Radioprotection 49(1), 27-33 (2014)

DOI: 10.1051/radiopro/2013070

Available online at:
www.radioprotection.org

ARTICLE

Transfer factors of ^{226}Ra, ^{210}Pb and ^{210}Po from NORM-contaminated oilfield soil to some *Atriplex* species, *Alfalfa* and *Bermuda grass*

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Received 13 August 2012 – Accepted 29 April 2013

Abstract – Transfer factors of ^{226}Ra, ^{210}Pb and ^{210}Po from soil contaminated with naturally occurring radioactive materials (NORM) in oilfields to some grazing plants were determined using pot experiments. Contaminated soil was collected from a dry surface evaporation pit from a Syrian oilfield in the Der Ezzor area. Five types of plants (*Atriplex halimus L., Atriplex canescens, Atriplex Leucoclada Bioss, Alfalfa and Bermuda grass*) were grown and harvested three times over two years. The results show that the mean transfer factors of ^{226}Ra from the contaminated soil to the studied plant species were 1.6×10^{-3} for *Atriplex halimus L.,* 2.1×10^{-3} for *Atriplex canescens*, 2.5×10^{-3} for *Atriplex Leucoclada Bioss*, 8.2×10^{-3} for *Bermuda grass*, and the highest value was 1.7×10^{-2} for *Alfalfa*. Transfer factors of ^{210}Pb and ^{210}Po were higher than ^{226}Ra TFs by one order of magnitude and reached 7×10^{-3}, 1.1×10^{-2}, 1.2×10^{-2}, 3.2×10^{-2} and 2.5×10^{-2} for *Atriplex halimus, Atriplex canescens, Atriplex Leucoclada Bioss, Bermuda grass* and *Alfalfa*, respectively. The results can be considered as base values for transfer factors of ^{226}Ra, ^{210}Pb and ^{210}Po in semiarid regions.

Keywords: transfer factor / Radium-266 / Lead-210 / Polonium-210 / *Atriplex*, *Alfalfa*, *Bermuda grasses* / contaminated soil / NORM / Syrian oilfield

1 Introduction

Many studies have been carried out to determine TFs (the ratio of radionuclide concentration in plants to the radionuclide concentration in soil per unit mass) for the most important artificial radionuclides (^{90}Sr and ^{137}Cs) (IAEA, 2010). The TF is usually used for evaluating the impact of releases of radionuclides into the environment. On the other hand, natural environmental radioactivity arises mainly from primordial radionuclides, such as ^{40}K, and the radionuclides from the ^{232}Th and ^{238}U series and their decay products are also considered important due to their contributions to the internal radiation dose. Several studies on transfer of natural radionuclides from soil to plants have been carried out in different regions in the world (Sheppard and Evenden, 1992; Martinez-Aguirre and Perianez, 1998; Ewers *et al.*, 2003; Staven *et al.*, 2003; Vera Tomé *et al.*, 2003; Pulhani *et al.*, 2005; Blanco Rodríguez *et al.*, 2006, 2010; Al-Masri *et al.*, 2008).

Enhanced concentrations of naturally occurring radionuclides enter the environment via disposal of wastes generated by several industries such as mining and milling of uranium, phosphate processing, and oil and gas exploration and production (IAEA, 2003, 2004). There is increasing interest in radiological assessment of these discharges into the terrestrial environment. Such assessments require parameter values for the pathways considered in predictive models. An important pathway for human exposure is via ingestion of food crops and animal products. One of the key parameters in environmental assessment is the soil to plant transfer factors to food and fodder crops. Some of these studies are those related to transfer of ^{238}U, ^{232}Th and ^{226}Ra from uranium mining-impacted soil in southern China (Chen *et al.*, 2005), TFs of U and ^{226}Ra from contaminated soil in uranium mines to *Brassica Juncea* (Blanco Rodríguez *et al.*, 2006), and accumulation of ^{238}U, ^{230}Th and ^{226}Ra by wetland plants in the vicinity of uranium mill tailings in Zirovski vrh (Slovenia) (Ceme *et al.*, 2010) in field conditions. Others used greenhouse conditions for transfer factor studies on soil collected from a former uranium or processing facility in south Bohemia, Czech Republic (Soudek *et al.*, 2010).

