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Natural Radioactivity Level of ^{226}Ra, ^{232}Th, and ^{40}K Radionuclides in Drinking Water of Residential Areas in Kermanshah Province, Iran using Gamma Spectroscopy

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ABSTRACT

Introduction: Human has always been exposed to background ionizing radiation. Interaction between ionizing radiation and the biological system can lead to changes in cells or tissues inducing diseases, such as cancer. With this background in mind, this experimental study aimed to evaluate the specific activity of water radionuclides in Kermanshah province, western region of Iran.

Material and Methods: The specific activities of ^{226}Ra, ^{232}Th, and ^{40}K radionuclides in drinking water were assessed by gamma-ray spectrometer with high-purity Germanium detector. The water samples were collected from different towns (14 sites) in Kermanshah province on winter and summer seasons.

Results: The mean specific activity levels of ^{226}Ra, ^{232}Th, and ^{40}K radionuclides in Bq/l were 0.53±0.28, 1.07±0.43, and 7.17±5.37 in winter, respectively. In addition, during summer the mean specific activities of ^{226}Ra, ^{232}Th, and ^{40}K were 0.61±0.20, 0.76±0.36, and 5.67±3.7 Bq/l, respectively. Contributions of the consumed water samples to annual effective dose for these radionuclides in adults was calculated to be in the range of 0.0015-0.24 mSv/y with the mean of 0.15 mSv/y.

Conclusion: Findings of the present study demonstrate that the radioactivity level in drinking water due to ^{226}Ra, ^{232}Th, and ^{40}K radionuclides in Kermanshah province is lower than the guidance levels recommended by the World Health Organization report (WHO-2011). Moreover, the mean annual effective dose caused by these radionuclides in Kermanshah province is lower than the global average level (0.29 mSv/y) reported by United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR 2000).

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Introduction

Human has always been exposed to environmental ionizing radiation. Radionuclides, as the most important source of exposure, are found at different levels in air, water, soil, and rocks. Ionizing radiation is hazardous to the human body and depending on the amount of radiation dose might cause changes and diseases, such as cancer and genetic mutations [1].

Water is an important subject in environmental studies due to its daily consumption by human and the possibility of its associated diseases [2]. Drinking water contains natural radioactive materials, including ^{238}U, ^{235}U, and ^{232}Th, as well as their decay products, such as ^{226}Ra and ^{228}Ra [2, 3]. Long-term consumption of such radioactive substances in low doses by drinking water can increase the potential radiobiological damages in body [1, 2]. ^{226}Ra and ^{228}Ra isotopes in water can enter bloodstream and different body tissues. These isotopes have a calcium-like behavior regarding absorption in the body [2, 3].

Nowadays, precise measurement of natural radionuclides concentration in drinking water and food is of high importance for human populations [3]. According to the UNSCEAR 2000, the annual average human exposure to natural sources of radiation is 2.4 mSv, among which 0.4, 0.5, 1.2, and 0.3 mSv are related to cosmic rays, soil and building materials, radon gas, in addition to food and water, respectively. Therefore, awareness of ionizing radiation coming from various sources needs accurate local measurements [3]. The present study aimed to investigate the activities of ^{226}Ra, ^{232}Th, and ^{40}K radioisotopes in drinking water of Kermanshah province, Iran.

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Materials and Methods

Sample Collection

In order to measure gamma radiation from natural radionuclides in water, 28 water samples as about 1.5 liters of drinking water for each sample were collected on winter and summer. In each season, we collected 14 samples from 14 stations in each city in Kermanshah province. Three samples were obtained from the city of Kermanshah (three stations) and one sample from each of the other 11 cities in Kermanshah province (Table 1).

