

Original Article

A Study on Transfer Factors of Environmental Radionuclides: Radionuclide Transfer from Soil to Different Varieties of Rice in Gorgan, Iran

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Abstract

Introduction

Natural and artificial radionuclides are the main sources of human radiation exposure. These radionuclides, which are present in the environment, can enter the food chain. Rice is one of the most important food components in Iran. Radionuclides by transferring from soil to rice and entering the human body can affect human health.

Materials and Methods

Fourteen samples of different varieties of rice, nine soil samples from rice fields and four samples of consumed water were collected from four villages around Gorgan, Iran. Specific activities of ²²⁶Ra, ²³²Th, ⁴⁰K and ¹³⁷Cs were determined in the samples, using gamma ray spectrometry and a high-purity germanium (HPGe) detector. Moreover, transfer factors of radionuclides from soil to rice were determined.

Results

Specific activities of ²²⁶Ra, ²³²Th, ⁴⁰K and ¹³⁷Cs were determined in the soil and rice samples. The annual effective dose due to rice grain consumption in Iranians varied from 20.50±0.74 to 68.40±11.71 μSv/y. Transfer factors from soil to rice for ⁴⁰K and ²²⁶Ra varied from 0.09 to 0.13 and 0.02 to 0.07, respectively.

Conclusion

The calculated annual effective dose due to rice grain consumption by Iranians was within the average annual global range. Therefore, this study indicated that radionuclide intake due to rice consumption had no consequence for public health. The calculated transfer factors were higher than that reported by the International Atomic Energy Agency (IAEA) in 2010; however, the values were much lower than measurements in Malaysia.

Keywords: HPGe Detector, Natural Radiation, Rice, Soil, Transfer Factor

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1. Introduction

Natural and artificial radionuclides are the main sources of human radiation exposure. Uranium, thorium series and potassium are the main elements, contributing to natural terrestrial radioactivity [1]. The average uranium-238 (^{238}U) content in the Earth's crust has been estimated at 2.7 mg/kg and its concentration may be as high as 120 mg/kg in phosphate rocks [2]. Meanwhile, the average thorium-232 (^{232}Th) content in the Earth's crust is approximately 9.6 mg/kg [3].

Environmental pollution by radioactive isotopes results from nuclear weapon tests; accidents in nuclear power plants also contribute to human exposure [4]. Release of radioactive materials from different nuclear industries causes an increase in radioactivity level in the environment. The increase in environmental radioactivity is also responsible for the increased radiation dose to the general population.

Safety measures changed dramatically after the Chernobyl nuclear accident in 1986, and management of contaminated areas became crucial. Overall, radiocesium pollution constitutes a serious hazard to human health as radioactive elements can be transferred through the food chain [5]. Considering the presence of ionizing radiation sources in our environment, their entrance to the food chain is unavoidable.

One of the pathways for ionizing radiation is the soil-rice-human chain. Rice is one of the popular dietary components in the world, particularly in Asian countries. Consumption of rice per capita each year was 57.50 kg in the world in 2014. Overall, China accounts for the highest rate of rice consumption around the world. Rice is also a principal food in Iranian cuisine, with the quality of cooked rice outweighing all other considerations among Iranian consumers [6].

The total area under rice in Iran is more than 600,000 hectares and rice is grown in 15 provinces. It is estimated that 265,000 hectares in Mazandaran province (including areas in Gorgan) are under rice cultivation. The consumption of rice in Iran has been estimated

at 28 kg per capita each year. As the demand for rice and its supply in Iran are not yet evenly balanced, Iran imports around 400,000 to 500,000 tons of rice for domestic consumption [6].

In this study, the specific activities of radionuclides were determined in soil samples under rice cultivation. Different varieties of rice in four villages around Gorgan in Golestan province were evaluated, using gamma ray spectrometry. Transfer factors (TFs) of radionuclides from soil to rice were calculated. Radium equivalent (R_{eq}), internal and external hazard indices for soil samples and the annual effective dose (AED) for rice consumption in Iran were also measured.

2. Materials and Methods

2.1 Sampling and Sample Preparation

Samples were collected from four villages within a 5-15 km distance from Gorgan in Golestan province, Iran. The sampling region is demonstrated in Figure 1. In this study, 14 rice samples, 9 soil samples from rice fields and 4 samples of consumed water in rice fields were investigated. By employing random integration and experimental sampling, a combined operation was undertaken to collect the samples.