Co-produced water containing mainly radium isotopes is usually separated from oil and disposed of by circulating down an injection well and disposal wells (IAEA, 2004). In the past, uncontrolled disposal of production water has been practiced for several years in all Syrian oilfields (Al-Masri and Suman, 2003; Othman and Al-Masri, 2004). Production water has been collected in unlined artificial lagoons for evaporation; some run-off channels were built to allow water to run-off into the Badia. Soil has become highly contaminated with NORM, which has led to radiation exposure of members of the

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public. Grazing plants are spread in several areas of the oilfields, where camels and sheep are fed. This radioactive contamination problem has urged the operating oil companies to initiate remediation programs in cooperation with the Atomic Energy Commission of Syria. Radiological assessment of this contamination was part of the remediation programs. One of the main parameters used for such an assessment is the transfer factor of radionuclides to plants grown in the area. Therefore, the present work aimed to determine TFs for ^{226}Ra, ^{210}Po and ^{210}Pb from contaminated soil to some grazing plants in a semiarid region.

2 Materials and Methods

2.1 Description of plant species

Five plant species were selected as grazing plants in this investigation; namely, *Atriplex halimus L.*, *Atriplex canescens*, *Atriplex Leucoclada Bioss*, *Medicago Sativa alfalfa* and *Bermuda grass.* These species are grown in the Syrian Badia. Livestock such as camels, sheep and cows are widely fed on such crops as a source of nutrition. The first three species belong to the Atriplex genus, which consists of 100–200 species, known by the common name of saltbush. The genus is quite variable and widely distributed. Saltbush is well adapted to a wide range of temperatures and soil conditions. It is highly tolerant of drought and alkalinity and grows on sand dunes, gravelly washes, mesas, ridges, alluvial plains and slopes. Saltbushes are extremely tolerant of salt content in the ground; their name derives from the fact that they retain salt in their leaves, which makes them of great use in areas affected by soil salination.

The species *Medicago truncatula* is a model legume due to its relatively small stature, short generation time (~3 months) and ability to reproduce both by outcrossing and selfing, and is distributed mainly around the Mediterranean basin. The best-known member of the genus is *alfalfa*, an important grazing crop because of its high content of protein, vitamin and mineral salts, and considered as an irrigated crop: it consumes a lot of water and reaches a height of 1 meter. Most livestock relish its taste, even rabbits and birds, and farmers plant *Alfalfa* near the towns to feed livestock for milk and meat production.

Bermuda grass (Cynodon dactylon) is an irrigated grazing crop. *Bermuda grass* is also easily made into hay for winter grazing, making it a popular grazing crop for year-round production. It is a creeping grass and can grow in poor soil, with less tolerance to soil salt content. Its gray-green-colored blades are short (3–10 cm) with rough edges.

2.2 Soil collection and soil physical and chemical characterization

Contaminated soil was collected from a dried produced water evaporation pit in one of the Syrian oilfields located 60 km north of Der Ezzor City. The soil sample was taken from the top 20 cm layer from an area of 50 m^2; around 900 Kg was collected using a shovel, placed in 200-L drums and transferred to the experimental site near Damascus City. The chemical and physical properties of the contaminated soil were determined. Soil pH was determined using $CaCl_2$ solution and found to be 7.65. Exchangeable Ca and Mg were found to be 0.6 and 45.41 (Meq/100 g), respectively. Total organic matter in the soil was 1.02% using the ignition technique. The cation exchange capacity (CEC) was 19.65 (Meq/100 g) according to Page *et al.* (1982). The composition of the contaminated soil was determined by the hydrometer technique, and the soil was found to contain 15.67% clay, 26.11% silt and 58.22% sand. Uncontaminated soil was also collected from the area, which was classified as coarse loamy and consisted of 2.85% clay, 45.58% silt and 51.57% sand (Tabs. 1 and 2).

Table 1. Physical and chemical characteristics of soils.

