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Activity Concentrations and Associated Gamma Doses of ^{238}U and ^{235}U in Jordan

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Abstract: In this study, sixteen soil and vegetable samples from Tafila district were collected and analyzed from eight locations. Measurements of specific activity of natural gamma emitter radionuclides, ^{238}U and ^{235}U, in these samples using gamma spectrometry, with the help of Genie 2000 software. Measurements were used to calculate the soil-vegetable transfer factor, and then the external radiation dose and internal radiation dose due to radioactivity of the ingested food. The specific activity of ^{238}U and ^{235}U in soil were found to vary from (in Bq/kg): 26-575 and 1.4-35.5, respectively. The specific activity of ^{238}U and ^{235}U in vegetables were found to vary from (in Bq/kg): 0.019 to 0.632 and 0.0013-0.0375, respectively. The calculated transfer factor of ^{238}U and ^{235}U range from 5.9×10^{-4} to 14.6×10^{-4} for ^{238}U and 4.9×10^{-4} to 16.1×10^{-4} for ^{235}U. External absorbed dose rates were calculated to be in the range from 12.42 to 266.00 nGy/h. The annual effective dose was found to vary from 28.94 to 619.78 μSv/y. The annual internal effective dose due to ^{238}U and ^{235}U for fresh weights of vegetables, were found to vary from 0.9×10^{-3} to 35.1×10^{-3} μSv/y for ^{238}U and 0.61×10^{-4} to 17.62×10^{-4} μSv/y for ^{235}U.

Key words: Soil, vegetables, gamma spectrometry, environmental radioactivity, Tafila, Jordan, transfer factor, internal dose, external dose.

1. Introduction

Tafila District is unique in the presence of phosphate mines and hot spa which are the major sources of natural radioactivity. Ingestion of radionuclides through food intake accounts for a substantial part of average radiation doses to various organs of the body and also represents one of the important pathways for long term health considerations. The status of the soil on which food crops are grown will determine, to a significant extent, the quality of foodstuffs produced. An essential feature of soil is its ability to accumulate and retain over long periods radioactive isotopes introduced into the environment from external sources. Human dietary composition varies from place to place and from one individual to another. Natural radionuclides entering the food chain are mostly derived from the soil and, as a result, variation in soil radionuclide content is a prime source of geographic variability.

Plant uptake also varies from species to species; Hence, the intake of different food products forms a secondary source of variability.

In this part of Jordan, the most important food consumed consists of tomato, onion, potato, carrot and radish. These crops constitute a large percentage of the total diet for both low and medium income consumers in this part of the country.

Since the studied area is rich in natural radionuclides and it is possible that they may accumulate in food chain of the people, this present study aims to determine the activity concentrations of ^{238}U and ^{235}U in some farming products, grown in the area, and to estimate the effective ingestion doses to individuals consuming these types of local food.

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2. Materials and Methods

2.1 Sample Collection

8 soil samples and 8 vegetable samples has been collected in the present study from 8 locations in the Tafila District, denoted as location-1, up to location-8 (Fig. 1), following the adopted international scientific standards. Soil samples were collected using the template method: sharp stainless steel template of 30 × 30 cm^2 and 5 cm depth. The template was fixed on the surface down to 5 cm and soil was collected. The vegetable samples were tomato in location-1, potato in location-2, onion in location-3, tomato in location-4, carrot in location-5, radish in location-6, tomato in location-7, potato in location-8.

The 500 g uniform mass samples were samples counted for 20 h using a low-level gamma spectrometry system consisting of a 3″ × 3″ (76 mm × 76 mm) NaI (Tl) detector (Model No. 802-series, Canberra Inc.) joined toward a Canberra Series 10 plus Multichannel Analyzer (MCA) (Model No. 1104) through a preamplifier base. The net area under each photo-peak, after background corrections, was used to calculate the activity concentration of each radionuclide in the samples. The sample activity per unit of mass (Bq/kg) is achieved by using the following relation (UNSCEAR, 2000):

$$C(Bq/kg) = \frac{N_C}{\varepsilon PM} \tag{1}$$

where, N_C is the count rate under each photo-peak due to each radionuclide, ε is the detector efficiency for the specific γ-ray, P is the absolute transition probability of the specific γ-ray and M is the mass of the sample (kg).