Nine rice samples from four villages as the dominant varieties, one sample of rough rice, one sample of imported rice and three samples of wholesale rice were collected and coded. Polyethylene bottles were used for sampling water, and nitric acid was added to decrease the samples' pH down to 2; this process was necessary to prevent wall absorption of radionuclides [7].

Soil samples were taken from rice fields at 5 cm depth and were coded according to rice variety and sampling locality via employing the template method. Sample coding is presented in tables 1 and 2. All rice and soil samples were dried in the oven at 200 °C for 12 hours. In order to obtain homogeneous samples, dried rice and soil samples were pulverized by a grinder into fine powder and

passed through 10-mesh and 50-mesh screens [8].

All samples were prepared in Marinelli beaker containers for gamma-ray spectrometry. Given the fact that radon is a short-lived, gaseous nuclide, with a tendency to escape from the samples, the collected samples required particular care. In this study, a Marinelli

beaker with volume 800 cc was used for packing 950 g of soil, 330 g of rice and 800 cc of water samples. After a minimum of 60 days for preparing the sealed samples, gamma rays were registered, since a time interval is necessary to attain radioactive chain equilibrium [8].



Figure 1. Sampling location around Gorgan, Iran, marked on the map by (+)

2.2. Experimental setup

Gamma-ray spectra were registered, using a high-purity germanium (HPGe) detector (coaxial P-type, model GCD30195 BSI), with a relative efficiency of 30% and a multi-channel analyzer (8192 channels). The energy resolution in this detector is 1.95 keV for ^{60}Co gamma energy line at 1332.520 keV. The operating voltage was 3000 V and the detector was shielded by lead, cadmium and copper (10 cm, 2 mm and 2.5 mm, respectively); the shielding served to reduce background radiation.

The soft components of cosmic ray were reduced to a very low level by 100 mm of lead shielding. The X-ray (73.9 keV) emitted from the lead due to its interaction with external radiation was suppressed by copper and cadmium layers, which successively absorbed thermal neutrons produced by the cosmic ray [9]. To minimize the effect of scattering radiation from the shield, the detector was located in the center of the chamber.

The samples were placed in a face-to-face geometry over the detector for 86,400 s.

regarding efficiency calibrations, the coincidence correction transition was carried out for the standard sources of Marinelli beaker including ^{241}Am , ^{152}Eu and ^{137}Cs . According to the registered gamma ray spectra, the absolute efficiency of detector configuration (ε_i) was calculated, using equation 1[10]:

$$\varepsilon = \frac{N_i}{Act.P_n(E_i).t} 100 \quad (1)$$

Where N_i is the net count under the full energy peak, corresponding to E_i , Act is the radionuclide activity at the measured date, $P_n(E_i)$ denotes the probability of E_i photon emission and t is the counting time. The ^{226}Ra activity of the samples was determined by the intensities of 351.9 keV ^{214}Pb and 609.3 keV ^{214}Bi gamma lines, respectively. Moreover, ^{232}Th activity was determined, using 911.21 keV and 968.97 keV ^{228}Ac gamma lines, with 26.6% and 17.4% intensity, respectively. Additionally, ^{40}K and ^{137}Cs were obtained, using 1460.70 and 661.66 keV gamma ray lines, respectively.

Table 1. Sample codes of rice varieties and water and the sampling location

Sample code	Type of samples	Rice variety	Sampling location (village name)
Bmkd	Rice	Dh	Marzan Kalateh
Bmkf	Rice	Fr	Marzan Kalateh
Bamd	Rice	Dh	Ahangar Mahalleh
Bamf	Rice	Fr	Ahangar Mahalleh
Bmmd	Rice	Dh	Mir Mahalleh
Bmmf	Rice	Fr	Mir Mahalleh
Btad	Rice	Dh	Taghi Abad
Btaf	Rice	Fr	Taghi Abad
Btas	Rice	Si	Taghi Abad
B1121	Rice	11	India
Bgst	Rice	Sm	Gorgan wholesale
Bgge	Rice	Ge	Gorgan wholesale
Bgeh	Rice	Hi	Guilan wholesale
ShSh	Rough rice	Si	Taghi Abad
Wmk	Water	Dh	Marzan Kalateh
Wam	Water	Dh	Ahangar Mahalleh
Wmm	Water	Dh	Mir Mahalleh
Wta	Water	Fr	Taghi Abad

