BEÜ Fen Bilimleri Dergisi
9 (2), 703-710, 2020

BEU Journal of Science
9 (2), 703-710, 2020

Araştırma Makalesi / Research Article

Evaluation of Soil Radon Gas and Earthquake on the Fault Zone

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Abstract
Four radon monitoring stations are located on the Sivrice Fault Zone of the East Anatolia Fault System (DAFS) which is one of the most important active fault systems that creates big earthquakes in Turkey. Soil radon measurements were performed by using a sensing system that includes a Nuclear Spectroscopic system located at certain monitoring stations which have been placed on the fault zone and by applying passive sensors method using plastic detectors (CR-39) at these same locations. In this study, the soil radon gas values from the monitoring stations were analyzed with different topics and the results: (i) Station II is located on the southern part of the Sivrice Fault Zone that has a higher seismic activity, (ii) There is a relationship between the alterations of soil radon expansion and the occurrence of earthquakes, however, it has been seen that some other parameters (temperature, humidity and pressure) also have an effect on radon expansion, (iii) The radon gas change according to the active and passive detection systems is parallel at each monitoring station but it is different in comparison with other monitoring stations.

Keywords: Radon, CR-39, Earthquake, Fault Zone.

Fay Zonunda Toprak Radon Gazı ve Depremin Değerlendirilmesi

Öz
Türkiye'de büyük depremler yaratan en önemli aktif fay sistemlerinden biri olan Doğu Anadolu Fay Sisteminin (DAFS) Sivrice Fay Zonu üzerinde dört radon istasyonu bulunmaktadır. Toprak radon ölçümleri, fay bölgesine yerleştirilmiş belirli istasyonlarda bulunan bir Nükleer Spektroskopik sistem içeren bir algılama sistemi kullanılarak ve aynı yerlerde plastik detektörler (CR-39) kullanılarak pasif sensörler yöntemi kullanılarak gerçekleştirilmiştir. Bu çalışmada istasyonlardan elde edilen toprak radon gazı değerleri farklı konular ile analiz edilmiş ve sonuçlar: (i) II. İstasyon Sivrice Fay Zonunun daha yüksek sismik aktiviteye sahip güney kısmında yer almaktadır, (ii) toprak radon gazı çıkışlarındaki değişiklikler ile depremlerin meydana gelmesi arasındaki ilişki, diğer bazı parametrelerin (sıcaklık, nem ve basınç) radon çıkışına da etki ettiği görülmüştür, (iii) Radon gazı aktif ve pasif algılama sistemleri her istasyonda paraleldir ancak diğer istasyonlara göre farklıdır.

Anahtar kelimeler: Radon, CR-39, Deprem, Fay Zonu.

1. Introduction

Sivrice Fault Zone, which is a part of the East Anatolia Fault System (EAFS) is an active fault that produced earthquakes in several magnitudes and some of them were destructive.

Radon isotopes are formed by the disintegration of radium in minerals and all isotopes are also a natural member of a chain decay that begins with ^{238}U, ^{235}U or ^{232}Th. The primary source of radon is earth, groundwater and building materials. ^{222}Rn is in a gas form and is about seven times heavier than air and dissolves in water. ^{222}Rn naturally occurs during the period of radioactive disintegration reactions and is very important in terms of human health [1,2].

^{222}Rn is a naturally occurring and α-emitting radioactive noble gas and is ubiquitous at the Earth's surface. It is a daughter of ^{226}Ra in the ^{238}U series. It is estimated that the average concentration of uranium in soil is 3 ppm or 35 Bq kg^{-1} [3,4]. ^{222}Rn has a half-life of 3.8 d and is the most important

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Geliş Tarihi: 20.01.2020, Kabul Tarihi: 03.03.2020

among the radon isotopes. Owing to their short half-lives ^{220}Rn and ^{219}Rn have lower levels. The major source of human exposure to radon and its daughters are buildings, because of the radon emanation from building materials and from the ground below [5].

