IRAQI JOURNAL OF APPLIED PHYSICS Vol. 21, No. 1, January-March 2025, pp. 43-48

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Iraqi Journal of Applied Physics
Q4 Electronic, Optical and Magnetic Materials best quartile
SJR 2023 0.18
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Transfer Factor and Related Doses of U-238 from Soil to Root-Plants at Some Areas of al Tarmiyah City, Iraq

The existence of radioactive concentration in both soil and plants results in some committed dose to the working individuals and their families. Hence, this work was conducted to calculate the transfer factor in plants to absorb radionuclides from soil. A CR-39 detector was used to measure the uranium concentrations in six samples of root plants (and their soil) grown in the region of Tarmiyah city, Baghdad- Iraq. The highest concentration of uranium was in the Turnips plant sample (0.530 ppm) and the lowest concentration was in the Jerusalem artichoke plant sample (0.208 ppm), while the activity concentrations in soil were the highest for carrots and the onion had the lowest concentration (i.e. 0.898 ppm and 0.632 ppm, respectively). The committed dose resulting from eating the root plants of all the studied plants and the radioactive contamination from soil to the field working member were within the world accepted limits.

***Keywords*:** CR-39 detector; Polluted soil; Root plants; Uranium; Committed dose
Received: 25 August 2024; **Revised:** 13 October; **Accepted:** 20 October 2024

1. Introduction

Soil is the main medium through which radiation is transmitted to plants. When soil is contaminated with radioactive materials, these materials remain in the soil for long periods and become available to plants. The absorption of radioactive materials from soil results in radioactive accumulation in various plant tissues (i.e. roots, leaves, fruits). These plants are consumed by humans and animals; hence radiation is transmitted through the food chain, increasing the potential exposure of living organisms to harmful radiation [1].

Uranium is a very heavy natural metal with a lustrous silver-grey color and a high density of 18.9gm/cm^3 [2]. It is a radioactive source present in Earth's crust and its concentration therein reaches 4×10^{-4}% of its weight and is also present in igneous rocks at a rate of 3ppm [3]. Similarly, uranium can be found in the human body, plants, animals, and sediments in small and varying amounts. As a general average, the human body contains approximately 90mg of uranium through the natural intake of water and food [4].

The process of uranium absorption by plant roots occurs because of ion exchange reactions between uranium carried in the soil solution and root tissues. Plants differ in this from one element to another, and the difference may be due to the lack of environmental factors that help in this [4].

Uranium is better absorbed in plants with high exchange capacity and plants with high rates of transpiration. Most of the ions, including uranium, travel to the upper parts of the plant. The plant's ability to absorb uranium increases from soils that contain low concentrations of carbonates [5].

Uranium absorption is active when the level of potassium concentration is low in the soil. When the concentration of some salts increases by a high percentage in the soil, uranium tends to remain in it and not move to the roots of the plant [6]. The absorption of elements by plants varies according to the type of plants as well as the nature of the elements [5]. Some types of plants have a selective ability to absorb some metals. As a result, there are several behavioral patterns of plants like the activities of the selective tendency to absorb elements or chemical compounds, which leads to a noticeable variation in the concentration of the element in plants compared to its concentration in the soil [7].

The technique of counting the effects of fission fragments was used for low concentrations of uranium due to its ease and accuracy in determining the emitted elements of alpha particles. The CR-39 is used for recording traces of alpha particles and fission fragments, due to its high sensitivity and high efficiency [8]. The concentration of U-238 in soil and root plants has an accumulated effect on the working individuals and their families, who have a daily contact with the polluted soil and plants during the term of farming to harvesting (estimated by 6 months for the selected studied root-plants). The build-up and preservation of uranium within organs or tissues (such as the kidney, liver, and bone) due to the natural exposing to uranium primarily through food and water consumption may persist for several days to years, potentially resulting in unanticipated negative health consequences. The main organs that uranium poisoning causes health issues are kidney (36.22%), bone (19.48%), liver (17.58%), reproductive system (13.90%), lung (7.24%), and nervous system (5.58%). Radiation exposure beyond the recommended level can cause a variety of health issues and harmful effects, including oxidative stress (33.86%), protein interaction (21.52%), metabolic abnormality (13.39%), cell death (13.25%), genetic damage (11.42%), and inflammation (6.56%) [9].