2.2 External Doses

The external dose rates (D), at 1m above the ground surface in units of nGy/h, can be calculated by the following equation (UNSCEAR, 2000):

$$D = A_E \times C_F \tag{2}$$

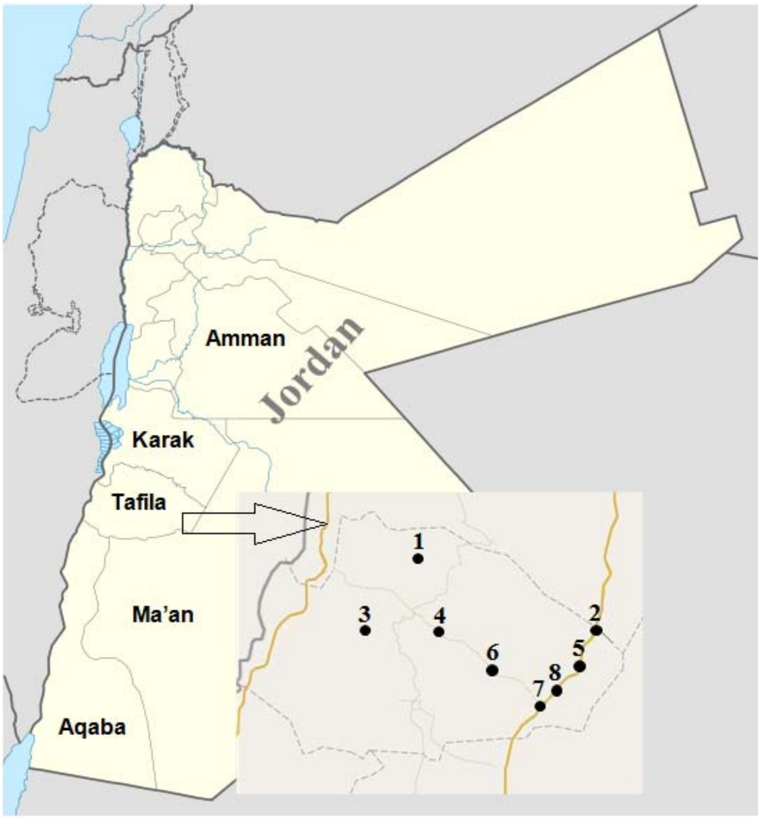

Fig. 1 The sampling area of Tafila District.

where, A_E is the activity concentration of nuclides (in Bq/kg), and C_F is the dose rate conversion factor (in nGy/h per Bq/kg). The dose conversion factors were taken from the MC, GEANT, MCNP codes, and UNSCEAR (2000) report which are based on the Monte Carlo simulation technique and represented in Table 1. The average values of the dose rate conversion factors in Table 1 were used in the present calculations and the results are shown in Table 2. The annual effective dose rate to the population, H_E (in μSv/y), is calculated by the following equation (UNSCEAR, 2000):

$$H_E = D \times T \times F \tag{3}$$

where, D is the absorbed dose rate (nGy/h*),* T is the annual time outdoors (2920 h/y) and F is the absorbed-to-effective dose conversion factor. For adults, children, and infants, this factor is 0.7×10^{-6}, 0.8×10^{-6}, 0.9×10^{-6} m Sv/nGy, respectively, with average value of 0.8×10^{-6} m Sv/nGy for the general public.

2.3 Internal Doses

Internal exposures arise from the intake of terrestrial radionuclides by inhalation and ingestion. Doses by inhalation result from the presence in air of dust particles containing radionuclides of the ^{238}U and ^{232}Th decay chains. The dominant component of inhalation exposure is the short-lived decay products of radon. Doses by ingestion are mainly due to ^{40}K and to the ^{238}U and ^{232}Th series radionuclides present in foods and drinking water.

In calculating the internal dose which results from the transfer of radionuclides from vegetables to human body, a possible risk of radioactivity for human health is expressed by internal effective dose ($D_{internal}$) given in mSv and may be calculated from (ICRP, 1996):

$$D_{internal} = A \times d_k \tag{4}$$

where, A is the activity concentration (in Bq/kg), d_k is the dose coefficient (conversion factor), defined as the dose received by an adults per unit intake of radioactivity, the conversion factor for ^{238}U is 45×10^{-3} μSv/Bq and 47×10^{-3} μSv/Bq for ^{235}U is equal (see Tables 4.13, 4.14 and 4.15). The activity A is the activity concentration (in Bq/kg) multiplied by the intake (kg/y) fresh weight. The Internal effective doses in are based on a 1 kg fresh weight intake per year.