Table 2. The location and code of soil samples in Gorgan rice fields

Soil sample code	Type of cultivated rice	Village name	Longitude (E)	Latitude (N)	Altitude (m)
Kmkd	Dh	Marzan Kalateh	54° 35' 13.1"	36° 52' 24.2"	102
Kmkf	Fr	Marzan Kalateh	54° 35' 11.5"	36° 52' 24.2"	105
Kamd	Dh	Ahangar Mahalleh	54° 35' 18.5"	36° 49' 32.0"	269
Kamf	Fr	Ahangar Mahalleh	54° 35' 00.7"	36° 49' 59.3"	215
Kmmd	Dh	Mir Mahalleh	54° 36' 58.1"	36° 54' 29.1"	47
Kmmf	Fr	Mir Mahalleh	54° 38' 35.7"	36° 52' 05.0"	47
Ktad	Dh	Taghi Abad	54° 38' 35.8"	36° 52' 05.5"	114
Ktaf	Fr	Taghi Abad	54° 38' 35.7"	36° 52' 05.0"	110
Ktas	Si	Taghi Abad	54° 38' 43.5"	36° 52' 01.5"	111

All 24 registered gamma ray spectra were analyzed and specific activities of radionuclides in the samples were determined, using Gamma Vision 32 EG&G Ortec software. In all the analyzed spectra, correction was performed for the background gamma ray, which was registered using the empty Marinelli container under similar

conditions. In order to determine the activities, equation 2 was applied [11]:

$$Act = \frac{Net\ Area}{\epsilon \cdot (B.R\%) \cdot t \cdot m\ or\ v} \times 100 \quad (2)$$

Where *Net Area* is the net count under the peak, *Act* (Bq/kg or Bq/l) is the specific activity, ϵ is the energy efficiency for the gamma ray by the detector, *B.R.* is the

branching ratio of gamma intensity (%), t (s) is the time of spectra, m denotes the mass (kg) of the samples and v refers to the volume (liter) of the samples.

2.3 Radium equivalent

Since the distribution of natural radionuclides was not uniform in the samples under analysis, a radiological index, called radium equivalent (Ra_{eq}) activity, was defined to estimate the radiation risk, associated with these radionuclides. This index was calculated, using equation 3 [12]:

$$Ra_{eq} = A_{Ra} + 1.43 A_{Th} + 0.077 A_K \quad (3)$$

where A_{Ra} , A_{Th} and A_K are the specific activities (Bq/kg) of ^{226}Ra , ^{232}Th and ^{40}K in the studied samples, respectively.

2.4 Hazard indices

The external (H_{ex}) and internal (H_{in}) hazard indices related to the emitted gamma rays of the samples were calculated, using equations 4 and 5 [12]:

$$H_{ex} = A_{Ra}/370 + A_{Th}/259 + A_K/4810 \leq 1 \quad (4)$$

$$H_{in} = A_{Ra}/185 + A_{Th}/259 + A_K/4810 \leq 1 \quad (5)$$

2.5. Dose calculations

According to equation 6, proposed by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) report in 2008, the absorbed gamma radiation dose can be estimated in outdoors from soil and rocks one meter above the ground [1]:

$$D(nGy h^{-1}) = [0.427 A_{Ra} + 0.662 A_{Th} + 0.0432 A_K] \quad (6)$$

In equations 4, 5 and 6, A_{Ra} , A_{Th} and A_K are the specific activities (Bq/kg) of ^{226}Ra , ^{232}Th and ^{40}K in soil samples, respectively.