Hence, the research aims to study the transfer coefficient of uranium concentration from soil to root plants grown in Tarmiyah City - Baghdad - Iraq, using the CR-39 nuclear track detector. Additionally, calculating the accumulated dose to the working individuals and their families due to the consumption of uranium contaminated root-plants. The effective dose to the field working individuals during working term, which results from contacting the radioactive polluted soil is aimed to be estimated, too.

2. Materials and Method

Tarmiyah City is located on Tigris River, about 50 km to the north of Baghdad, Iraq. It is chosen for this study as it is one of the main sources of vegetables and fruits for the city of Baghdad- Iraq. Six samples of root plants with their soil were collected from the agricultural sites. The root plants under study were carrots, beets, turnips, potatoes, Jerusalem artichokes, and onions. To prepare the samples, following the collection of samples, the vegetables were washed thoroughly with water to eliminate any traces of dust. Subsequently, they were cut, dried at a temperature of 80 °C, and ground to form a powder.

The soil samples that were used to grow vegetables were subjected to a drying process at a temperature of 80°C. Foreign bodies were sifted out, and the remaining samples were ground to become a fine powder. The resulting powder was mixed with a proportion of starch as a binder and compressed as discs with a diameter of 1.3 mm and a 1.5 mm thickness. The discs were positioned in contact with the CR-39 track detector (area 1.5 x 1.5 cm^2) in paraffin wax as a moderator at 5cm from (Am-Be) neutron source for seven days, as in Fig. (1). Upon completion of the irradiation period, the chemical etching process is performed using NaOH (6.25 N at a temperature of 60 °C) for 5 hours [4].

The density of the tracks was calculated using an optical microscope (400X) using Eq. (1):

$$\rho = {}^{N_{av}}/_{A} \qquad (1)$$

where ρ is the density of the fission fragment tracks in a unit of Track/mm^2, N_{av} is the average number of total traces in the Track unit, and A is the area of the field of view in mm^2 [10].

Uranium concentrations were calculated in samples of root plants and their soil in comparison with standard samples with known concentrations that were irradiated under the same irradiation conditions as standard samples:

$$C^U_{Samples}/C^U_{standard} = \rho^U_{samples}/\rho^U_{standard} \qquad (2)$$

where, ρ^U_{Sample} and $\rho^U_{standard}$ are the number of tracks per unit track in the detector for samples and standard, respectively. $C^U_{Samples}$ and $C^U_{standard}$, Uranium concentrations in unit ppm for samples and standard, respectively [10].

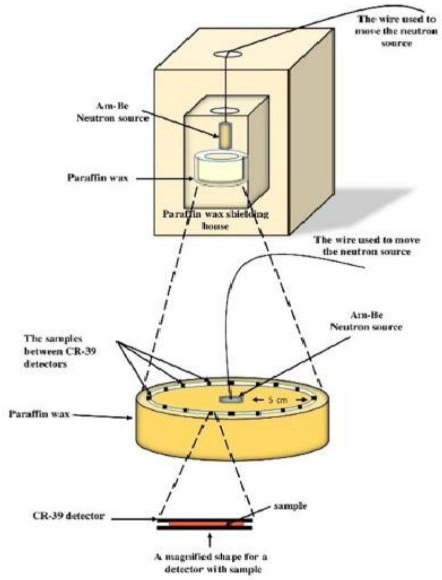

Fig. (1) Neutron source used to irradiate the CR-39 detector, soil samples, and root plants [3]

The transfer factor TF is used to estimate the values of the concentrations of radionuclides transferred into the food chain. It is calculated based on the dry weight of the plant sample and through Eq. (3) [11,12] :

$$TF = \frac{\text{uranium concentration in fresh plant}}{\text{uranium concentration in dry soil}} \qquad (3)$$