2.4 Transfer Factors

The TF (Transfer factors) of radionuclides from soil to vegetables were calculated by comparing the soil and vegetable samples taken from the same collection place. The transfer factor can be calculated by the following equation:

$$TF = \frac{Activity\ concentration\ in\ planet\ (Bq/kg)(fresh\ weight)}{Activity\ concentration\ in\ soil\ (Bq/kg)} \tag{5}$$

3. Results and Discussion

This study is the first one in the studying area, which is Tafila District, where the largest phosphate mines, hot spa, and other non discovered sources of natural radioactivity are available. Here, we present the results of radioactivity measurements of soil and vegetable samples collected from Tafila District, and the radiation doses related to these concentrations.

3.1 Activity in Soil

Tables 1 and 2 summaries the activity concentrations (in Bq/kg) for the radionuclides, U^{238} and U^{235}, for the 8 soil samples collected from several regions in Tafila District. The activity concentration (in Bq/k*g*) varies from 26 - 575 for U^{238} and from 1.4-35.5 for U^{235}. These results are comparable with others obtained in Jordanian areas (Al-Jundi, 2002, Ahmad et al., 1997), while it is higher than other activity concentrations of U^{238} and U^{235} in different regions in the world (Boston et al., 2005, Al-Masri et al., 2006, Shenber, 1997).

3.2 Activity in Vegetables

Tables 1 and 2 summaries also, the activity concentrations (in Bq/kg) for the radionuclides (U^{238} and U^{235}) for the vegetable samples collected from several regions in Tafila District. As can be seen, the activity concentration (in Bq/kg) varies from 0.019 to 0.632 for U^{238} and 0.0013 to 0.0375 for U^{235}. We can see that some our results are within the national and international ranges while others are higher than these ranges (Hernandez et al., 2004, Pilhani et al., 2005, Arogunjo et al., 2009).

3.3 Transfer Factors

Tables 1 and 2 show also, the transfer factors for the radionuclides ($U^{238}$and U^{235}) for the 8 samples in the present study, as it can be it varies from 5.9×10^{-4} to 14.6×10^{-4} for U^{238} and from 4.9×10^{-4} to 16.1×10^{-4} for U^{235}. This shows that the transfer factors are variable parameters that appear to be independent of the soil activity.

3.4 External Doses

Table 3 shows the results obtained for the external dose and for the annual effective dose H_E assessment for the ^{238}U for all soil samples. Most calculated doses in this study are higher than the worldwide ranges of the dose rate value (18-93) nGy/h (UNSCEAR, 2000). Dose rate conversion factors for external exposure in soil for U^{238} is 0.462 nGy/h per Bq/kg (UNSCEAR, 2000).

3.5 Internal Doses

Tables 4 and 5 show the specific activity (*Bq/kg*) and the internal effective dose (*μSv/y*) for fresh weights of vegetable samples due to ^{238}U and U^{235} respectively. The annual internal effective dose due to U^{238} and ^{235}U for fresh weights of vegetables, were found to vary from 0.9×10^{-3} to 35.1×10^{-3}μSv/y for ^{238}U and 0.61×10^{-4} to 17.62×10^{-4}μSv/y for ^{235}U. The results found in the present study are within these ranges.

On the basis of the measurements carried out for the sites investigated during the study, Uranium does not pose a radiological hazard to the residents in Tafila District. Estimated annual radiation doses that could arise from exposure to Uranium residues are very low and of little radiological concern. Estimated annual radiation doses that could arise in the different areas are of the order of a few hundred microsieverts, well above the annual doses received by the world population from natural sources of radiation in the environment, but it is very far below the action level of 10 mSv suggested by the ICRP as a criterion to establish whether remedial actions are necessary.

Table 1 The specific activity of U^{238} of radionuclides in soil and vegetable samples, and the TF for U^{238}.

Sample (site) #	The specific activity of U^{238} (Bq/kg) in soil	The specific activity of U^{238} (Bq/kg) in vegetable	Transfer factor
1	46.032	0.042	9.1×10^{-4}
2	371.699	0.221	5.9×10^{-4}
3	26.897	0.019	7.1×10^{-4}
4	72.901	0.056	7.7×10^{-4}
5	575.774	0.780	13.5×10^{-4}
6	306.981	0.449	14.6×10^{-4}
7	352.168	0.161	5.10×10^{-4}
8	490.628	0.632	12.9×10^{-4}

Table 2 The specific activity of U^{235} of radionuclides in soil and vegetable samples, and the TF for U^{235}.

