothives	227±1	12±0.1	15±0.1	20 ± 2
Thes/niki	244±2	15±0.2	15±0.1	26 ± 2

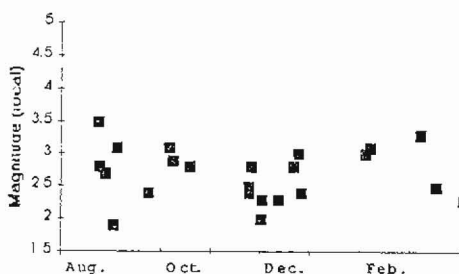


Fig.4. The seismic events in the Thessalian Fault.

The data of Table 1 shows no significant differences in the activity concentrations of the natural radionuclides as well as the ^{222}Rn emanation factor* in soils at the stations area. So the ^{222}Rn emanation factor might not cause higher ^{222}Rn flux from the

*Emanation factor is determined as the fraction of radon in the porous space of a material to the total radon in the material. (UNSCEAR, 19 82).

ground at the stations in Thessalian Fault. Therefore, these high ^{222}Rn fluxes must be attributed to the cracks existing at the stations area. On the other hand, the activity concentrations of the natural radionuclides in soils are comparable with the average activity concentrations in soils in world-wide scale which were summarized in Table 2.

Table 2. Average activity concentrations of K-40, U-238 (in equilibrium with Ra-226) and Th-232 in soils (UNSCEAR, 1982).

Radionuclide	Bq·kg ⁻¹
K-40	370 (100-700)
U-238 (Ra-226)	25 (10-50)
Th-232	25 (7-50)

It was observed from Fig.3. and Table 3. that the mean value of radon flux at the station D was about 3 times larger than that of station C, which appeared to be relatively stable with time, although both the stations are located on the main crack that caused an earthquake of $M_L = 6.5$ on July 9, 1980 (Papazachos et al., 1993). This difference might be attributed to various geological processes that eliminated any passage of subsurface soil radon, e.g. ground water penetration in the subsurface crack.

Table 3. ^{222}Rn flux measurements per day (Arbitrary units).

	Mean $\pm \sigma$ (min - max)
Station A	176 \pm 116 25 - 371
Station B	251 \pm 107 138 - 445
Station C	140 \pm 30 94 - 185
Station D	467 \pm 121 310 - 721
Thessaloniki	43 \pm 24 11 - 84

Radon fluxes in the western part of Thessalian Fault, Fig.1, (stations A and B) show larger deviations from the mean value

(66% and 43%, respectively) as compared with those of stations C and D (21% and 26%, respectively) (Table 3).

It was also observed, from Fig.3, that there is an inverse relationship between the radon fluxes at the two locations (stations A and B). That means when the radon flux started decreasing (November 1992) at the stations A, then the radon flux at station B started increasing. This effect repeated again on February 1993. This must be attributed mainly to changes of meteorological conditions, since alterations of radon fluxes started simultaneously with the beginning of the rainfall period.

In order to confirm the above hypotheses, installation of some more stations was planned to be established in the area of Thessalian Fault. For this purpose an appropriate survey of ^{222}Rn flux over Thessalian Fault, including the ground waters, was scheduled to be carried out by using a Lucas scintillation cell.

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