Iranian Journal of Medical Physics
Vol. 12, No. 3, Summer 2015, 189-199
Received: May 30, 2015; Accepted: October 1, 2015

**Original Article**

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

Reza Pourimani[1*], Fatemeh Anoosheh[1]

## 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 $^{226}$Ra, $^{232}$Th, $^{40}$K and $^{137}$Cs 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 $^{226}$Ra, $^{232}$Th, $^{40}$K and $^{137}$Cs 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 $^{40}$K and $^{226}$Ra 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

*1- Department of Physics, Faculty of Science, Arak University, Iran*
* Corresponding author: Tel: 0918161224 E-mail: r-pourimani@araku.ac.ir

# 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 ($Ra_{eq}$), 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 $^{\circ}$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 ($\varepsilon_i$) was calculated, using equation 1[10]:

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

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″ | 36º 52′ 24.2″ | 102 |
| Kmkf | Fr | Marzan Kalateh | 54° 35′ 11.5″ | 36º 52′ 24.2″ | 105 |
| Kamd | Dh | Ahangar Mahalleh | 54° 35′ 18.5″ | 36º 49′ 32.0″ | 269 |
| Kamf | Fr | Ahangar Mahalleh | 54° 35′ 00.7″ | 36º 49′ 59.3″ | 215 |
| Kmmd | Dh | Mir Mahalleh | 54° 36′ 58.1″ | 36º 54′ 29.1″ | 47 |
| Kmmf | Fr | Mir Mahalleh | 54° 38′ 35.7″ | 36º 52′ 05.0″ | 47 |
| Ktad | Dh | Taghi Abad | 54º 38′ 35.8″ | 36º 52′ 05.5″ | 114 |
| Ktaf | Fr | Taghi Abad | 54° 38′ 35.7″ | 36º 52′ 05.0″ | 110 |
| Ktas | Si | Taghi Abad | 54° 38′ 43.5″ | 36º 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]:

$$Act = \frac{\text{Net Area}}{\varepsilon.(\text{B.R}\%).\text{t. } m \text{ or } v} \times 100 \qquad (2)$$

Where *Net Area* is the net count under the peak, *Act* (Bq/kg or Bq/l) is the specific activity, $\varepsilon$ 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 equation6, 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]:

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

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 μSv/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].

$$\text{AED outdoor (μSv/y)} = \text{Dose rate (nGy/h)} \times 8766\ (h/y) \times 0.2 \times 0.7\ (Sv/Gy) \times 10^{-3} \quad (7)$$

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

### 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 ($2.8\times10^{-7}$ Sv/Bq for $^{226}$Ra, $2.3\times10^{-7}$Sv/Bq for $^{232}$Th and $6.2\times10^{-9}$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]:

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

## 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 |

Table 6. The values of radium equivalent (Bq/kg), external and internal hazard indices, dose rate (nGy/h) and AED (μSv/y) for soil samples

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

Table 7. The annual committed effective dose (μSv/y)

| Sample code | $^{226}$Ra (μSv/y) | $^{232}$Th (μSv/y) | $^{40}$K (μSv/y) | $^{137}$Cs (μSv/y) | Total (μSv/y) |
|---|---|---|---|---|---|
| Bamd | 17.00±7.21 | - | 18.00±0.72 | - | 35.00±7.28 |
| Bamf | 17.00±5.80 | - | 21.20±0.85 | - | 38.20±6.65 |
| Bmkd | 10.00±2.82 | 42.80±8.11 | 15.60±0.78 | - | 68.40±11.71 |
| Bmkf | - | - | 20.50±0.74 | - | 20.50±0.74 |
| Bmmd | 10.40±4.57 | - | 14.60±0.58 | - | 25.00±5.15 |
| Bmmf | 22.60±6.74 | - | 17.40±0.69 | - | 40.00±7.43 |
| Btad | 8.50±1.80 | 78.82±10.81 | 18.60±0.74 | - | 105.92±9.98 |
| Btaf | 8.30±3.84 | | 20.00±0.80 | | 28.30±3.82 |
| Btas | 10.20±4.93 | - | 14.50±0.58 | 0.36±0.09 | 24.70±4.80 |
| Bgst | 10.90±3.92 | - | 19.20±0.06 | 0.31±0.10 | 30.41±3.90 |
| Bgge | 22.90±4.07 | 56.50±9.01 | 15.70±0.62 | - | 95.10±9.01 |
| Bgeh | 17.80±6.03 | - | 16.80±0.84 | - | 34.60±6.04 |
| B1121 | 14.00±5.64 | - | 19.00±0.95 | 0.27±0.10 | 33.20±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 μSv/y. The calculated values were lower than the average permitted annual external effective dose (i.e., 460 μSv/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 (μSv/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 verities ** < 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.

