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# Radiological Hazard Resulting from Natural Radioactivity of Soil in East of Shazand Power Plant

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**ABSTRACT**

***Introduction***: Nuclear radiation is potentially harmful to humans and soil contamination with radionuclides is the main source of human radiation exposure. These radionuclides can., enter to human body through the food chain. In this study, 34 soil samples were collected from between Arak city and Shazand Power Plant over 20 km length and analyzed.

***Materials and Methods:*** The specific activities of $^{226}$Ra, $^{232}$Th, $^{40}$K, and $^{137}$Cs were measured in soil samples, using gamma-ray spectrometry and a high-purity germanium (HPGe) detector. For all the samples, we calculated radiological hazards such as radium equivalent ($Ra_{eq}$), dose rate in air (D), internal and external hazard indices ($H_{in}$, $H_{ex}$), annual gonadal dose equivalent (AGDE), and excess lifetime cancer risk.

***Results:*** The specific activities of $^{226}$Ra, $^{232}$Th, $^{40}$K, and $^{137}$Cs in the soil samples varied from 18.92 to 43.11, 25.31 to 54.27, 230.17 to 728.25, and from <1.49 to 9.52 Bq/kg, respectively. For all the samples, the obtained $H_{in}$ and $H_{ex}$ were less than unity. Excess lifetime cancer risk of the samples ranged from $0.21\times10^{-3}$ to $0.31\times10^{-3}$, which are close to the mean world value ($0.29\times10^{-3}$) but lower than the acceptable value ($10^{-3}$).

***Conclusion:*** The radiological parameters estimated from the specific activities of the radionuclides in soil were within the acceptable range, and therefore, radiation exposure poses no significant risks to the resident population in the vicinity of the power plant.

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## Introduction

Natural and artificial radionuclides are the main sources of human radiation exposure. Uranium, thorium series, and potassium are the primary elements contributing to natural terrestrial radioactivity [1]. The specific activities of radionuclides in the earth's crust vary from 16 to 110 Bq/kg (mean: 35 Bq/kg) for $^{238}$U, from 17 to 60 Bq/kg (mean: 35 Bq/kg) for $^{226}$Ra, from 11 to 64 Bq/kg (mean: 30 Bq/kg) for $^{232}$Th, and from 140 to 850 Bq/kg (mean: 400 Bq/) for $^{40}$K [2, 3].

The artificial distribution of radionuclides in the biosphere as a result of nuclear weapons testing and accidents in nuclear power plants increased the levels of environmental radioactivity and human exposure [4]. After the Chernobyl nuclear accident in 1986, management of contaminated areas became more crucial because $^{137}$Cs and $^{90}$Sr pollution, which can be transferred to human body via food chain, poses serious hazards to human health [5].

Power Plant, which used coal fuel, showed the high radioactivity discharged into the atmosphere. However, regarding the specific activities of radionuclides in fuel and amount of burning fuel, the high quantity of ash produced and dispersed into the surrounding atmosphere, and cause increasing of level of radiation and toxic heavy metals in environment.

Population radiation absorbed dose is mainly through the inhalation of smoke contaminated with radionuclides during the passage of the fly ash emitted from chimneys and through the ingestion of foodstuffs contaminated by deposition on crops and pastures [6]. Fly ash is a waste product of coal-fired power stations [6].

Shazand Oil Power Plant is located 20 kilometers west of Arak city, Iran, and has been operating since 2000 with 1215 MWe power, and its geographical coordinates are the same as S1 sample locality mentioned in Table 1. During the years up to 2014, the main fuel of this facility was mazut, a byproduct of Arak refinery distillation towers. Mazut contains some quantities of radionuclides, which fall out of fly ash during burning, enter the atmosphere, and pollute the region surrounding the power plant. During mazut burning process, radon gas, a decay product of the U and Th series, is also released into the atmosphere

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and is dispersed into the surrounding environment. Besides the radon inhalation problem, soil contamination by long-lived decay products, such as $^{210}$Po and $^{210}$Pb, is a hazardous issue.

Since 2014, year, because Arak's air has been severely polluted due to the combustion, changed its fuel into natural gas [7]. Nevertheless, in the cold season, when household gas consumption increases, the plant employs mazut. The dust from the fuel flows through two chimneys to a height of 200 meters and is driven by the wind towards the city of Arak and along its path causes pollution of water, soil, and plants. In this study, we sought to determine the specific activities of radionuclides of soil and evaluate radiological parameters due them of soil in 20 km distance from the power plant facility to Arak city. Before operating of this power plant there is no study about specific activity of radionuclides of soil around of power plant. Texture of soil is clay silt; this region includes many villages, farms, and industrial factories with residential population of about 100000. This study was carried out on virgin soil samples collected from the fields between Shazand Power Plant and Arak city considering the dominant wind directions.