Atmospheric radon concentration could have significant alterations depending on the seasons and different geological structures. It is generally accepted that surface radon concentration level is high during autumn and in the first half of the winter, and is low during spring. It is estimated that the annual radon emanation from soil is about 9×10^{19} Bq [6]. Radon transition from the rocks to groundwater system increases because of the expansions that occur due to deformations in the earth's crust and stretching in epicenter zones or on the near rocks [7]. Alpha particles emitted by radon gas produces a track on the plastic detectors. By counting the tracks over a given time the radon concentration (Bq/m^3) is calculated [6,8]. In these observations, it is accepted that there is a natural balance between radon and its other products.

Plastics are the most delicate of all known nuclear track detectors. The same sensing capability goes for CR-39 (allyl diglycol carbonate polymer or in other words poli-dietilen glycol-bis) track detectors and several detectors of cellulose nitrate. All cellulose nitrates can save alpha particles (depending on etched conditions, within a certain energy range). Scraped tracks, during the enlargement period, are made apparent under an optical microscope that has specific properties (has 10x-40x zoom). The amount of damage, the magnitude of scraped track and the level of being etched, depends on the amount of linear energy transfer rather than the way it is tracked by the charged particle. The total amount of energy lost by the particle in the environment plays an essential role in determining the magnitude of scraped blank on detector depending on applied etched conditions [6,8].

2. Material and Methods

2.1. Geology of the area

The Sivrice Fault Zone (SFZ) is a 2-6 km wide, 180 km long and NE trending sinistral strike-slip fault zone located between the district of Palu in the northeast and the district of Yarpuzlu in the southwest (Figure 1). The SFZ also contains the master fault of the EAFS, and consists of three fault sets (Gezin-Sivrice fault set, Kartaldere-Gölardı fault set, Uslu-Karaçalı fault set) and a number of isolated faults of dissimilar size, nature and lengths [9].

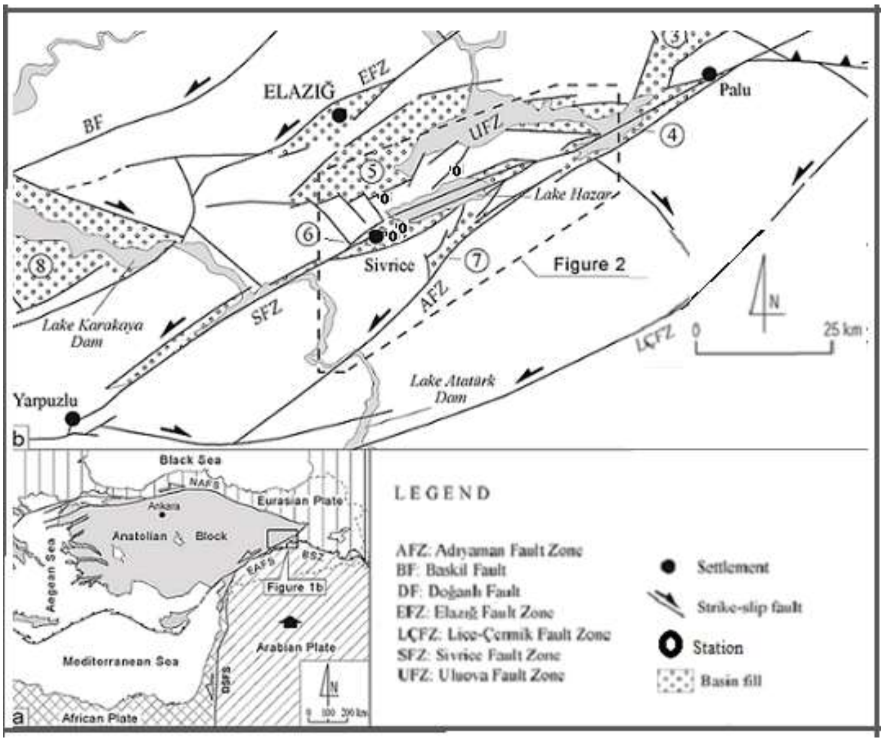

Figure 1. Simplified map showing location of the study area; (b) simplified neotectonic map showing the East Anatolian Fault System (EAFS) [9].

