Determination of Natural Radionuclides Concentrations in Surface Soil in Tafila/Jordan

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Abstract

A first comprehensive study is presented on natural radionuclide activity concentrations in surface soils in different divisions of Tafila city. The natural radioactivity of ^{238}U, ^{232}Th and ^{40}K is determined using gamma spectroscopy. The soil activity concentrations ranged from 1.8 to 76.4 Bq kg^{-1} for ^{238}U, 6.3 to 85.5 Bq kg^{-1} for ^{232}Th, and 84 to 516.7 Bq kg^{-1} for ^{40}K. The activity concentrations of the radionuclide in soils are directly relevant to outdoor exposure. Absorbed dose rates in air outdoors were calculated to be in the range of 22.28 – 62.71 nGy h^{-1} with an overall average value of 40.12 nGy h^{-1}. The study showed an annual effective dose equivalent in the range of 27.34 – 76.96 μSv y^{-1}. A comparison of the measured values with the corresponding worldwide average values shows that the activities of natural radionuclides in the studied samples are below the world average activity values.

Keywords: Radioactivity concentrations, HPGe gamma spectrometry, ^{40}K, ^{232}Th, ^{238}U

1. Introduction

Radionuclides have been present always in every environment of the earth's surface. Only nuclides with half-lives comparable to the age of the earth or their corresponding decay products, existing in terrestrial materials, can still be found today on earth, e.g. ^{40}K, and the radionuclides from the ^{238}U and ^{232}Th series (UNSCEAR, 2000). Gamma radiation, emitted from these naturally occurring radionuclides and from radionuclides deposited on the ground, represents the main external source of irradiation of the human body. It is generally realized that natural environmental radioactivity and the associated external exposure due to gamma-radiation depend primarily on the geological and geographical conditions, and appear at different levels of radionuclides in the soils of each region in the world (Shenber, 1997; Karahan, et al., 2000; Chikasawa, et al., 2001; AL-Masri, et al., 2006). Therefore, to evaluate the dose rate caused by these radionuclides, their concentrations in soil have to be determined. It turned out that understanding the behavior of natural radionuclides in environment is so important, because such information can be used as the associated parameter values for radiological estimations (Vera Tome, et al., 2003). It is interesting to mention that only few previous studies were conducted to determine the radioactivity levels and associated dose rates from surface soils in Jordan. Among them, Ahmad et al. (1997) have been measured the indoor radon concentration levels and natural radioactivity in soil in different areas of Jordan. Al-Hamarneh et al. (2003) have made a study on surface and core soil samples collected from different regions of Jordan. In their work, they focused on measuring the concentrations of artificial radionuclides. The estimations of the annual effective dose equivalent due to ^{137}Cs were found to have values more than 200 μSv. AL-Jundi (2002) has found that the values of the concentrations of ^{40}K and ^{232}Th are normal in comparison to other worldwide standards in other countries, while the concentrations of ^{238}U, in samples obtained from old phosphate mine, are much more higher than the worldwide range. Similar study has been made by AL-Jundi et al. (2003) on a measurement of the specific activity and the gamma-ray absorbed doses of the naturally occurring radionuclides in soil cores obtained from eight sites along Amman Aqaba National Highway. Recently, Kharisat (2010) has used alpha spectrometry technique to measure the specific activity of ^{238}U in soil and vegetables of Tafila city. In this paper, an attempt has been made to determine the concentration of ^{40}K, ^{232}Th and ^{238}U in soil samples collected from ten different divisions of Tafila city using HPGe gamma ray spectrometer and to compute the total absorbed gamma dose rate in air due to the presence of ^{40}K, ^{232}Th and ^{238}U in the samples.

2. Experimental

A total of fifty samples were collected from ten divisions (samples from five selected sites of each division) at 0 - 10 cm depth level all over Tafila city. These samples were collected from uncultivated fields using a stainless steel template. The samples were first crushed and milled to a fine powder. Then, they oven dried at temperature of 70 ℃ for 24 hours to ensure that moisture was completely removed and sieved through a 1 mm mesh to remove stone, pebbles and other macro-impurities. Last, each sample was weighed, carefully sealed in standard plastic Marinelli beakers prior being taken for gamma spectrometric analysis.