Property	Contaminated soil	Witness soil
	Sandy clay	Coarse loamy
pH (CaCl2)	7.65	7.63
Organic matter %	1.02	1.1
Available K (Meq/100 g)	0.6	0.29
Available Ca (Meq/100 g)	45.41	19.72
Electrical Conductivity E.C mS/cm	3.52	5.51
Cationic exchange capacity CEC Meq/100 g	19.65	13.65

Table 2. Mechanical analysis results of soils.

	Contaminated soil	Witness soil
	Sandy clay	Coarse loamy
% Clay	15.67	2.85
% Silt	26.11	45.58
% Sand	58.22	51.57

2.3 Soil preparation and homogeneity test

The collected soil sample was divided and placed into 20 plastic pots (0.05 m^3 each). Each sub-sample was mixed in each pot for homogeneity. A homogeneity test was performed for each sub-sample by analyzing 4 aliquots by gamma spectrometry for determination of ^{226}Ra. The results are presented in Table 3.

2.4 Planting

Plant seeds were provided by the Ministry of Agriculture. The seeds were spread in each plastic pot and covered with some soil. Each type of plant was planted in four plastic pots as replicates; no fertilizers were added. The plastic pots were watered three times a week. Seeds of all studied plants were planted in January 2005, and the first harvest season started in August 2005. The second harvest season was in February 2006, and in order to obtain a reasonable amount of dry materials, the third harvest was in July 2006.

Table 3. ^{226}Ra mean activity concentration for homogeneity tests of contaminated soil before planting (Bq.Kg^{-1}).

Sample	Pot 1	Pot 2	Pot 3	Pot 4	Average ($\pm 1\sigma$)
Soil of *Atriplex halimus*	16290	15860	15980	15365	15874 ± 385
Soil of *Atriplex canescens*	15412	15800	14890	14690	15198 ± 504
Soil of *Atriplex Leucoclada Bioss*	16590	15995	16790	16289	16416 ± 348
Soil of *Medicago Sativa Alfalfa*	17552	16983	15642	16195	16593 ± 844
Soil of *Bermuda grass*	15879	13568	13847	15210	14626 ± 1101

2.5 Sample preparation

The plant samples were taken from the leaves and soft shoots; the hard shoots were left to grow until the next harvest. Soil samples were taken from the middle of the pots at 0–15-cm depth. The plant samples were washed carefully with tap water and then with deionized water until free of soil particles. The samples were air-dried for 48 h and then in an oven at 105 °C for 24 h. Soil and plant samples were ground and sieved through a 150-μm stainless steel sieve; the residual was recycled. The samples were then homogenized using a three-dimensional mixer before analysis.

2.6 Radioactivity measurements

Determination of ^{226}Ra

The dried samples were measured by gamma spectrometers (Eurysis Systems) using high-resolution (1.85 keV at 1.33 MeV), high relative efficiency (80%), low-background HPGe detectors to determine ^{226}Ra. The samples were placed into cylindrical plastic bottles, closed tightly and left for one month to reach secular equilibrium. Determination of ^{226}Ra was carried out by measuring its gamma-emitting daughters: ^{214}Pb and ^{214}Bi (295, 351 and 1794 keV). Efficiency calibration was performed using reference samples (RGU, RGTH and RGK) provided by the International Atomic Energy Agency, IAEA. The lower limit of detection for the measured ^{226}Ra derived from the background measurements at 100 000 sec was found to be 3 Bq.Kg^{-1}.

Determination of ^{210}Po and ^{210}Pb

The ^{210}Po and ^{210}Pb activity concentrations were determined using the standard technique (the silver disc technique) (Flynn, 1968). Two grams of each soil or plant sample (dry wt.) were placed in glass beakers and spiked with 0.2 Bq of ^{208}Po (Polonium chloride in 0.1 M HCl provided by Amersham International, UK) as a yield tracer. Each sample was digested on a hot plate (150 °C) using concentrated nitric acid (65%) for at least 24 h; hydrogen peroxide (33%) was added to oxidize the organic compounds. The samples were left to cool down to room temperature and then the residuals were separated by centrifuging. The clear solution was gently evaporated to dryness and digested three times with concentrated nitric acid and then digested three times with concentrated hydrochloric acid followed by gentle evaporation to near dryness. The residue was then dissolved in 100 ml of 0.5 M hydrochloric acid. The solution was then heated to 80 °C and ^{210}Po was spontaneously plated onto a rotating silver disc for a period of 3 hours after reduction of iron (Fe^{+3} to Fe^{+2}) with ascorbic acid. The silver disc was washed with water and ethanol, and alpha counting of ^{208}Po (5.15 MeV) and ^{210}Po (5.3 MeV) was done using an alpha spectrometer (Oasis, Oxford) with a passive ion-implanted silicon detector (active area 300 mm^2, background counts per day 3.6 and the minimum depletion thickness 100 μm).