The total annual exposure (effective dose) due to uptake of uranium in root plants can be calculated using Eq. 4:

$$Dose_{AE} = \sum_{ik}(DC \quad \times R \quad \times C \quad \times 1000) \qquad (4)$$

where $Dose_{AE}$ is the annual exposure dose (mSv/year) caused by the ingestion of radioactive uranium in the root plants consumed by adults, children and infants; DC: the does convection for ingestion for uranium in age dependent (Sv/Bq), R is the rate of consumption (kg/year) [13]

Several parameters should be considered for all human tissues and organs according to what was published by ICRP. Those parameters include the annual exposure factors, the biological half-life of each radiation, the type of the emitted radiation, and the sensitivity [6].

Dose rate deposited in the basal layer of skin resulting from alpha particles emitted from the

Vol. 21, No. 1, January-March 2025, pp. 43-48

contaminated soil can be calculated using the following equation [14]:

$$\dot{D}(t) = C_{skin}(t).DRF_{skin} \quad (5)$$

where $\dot{D}(t)$ is the skin dose rate at time=t measured with rem.h^{-1}, $C_{skin}(t)$ is the activity concentration resulting from the contaminated soil on skin during time (t) measured with μCi.cm^{-2}, and DRF_{skin} is the dose rate factor (i.e. 3.7 rem.h^{-1} per μCi.cm^{-2} for U-238).

The equation is modified to account for the area of detection (2.25 cm^2) and sample mass (5×10^{-3} kg) used at this work, to be at SI units:

$$\dot{D}(t) = 6.48 \times 10^{-7} C_{skin}(t).DRF_{skin}\ (mSv/term) \quad (6)$$

where "term" refers to the time the farmer spending from ploughing to harvesting, which was calculated as: 6 h/day × 30 day/mth × 6 mth/term

4. Results and Discussion

Table (1) shows the concentrations of uranium in soil and root plants, which were determined by comparing with standard samples using Eq. (2). The measured uranium concentration for the root-planted soil varied between 0.898 ppm for carrots to 0.632 ppm for onion (i.e. 11.09 Bq/kg to 7.805 Bq/kg, respectively). The results show that the highest activity was in the soil of carrot plants (0.898 ppm), while the lowest is in the soil of onion (0.632 ppm). The average concentration of uranium (0.768 ppm) is significantly lower than the world average concentration published by UNSCEAR report (i.e. 2.834 ppm or 35 Bq/kg) [15].

The radioactivity concentration of uranium was also measured in the edible parts of the roots of the plants listed in table (1). The maximum concentration was in Turnips plants (0.53 ppm) and the minimum was in jerusalem artichoke plants (0.208 ppm) with an average of 0.366 ppm for all the collected samples. The concentration levels in both soil and root plants are presented in Fig. (2). The figure manifests the variation in uranium concentration levels between soil and plants, where the higher concentration in a soil of a plant does not necessitate the higher concentration in the plant itself.

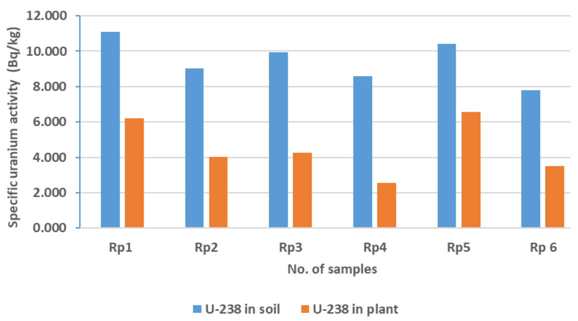

Fig. (2) The concentrations of uranium in soil and root plants (Bq/kg)

The TF, calculated using Eq. (3), for all the collected samples was at average of 0.47, with the highest TF for Turnips (0.63) and the lowest (0.3) for Jerusalem artichokes (table 1 and Fig. 3). The results presented in table (2) and Fig. (4) show the amount of annual exposure dose resulting from ingestion of radioactive uranium nuclides in root plants grown in the Tarmiyah region, Baghdad (Iraq) for different age groups. The infants for this study are aged 6 months to 2 years.