In order to estimate annual effective dose (AED) in $\mu Sv/y$ used equations 7 and 8. In these equations according to the UNSCEAR reports used the value 0.7 Sv/Gy as the conversion factor from the absorbed dose rate in air to effective dose rate for population in situation outdoor or indoor. Occupancy factors should be taken into account. Occupancy factors 0.2 and 0.8 used for outdoor and indoor occupancy respectively [1].

$$AED \text{ outdoor } (\mu Sv/y) = \text{Dose rate (nGy/h)} \times (7)$$

$$8766 \text{ (h/y)} \times 0.2 \times 0.7 \text{ (Sv/Gy)} \times 10^{-3} \\ AED \text{ indoor } (\mu Sv/y) = \text{Dose rate (nGy/h)} \times 8766 \text{ (h/y)} \times 0.8 \times 0.7 \text{ (Sv/Gy)} \times 10^{-3} \quad (8)$$

2.6 Absorbed dose to human

AED to an individual due to the intake of ^{226}Ra , ^{232}Th and ^{40}K radionuclides caused by rice consumption was determined, using equation 9 [14]:

$$E_{eff} (\mu Sv/y) = A_c A_{if} D_{cf} \quad (9)$$

where E_{eff} refers to AED ($\mu Sv/y$) in an individual, owing to the ingestion of radionuclides, A_c is the average activity concentration of radionuclides (Bq/kg), A_{if} denotes the annual intake of rice (kg/y) per capita rice grain consumption (28 kg/y for Iran) and D_{cf} is the ingestion dose conversion factor for the radionuclides of interest (2.8×10^{-7} Sv/Bq for ^{226}Ra , 2.3×10^{-7} Sv/Bq for ^{232}Th and 6.2×10^{-9} Sv/Bq for ^{40}K) [14].

2.7 TF calculation

TF values were considered to be in compliance with the definition proposed by Shyamal Ranjan et al., expressed as equation 10 [15]:

$$TF = \frac{\text{Concentration of radionuclide in crop (Bq/kg dry crop mass)}}{\text{Concentration of radionuclide in soil (Bq/kg dry soil mass)}} \quad (10)$$

3. Results

In this study, the specific activities of ^{226}Ra , ^{232}Th , ^{40}K and ^{137}Cs were determined in 14 rice samples, nine soil samples from rice fields and four samples of consumed water in rice fields. These measurements are presented in tables 3-5. Moreover, the results of calculation of radium equivalent, external and internal hazard indices, absorbed dose in air (in 1m height from the surface above soil and rocks) and AED rate are presented in Table 6.

The absorbed dose calculations in Iranian adults are demonstrated in Table 7. Also, the radionuclide TF calculations from soil to rice are presented in Table 8. In the last row, the results of TF measurements in Malaysia are demonstrated [16].

Table 3. Specific activities (Bq/kg) of ^{226}Ra , ^{232}Th , ^{40}K and ^{137}Cs in soil samples

Sample code	^{226}Ra	^{232}Th	^{40}K	^{137}Cs
Kamd	63.45±1.16	82.96±1.41	904.81±5.51	2.46±0.19
Kamf	29.77±0.77	76.08±1.21	899.00±5.57	6.77±0.23
Kmkd	34.28±0.89	82.48±1.31	961.15±5.76	3.04±0.20
Kmkf	32.72±0.98	84.33±1.26	935.10±5.70	4.47±0.23
Kmmd	44.30±1.06	63.74±1.27	826.53±4.95	7.98±0.23
Kmmf	50.45±1.24	68.64±1.36	1034.67±5.17	5.87±0.23
Ktad	40.02±0.96	55.77±1.11	911.32±5.46	3.40±0.20
Ktaf	44.53±1.01	59.71±1.19	973.57±5.84	8.13±0.23
Ktas	41.96±1.02	54.14±1.13	923.56±5.54	4.28±0.20

Table 4. Specific activities (Bq/kg) of ^{226}Ra , ^{232}Th , ^{40}K and ^{137}Cs in rice samples and the radium equivalent values (Ra_{eq}) of the samples