The activity of ^{210}Po was corrected for recovery and for radioactive decay since the time of sampling.

The chemical recovery was calculated using the following equation:

$$Y(\%) = \frac{Net_{counts}^{Po^{208}} \times (2) e^{\frac{ln2}{T_{1/2}} t1}}{A(Po^{208})_{add} \times eff \times T} \times 100$$

where:

- $Y(\%)$: chemical recovery,
- Net_{counts} (^{208}Po): the net counts of ^{208}Po background subtraction (counts),
- $A(^{208}Po)_{add}$: the added activity of ^{208}Po (Bq),
- *eff*: counting efficiency of alpha spectrometry,
- T: counting time (sec),
- $T_{1/2}$ (^{208}Po): half-life of ^{208}Po (day),
- t_1: elapsed time between the reference date of ^{208}Po and the measurement time,
- 2 is constant, assuming that polonium has homogeneous deposition on the two faces of the silver disc.

The activity concentration of ^{210}Po in the sample was calculated as follows:

$$A(Po^{210}) = \frac{Net_{counts}^{Po^{210}} \times (2) \times 1000 \times s^{\frac{ln2}{T_{1/2}} t2}}{W \times Y \times eff \times T}$$

where:

- A (^{210}Po): activity concentration of ^{210}Po in the sample at separation time (Bq.Kg^{-1} dry),
- Net_{counts} (^{210}Po): net counts of ^{210}Po after background subtraction (counts),
- W: sample size (gram),
- *eff*: counting efficiency of alpha spectrometry,
- T: counting time (sec),
- $Y(\%)$: chemical recovery,
- $T_{1/2}$ (^{210}Po): the half-life of ^{210}Po (138.38 days),
- t_2: elapsed time between the separation date of ^{210}Po and the measurement time (day).

The plating and counting were repeated after six months of storage of the solution to measure the in-growth of new ^{210}Po from ^{210}Pb and to calculate the ^{210}Pb concentration in the original sample. The activity concentration of ^{210}Pb was calculated using the following equation:

$$A_{0(Pb210)} = A_{(Po210)} e^{\frac{ln2}{T_{1/2}} t3}$$

Table 4. ^{226}Ra, ^{210}Po and ^{210}Pb mean activity concentrations in uncontaminated soil and plants (Bq.Kg^{-1}) and their Tfs.

Matrix	^{226}Ra	^{210}Pb	^{210}Po
Atriplex halimus	11 ± 2	11 ± 1	10 ± 1
Atriplex Leucoclada Bioss	9 ± 2	7 ± 1	8 ± 1
witness soil	33 ± 5	30 ± 5	25 ± 4
Atriplex halimus (TF)	0.33 ± 0.07	0.36 ± 0.06	0.4 ± 0.07
Atriplex Leucoclada Bioss (TF)	0.27 ± 0.07	0.23 ± 0.04	0.32 ± 0.06

where:

– $A_0(^{210}Pb)$: activity concentration of ^{210}Pb at the sampling date (Bq.Kg^{-1} dry),
– $T_{1/2}$: half-life of ^{210}Pb (day),
– t_3: elapsed time between the second separation of ^{210}Po and the sampling date.

The lower limit of detection of the above method used was 0.4 Bq.Kg^{-1}.