In terms of geological structure, the study area (Hazar Complex and Maden Complex) consists of volcano-sedimentary rocks, limestone, andesite, basalt, volcanic breccia and diabase dikes cutting them [10,11]. Hazar Complex is formed from layers of conglomeratic features of the Ceffan: sandstone, mudstone and Simaki, pink and gray pelagic limestone and rarely volcanic features of the Gehroz. Simaki of the formation is represented by sandstone, mudstone and shale. The Maden Complex is formed from volcano-sedimentary rocks, limestone, andesite, basalts, and volcanic breccia and diabase dikes cutting those [10].

2.2. Active detection method

The active measurement system is formed by Nuclear Spectroscopy. Silisium detector was used as a radon detector inside the spectroscopic system. The system is equipped with a cylindrical pipe that is approximately 30 cm long and with a 5cm radius. The detector was mounted about 8cm below the end of the pipe (see Fig. 2). At the top of the space at the bottom of the device (Alphameter 611, Figure 3), there is a silicon (diffused junction) detector located within steel tube, that has a measuring range of 400 mm^2 and it is sensitive to energy greater than 1.5 MeV. The alpha particles emitted to the medium from the decomposition of radon gas is relatively determined by the detector and it is recorded to a built-in memory at 15 minute intervals with date information [12,13].

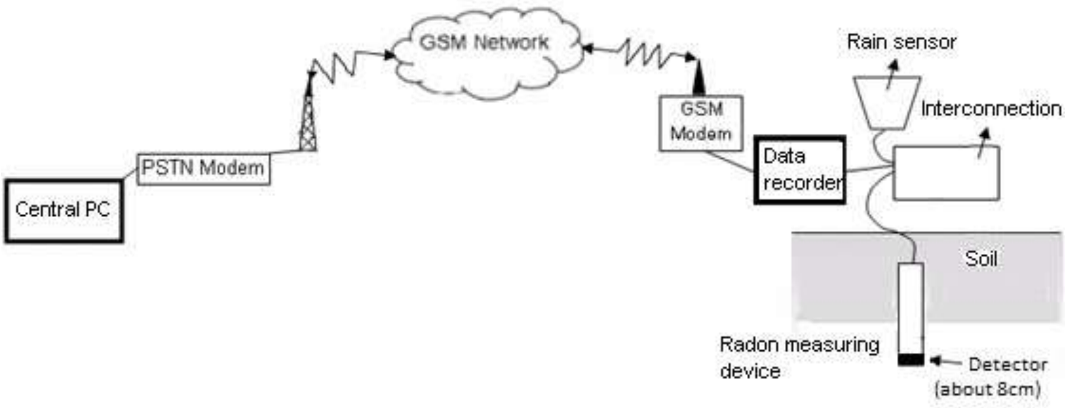

Figure 2. Active radon measuring system.

