Special issue of the 3rd International Conference on Computational and Experimental Science and Engineering (ICCESEN 2016)

Assessments of Natural Radioactivity Concentration and Radiological Hazard Indices in Surface Soils from the Gözlek Thermal SPA (Amasya–Turkey)

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The concentration of natural radioactivity was determined in the surface soil of the Gözlek Thermal SPA in Amasya. The activity concentrations of natural radionuclides in soil samples were determined using gamma-ray spectrometer, containing a $3'' \times 3''$ NaI(Tl) detector connected to multi-channel-analyser. The photo-peaks at 1460, 1764 and 2615 keV are due to ^{40}K, ^{226}Ra and ^{232}Th, respectively. The radiological hazard indices of the natural radionuclides content, radium equivalent activities Ra_{eq}, absorbed dose rate (ADR), annual effective dose rate (AEDR) and external hazard index H_{ex} were also calculated.

DOI: 10.12693/APhysPolA.132.1200

PACS/topics: 29.90.+r, 29.30.–h

1. Introduction

Natural radioactivity is caused by radionuclides originating from the Earth's crust and from cosmic rays [1]. The human population is always exposed to natural radioactivity. The main source of natural radioactivity is the radioactive series such as thorium, uranium and actinium.

It is important to know the gamma radiation coming from the natural sources because the natural radiation constitutes the largest part of the external dose [2]. For this purpose, several studies have been carried out to measure the natural activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th in different materials [3–11].

Natural radioactivity levels depend on the geological and geographical characteristics of the region. Assessment of the concentrations of natural radionuclides, such as ^{40}K, ^{226}Ra and ^{232}Th, in Gözlek thermal SPA soil is important for determining these environmental effects in the local area.

2. Materials and methods

2.1. Sample collection and preparation

A total of six different soil samples were collected from thermal SPA area (Fig. 1) and natural radioactivity for ^{40}K, ^{226}Ra and ^{232}Th radionuclides has been measured.

The samples were prepared for the measurement [10, 11]. Each sample was then placed into a cylindrical container and sealed. Samples were stored for four weeks before counting, to allow ^{226}Ra and its short-lived decay products to reach the secular equilibrium.

Fig. 1. Thermal SPA area.

2.2. Radiometric analysis

The natural radionuclides are ubiquitous. They belong to the uranium and thorium series and their decay products, as well as to single decay radionuclides, such as ^{40}K [12]. Measurements of the natural radioactivity concentrations of ^{40}K, ^{226}Ra and ^{232}Th (Bq/kg) of the collected samples were carried out using a $3'' \times 3''$ NaI(Tl) gamma-ray spectrometer. The spectra were analyzed using the MAESTRO32, obtained from ORTEC. The energy calibration was done using radioactive sources of ^{137}Cs (662 keV) and ^{60}Co (1173 and 1332 keV). The calibration γ-ray energy spectrum for ^{60}Co source and the related fit obtained from this source for the detector system calibration are displayed in Fig. 2.

After calibration of the detection system, the background and sample measurements have been done during 72 000 s. The ^{226}Ra and ^{232}Th activity concentrations were determined through the photo-peaks of their daughters, respectively, ^{214}Bi (1760 keV) and ^{208}Tl (2615 keV). The ^{40}K activity concentration was determined directly using ^{40}K (1460 keV) photo-peak [13].

The activities for the natural radionuclides in the measured samples can be calculated by the following relation:

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$$A(\mathrm{Bq/kg}) = \frac{N}{\varepsilon\gamma mt}, \quad (1)$$

where N is the net background-subtracted count, ε is the detector efficiency, γ is the absolute transition probability of gamma decay, m is the mass of the sample (kg) and t is the counting time (s).