The transfer factor (TF) is calculated from the mean activity concentrations for the plants and soils presented in Table 5 using the following equation:

$$TF = \frac{Activity_{(plants)}(Bq.Kg^{-1}dry\,wt.)}{Activity_{(soil)}(Bq.Kg^{-1}dry\,wt.)}.$$

Quality control procedures

Quality control procedures were applied using home-made control samples, reference samples provided by the IAEA and duplicate analysis. In addition, all methods and laboratories used in this study are validated according to ISO17025.

3 Results and discussion

3.1 ^{226}Ra, ^{210}Pb and ^{210}Po activity concentrations in soil and plant samples

Two types of witness plants were available on-site near the contaminated pit during the sampling campaign. These were *Atriplex halimus* and *Atriplex Leucoclada Bioss*. The plants and their soils were collected and analyzed. Relatively low activity concentrations of ^{226}Ra, ^{210}Po and ^{210}Pb were observed for the soil and plants (see Tab. 4). The witness soil is different from the contaminated soil even though it is from the same site, and this is due to past discharge of production saline water, which was evaporated. The witness soil is inorganic soil and can be classified as coarse sand. Cations in soil are bound to clay particles and have to be dissolved before they are available to plants (Mauseth *et al.*, 2003; Taiz and Zeiger, 2006). Pit soil samples contain more Ca^{+2} and K^{+} due to evaporation of produced saline water (Tab. 1). These can displace other cations on the surface of soil particles and make them available for root uptake (Mauseth *et al.*, 2003; Taiz and Zeiger, 2006).

^{226}Ra activity concentrations in soils collected from the pots (soil collected from the immediate root zone of each plant) during the experiments were comparable, while ^{210}Pb and ^{210}Po activity concentrations varied from one harvest to another (Tab. 5); the highest values were found to be at the third harvest and this is due to the ^{222}Rn emanations from soils and decay to ^{210}Po and ^{210}Pb, which precipitate on the surface of soil and plants; emanation increases with soil air temperature increase, and the third harvest was in July. The lowest values were in February. The effect of moisture content on radon exhalation from soil has been studied by many authors (Stranden *et al.*, 1984; Karamdoust, 1989). In addition, radon exhalation from soil increases with an increase in moisture content up to about 18% (% by weight of water in the sample) and then decreases with further increase in the moisture (Shweikani *et al.*, 1995). This is the case for February, where moisture content is much higher than 18% (rainy month).

Each plant species was planted in four pots as replicates; a total of 20 pots. Table 5 summarizes the results of the three harvests for the plants and soils. The results show that the mean activity concentrations of ^{226}Ra in plants increased with the time of harvesting, except *Atriplex halimus*, which showed a low activity concentration in the second harvest. The mean activity concentrations of ^{210}Pb increased with the time of harvesting, except *Medicago sativa*, which also showed a low activity concentration compared with the first harvest. For ^{210}Po, the mean activity concentrations for all types of studied plants increased with the time of harvesting. ^{226}Ra mean activity concentrations in *Atriplex halimus* and *Atriplex Leucoclada* at the first harvest were relatively higher than the witness plants (10 Bq.Kg^{-1} dry wt.). The mean activity concentrations in the first harvest of ^{226}Ra in the four replicates of the *Atriplex species halimus*, *canescens* and *Leucoclada* were 27, 16 and 40 Bq.Kg^{-1} dry wt., respectively, while mean activity concentrations for *Medicago Sativa* and *Bermuda grass* were relatively higher; 44 and 70 Bq.Kg^{-1} dry wt., respectively. ^{210}Pb mean activity concentrations in the first harvest in the *Atriplex species halimus*, *canescens* and *Leucoclada* in the four replicates were also relatively higher than the activity concentration in the witness samples of 11 Bq.Kg^{-1}; 10, 12 and 15 Bq.Kg^{-1} dry wt., respectively. Mean activity concentrations of ^{210}Po for *Atriplex Leucoclada*, *Medicago sativa* and *Bermuda grass* were also relatively higher than that of the witness plants of 10 Bq.Kg^{-1} dry wt.; 19.4, 21 and 25 Bq.Kg^{-1} dry wt., respectively. In addition, at the second harvest, ^{226}Ra mean activity concentrations in *Atriplex halimus, Atriplex canescens*, *Atriplex Leucoclada*, *Medicago Sativa* and *Bermuda grass* were slightly higher than the first harvest and found to be 18, 20, 19, 67 and 70 Bq.Kg^{-1} dry wt., respectively. ^{210}Pb mean activity concentrations were 22, 13, 18, 22 and 52 Bq.Kg^{-1} dry wt., and ^{210}Po mean activity concentrations were 11, 17, 21, 31 and 45 Bq.Kg^{-1} dry wt., respectively. However, mean activity concentrations for the third harvest were found to be the highest: ^{226}Ra, ^{210}Pb and ^{210}Po mean activity concentrations were 24, 61, 68, 704 and 220 Bq.Kg^{-1} dry wt., 29, 32, 41, 244 and 114 Bq.Kg^{-1} dry wt., and 23, 31, 50, 171 and 114 Bq.Kg^{-1} dry wt., for *Atriplex halimus*, *Atriplex canescens*, *Atriplex Leucoclada*, *Medicago Sativa* and *Bermuda grass*, respectively. Therefore, it is clear