1.5 liter of drinking water was collected from each sample in polyethylene containers. At the same time of collecting water samples, water microorganisms were destroyed based on the Environmental Protection Agency (Krieger 76) protocol [4]. For this purpose, 2 ml nitric acid (65%) was added to each 250 ml of water so that the pH reached about 1.5-2 [4]. After transferring the samples to the laboratory, we poured 800 ml from each sample of water in standard Marinelli beaker containers. In order to prevent radon gas escape from the sample and creation of secular equilibrium between ^{226}Ra and its decay products in the ^{238}U series, as well as ^{232}Th and its decay products in ^{232}Th series, the samples were sealed and stored for a month [5].

Gamma Spectrometer Calibration

Type P high-purity Germanium (HPGe) detector (ORTEC&AMETEK, USA) with the relative efficiency of 38.5% was applied to measure the activity of samples. The HPGe detector was placed in a lead shield to reduce the effects of background radiation. The lead shield had a thickness of 10 cm with the inner surface covered in a cadmium layer with a thickness of 1.5 mm and copper with a thickness of 2.5 mm [6]. Full width at half maximum (FWHM) of device energy resolution was about 1.98 keV for the peak of 1332 keV. The output was connected to a 4096 channel analyzer with the amplifier and analog-to-digital converter.

Three types of calibration were carried out on the device, including calibration energy, energy resolution, and efficiency [7]. Energy calibration was carried out using two standard ^{241}Am and ^{226}Ra point sources. Energy resolution calibration was completed using standard sources of ^{60}Co, ^{57}Co, and ^{137}Cs [8]. The standard sources of ^{241}Am, ^{109}Cd, ^{57}Co, ^{133}Ba, ^{137}Cs, and ^{60}C0 at different energies were used for calibrating the absolute efficiency of each photopeak. The calibrated energy range for the detector was 59.54-2000 keV [8]. The plot of detector efficiency versus gamma ray energy is depicted in Figure 1. Furthermore, curve fitting for the experimental data was performed and the function fitted to the data was as follows:

$$y=a+b(\ln x)+c(\ln x)^2+d(\ln x)^3+e(\ln x)^4 \quad (1)$$

Where **y** refers to efficiency, a, b, c, d, and e are the constants shown in the figure, and x is the gamma ray energy in keV.

Sample Counting and Specific Activity Measurement

Following samples preparation, each sample was placed in the device and was counted for 66,000 sec. Measurement of the samples spectrum was carried out using the AKWIN software (Atom Komplex Prylad Ltd, Kiev, UKR). The obtained spectra was analyzed using the OMNIGAM software (EG&G ORTEC, USA). Next, the activities of radionuclides were obtained using the detected energy peaks, including ^{214}Pb (295.22 and 351.93 keV), and ^{214}Bi (609.31 keV) for ^{226}Ra, in addition to ^{228}Ac (911.2, 968.97, and 338.32 keV) for ^{232}Th and ^{40}K at 1461 keV [9]. We obtained the activity of the samples based on the special activity of radionuclides, using the following equation [5, 10]:

$$A=\frac{Net\ Area}{\varepsilon(\%)\times(B.R\ \%)\times t\times v}\times 100 \quad (2)$$