Sample (site) #	The specific activity of U^{235} (Bq/kg) in soil	The specific activity of U^{235} (Bq/kg) in vegetable	Transfer factor
1	2.0	0.0027	6.8×10^{-4}
2	16.6	0.0082	4.9×10^{-4}
3	1.4	0.0013	9.3×10^{-4}
4	3.0	0.0023	7.7×10^{-4}
5	35.5	0.0375	10.5×10^{-4}
6	20.6	0.0331	16.1×10^{-4}
7	16.3	0.0183	11.2×10^{-4}
8	22.5	0.0362	16.1×10^{-4}

Table 3 The external dose rate (nGy/h) and the annual effective dose (μSv/y).

Sample (site)	The specific activity of U^{238} (Bq/kg) in soil	The dose rate (nGy/h)	The annual effective dose (μSv/y)
1s	46.032	21.21	49.42
2s	371.699	171.32	399.18
3s	26.897	12.42	28.94
4s	72.901	33.68	78. 47
5s	575.774	266.00	619.78
6s	306.981	141.82	330.44
7s	352.168	162.70	379.09
8s	490.628	226.67	528.14

Table 4 The internal effective dose (μSv/y) due to ^{238}U for fresh weights of vegetables.

Sample symbol	The specific activity of U^{238} (Bq/kg) in vegetable	Internal effective dose (μSv/y)
1v	0.042	2.1×10^{-3}
2v	0.221	9.9×10^{-3}
3v	0.019	0.9×10^{-3}
4v	0.056	2.5×10^{-3}
5v	0.780	35.1×10^{-3}
6v	0.449	20.2×10^{-3}
7v	0.161	7.2×10^{-3}
8v	0.632	28.4×10^{-3}

Table 5 The internal effective dose (μSv/y) due to ^{235}U for fresh weights of vegetables.

Sample (site)	The specific activity of ^{235}U (Bq/kg fresh weight)	Internal effective dose (μSv/y)
1v	0.0027	1.269×10^{-4}
2v	0.0082	3.85×10^{-4}
3v	0.0013	0.61×10^{-4}
4v	0.0023	1.08×10^{-4}
5v	0.0375	17.62×10^{-4}
6v	0.0331	15.55×10^{-4}
7v	0.0183	8.60×10^{-4}
8v	0.0362	17.01×10^{-4}

4. Conclusions

In the present study, 8 soil samples and 8 vegetable samples collected from Tafila District have been analyzed using gamma spectroscopy, supported by Genie 2000 software. The specific activity of ^{238}U and ^{235}U in soil were found to vary from (in Bq/kg): 26-575 and 1.4-35.5, respectively. These results are very similar to other results obtained using alpha–spectrometry techniques (Ajlouni et al., 2011, and Ajlouni, 2015), for soil samples from the same region. These findings are presented in Tables 1 and 2, The specific activity of ^{238}U and ^{235}U in vegetables were found to vary from (in Bq/kg): 0.019 to 0.632 and 0.0013-0.0375, respectively. These concentrations were then used to calculate the transfer factor of ^{238}U, and ^{235}U, which were found to range from 4.9×10^{-4} to 1.7×10^{-3} for ^{238}U and 5.9×10^{-4} to 14.6×10^{-4} for ^{235}U.

External absorbed dose rates were calculated to be in the range from 12.42 to 266.00 nGy/h, with an overall mean value of 129.47 nGy/h. This value is higher than the corresponding population-weighted (world averaged) value of 60 nGy/h (UNSCEAR, 2000). The annual effective dose was found to vary from 49.42 to 619.78 μSv/y with an average of 381.68 μSv/y, which is higher than the international ranges (UNSCEAR, 2000).

The annual internal effective dose due to U^{238} and ^{235}U for fresh weights of vegetables, were found to vary from 0.9×10^{-3} to 35.1×10^{-3} µSv/y for ^{238}U and 0.61×10^{-4} to 17.62×10^{-4} µSv/y for ^{235}U.

On the basis of the measurements carried out for the sites investigated during the study, Uranium does not pose a radiological hazard to the residents in Tafila District. Estimated annual radiation doses that could arise from exposure to Uranium residues are very low and of little radiological concern. Estimated annual radiation doses that could arise in the different areas are of the order of a few hundred microsieverts, well above the annual doses received by the world population from natural sources of radiation in the environment, but it is very far below the action level of 10 mSv suggested by the ICRP as a criterion to establish whether remedial actions are necessary.

As our findings are encouraging, there should be a large number of investigations, programs, and studies to be implemented in this region.

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