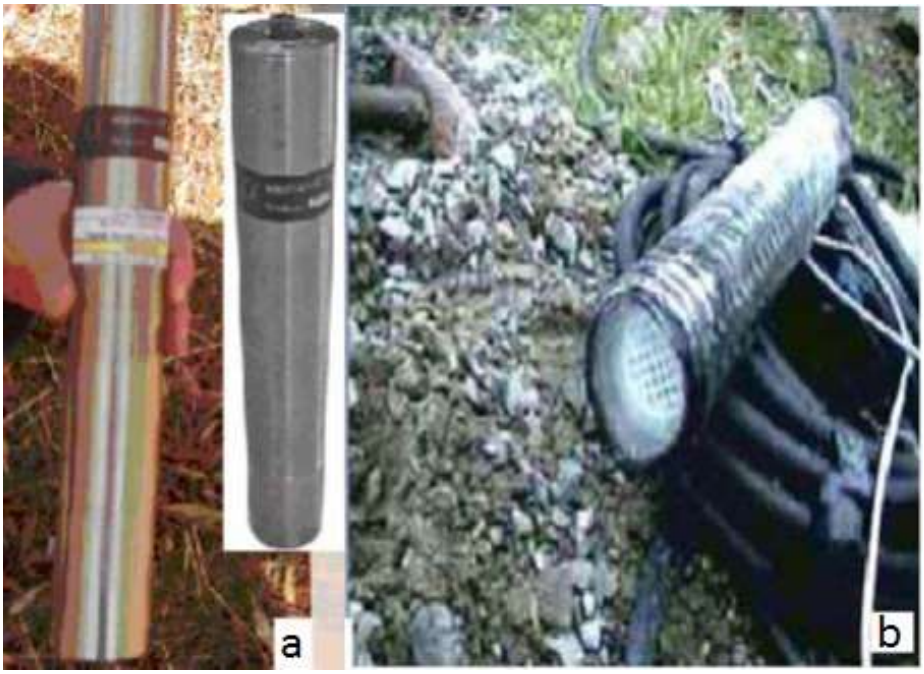

Figure 3. (a) Alphameter 611 model, (b) Prepared to bury the Alphameter probe.

Four monitoring stations (see Fig. 4) were placed along the fault zone to obtain the active measurements. The data have been collected at every fifteen minutes and stored to be transferred for the analysis. The system also allows the data transfer to the laboratory to be made via on-line system over GSM or fixed telephone line by using remote data transfer systems. The data collected by AlphaMeter 611 sensors are given in counts per 15 min integration time. Calibration by the manufacturer provides for the conversion of the count rates into radon activity. For example, 10 counts per 15 min of integration time recorded by the AlphaMeter equals to about 20 kBq/m^3 soil gas [12].

2.3. Active detection method

The passive detection has been practiced by using CR-39 detectors. To get the average values, three passive detectors were embedded in earth about 15-20 cm over the surface, around each active monitoring stations. The passive detectors were cut into 2cmx2cm pieces, and were inserted into plastic radon diffusion cups with 4,5cm x 9cm dimensions. The measurements have been obtained by the track counting caused by alpha particles, emitted by radon decay, which interacted with the passive detector. Number of tracks, which occur due to the interaction between the detector and the alpha particles that has arisen from radioactive disintegration of radon into the diffusion cup, and this is proportionate to radon concentration that has entered into the cup [14].

The activity concentration of radon has been calculated by using;

$$C_{Rn} = \frac{\rho}{\eta T} \quad . \tag{1}$$

Here, C_{Rn} is the radon concentration in (kBq/m^3) units, ρ is the track density (track/cm^2), η is the detection efficiency (0,089 (track cm^{-2} day^{-1})/(Bq m^{-3})) and T is the period during which the detector is exposed to radon [15].

3. Results and Discussion

The radon variations obtained from four monitoring stations (see Fig. 4) are illustrated in Figure 5.

Figure 4. Radon monitoring stations locations on the Sivrice Fault Zone.

It is can be easily seen at Figures 5 and Table 1 that the radon variations are not the same for all locations. It is assumed that the difference in the variations is the result of being founded on faults of the Sivrice Fault Zone that have seismic activities different from each other. Station II is located on the southern part of the Sivrice Fault Zone that has a higher seismic activity (considering Hazar Lake) [16].

Through the active fault zones, deformations in the earth's crust and secondary fractures and cracks in rocks that make up the earth's crust are increasing; this increase is accelerating the exit of radon. Higher seismic activity causes more radon emanation in the area. The increase of emission of soil radon in period of earthquakes that occur at short intervals is lower according to in period of earthquakes that occur at long intervals. This situation indicates that the fault and fractures, which occur on the rocks of this zone before an earthquake, are controlled by the movement of the fault [17].