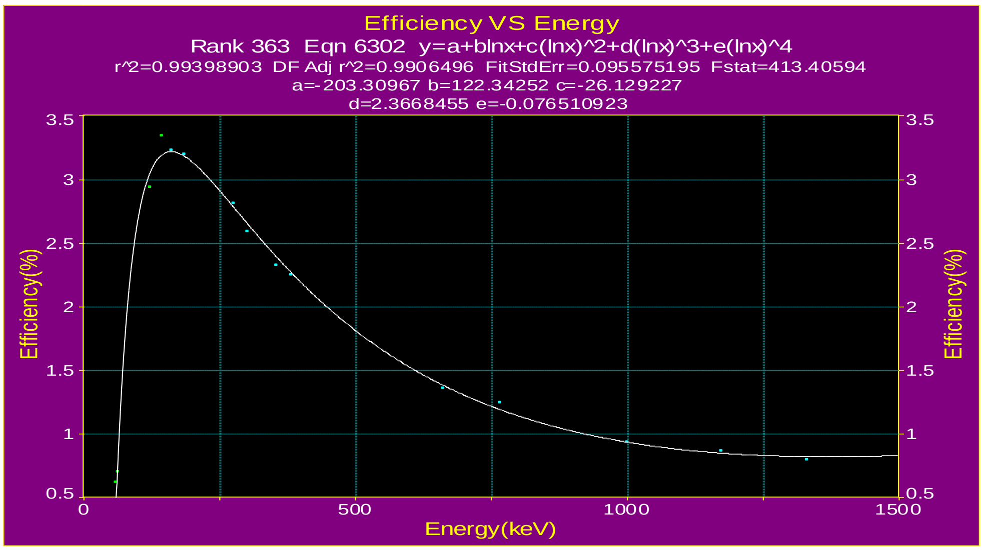

Figure 1. Detector efficiency curve for the standard Marinelli Beaker source

According to the specific activities of the water samples, the external (H_{ex}) and internal radiations (H_{in}) risk indicators [2, 11] were obtained applying equations (3) and (4):

$$H_{ex}=A_{Ra}/370 + A_{Th}/259 + A_K/4810 \quad (3)$$

$$H_{in}=A_{Ra}/185 + A_{Th}/259 + A_K/4810 \quad (4)$$

Where A_{Ra}, A_{Th}, and A_k are the specific activities of ^{226}Ra, ^{232}Th, and ^{40}K radionuclides in Bq/l, respectively.

Annual Effective Dose Calculation

The annual effective dose of drinking water (AED_{dw}) in mSv/y was obtained for the members of public due to the radionuclides in water samples using the following equation [12, 13]:

$$AED_{dw}=A\times DCF \times CRW \quad (5)$$

Where, A (Bq/l) is the activity of ^{226}Ra, ^{232}Th, and ^{40}K radionuclides. DCF (Sv/Bq) is Dose Conversion Factor for ^{226}Ra, ^{2323}Th, and ^{40}K radionuclides, which is equal to 2.8×10^{-7}, 2.3×10^{-7} and 6.2×10^{-9} (Sv/Bq), respectively. In addition, Consumption Rate of Water (CRW) is the annual water consumption for adults that was considered as 730 liters based on the WHO-2011 report [2, 13].

Results

Specific Activity of the Samples

Specific activities of the water samples in both winter and summer are shown in Table 1. The mean specific activities of ^{226}Ra, ^{232}Th, and ^{40}K radionuclides in Bq/l were 0.53±0.28 (range of 0.1-0.98), 1.07±0.43 (range of 0.57-2.13), and 7.17±5.37 (range of 1.23-15.74) for the whole province in winter, respectively. These values in summer were obtained as 0.61±0.20 (range of 0.23-0.84), 0.76±0.36 (range of 0.27-1.21), and 5.67±3.7 (range of 0.56-9.45) Bq/l, respectively.

The Annual Effective Dose, External, and Internal Radiation Risk Indices

Based on the results obtained in the present study (Table 2), the mean H_{ex} and H_{in} indices were 0.004 and 0.005 in winter, as well as 0.0030 and 0.004 in summer, respectively. The mean value of the annual effective dose due to ^{226}Ra, ^{232}Th, and ^{40}K radionuclides in mSv/y from water samples for adults was 0.88 (range: 0.003-0.23) in winter, 0.062 (range: 0.001-0.18) in summer, and 0.15 (range: 0.003-0.25) mSv/y in both summer and winter. The highest and lowest annual effective doses in winter belonged to Kangavar and Qasr-e-Shirin, respectively. Moreover, the highest value in summer was for Islamabad-e-Gharb, while the lowest was attributed to Paveh. Generally, Islamabad-e-Gharb and Paveh had the maximum and minimum annual effective doses in both winter and summer. All indices obtained in winter were more than those of summer for the water samples in Kermanshah province.