## Materials and Methods

### Sampling and Sample Preparation

Thirty-four soil samples were collected from Arak Power Plant facility, which is located 20 km west of Arak to Arak city with each of mass about 1 kg. Samples collected from 7 points of square 2×2 m$^2$ area from surface to 5 cm depth and mixed. The geographical locality of the sampling map is shown in Figure 1 and detailed information regarding the samples are presented in Table 1. All the samples were mild, homogenized, pulverized to a fine powder, and sieved through a 0.25 mm$^2$ mesh screen in laboratory [8]. All the samples were completely dried using oven at 100°C for 12 h. The samples were packed in Negin container with a volume of 300 cc. Each sample was coded according to the distance of the power plant. The mass of each sample were 255 g. The collected samples required particular care, since radon is a short-lived gaseous nuclide that tends to escape from samples. In this work, all the containers were sealed and after a minimum of 50 days of sample preparation, gamma ray spectra were registered. This time is essential for taking radioactive chain equilibrium where the decay rate of the daughters became similar to those of the parents [9].

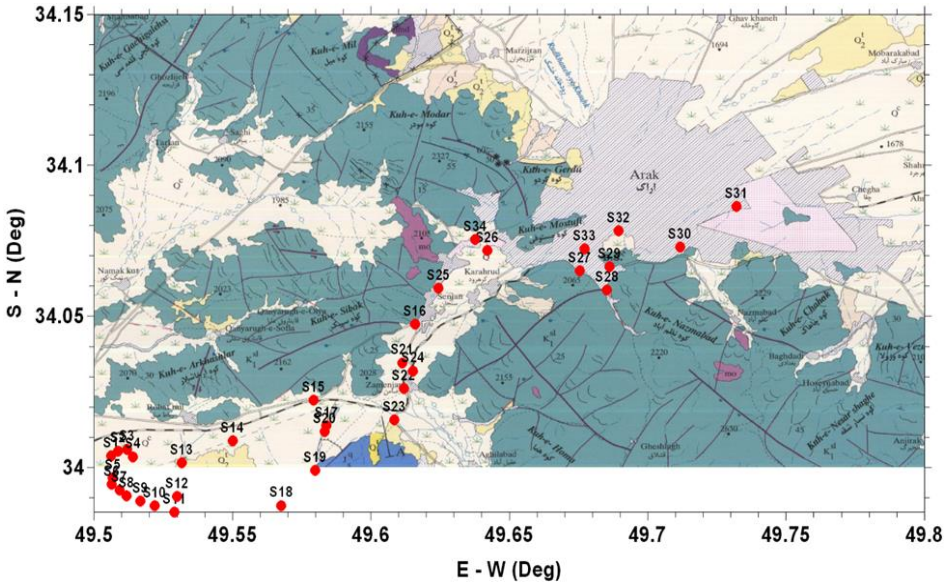


**Figure 1.** Geographical sampling locations between Arak Power Plant and Arak city

**Table 1.** Details of soil sampling locations including codes of the samples, distance from the power plant, and GPS coordinates