## Acknowledgment

This study was funded by the Department of Research at Arak University.

## References

1.UNSCEAR,United Nations Scientific Committee on the Effects of Atomic Radiation. Exposure from natural sources of radiation, United Nations publication sales No. 10.IX.3. . 2008, United Nations, United Nations Office at Vienna.

2. Singh P, Rana N, Azam A, Naqvi A, Srivastava D. Levels of uranium in waters from some Indian cities determined by fission track analysis. Radiation Measurements. 1996;26(5):683-7.

3.Fireston BR, Shirley SV, Baglin MC, Frank Chu SY, and Zipkin J,The $8_{th}$ Edition of Table of Isotopes. 1996; CD-ROM, John Wiley &SonsInc.

4. Kalač P. A review of edible mushroom radioactivity. Food Chemistry. 2001; 75 (1):29-35.

5.Dupré A , Boyer-Chatenet L , Sattler RM , Modi AP , Lee JH , Nicolette ML, et al. A forward chemical genetic screen reveals an inhibitor of the Mre11-Rad50-Nbs1 complex. Nat Chem Biol. 2008; 4(2) : 119-25.6. International Rice Commission Newsletter,1997; Vol. 47. Available from: http://www.fao.org/docrep/003/w8595t/w8595t01.htm

7. Perez-MorenoJP, Bolivar JP, Garcia-TenorioR, San Miguel E, AguadoJL,Mas JL, VacaF. A simple method for efficiency calibration of HPGe in γ-spectrometric measurements. Radiat Phys Chem. 2001; 61(3): 437-8.

8. International Atomic Energy Agency. Vienna 2003,IAEA-TECDOC-1360. Collection and preparation of bottom sediment samples for analysis of radionuclides and trace elements,2003. Available from: http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/34/066/34066609.pdf

9.International Atomic Energy Agency, Vienna, 1981,. Methods of Low-Level Counting and Spectrometry Symposium. Berlin. 1981; Vol. 221 Available from: http://www-naweb.iaea.org/napc/ih/documents/IAEA%20Monographs/STI%20592%20Methods%20of%20Low%20level%20counting%20and%20spectrometry%201981.pdf

10.American Natural Standard for calibration and use of Germanium spectrometer for the measurement of Gamma-ray emission rates of Radionuclides. ANSIN.1999.

11. Beretaka J and Mathew PJ. Natural Radioactivity of Australian Building Materials, Industrial Wastes and By- Products. Health Physics.1985; 48(1): 87-95.

12. United Nations Scientific Committee on the Effects of Atomic Radiation. Sources, Effects and Risk of Ionizing Radiation.United Nations 2000; New York. Available from: http://www.unscear.org/unscear/publications/2000_2.html

13.Khandaker MU, Norfadira BW, AminYM, Bradley DA. Committedeffective dose from naturally occurring radionuclides in shellfish. Radiat Phys Chem. 2013: 88: 1–6.

14.Khandaker MU, Jojo PJ, Kassim HA, AminYM, 2012. Radiometric analysis of construction materials UsingHPGe gamma-ray spectrometry. Radiat Prot Dosim. 2012; 152 (1–3): 33- 37

15. Chakraborty SR, Azim R, Rahman A, Sarker R..Radioactivity Concentrations in Soil and Transfer Factors of Radionuclides from Soil to Grass and Plants in the Chittagong City of Bangladesh.J Phys Sci. 2013; 24(1): 95–113.

16.Asaduzzaman K, Khandeker M, Amin Y, Mahat R. Uptake and distribution of natural radioactivity in rice from soil in north and west part of peninsular Malaysia for the estimation of ingestion dose to man. Annuals of Nuclear Energy 2015; 76: 85-93

17. UNSCEAR, Effects and Risks of Ionizing Radiations. United Nations publication. 2006; Accessed from http://www.unscear.org/unscear/en/publications/2006

18.Venturini L, Sordi GA.Radioactivity and committed effective dose from some Brazilian food stuffs**.**Health Phys. 1999; 76(3): 311–3.

19. Alrefae T, Nageswaran TN.Radioactivity of long lived gamma emitters in rice consumed in Kuwait. Journal of the Association of Arab Universities for Basic and Applied Science. 2013;13**(1)**_: 24–7.
20. Yu KN, Mao SY. Assessment of radionuclide contents in food in Hong Kong, Health Physics. 1999; 77: 686–96.
21. IAEA 2010. Handbook of parameter value for the prediction of Radionuclide Transfer in Terrestrial and freshwater Environments. Technical Report 2010; 472:79.