Sample code	^{226}Ra	^{232}Th	^{40}K	^{137}Cs	Ra_{eq} (Bq/kg)
Bamd	2.21±0.92	<3.06	104.93±4.19	<0.45	10.79±1.04
Bamf	2.18±0.74	<2.93	122.66±4.90	<0.36	15.88±0.83
Bmkd	1.28±0.36	6.66±1.26	90.18±4.50	<0.27	18.11±1.89
Bmkf	<1.27	<0.42	118.21±4.27	<0.57	16.53±0.38
Bmmd	1.33±0.58	<3.81	84.66±3.38	<0.60	13.66±3.18
Bmmf	2.89±0.86	<1.36	100.51±4.02	<0.54	13.27±0.95
Btad	1.09±0.23	15.24±1.68	107.24±4.28	<0.30	38.93±2.93
Btaf	1.07±0.49	<1.30	115.27±4.61	<0.63	11.85±0.65
Btas	1.31±0.63	<3.42	83.87±3.35	1.00±0.26	13.17±0.71
Bgst	1.40±0.50	<3.57	111.09±0.04	0.87±0.29	16.39±0.63
Bgge	1.46±0.52	8.78±1.40	90.45±3.61	<0.60	21.68±2.11
Bgeh	2.28±0.77	<3.51	97.06±4.85	<0.63	15.49±0.86
B1121	1.81±0.72	<4.20	109.72±5.48	0.75±0.30	16.54±0.87
shsh	1.19±0.38	<1.42	211.96±4.23	<0.66	20.04±0.59

Table 5. Specific activities (Bq/kg) of ^{232}Th , ^{40}K , ^{226}Ra and ^{137}Cs in water samples

Sample code	^{226}Ra	^{232}Th	^{40}K	^{137}Cs
Wam	1.16±0.27	2.78±0.55	24.02±1.44	<0.36
Wmk	1.10±0.23	<0.23	24.26±1.69	0.25±0.08
Wmm	0.98±0.17	<5.02	23.77±1.66	<0.10
Wta	1.00±0.36	<0.63	<5.23	<0.25

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Table 6. The values of radium equivalent (Bq/kg), external and internal hazard indices, dose rate (nGy/h) and AED ($\mu\text{Sv/y}$) for soil samples

Sample code	R_{eq} (Bq/kg)	H_{ex}	H_{in}	D (nGy/h)	AED ($\mu\text{Sv/y}$)
Kamd	251.77 \pm 2.39	0.68 \pm 0.01	0.85 \pm 0.01	117.16 \pm 1.05	148.51
Kamf	207.80 \pm 1.98	0.56 \pm 0.01	0.64 \pm 0.01	97.20 \pm 0.86	124.97
Kmkd	226.25 \pm 2.14	0.61 \pm 0.01	0.70 \pm 0.01	105.74 \pm 0.93	135.82
Kmkf	225.33 \pm 2.10	0.61 \pm 0.01	0.70 \pm 0.01	105.05 \pm 0.92	137.62
Kmmd	199.11 \pm 2.16	0.54 \pm 0.01	0.66 \pm 0.01	93.44 \pm 0.94	118.71
Kmmf	228.03 \pm 2.37	0.62 \pm 0.01	0.75 \pm 0.01	107.81 \pm 1.04	136.93
Ktad	189.95 \pm 2.18	0.51 \pm 0.01	0.62 \pm 0.01	90.18 \pm 0.95	113.44
Ktaf	204.90 \pm 2.04	0.55 \pm 0.01	0.67 \pm 0.01	97.25 \pm 0.89	123.35
Ktas	190.51 \pm 1.97	0.51 \pm 0.01	0.63 \pm 0.01	90.61 \pm 0.87	114.84

Table 7. The annual committed effective dose ($\mu\text{Sv/y}$)

Sample code	^{226}Ra	^{232}Th	^{40}K	^{137}Cs	Total ($\mu\text{Sv/y}$)
	($\mu\text{Sv/y}$)	($\mu\text{Sv/y}$)	($\mu\text{Sv/y}$)	($\mu\text{Sv/y}$)	
Bamd	17.00 \pm 7.21	-	18.00 \pm 0.72	-	35.00 \pm 7.28
Bamf	17.00 \pm 5.80	-	21.20 \pm 0.85	-	38.20 \pm 6.65
Bmkd	10.00 \pm 2.82	42.80 \pm 8.11	15.60 \pm 0.78	-	68.40 \pm 11.71
Bmkf	-	-	20.50 \pm 0.74	-	20.50 \pm 0.74
Bmmd	10.40 \pm 4.57	-	14.60 \pm 0.58	-	25.00 \pm 5.15
Bmmf	22.60 \pm 6.74	-	17.40 \pm 0.69	-	40.00 \pm 7.43
Btad	8.50 \pm 1.80	78.82 \pm 10.81	18.60 \pm 0.74	-	105.92 \pm 9.98
Btaf	8.30 \pm 3.84	-	20.00 \pm 0.80	-	28.30 \pm 3.82
Btas	10.20 \pm 4.93	-	14.50 \pm 0.58	0.36 \pm 0.09	24.70 \pm 4.80
Bgst	10.90 \pm 3.92	-	19.20 \pm 0.06	0.31 \pm 0.10	30.41 \pm 3.90
Bgge	22.90 \pm 4.07	56.50 \pm 9.01	15.70 \pm 0.62	-	95.10 \pm 9.01
Bgeh	17.80 \pm 6.03	-	16.80 \pm 0.84	-	34.60 \pm 6.04
B1121	14.00 \pm 5.64	-	19.00 \pm 0.95	0.27 \pm 0.10	33.20 \pm 5.71