| Sample code | Longitude | Latitude | Distance from the power plant (m) |
|---|---|---|---|
| S1 | 49°.50616′ | 34°.00386′ | 0 |
| S2 | 49°.50859′ | 34°.00544′ | 284.78 |
| S3 | 49°.5118′ | 34°.00599′ | 571.8 |
| S4 | 49°.51404′ | 34°.00351′ | 728.99 |
| S5 | 49°.50671′ | 33°.99648′ | 820.17 |
| S6 | 49°.50637′ | 33°.99435′ | 1054.76 |
| S7 | 49°.50908′ | 33°.99242′ | 1297.03 |
| S8 | 49°.5116′ | 33°.99049′ | 1565.44 |
| S9 | 49°.51663′ | 33°.9888′ | 1929.85 |
| S10 | 49°.52177′ | 33°.9872′ | 2343.45 |
| S11 | 49°.52898′ | 33°.98512′ | 2960.36 |
| S12 | 49°.5299′ | 33°.99038′ | 2653.95 |
| S13 | 49°.53159′ | 34°.00153′ | 2362.99 |
| S14 | 49°.54997′ | 34°.00872′ | 4082.06 |
| S15 | 49°.57924′ | 34°.02223′ | 7049.92 |
| S16 | 49°.61587′ | 34°.04744′ | 11224.75 |
| S17 | 49°.58394′ | 34°.01371′ | 7266.23 |
| S18 | 49°.56762′ | 33°.98737′ | 5964.48 |
| S19 | 49°.57983′ | 33°.99895′ | 6826.5 |
| S20 | 49°.58325′ | 34°.01188′ | 7175.28 |
| S21 | 49°.61125′ | 34°.0346′ | 10286.4 |
| S22 | 49°.6118′ | 34°.02606′ | 10062.09 |
| S23 | 49°.60841′ | 34°.01567′ | 9534.12 |
| S24 | 49°.61519′ | 34°.03194′ | 10539.35 |
| S25 | 49°.62437′ | 34°.0593′ | 12527.53 |
| S26 | 49°.64197′ | 34°.07185′ | 14631.7 |
| S27 | 49°.67545′ | 34°.06507′ | 17041.18 |
| S28 | 49°.68531′ | 34°.05869′ | 17623.98 |
| S29 | 49°.68618′ | 34°.06633′ | 18007.39 |
| S30 | 49°.71164′ | 34°.07289′ | 20457.67 |
| S31 | 49°.73207′ | 34°.08637′ | 22774.92 |
| S32 | 49°.68949′ | 34°.07826′ | 18829.88 |
| S33 | 49°.67715′ | 34°.07232′ | 17517.87 |
| S34 | 49°.63766′ | 34°.07542′ | 14504.43 |

## Gamma ray spectrometry

Specific activities of the radionuclides were determined by using the gamma ray spectrometry method using high purity germanium (HPGe), P-type coaxial detector, GCD30195BSI model with 30% relative efficiency, and multi-channel analyzer unit with 8192 channels, manufactured by Baltic Scientific Instrument company (00-5- Latvia) in nuclear laboratory of Arak University. The energy resolution (full width at half maximum) of this detector is 1.95 keV for gamma energy line at 1332.520 keV due $^{60}$Co and a peak-to-Compton ratio of 60. The operating voltage was 3000 V, and the detector and preamplifier were shielded in a chamber of three layers composed of 10-cm thick lead, 1.5-mm thick cadmium, and 3-mm thick copper. This shield effectively reduces background radiation. Low-energy gamma rays and electrons originating from cosmic rays are reduced to very low

levels by lead shielding with 100 mm thickness. The lead interaction with the external radiation produces 73.9 keV X-ray energy, which is suppressed by the copper layer and thermal neutrons produced by cosmic radiation that are successively absorbed by the Cadmium layer [10]. In order to minimize the effect of scattering radiation from the shield, the detector was placed in the center of the chamber. The samples were placed on the detector cover. Finally, the spectra of all the samples were registered using the Lsrmbsi software (manufactured by Baltic Scientific Instrument company (00-5- Latvia) with the counting time of 86400 s for each sample. Performance calibration was carried out using a standard Negin source, including $^{241}$Am, $^{152}$Eu, and $^{137}$Cs with accuracy activities and taking into account the coincidence correction covering the energy range from 59.5 to 2000 keV. According to the recorded spectrum of gamma radiation, the absolute efficiency of the detector configuration was calculated as [8]:

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

where Ni is the net count under the full-energy peak corresponding to the Ei energy, Pn(Ei) is the photon emission probability for the particular energy Ei, Act denotes activity concentrations in Bq, and T is the counting time. The detector efficiency calibration was obtained based on the IAEA 154 instruction [11].

**Activity measurement**

The gamma ray spectrum for each sample was recorded for 864,000 seconds (24 h). Assuming that the Ra and Rn in uranium series are in equilibrium, $^{226}$Ra activity was estimated based on the gamma emissions of $^{214}$Pb (351.93keV) and $^{214}$Bi (609.31keV). In order to determine the specific activity of $^{232}$Th, gamma ray energies from $^{212}$Pb (238.6 keV), $^{228}$Ac (911.21, 968.97keV), and $^{208}$Tl (583.2keV) were used. The specific activity of $^{40}$K was assessed directly using its own gamma ray (1460.75 keV). The recorded gamma ray spectra were analyzed and specific activities and standard deviations were calculated using the Gamma vision32 EG and Ortec software. In all the analyzed spectra, correction was made for the background of gamma ray spectra measured for an empty Negin container in the same condition. Specific activities were calculated based on the intensity of several gamma rays emitted by the above-mentioned nuclei using Equation 2 [8].

$$Act(Bq/kg) = \frac{Net\ Area}{\varepsilon \times BR(\%) \times t \times m} \times 100 \quad (2)$$

where the net area is the net count in the photopeaks, act (Bq / kg) is the specific activity of radionuclide, ε presents the absolute efficiency of the gamma line by detector, BR is the branching factor of gamma radiation intensity (%), t is the recording time of spectra in second, and m is the sample mass in kg.