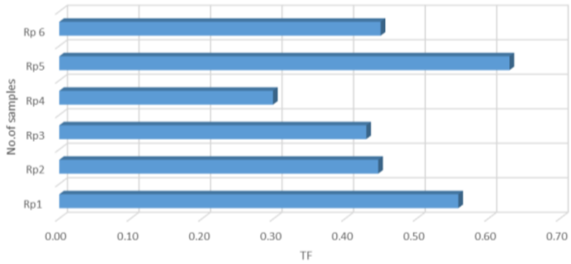

Fig. (3) TF (transfer factor) values for rooted plants grown in the Tarmiyah region, Baghdad (Iraq)

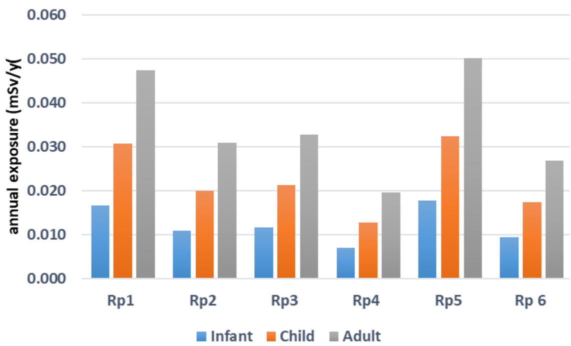

Fig. (4) Comparison of annual exposure values (equivalent dose) for all studied root plants

The highest annual exposure dose for all age groups resulted from Turnips, which has the highest specific activity (i.e. 6.546 Bq/kg), as mentioned earlier. The average of annual exposure from root-plants for adult was 0.035 mSv/y that is less than individual annual dose from ingestion according to WHO, i.e. 0.29 mSv/y per person [16]. Uranium-238 decays to thorium-234 by emitting alpha particles as the only decay product [17]. Figure (5) shows the effective skin dose committed by the working individuals from the alpha particles in soil of the targeted root plants. The working individuals spend around 6 months in contact with soil, or farm soil-related areas. This imposes calculating the effective skin dose resulting from contact contamination with soil. The highest effective skin dose resulted from the soil of carrots (0.0265 mSv/term), shown in table (3), which is within the annual exposure dose rate resulting from the terrestrial background effective dose (0.5 mSv/y) [15,16] and the annual public effective dose mentioned above.

Natural background radiation is a normal part in our existence. Humans are exposed daily to unavoidable

ISSN (print) 1813-2065, (online) 2309-1673

percentage of this radiation which comes from different sources; the major source comes from radioactive decay (89%) received internally from food, water and radon gas in air [18]. One of the greatest important naturally occurring radioactive element is U-238 series, which taken into our bodies by consuming agricultural products containing this element. This led to wide range of studies worldwide, along with cohort studies such as UNSEAR 1993 [19] and UNSCEAR 2000 [15], National Low-Level Waste Management Program 1995 [20], and IAEA TecDoc 1788 in 2016 [21].

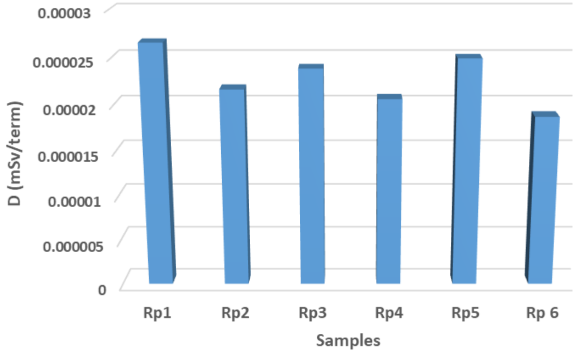

Fig. (5) Effective skin dose committed by the field working individual from alpha particles emitted from U-238 concentrated in root-plant soil