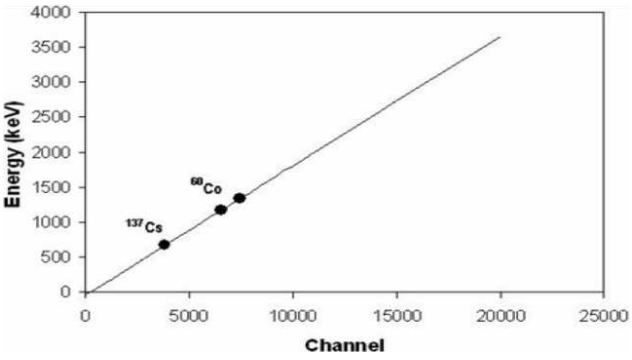

Fig. 2. Calibration fit of the detector.

3. Results and discussion

3.1. Specific activity

The results of the specific activity (A, Bq/kg) of soil samples are shown in Fig. 3. The worldwide concentrations of the radionuclides are 412 Bq/kg for ^{40}K, 32 Bq/kg for ^{226}Ra and 45 Bq/kg for ^{232}Th [14].

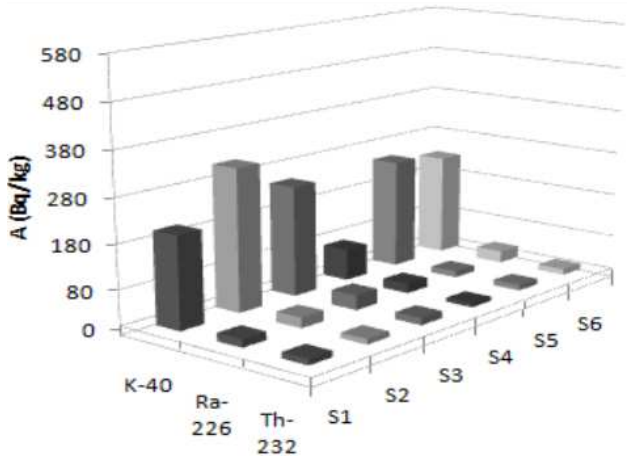

Fig. 3. 3D spectrum for ^{40}K, ^{226}Ra and ^{232}Th activity concentration.

The measured radioactivity concentrations have ranged from 71.85 to 321.35 Bq/kg for ^{40}K, from 14.16 to 26.74 Bq/kg for ^{226}Ra, and from 9.04 to 16.03 Bq/kg for ^{232}Th (Fig. 3). All measured activity concentrations are lower than the recommended UNSCEAR values.

3.2. Radium equivalent activity

The radium equivalent activity ($\mathrm{Ra_{eq}}$, Bq/kg) is related to the external and internal effective dose due to radon and its daughters. It can be calculated by the following equation [15]:

$$Ra_{\mathrm{eq}} = 0.077A_{\mathrm{K}} + A_{\mathrm{Ra}} + 1.43A_{\mathrm{Th}}, \quad (2)$$

where A_{K}, A_{Ra} and A_{Th} are the activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th in Bq/kg, respectively. The results have ranged from 40.16 to 75.80 Bq/kg (Fig. 4). The calculated $\mathrm{Ra_{eq}}$ values are lower than the recommended maximum limit value of 370 Bq/kg [15, 16].

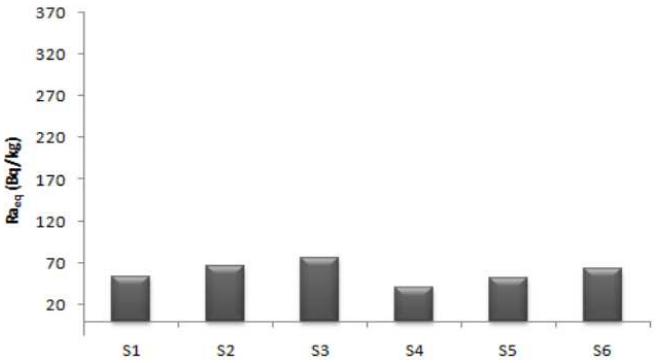

Fig. 4. Radium equivalent activity for soil samples.