Table 1. Results of specific activity measurements in the drinking water samples during winter and summer seasons in Kermanshah province, Iran

City	Sample	^{226}Ra (Bq/l)		^{232}Th (Bq/l)		^{40}K (Bq/l)	
		Winter	Summer	Winter	Summer	Winter	Summer
Harsin	W_1	< MDA*	0.57±0.25	< MDA	1.21±0.45	< MDA	9.45±0.90
Gilan-e-Gharb	W_2	0.71±0.22	< MDA	1.29±0.35	0.27±0.10	14.21±1.00	< MDA
Sahneh	W_3	0.98±0.27	< MDA	1.2±0.50	< MDA	15.74±1.18	5.56±0.67
Eslamabad-e-Gharb	W_4	0.56±0.16	0.84±0.36	< MDA	0.94±0.31	9.00 ±0.82	7.29±0.77
Ghasr-e-Shirin	W_5	< MDA	0.23±0.11	< MDA	0.83±0.23	< MDA	6.16±0.62
Sonqor	W_6	0.50 ±0.17	0.66±0.20	0.99±0.45	< MDA	8.17±1.00	< MDA
Javanroud	W_7	0.43±0.14	0.52±0.08	0.85±0.47	< MDA	< MDA	1.67±0.32
Paveh	W_8	< MDA	< MDA	< MDA	< MDA	1.23±0.35	< MDA
Sarpol-e-Zahab	W_9	0.29±0.11	0.80 ±0.24	< MDA	< MDA	2.40 ±0.52	9.26±1.14
Ravansar	W_{10}	0.10 ±0.04	< MDA	< MDA	< MDA	< MDA	0.56±0.20
Kermanshah (Region 4)	W_{11}	< MDA	< MDA	0.57±0.23	< MDA	3.81±0.57	1.21±0.26
Kermanshah (Region 1)	W_{12}	0.69±0.16	0.64±0.21	< MDA	< MDA	8.52±1.05	9.88±0.95
Kermanshah (Region 6)	W_{13}	< MDA	< MDA	< MDA	0.56±0.18	1.47±0.46	< MDA
Kangavar	W_{14}	0.57±0.18	< MDA	2.13±0.45	< MDA	< MDA	< MDA

*MDA: Minimum Detectable Activity

Table 2. Results of external and internal radiation risk indicators (H_{ex} and H_{in}), in addition to Annual Effective Dose (AED_{dw}) calculation of the water samples in winter and summer seasons in Kermanshah province, Iran

City	Sample	H_{ex}		H_{in}		AED_{dw} (µSv/y)	
		Winter	Summer	Winter	Summer	Winter	Summer
Harsin	W_1	---	0.008	---	0.010	---	182.2
Gilan-e-Gharb	W_2	0.010	0.001	0.011	0.001	213.01	22.66
Sahneh	W_3	0.010	0.001	0.013	0.001	236.5	12.58
Eslamabad-e-Gharb	W_4	0.003	0.007	0.004	0.010	75.59	181.24
Ghasr-e-Shirin	W_5	---	0.005	---	0.006	---	107.11
Sonqor	W_6	0.006	0.005	0.008	0.004	152.69	67.45
Javanroud	W_7	0.004	0.002	0.005	0.003	115.29	56.91
Paveh	W_8	0.0002	---	0.0002	---	2.78	---
Sarpol-e-Zahab	W_9	0.001	0.004	0.002	0.006	35.06	102.71
Ravansar	W_{10}	0.0002	0.0001	0.0005	0.0001	10.22	1.26
Kermanshah (Region 4)	W_{11}	0.003	0.0002	0.003	0.0002	56.47	2.73
Kermanshah (Region 1)	W_{12}	0.004	0.004	0.005	0.005	89.79	87.75
Kermanshah (Region 6)	W_{13}	0.003	0.002	0.003	0.002	3.32	47.01
Kangavar	W_{14}	0.007	---	0.009	---	237.05	---