Table 5. ^{226}Ra, ^{210}Po and ^{210}Pb mean activity concentrations in soils and plants for the three harvests.

Plant type	Matrices	Harvest season	Radionuclide concentration Bq/Kg dry wt.		
			^{226}Ra$^{(1)}$	^{210}Pb$^{(1)}$	^{210}Po$^{(1)}$
Atriplex halimus	*P*$^{(2)}$	*1*	27.0 ± 2.0	19.7 ± 2.7	7.2 ± 1.1
	S$^{(3)}$		15 975 ± 446	1744 ± 46	3893 ± 24
	P	2	18 ± 1.0	22 ± 1.6	19 ± 3.6
	S		10 000 ± 1000	1220 ± 27	1107 ± 53
	P	*3*	23 ± 2.9	29 ± 0.9	23 ± 0.7
	S		16 800 ± 930	5483 ± 73	3456 ± 40
Atriplex canescens	*P*	*1*	16.3 ± 2.2	11.9 ± 2.1	8.6 ± 0.4
	S		14 775 ± 210	2041 ± 57	2772 ± 17
	P	2	20 ± 0.8	13 ± 0.9	17 ± 1.9
	S		14 765 ± 1500	1844 ± 44	798 ± 48
	P	*3*	61 ± 2.2	32 ± 0.9	31 ± 0.9
	S		15 320 ± 800	4991 ± 77	3945 ± 47
Atriplex Leucoclada Bioss	*P*	*1*	40.3 ± 2.2	14.7 ± 3.2	19.4 ± 0.4
	S		16 390 ± 541	5034 ± 102	2600 ± 20
	P	2	19 ± 0.8	18 ± 0.3	21 ± 1.2
	S		16 890 ± 800	1380 ± 30	1431 ± 98
	P	*3*	68 ± 9.3	41 ± 5.2	50 ± 1.2
	S		17 550 ± 850	4615 ± 78	3464 ± 57
Medicago Sativa Alfalfa	*P*	*1*	44 ± 5.3	47.3 ± 5.8	21.0 ± 3.3
	S		17 467 ± 312	2330 ± 47	4096 ± 53
	P	2	67 ± 6.6	22 ± 0.4	31 ± 1.7
	S		17 500 ± 950	1191 ± 25	1526 ± 101
	P	*3*	709 ± 13.2	244 ± 4.1	171 ± 1.9
	S		16 140 ± 700	5306 ± 86	3464 ± 57
Bermuda grass	*P*	*1*	69.8 ± 6.3	56.5 ± 7.8	24.8 ± 0.5
	S		13 085 ± 335	2117 ± 27	3802 ± 24
	P	2	70 ± 6.7	52 ± 1.5	45 ± 2.1
	S		14 600 ± 700	1214 ± 26	773 ± 43
	P	*3*	220 ± 5.0	114 ± 1.5	114 ± 0.9
	S		15 200 ± 700	5026 ± 108	3641 ± 37

(1) Each result represents the geometric mean for four replicate pots.
(2) Plant.
(3) Relevant soil.

that the mean activity concentrations in plants increase with time and this is due to the fact that the contaminated soil contains more Ca^{+2} and K^{+}, that can displace other cations such as Ra on the surface of soil particles and make them available for root uptake (Mauseth *et al.*, 2003; Taiz and Zeiger, 2006).