3.3. Absorbed dose rate

The absorbed dose rate (ADR, nGy/h), due to gamma radiations in air, at 1 m above the ground surface, for the uniform distribution of naturally occurring radionuclides (^{40}K, ^{226}Ra and ^{232}Th), can be calculated by the following relation [17]:

$$D(\mathrm{nGy/h}) = 0.042A_{\mathrm{K}} + 0.429A_{\mathrm{Ra}} + 0.666A_{\mathrm{Th}}. \quad (3)$$

The results have ranged from 18.35 to 35.60 nGy/h (Fig. 5). This is within the world value range of 18–93 nGy/h [18]. The recommended average value is 55 nGy/h [2]. The absorbed dose values are lower than the average value and within the world values range.

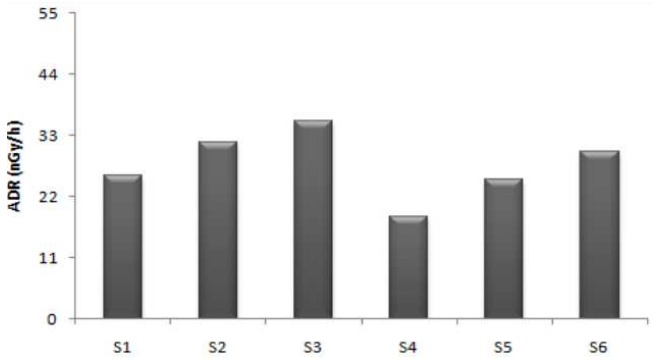

Fig. 5. Absorbed dose rate for soil samples.

3.4. Annual effective dose rate

The health effect of the ADR is characterized by the annual effective dose rate (AEDR, mSv/y). AEDR from the radionuclides in the natural materials have been calculated based on the ADR.

AEDR was calculated using the following formula [2]:

$$\mathrm{AEDR(mSv/y)} = \mathrm{ADR} \times t \times Q \times Q_f \times 10^{-6}, \quad (4)$$

where t is time in hours in 1 year (8760 h), Q is the conversion coefficient (0.7 Sv/Gy) from the absorbed dose in air to the effective dose and Q_f is the outdoor occupancy factor (0.2) proposed by UNSCEAR [17]. The results have ranged from 0.022 to 0.043 mSv/y. This is lower than the ICRP recommended value (the annual effective dose equivalent limit of 1 mSv/y for the individual members of the public and 20 mSv/y for the radiation workers [19, 20]).

3.5. External hazard index

The external hazard index, H_{ex}, can be calculated by the following equation [12];

$$H_{\mathrm{ex}} = \frac{A_{\mathrm{Ra}}}{370} + \frac{A_{\mathrm{Th}}}{259} + \frac{A_{\mathrm{K}}}{4810}, \quad (5)$$

where A_{Ra}, A_{Th} and A_{K} are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in Bq/kg, respectively (Fig. 6). The value of this index must be less than or equal to unity [16]. The results have ranged from 0.11 to 0.20. The calculated H_{ex} values are lower than the recommended limit value.

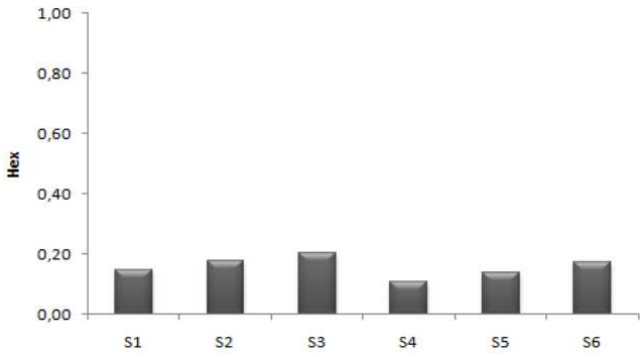

Fig. 6. Hazard index for soil samples.

4. Conclusions

In this study, the natural radioactivity concentration and radiological hazard indices in soil samples, collected from in thermal SPA area, were investigated. The measured natural radioactivity concentrations (^{40}K, ^{226}Ra and ^{232}Th) and calculated radium equivalent activities $\mathrm{Ra_{eq}}$, absorbed dose rate ADR, annual effective dose rate AEDR and external hazard index H_{ex} in the thermal SPA soil samples were significantly lower than the worldwide average values.

Acknowledgments

This work has been supported by Scientific Research Projects Unit of Amasya University (FMB-BAP 15-0130).

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