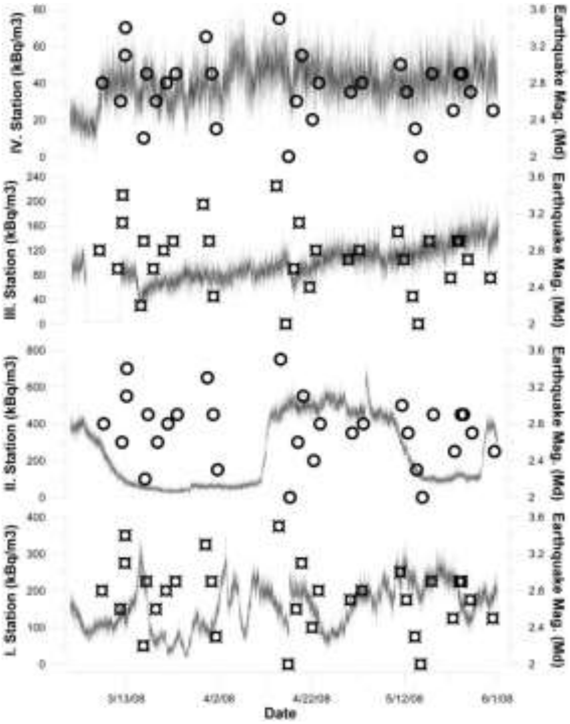

Figure 5. Radon concentration in soil and earthquake versus time.

Table 1. The relevant information with earthquakes that occurred within a radius of 150 km centered Sivrice at March - May 2008.

Date (dd.mm.yyyy)	I-Station Radon (kBq/m^3)	II-Station Radon (kBq/m^3)	III-Station Radon (kBq/m^3)	IV-Station Radon (kBq/m^3)	Latitude (N)	Longitude (E)	Depth of Earthquake (km)	Magnitude of Earthquake (Mw)
01.03.2008	154	358	68	30	38.3105	39.1960	07.0	2.8
05.03.2008	80	372	-	18	38.4065	39.1280	07.0	2.3
06.03.2008	90	320	-	20	38.2598	38.7397	07.0	3.1
06.03.2008	106	342	-	12	38.2478	38.7500	07.0	2.5
06.03.2008	108	302	-	16	38.3323	38.6955	05.6	3.4
10.03.2008	106	144	-	34	38.6843	39.0722	07.0	2.2
11.03.2008	116	140	-	30	38.2837	38.8605	07.0	2.9
12.03.2008	110	100	62	30	38.3560	39.0558	07.0	2.8
17.03.2008	204	52	66	42	38.3025	38.2715	07.0	2.4
18.03.2008	82	46	46	48	38.2455	38.8090	07.0	2.9
20.03.2008	74	44	68	40	38.4013	39.1053	07.0	2.3
25.03.2008	66	30	82	42	38.4215	39.1225	07.3	3.3
27.03.2008	96	60	88	38	38.3145	38.7115	05.5	2.3
11.04.2008	176	80	90	44	38.5215	39.6757	16.3	3.5
13.04.2008	204	458	112	42	38.3258	38.9747	07.0	2.0
16.04.2008	140	484	98	44	38.4743	38.9840	07.1	3.1
09.05.2008	202	426	110	32	38.3023	38.9990	07.0	2.3
10.05.2008	230	318	106	38	38.7578	40.0485	23.5	3.3
13.05.2008	228	188	124	28	38.3510	38.9890	07.0	2.0
16.05.2008	222	98	122	40	38.6747	39.7728	06.9	2.9
18.05.2008	242	100	132	36	38.3920	39.2598	07.0	2.4
22.05.2008	214	104	136	44	38.8810	40.0535	10.4	2.9
30.05.2008	168	392	162	40	38.7490	39.0375	07.0	2.5

When soil radon emanation alterations obtained from the monitoring stations and from similar studies [7,12] in the literature are examined in terms of the relationship of the earthquake with the soil radon emissions, it was seen that almost all the earthquakes during the time period of the study occurred in the decrease of radon period following the increase of radon (Figure 6). This situation can be explained with the increase of secondary fractures that increase the permeability of rocks before the earthquake, as deformations cause an accumulation of energy throughout the fault zone. After the accumulation of stretching reaches the maximum value, the increase in radon concentration or emission stops and the earthquake occurs at the following decrease period.