**Radiological hazard parameters**

***Radium equivalent ($Ra_{eq}$)***

The radium equivalent index ($Ra_{eq}$) in Bq/kg is usually used as an indicator of radiological hazard. It is an appropriate indicator for comparing the total specific activities of sample radionuclides, including $^{226}$Ra, $^{232}$Th, and $^{40}$K. This parameter was determined based on the assumption that 10 Bq/kg $^{226}$Ra, 7 Bq/kg $^{232}$Th, and 130 Bq/kg $^{40}$K give the same dose rate. This index was calculated using Equation 3 [12].

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

***Absorbed gamma dose rate (D)***

The quantity of absorbed dose rate in air (D) depends on $^{226}$Ra, $^{232}$Th, and $^{40}$K contamination of soil. If the specific activities of the radionuclides are known, the absorbed dose rate (nGy/h) can be assessed at 1 m above the ground surface using Equation 4 [13, 14].

$$D(nGy/h) = 0.462A_{Ra} + 0.604A_{Th} + 0.0417A_K \quad (4)$$

where 0.462, 0.604, and 0.0417 are the conversion factors in nGy/h per 1 Bq/kg of specific activities of the corresponding radionuclides, respectively [2].

***Internal Hazard Index ($H_{in}$)***

The internal exposure to radon and its products is quantified using the internal hazard index, which is defined by Equation 5 [15].

$$Hin = A_{Ra}/185 + A_{Th}/259 + A_K/4810 < 1 \quad (5)$$

***External Radiation Hazard ($H_{ex}$)***

The external hazard index (Hex) represents exposure to external radiation associated with gamma irradiation emitted from $^{226}$Ra, $^{232}$Th and $^{40}$K the above-mentioned radionuclides. The $H_{ex}$ value should not exceed the permissible value of unity, so that the threat is negligible. The maximum $H_{ex}$ value, which is equal to one, corresponds with the $Ra_{eq}$ upper limit (370 Bq/kg). The external hazard index is defined by Equation 6 [16].

$$Hex = A_{Ra}/370 + A_{Th}/259 + A_K/4810 < 1 \quad (6)$$

***Annual Gonadal Dose Equivalent (AGDE)***

AGDE is a measure of the genetic significance of the annual equivalent dose received by the reproductive organs of the population (gonads) [13, 14]. In the same context, bone marrow and bone surface cells are considered as the organs of interest by UNSCEAR. The annual AGDE due to the specific activities of $^{226}$Ra, $^{232}$Th, and $^{40}$K was calculated using Equation 7 [17].

$$AGDE(mSv/y) = (3.09A_{Ra} + 4.18A_{Th} + 0.314A_K) \times 10^{-3} \quad (7)$$

where $A_{Ra}$, $A_{Th}$, and $A_K$ in equations 3 to 7 are specific activities of $^{226}$Ra, $^{232}$Th, and $^{40}$K in Bq/kg, respectively.

***Annual effective dose equivalent outdoor (mSv/y)***

The annual effective dose equivalent (AEDE) in mSv/y from natural radioactivity is calculated using Equation 8 [2].

$$AEDE(mSv/y)=D\times F\times 365.25d\times 24h\times 0.7\times 10^{-3} \quad (8)$$

where D is dose rate in nGy/h, 24h*365.25d is the outdoor occupancy time, F denotes occupancy factor as 0.2 for outdoor, and $0.7\times10^{-3}$ is the conversion coefficient in mSv/Gy [18].

***Excess lifetime cancer risk (ELCR)***

ELCR denotes the excess probability of developing cancer during lifetime due to natural gamma radiation exposure to the resident population by radionuclides content of soil. ELCR is calculated using Equation 9 [19].

$$ELCR=AEDE\times DL(70y)\times RF(0.05Sv^{-1}) \quad (9)$$

where AEDE is the annual effective dose equivalent, DL duration of life (70 y), and RF is the risk factor for one Sievert absorbed dose. As calculated by the International Commission on Radiological Protection, this factor is 0.05 $Sv^{-1}$[ 20].