The spectral analysis of the radionuclides of these samples was carried out using a γ–ray spectrometer equipped with high purity germanium (HPGe) detector of 20% relative efficiency and an energy resolution (FWHM) of 1.8 keV for the 1.33 MeV reference transition of ^{60}Co. The detector was placed inside a thick lead shield to reduce the background radiation. The detector output signal was taken to the PC equipped with a MCA (Multi Channel Analyzer, model DSA-1000). The software utilized for data acquisition is Canberra software package Genie-2000, including peak search and nuclide identification modules. The system was calibrated for energy and efficiency on a regular basis. The energy calibration was carried out by acquiring a spectrum from certified calibration sources of known energies such as ^{60}CO, for E_γ = 1332.5 and 1173.2 keV, and ^{137} Cs, for E_γ= 661.6 keV. The detector energy-dependent efficiency was determined using reference samples (RGU, RGTH and RGK) provided by the International Atomic Energy Agency, IAEA in the same geometry as the measured samples. The gamma-rays of interest ranged from 50 – 3000 keV. The prepared Marinelli beakers (samples) were placed on the detector end cap a distance 10 mm approximately. Each sample was counted for a period of 10 hours to obtain good statistics and the dead time was smaller than 10%. Measurements with an empty Marinelli beaker, under identical conditions, were also carried out to determine the background counts. The latter was subtracted from the measured spectra of each sample to obtain the net radionuclide activities.

3. Results and Discussion

The measured activity concentrations of the natural radionuclides ^{238}U, ^{232}Th and ^{40}K for the collected samples from Tafila city are shown in Table 1. The activity concentration of each radionuclide was measured for five different samples coming from the same site and then averaged. The concentrations of ^{238}U were in the range of 1.8 to 76.4 Bq kg^{-1} with a mean value of 22.03 Bq kg^{-1}. It can be seen in this table that the mean activity concentrations of ^{232}Th and ^{40}K were 27.91 Bq kg^{-1} and 285.02 Bq kg^{-1}, respectively. A mean value of 17.9 Bq kg^{-1} for ^{232}Th and 558.4 Bq kg^{-1} for ^{40}K were measured in soils collected in 1997 from Tafila city (Ahmed, et al., 1997). Our result for ^{232}Th is seen to fall above the previous measured value of Ahmad et al. (1997). However, our result for ^{40}K is less than their result by a factor of two. The variation in the results can be attributed to many factors like number of soil samples, soil characteristics and location of the sites. Another comparison can be made between our results and that of UNSCEAR (2000) report. According to this report, the worldwide average concentration values of the natural radionuclides ^{238}U, ^{232}Th and ^{40}K are 40 Bq kg^{-1}, 40 Bq kg^{-1} and 370 Bq kg^{-1}, respectively. It is obvious that our findings are in general agreement with the worldwide measured values. Table 2 presents the activity concentrations of natural radionuclides in soil samples of different regions in the world. The comparison of our findings of the activity concentration with those obtained by other workers worldwide, reveals that we have reasonable values.

In this work, the estimate of the absorbed gamma dose rate in outdoor air was calculated using the following formula (Chikasawa, et al., 2001):

$$\text{Dose rate (nGy h}^{-1}\text{)} = \text{Concentration of nuclide} \times \text{Conversion factor} \quad (1)$$

Here the conversion factor is 0.427 nGy h^{-1}/Bq kg^{-1} for ^{238}U, 0.662 nGy h^{-1}/Bq kg^{-1} for ^{232}Th and 0.043 nGy h^{-1}/Bq kg^{-1} for ^{40}K. The calculations for the absorbed dose rates were made for a height of one meter above the ground surface from different locations, assuming that naturally occurring radionuclides are uniformly distributed in the ground. In addition, the absorbed doses were calculated only from outdoor terrestrial gamma radiation.

Furthermore, the effective dose outdoors over one year was calculated based on UNSCEAR reports (1993, 2000) using the following relation:

$$\text{Effective dose rate (Sv y}^{-1}\text{)} = \text{Dose rate (nGy h}^{-1}\text{)} \times 8766\ \text{h} \times 0.2 \times 0.7\ \text{mSv Gy}^{-1} \quad (2)$$

where 0.2 is the occupancy factor and 0.7 is the conversion coefficient.

The total absorbed gamma dose rate in air outdoors, D (nGy h^{-1}), along with the annual committed effective dose equivalent, E (μSv y^{-1}), due to external exposure of ^{238}U, ^{232}Th and ^{40}K in soil of Tafila city are summarized in Table 3. The D-values were in the range 22.28 to 62.71 nGy h^{-1} with an overall average value of 40.12 nGy h^{-1}.