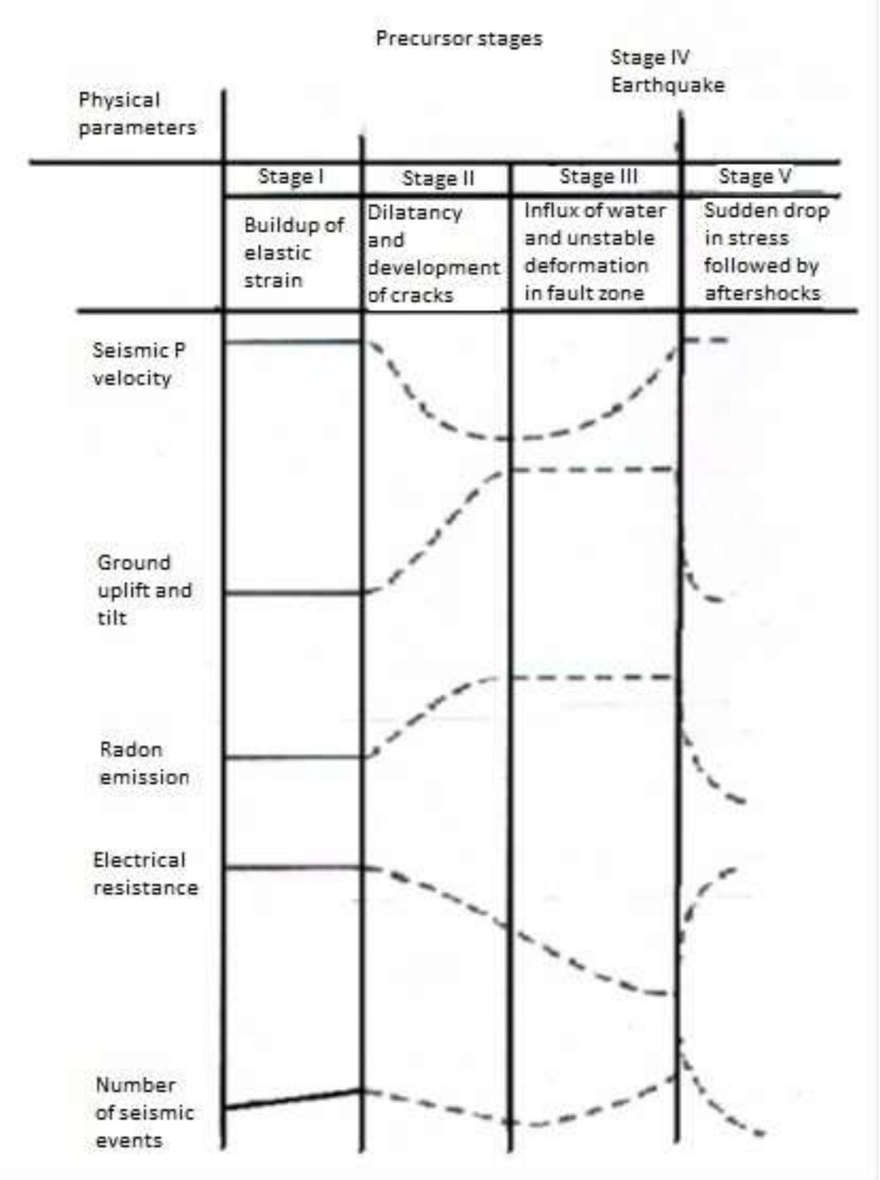

Figure 6. Changes of some physical parameters in pre-earthquake [17].