Table 8. The transfer factor (TF) values of radionuclides from soil to rice

Sample code	^{226}Ra	^{232}Th	^{40}K	^{137}Cs
Bamd	0.03±0.01	<0.03	0.11±0.00	<0.18
Bamf	0.07±0.02	<0.03	0.13±0.00	<0.05
Bmkd	0.03±0.01	0.08±0.01	0.09±0.00	<0.08
Bmkf	0.03<	<0.04	0.12±0.00	<0.12
Bmmd	0.03±0.01	<0.05	0.10±0.00	<0.07
Bmmf	0.05±0.01	<0.01	0.09±0.00	<0.09
Btad	0.02±0.00	0.27±0.01	0.11±0.00	<0.08
Btaf	0.02±0.00	<0.02	0.11±0.00	<0.07
Btas	0.03±0.01	<0.06	0.09±0.00	0.23±0.08
Shsh	0.02±0.00	<0.02	0.22±0.00	<0.15
Malaysia	0.16-0.32	0.17-0.47	0.52-1.21	--

4. Discussion

Specific activities of ^{226}Ra , ^{232}Th , ^{40}K and ^{137}Cs in soil samples varied from 32.72±0.98 to 63.45±1.16, from 54.14±1.13 to 84.33±1.26, from 826.53±4.95 to 1034.67±5.17 and from 2.46±0.19 to 8.13±0.23 Bq/kg, respectively. The mean specific activities of ^{226}Ra , ^{232}Th and ^{40}K have been estimated at 35, 40 and 400 Bq/kg, worldwide, respectively [1]. As the results indicated, the specific activities of ^{226}Ra , ^{232}Th and ^{40}K were higher than the mean global values, which is due to geological characteristics of this region and addition of potassium sulfate to soil as a fertilizer by farmers.

Radium equivalent values of soil samples were lower than the maximum permitted value by the UNSCEAR report in 2008 (i.e., 370 Bq/kg) [1]. Existence of ^{137}Cs in the samples indicated the pollution of this zone due to nuclear accidents or nuclear weapon tests. The effective outdoor dose rates in the studied soil samples varied from 113.44 to 148.51 $\mu\text{Sv/y}$. The calculated values were lower than the average permitted annual external effective dose (i.e., 460 $\mu\text{Sv/y}$) [13].

External and internal hazard indices for soil samples were within the range of 0.05-1, which is considered safe for farmers and workers (Table 6). The specific activities of ^{226}Ra , ^{232}Th , ^{40}K and

^{137}Cs in rice samples varied from <1.27 (MDa) to 2.89±0.86, from <0.42 to 15.24±1.68, from 84.66±3.38 to 122.66±4.90 and from <0.27 (MDa) to 1.00±0.26 Bq/kg, respectively (Table 4).

The present findings indicated that some radionuclides transferred from soil to rice, and ^{137}Cs pollution was reported in some rice varieties. In this study, all soil samples and some rice samples were polluted by ^{137}Cs radionuclide. Pollution of this area by fission fragments such as ^{137}Cs indicates that the radioactive dust originating from nuclear accidents or nuclear weapon tests in other countries has polluted this region, as well. Radium equivalent (Bq/kg) for all rice samples varied from 10.79±1.04 (Bamd code) to 38.93±2.93 (Btad code). Radium equivalent of a rice variety, known as Hi (with the code Bgeh) from Guilan province, lied within the same range. Moreover, rough rice contained much higher values of ^{40}K , compared to other rice samples. Although the rice imported from India was not substantially different from other evaluated varieties in terms natural radionuclides, ^{137}Cs pollution was detected.