This study presents a preliminary study for U-238 concentration in soil and root plants. The results sit with the world standard results for the radioactive concentration in soil (0.768 ppm or: 9.485 Bq/kg < standard 35 Bq/kg). The variation in the activity concentration of the soil presented in Table 1 among the different root plants can be linked with the type and concentration of fertilizers used for each plant, in addition to the procedure used for fertilization. Compared to some other areas in Asia, the uranium concentration in the soil of onion, for example, planted in Tarmiya-Iraq (7.805 Bq/kg) can be considered comparable to the concentration in the soil in Mosul-Iraq (12 Bq/kg) [22] and Kurdistan-Iraq (14.97 Bq/kg) [23], while it is significantly lower than the radioactivity in the soil in Malaysia (98.5 Bq/kg) [12] for the same root-plant. This can be noticed for all root-plant soil (table 4 and Fig. 6).

On the other hand, the radioactivity concentration level in the studied root plants ranged between 6.546 Bq/kg (0.53 ppm) for Turnips and 2.569 Bq/kg (0.208 ppm) for Jerusalem artichoke. The reason behind the difference in these levels is related to the variation in transfer factor (TF) among different plants. Figure (3) illustrates a noticeable variation in the values of TF in all studied root plants. Many factors affect the transfer of uranium from soil to plants, including clay content, calcium, magnesium, organic materials, leaching from the soil, pH, ... etc. It also can be attributed to the higher biological requirements for the plant for phosphate, where the plant has the proclivity to absorb soluble uranium more than what its need if it presented in a significant amount in the soil [9]. The difference in the plant's ability to absorb uranium due to its composition, selective ability, or behavioural patterns to absorb one element over another are other possible reasons. Furthermore, concentrations of uranium in phosphate fertilizers, and concentrations of some salts affect the values of the transfer factor [6]. It is also noted that all the TF values of the root plants studied were less than 1, which indicates a strong binding of the radioactive uranium element to the soil with little bioaccumulation in the plant. The varying proportions from one species to another is another possible reason. Additionally, plants usually absorb radioactive elements when they are in ionic form [16].

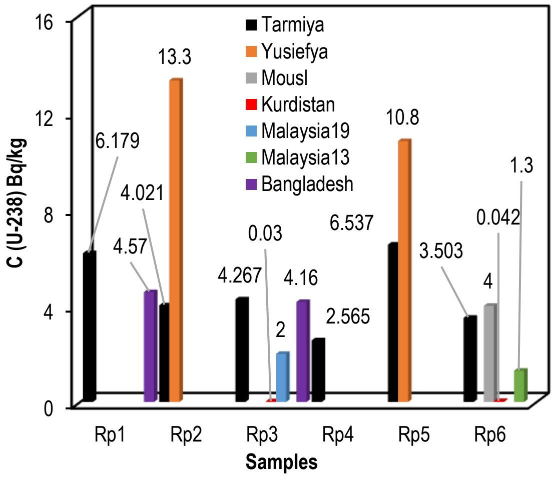

Fig. (6) Radioactivity concentration in root plants for current study as compared to previous studies

The techniques used in the previous studies, as presented in table (4), read the accumulated concentration for three main radioactive elements; U-238, Ra-228, and K-40 in general, yet the technique used for this work (i.e. CR-39) determines the concentration of U-238 only, as mentioned earlier. This can attribute to the variation between the results of this work and the results of previous studies.

Yet, the concentrations of uranium in plants are within the permissible limits by IAEA (2 ppm) [5], and the concentration in each root-plant was comparable to other studies for most of the studied plants as shown in the statistics illustrated in Figure 6. This variation results from the kinds of the phosphate fertilizers used in agriculture and the percentage of phosphate present in them [12], where the presence of uranium is very closely related to the presence of phosphate [14]. In fact, U-238 can be found in most of the soil and rocks of the crest, within different concentrations [15].

The data available for Iraqi dietary and terrestrial background radiation limits are few. Total effective dose per term resulting from consumption of the nominated root-plants planted at the studied area was less than the annual average dose per person worldwide for the three age group categories. The effective dose committed by working individuals due to alpha emission (U-238 emissions) in the soil of plantation is also within the safe limits of the annual dose of public exposure (0.5 mSv/y) [15]. This indicates the farming process, and the resulting products are considered radiologically safe.