3.2 ^{226}Ra, ^{210}Pb and ^{210}Po transfer factors

TF values for ^{226}Ra, ^{210}Pb and ^{210}Po are shown in Table 6. The results of the TF for each species were summarized as the geometric mean. TFs were calculated as the mean value for four replicates of each plant in one harvest and then the mean of the three harvests was taken as a representative value for transfer factors during the two-year experimental period.

TFs were found to increase along with time of planting, as the concentrations of relevant radionuclides in the second and the third harvests were higher than those in the first harvest. The three plant species, namely, *Atriplex halimus*, *Atriplex canescens* and *Atriplex Leucoclada*, showed a slight increase with time for TFs of ^{226}Ra and ranged from 1.6×10^{-3} to 2.8×10^{-3}, while *Medicago Sativa* and *Bermuda grass*, which were irrigated crops, showed higher TFs (1.7×10^{-2} and 8.2×10^{-3}, respectively). Some published studies (Ibrahim and Whicker, 1988; Markose *et al.*, 1993) reported a TF range for radium in pasture grown on uranium mill tailings of between 0.03 and 0.04, which is slightly higher than the values obtained in the present study. This may be due to the high temperature of the study site, low air humidity and low rainfall (semiarid region), which can lead to a decrease in the

Table 6. Mean transfer factors of ^{226}Ra, ^{210}Pb and ^{210}Po for the studied plants.

Types of studied plants	^{226}Ra TF (×10^{-3}) harvest			^{226}Ra mean TF	^{210}Pb TF (×10^{-3}) harvest			^{210}Pb mean TF	^{210}Po TF (×10^{-3}) harvest			^{210}Po mean TF
	first	second	third		first	second	third		first	second	third	
Atriplex halimus	1.7 ± 0.14	1.8 ± 0.2	1.4 ± 0.2	1.6 ± 0.3	11 ± 1.5	18 ± 1.4	5.3 ± 0.18	12 ± 2	1.9 ± 0.3	17 ± 3.3	6.7 ± 0.2	8.6 ± 2
Atriplex canescens	1.1 ± 0.15	1.2 ± 0.13	4 ± 0.3	2.1 ± 0.4	5.9 ± 1	7.1 ± 0.5	6.4 ± 0.2	6.4 ± 1.3	3.1 ± 0.15	21 ± 2.7	8 ± 0.3	10 ± 1.4
Atriplex Leucoclada Bioss	2.5 ± 0.16	1.1 ± 0.07	3.8 ± 0.6	2.5 ± 0.4	29 ± 0.6	13 ± 0.4	8.8 ± 1.1	8.3 ± 2	7.5 ± 0.17	14 ± 1.3	14 ± 0.4	12 ± 1
Medicago Sativa	2.3 ± 0.28	3.8 ± 0.4	44 ± 2	17 ± 3	20 ± 2.5	19 ± 0.5	46 ± 4	28 ± 4	5.1 ± 0.8	20 ± 1.7	49 ± 1	25 ± 4.5
Bermuda grass	5.3 ± 0.5	4.8 ± 0.5	14 ± 0.7	8.2 ± 1.2	27 ± 3.7	43 ± 1.5	23 ± 0.6	30 ± 4.4	6.5 ± 0.14	59 ± 4.3	31 ± 0.4	32 ± 2.5

* Each value represents the geometric mean for four replicate pots.

uptake of radionuclides (Lembrechts *et al.*, 1990). In addition, the value of the TF of ^{226}Ra to pasture reported in the IAEA Technical Report 472 (2010) is 0.08, which is higher than the value obtained for the studied species. The American Interstate Technology & Regulatory Council (ITRC, 2009) reported that *Medicago Sativa* and *Bermuda grass* sweat large quantities of water through their leaves in comparison with other grasses and this explains their high need for water for growing, subsequently increasing the TF of heavy metals from soil to plant. *Bermuda grass* can accumulate more than 6 mg.g^{-1} calcium, which is chemically similar to radium. In addition, *Medicago Sativa* can accumulate up to 43 mg.g^{-1} lead (ITRC, 2009).