When Figure 7, in which radon activity concentration of soil samples from different three points of each four monitoring stations are represented is examined; I-3 sample has the lowest radon expansion in 2.9±0.4 kBq/m^3 value and IV-2 sample has the highest radon expansion in 5.1±1.2 kBq/m^3 value. It is seen that radon expansion values of the soil samples from station IV are more than the values obtained from the soil samples from the other monitoring stations.

In consequence of both measurements, it is obvious that radon expansions of station I are lowest (3.2±1.0 kBq/m^3 of average) and expansions of station IV are highest (5.0±0.4 kBq/m^3 of average). The average radon concentration values collected from stations II and III are 4.0±0.5 kBq/m^3 and 4.2±0.1 kBq/m^3, respectively.

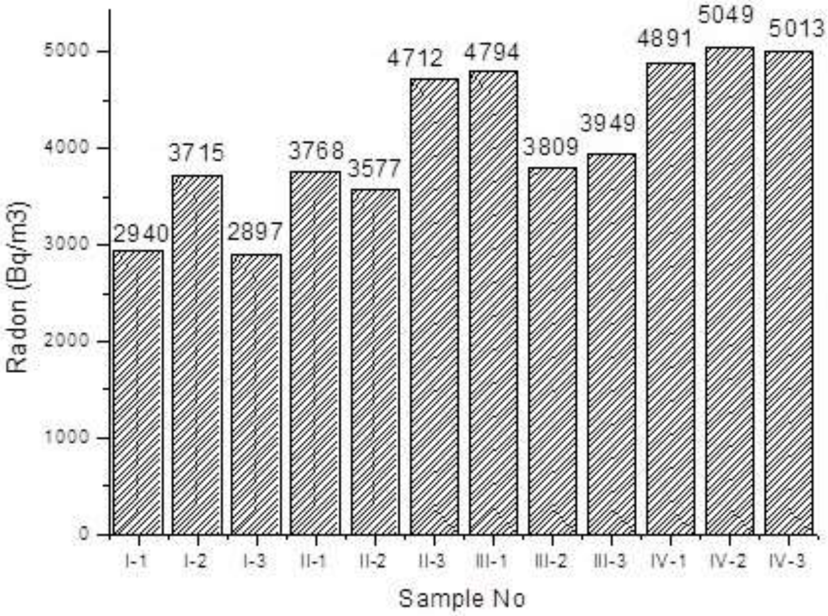

Figure 7. Changes of radon emissions by CR-39 in soil samples taken from monitoring stations.

4. Conclusion

It has been concluded that soil radon alteration can be used as an important parameter for earthquake prediction if it is founded at frequent intervals, by taking into consideration the character of the fault on the fault system and rock and soil that are surfacing throughout the fault zone, through continuous observation at long periods.

Whilst earthquakes occur, due to movement of rocks falling down or rising, an increase or a decrease occurs at radon expansion that accumulated underground. Through the data acquired in this study, some alterations have been seen at soil radon expansion and when it has been compared with the data from AFAD, it has been observed that these alterations are parallel to earthquakes that occur at small or severe levels in general [7,18]. There is a relationship between the alterations of soil radon expansion and the occurrence of earthquakes, however, it has been seen that some other parameters (temperature, humidity and pressure) also have an effect on radon expansion. Nevertheless, it is indicated that alterations at soil radon expansion can be used as an important parameter for earthquake predictions.

Acknowledgements

The author would like to thank Professor Soner ÖZGEN, Department of Physics, Faculty of Arts & Sciences, and Professor Ercan AKSOY, Faculty of Engineering, Department of Geological Engineering, for their help in defining the geological features of the studied area. This work was supported by TÜBİTAK with the project number 104Y158 and FÜBAP with the project number 1404.

Author’s Contributions

All authors contributed equally to the study.

Statement of Conflicts of Interest

There is no conflict of interest among the authors.

Statement of Research and Publication Ethics

The authors declares that this study complies with Research and Publication Ethics.

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