5. Conclusion

This study was designed to measure the concentration of uranium-238 in some selected root plants and their soil, calculate the transfer factor from soil to plant for each sample in this study using CR-39, which results in some radioactive uptake to the farmers and their families due to plant ingestion, and direct and indirect contact with soil. Hence The effective dose was calculated to the three main age group categories resulted from the ingestion, in addition to the dose to the worker due to his/her working activities. The results obtained from this preliminary study are within the world-wide acceptance for all the targeted quantities. However, further studies are required to verify the presented results at different areas along the country, using different techniques to make a proper comparison among the results after establishing strict selection criteria.

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Table (1) The concentrations of uranium in soil and root plants with values of TF, and specific uranium activity grown in the Tarmiyah region, Baghdad (Iraq)

Root plants	No. of samples	U-238 concentrations in Soil of root plant (ppm*)	Specific uranium activity in Soil of root plant (Bq/kg)	U-238 concentrations in root plant (ppm*)	Specific uranium activity in root plant (Bq/kg)	T.F.
Carrot	Rp1	0.898	6.187	0.501	6.187	0.56
Beet	Rp2	0.731	4.026	0.326	4.026	0.45
Potato	Rp3	0.806	4.273	0.346	4.273	0.43
Jerusalem artichoke	Rp4	0.696	2.569	0.208	2.569	0.30
Turnips	Rp5	0.842	6.546	0.530	6.546	0.63
Onion	Rp6	0.632	3.507	0.284	3.507	0.45
Average		0.768	4.518	0.366	4.518	0.47

* 1 ppm=12.35 Bq/Kg [14]

Table (2) Amount of annual exposure (equivalent dose) for all age groups, from root plants grown in the Tarmiyah region, Baghdad (Iraq)

Root plants	No. of samples	Infant[a] (mSv/y)	Child[b] (mSv/y)	Adult[c] (mSv/y)
Carrot	Rp1	0.017	0.031	0.047
Beet	Rp2	0.011	0.020	0.031
Potato	Rp3	0.012	0.021	0.033
Jerusalem artichoke	Rp4	0.007	0.013	0.020
Turnips	Rp5	0.018	0.032	0.050
Onion	Rp 6	0.009	0.017	0.027
Average		**0.012**	**0.022**	**0.035**

[a] From 1 to 2 years, [b] less than 12 years, [c] more than 17 years [15]

Table (3) Effective skin dose committed by the field working individual from alpha particles emitted from U-238 concentrated in root-plant soil

Root plants	No. of samples	D (mSv/term*)
Carrot	Rp1	0.0265
Beet	Rp2	0.0216
Potato	Rp3	0.0238
Jerusalem artichoke	Rp4	0.0206
Turnips	Rp5	0.0249
Onion	Rp 6	0.0187
Average		0.0227

* (term = 6 h/day × 30 day/mth * 6 mth/yr)

Table (4) A comparison between the results and techniques used in measuring the uranium transfer coefficient from soil to root plants

City or Country	Root plants	Detection method	Concentration U-238 (Bq/kg)			Reference
			U in soil	U in plant	T.F	
Malaysia (Cameron Highlands and Penang)	Onion	Neutron Activation Analysis	98.5	1.3	0.012	[24]
Bangladesh	Carrots	HPGe	48.07	4.57	0.09	[25]
	Potato		43.78	4.16	0.1	
the Iraqi Kurdistan	Onion	HPGe	14.97	0.59	0.042	[23]
	Potato		16.31	0.49	0.03	
Malaysia (Kedah and Penang)	Potato	HPGe	80	2	0.028	[12]
Iraq/Mosul	Onion	NaI(Tl)	12	4	0.35	[22]
Iraq/ Al-Yusiefya	Turnips	NaI(Tl)	11.3	10.8	0.95	[26]
	beet		15.3	13.3	0.86	