The mean values of TFs for ^{210}Pb in *Atriplex halimus*, *Atriplex canescens*, *Atriplex Leucoclada*, *Medicago Sativa* and *Bermuda grass* were 1.2×10^{-2}, 6.4×10^{-3}, 8.3×10^{-3}, 2.8×10^{-2} and 3×10^{-2}, respectively. *Atriplex halimus* was found to have the highest TF value (1.2×10^{-2}), which was higher than other species of *Atriplex* by one order of magnitude. Porêbska and Ostrowska (1999) reported the possibility of using *Atriplex* plant species as bioaccumulators for some heavy metals such as Cd, Pb, Cu and Zn. On the other hand, *Medicago Sativa* and *Bermuda grass* were found to have higher ^{210}Pb TFs than *Atriplex* plant species by an order of 10. Mulugisi *et al.* (2009) concluded that growing *Bermuda grass* in waste zones of gold mines can accumulate many species of heavy metals such as lead; accumulation can reach 6 mg.Kg^{-1}. Soleimani *et al.* (2009) showed that when the concentration level became above the normal level, *Bermuda grass* started to accumulate lead evidently in its leaves. Pietrzak-Flis and Skowrofiska (1995) derived soil- pasture TFs of about 4×10^{-2} and 2×10^{-2} for ^{210}Pb and ^{210}Po, respectively. In the present investigation, the ^{210}Po TF was higher than the ^{210}Pb TF. The average values for *Atriplex halimus*, *Atriplex canescens*, *Atriplex Leucoclada*, *Medicago Sativa* and *Bermuda grass* were 8.6×10^{-3}, 1×10^{-2}, 1.2×10^{-2}, 2.5×10^{-2} and 3.2×10^{-2}, respectively.

The uncertainties associated with the transfer factors of the various radionuclides are not always documented. However, uncertainties related to the TFs of the studied radionuclides were calculated and included in Table 6. There are some differences in the estimated uncertainties in TFs and these are due to differences in plant uptake, sources of ^{210}Po and ^{210}Pb (root uptake and atmospheric deposition) and soil contamination heterogeneity.

The TFs of the studied radionuclides from the witness soil were also calculated (Tab. 3); only two plants were found in the area (*Atriplex halimus* and *Atriplex Leucoclada*). The TFs from the witness soil were higher than the TFs from the contaminated soil and this is due to the fact that the TF is related to soil mechanical and chemical properties, which are different for both soils, as per Tables 1 and 2. TFs decrease with clay content of soil (Bergeik *et al.*, 1992): the clay content in the contaminated soil (15.67%) is much higher than the witness soil (2.85%).

Finally, since the TFs for the relevant radionuclides from feed to animals and their products are not considered in this study, the relevant radionuclides are transferred significantly to the food chain through pastures. Determination of transfer factors of relevant radionuclides can be considered an important stage for the evaluation of transfer to the food chain.

4 Conclusion

Transfer factors of ^{226}Ra, ^{210}Pb and ^{210}Po from contaminated soil in oilfields located in a semiarid area to some pasture species were determined and found to be lower than reported values in other NORM-contaminated areas such as uranium mining sites. Transfer of ^{226}Ra, ^{210}Pb and ^{210}Po from soil to plants increases with the time of the first planting. *Medicago Sativa (alfalfa)* and *Bermuda* grass were found to have the highest TFs among the studied plants. However, the data obtained can be used for radiological assessment models of a semiarid region.

Acknowledgements. The authors would like to thank Prof. I. Othman (G.D. of AECS) for his encouragement and support. Dr. Mohammad Al Oudat is highly appreciated for his comments.

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Cite this article as: M.S. Al-Masri, H. Mukalallati, A. Al-Hamwi. Transfer factors of ^{226}Ra, ^{210}Pb and ^{210}Po from NORM-contaminated oilfield soil to some *Atriplex* species, *Alfalfa* and *Bermuda grass*, Radioprotection 49(1), 27-33 (2014).