Water is an important element in rice cultivation in the early stages of growth. In this study, four water samples from four villages, used in rice fields, were investigated. The measurement

results are presented in Table 5. Specific activities of ^{226}Ra , ^{232}Th , ^{40}K and ^{137}Cs in water samples varied from 0.98 ± 0.17 to 1.16 ± 0.27 , from <0.23 (MDa) to 2.78 ± 0.55 , from <5.23 (MDa) to 24.26 ± 1.69 and from <0.10 (MDa) to 0.25 ± 0.08 Bq/kg, respectively.

Water can transfer Ra from water alterations of rocks and soil in mountains to rice fields. For all samples, the specific activity of ^{226}Ra was higher than the MDA of the measurement system. For calculating TF, radioactivity in water was disregarded, since in the last steps of wet rice cultivation, water is cut off from rice fields.

As presented in Table 7, the total annual committed effective dose ($\mu\text{Sv/y}$) due the consumption of rice grains by Iranians ranged from 20.50 ± 0.74 to 105.92 ± 9.98 in the studied location, which lies within the average annual range of global ingestion dose [17]. Therefore, consumption of rice would impose no health consequences on consumers. TF values of ^{226}Ra and ^{40}K radionuclides varied from 0.02 to 0.07 and 0.09 to 0.13, respectively.

Table 8 shows the TF values of radionuclides, depending on the variety of rice. This factor for ^{232}Th and ^{137}Cs in most rice varieties was less than the MDA of the system. TF of ^{232}Th was obtained only for Bmkd and Btad samples (a variety of rice named Dh). Also, TF of ^{137}Cs was only obtained for the Btas sample. Maximum TF for ^{40}K was obtained for rough rice, indicating more ^{40}K activity concentration in the aerial parts of rice. The calculated TF values in this study were higher than that reported by the International Atomic Energy Agency (IAEA) in 2010; however, the values were much lower than measurements in Malaysia. [21, 16].

Comparison of radionuclide concentrations obtained in this study with some reported findings from other countries is presented in Table 9. In this study, the specific activity of ^{40}K in rice samples was within the same range as the rice imported from Malaysia and Germany. However, presence of ^{232}Th in some rice varieties was more prominent than other reported results; this may be related to geological characteristics of Gorgan province, located near Alborz plutonic mountains.

Table 9. Comparison between radionuclides concentrations (Bq/kg) of ^{232}Th , ^{40}K and ^{137}Cs in rice samples studied in this work and some other countries

Origin	^{232}Th	^{40}K	^{137}Cs	References
Brazil	–	14.7	–	[18]
Egypt	0.60	36	–	[19]
France	0.32	51	–	[19]
Germany	0.4–0.5	87–101	0.1	[19]
Iran(Dh) *	$<3.06^{**}$ -15.24	84.66-107.24	<0.27 - <0.60	The present study
Iran(Si)	<3.42	83.87	1.00	The present study
Iran(Fr)	<0.42 -20.21	100.51-122.66	<0.36 - <0.63	The present study
India(11)	<4.20	109.72	0.75	The present study
China (Hong Kong)	–	15	0.26	[20]
India	0.36–0.62	36–81	–	[19]
Malaysia	35–65	65–110	–	[16]
Pakistan	0.06–0.08	7–50	0.02–0.04	[19]
Pakistan	0.43–0.46	33–38	–	[19]
Thailand	0.02–0.3	22–23	0.081	[19]

*- In parentheses denote kind of varieties

** < denote less than MDA (amount of MDA printed)

5. Conclusion

In the present study, the natural radioactivity of soil samples and different varieties of rice was measured, using gamma ray spectrometry. Radiological effects were calculated for soil and rice samples. The specific activities of ^{226}Ra , ^{232}Th and ^{40}K in soil samples were higher than the mean global value, which is due to geological characteristics of this region and addition of potassium sulfate to soil as a

fertilizer by farmers. The results of , this study indicated that radionuclide intake due to rice consumption had no consequence for public health.

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