Table 3. Comparison of the specific activity levels of ^{226}Ra, ^{232}Th, and ^{40}K radionuclides in several countries and cities with our findings in Kermanshah, Iran

Different countries/Iran cities	^{226}Ra (Bq/l)	^{232}Th (Bq/l)	^{40}K (Bq/l)	Reference No.
Saudi Arabia (Jeddah)	0.21-2.25	0.23-0.37	0.24-33.74	[14]
Turkey	0.517-1.22	0.232-0.676	1.54-2.57	[15]
Serbia	0.01-0.53	0.20-1.31	N/A*	[19]
Pakistan	0.008-0.015	0.004-0.006	0.092-0.216	[20]
Nigeria	0.57-26.86	0.35-60.6	0.35-29.1	[16]
Tuyserkan (Iran)	1.4	N/A	N/A	[17]
Shirvan (Iran)	2.092	N/A	N/A	[18]
Kermanshah (Iran)	0.1-0.98	0.27-2.13	0.56-15.74	This study

* N/A: Not Available

Discussion

The specific activities of 226Ra, 232Th, and 40K radionuclides of the water samples in Kermanshah province were 0.57±0.22, 0.98±0.49, and 6.42±3.84 (Bq/l), respectively. Comparing the activities of the samples in two seasons reveals that the mean specific activities of 232Th and 40K radionuclides in winter was higher than in summer and the mean activity of 226Ra was almost the same. According to the WHO guidelines for drinking water quality (WHO 2011 report) [2], the guidance levels for specific activities of 226Ra, 232Th, and 40K radionuclides for members of the public are 1, 1, and 10 Bq/l, respectively. Therefore, the mean specific activities of 226Ra, 232Th, and 40K radionuclides were obtained to be in the standard recommended level for all the samples in Kermanshah province in both winter and summer.

Table 3 indicates the findings of this study in comparison with several other countries and cities. The specific activity of 226Ra in the water samples of this study was lower than that of Saudi Arabia (Jeddah 0.21-2.25) [14], Turkey (0.517-1.22) [15], Nigeria (0.57-60.6) [16], as well as the cities of Tuyserkan (1.4) [17] and Shirvan (2.09) [18] in Iran. However, the level was higher than Serbia (0.01-0.53) [19] and Pakistan (0.008-0.015) [20]. The specific activity of 232Th in the water samples was less than Nigeria (0.35-60.6), while was more than Saudi Arabia (0.23-0.37), Serbia (0.2-1.13), Turkey (0.676-0.232), and Pakistan (0.006-0.004).

The specific activity of 40K in the water samples was lower than that of Saudi Arabia (0.24-33.74) and Nigeria (0.35-29.01). On the other hand, the value was higher than that of Turkey (1.54-2.57), and Pakistan (0.216-0.092). Comparing the results of this study with other countries demonstrates that the obtained values are within the world means.

The average Hex and Hin indices in winter during summer were 0.0035 and 0.0045, respectively. According to the WHO 2011 report [2] and UNSCEAR 2000 Report Vol. 1 [3], the recommended limit for both indices is one. The obtained values for these indicators at the provincial level were lower than the recommended limits. The mean annual effective dose caused by drinking water in Kermanshah province was 0.15 mSv/y. According to the UNSCEAR 2000 report [3], the global mean level of annual effective dose due to water consumption is 0.29 mSv/y and this level in Kermanshah province is less than the global mean level.

Conclusion

The radioactivity level in drinking water caused by ^{226}Ra, ^{232}Th, and ^{40}K radionuclides in Kermanshah province is lower than the guidance levels recommended by the WHO 2011 report. In the WHO 2011 report the guidance levels for ^{226}Ra, ^{232}Th, and ^{40}K radionuclides are 1, 1, and 10 Bq/l, respectively. Furthermore, mean of the annual effective dose due to these radionuclides in Kermanshah province is lower than the global mean level (0.29 mSv/y), which was reported by the UNSCEAR 2000.

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