The results are in agreement with the average world figures. The dose rate in air outdoors from terrestrial gamma rays in normal circumstances is around 57 nGy h^{-1}, while the national averages ranges between 24 to 160 nGy h^{-1} according to the report of UNSCEAR (2000). The *E*-values, on the other hand, were in the range of 27.34–76.96 μSv y^{-1} with an overall average value of 49.26 μSv y^{-1}. It is clear that the average value of the annual effective dose (0.049 mSv y^{-1}) obtained from Tafila city is lower than the worldwide average value for outdoor effective dose of 0.07 mSv y^{-1}, reported by UNSCEAR (2000).

4. Conclusions

To conclude, a study on natural radionuclide activity concentrations in surface soils of randomly selected divisions in Tafila city has been reported. The mean activity of ^{238}U, ^{232}Th and ^{40}K were found to be 22.03, 27.91 and 285.02 Bq kg^{-1}, respectively. Despite the fluctuation in the measurements of the activity concentrations of each natural radionuclide ^{238}U, ^{232}Th and ^{40}K in the studied soil samples, the data are found to be normal in comparison to the worldwide standards in other countries. The results for dose rate in air outdoors from terrestrial gamma rays are in agreement with the average world values. The annual effective dose was found to be 0.049 mSv y^{-1}, which is well below the permissible dose equivalent. This study is a complementary work added to other works on Jordan environment in order to establish a baseline data for radioactivity levels in the Jordan environment.

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Table 1. Natural radionuclide contents in soil samples

Sample Code	Activity Concentration of Radionuclides in Soil Samples (in Bq kg^{-1})					
	^{238}U		^{232}Th		^{40}K	
	Range	*Mean*	*Range*	*Mean*	*Range*	*Mean*
D_1	47.8 - 76.4	58.20	15.8 – 53.1	39.1	128.4 – 433.6	278.5
D_2	5 - 23	11.60	9.5 – 34.2	22.6	240.8 – 396.2	308.3
D_3	13 - 29	16.30	11 – 28.3	20.7	53.5 – 166.2	106.9
D_4	15 – 28.4	23.70	12.7 – 16.5	15.4	214 - 335	285.3
D_5	1.8 – 4.6	2.12	26.0 – 58.3	37.7	231 – 360.7	292.7
D_6	24.8 – 43.5	37.9	16.1 – 47.5	34.2	207.5 - 347.4	304.6
D_7	9.16 – 14.3	11.25	11.7 – 14.2	13.8	154 - 233	193.9
D_8	12.28 – 14.75	13.04	30.5 – 85.5	51.3	84 - 312	256.2
D_9	11.16 – 13.82	12.40	6.3 – 24.6	15.7	468.9 – 516.7	496.4
D_{10}	25.97 – 48.74	33.80	25.4 – 33.2	28.6	245.3 – 433.8	327.4
Average		22.03		27.91		285.02

Table 2. Reported values of gamma activity in soil (activity Bq kg-1) samples, from the work conducted worldwide

Region (country)	^{238}U	^{232}Th	^{40}K	Reference
Tripoli, Libya	10.5	9.5	270	Shenber (1997)
Istanbul, Turkey	21	37	342	Karahan and Bayulken (2000)
Russiafa, Jordan	48.3-523.2	8.7-27.1	44-344	Al-Jundi (2002)
Kalpakkam, India	5-71 (16)	15-776 (119)	200-854 (406)	Kannan et al. (2002)
Syria	19	24	336	Al- Masri et al. (2006)
World Average	40	40	370	UNSCEAR (2000)

Table 3. Dose rates in air from natural radionuclides in soil samples

Sample Code	Dose Rate in Air (nGy h^{-1})				Annual Effective Dose ($\mu Sv\ y^{-1}$)
	^{238}U	^{232}Th	^{40}K	*Total*	
D_1	24.85	25.88	11.98	62.71	76.96
D_2	4.95	14.96	13.26	33.17	40.71
D_3	6.96	13.70	4.59	25.25	30.99
D_4	10.12	10.19	12.27	32.58	39.98
D_5	0.91	24.96	12.59	38.46	47.20
D_6	16.18	22.64	13.10	51.92	63.72
D_7	4.80	9.14	8.34	22.28	27.34
D_8	5.57	33.96	11.02	50.55	62.04
D_9	5.29	10.39	21.35	37.03	45.44
D_{10}	14.43	18.93	14.08	47.44	58.22
Average	9.41	18.48	12.26	40.12	49.26

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