## Results

The measured specific activities of the $^{226}$Ra, $^{232}$Th, $^{40}$K, and $^{137}$Cs radionuclides of soil samples are listed in Table 2. The calculated values of $Ra_{eq}$ and absorbed dose rate (D) can be found in this table, as well. The calculated values of $H_{in}$, $H_{ex}$, AEDE outdoor, AGDE, and ELCR are presented in Table 3.

**Table 1.** Specific activities of radionuclides and radium equivalent in the soil samples and absorbed dose rate in air

| Sample code | Specific activity (Bq/kg) | | | | $Ra_{eq}$ (Bq/kg) | D(nGy/h) |
|---|---|---|---|---|---|---|
| | $^{226}$Ra | $^{232}$Th | $^{40}$K | $^{137}$Cs | | |
| S1 | 23.78±2.36 | 31.43±1.43 | 571.64±16.2 | 5.72±0.52 | 112.74±3.36 | 55.65±1.55 |
| S2 | 30.57±2.36 | 40.679±2.07 | 255.43±10.5 | 7.33±0.52 | 108.41±3.69 | 50.01±1.77 |
| S3 | 32.65±2.08 | 38.56±1.98 | 280.20±10.72 | 9.48±0.83 | 109.36±3.61 | 51.57±1.65 |
| S4 | 32.91±2.28 | 48.17±4.05 | 282.61±10.85 | 9.52±0.88 | 123.55±6.28 | 58.15±2.69 |
| S5 | 27.07±2.36 | 35.65±3.7 | 546.35±15.7 | 4.94±0.98 | 120.12±5.9 | 58.76±2.72 |
| S6 | 21.57±2.30 | 26.70±1.33 | 316.70±9.98 | 4.65±0.71 | 84.14±3.08 | 40.57±1.38 |
| S7 | 30.35±2.5 | 25.31±2.16 | 294.25±10.5 | 1.08±0.81 | 89.20±4.01 | 42.42±1.82 |
| S8 | 31.16±2.82 | 39.12±1.91 | 699.51±17.7 | 1.31±0.86 | 140.96±4.18 | 69.86±1.92 |
| S9 | 29.45±2.11 | 36.03±1.91 | 565.53±15.23 | 2.25±0.72 | 124.52±3.65 | 60.86±1.69 |
| S10 | 27.29±2.41 | 34.69±1.8 | 582.52±15.69 | 1.60±1.13 | 121.75±3.74 | 59.78±1.72 |
| S11 | 25.66±2.5 | 27.27±1.51 | 423.28±12.66 | 6.39±1.15 | 97.25±3.45 | 47.29±1.56 |
| S12 | 31.68±2.5 | 41.76±6.94 | 245.43±10.02 | 4.10±0.82 | 110.29±5.61 | 51.77±2.57 |
| S13 | 32.01±2.33 | 37.46±1.72 | 242.36±10.55 | 1.15±0.96 | 104.24±3.48 | 48.93±1.58 |
| S14 | 26.36±2.61 | 36.48±3.31 | 507.84±15.65 | 1.33±1.5 | 117.63±5.53 | 57.34±2.55 |
| S15 | 25.41±2.3 | 36.93±2.08 | 574.83±16 | 1.09±1 | 122.48±3.96 | 60.13±1.83 |
| S16 | 21.00±2.16 | 40.52±1.96 | 287.36±10.5 | <1.59 | 101.07±3.63 | 48.20±1.65 |
| S17 | 30.51±2.05 | 41.30±2.30 | 238.63±10.33 | 1.42±0.62 | 107.94±3.95 | 50.68±1.81 |
| S18 | 43.11±2.69 | 40.95±2.32 | 728.25±18.03 | 1.89±1.7 | 157.74±4.5 | 76.98±2.07 |
| S19 | 35.68±2.41 | 36.40±1.57 | 693.19±17.37 | 3.03±1.3 | 141.11±3.55 | 69.28±1.64 |
| S20 | 26.00±2.23 | 44.47±3.56 | 619.11±1.41 | 3.57±1.07 | 137.26±5.7 | 67.28±2.64 |
| S21 | 22.03±3.56 | 33.90±2.6 | 566.48±15.32 | 5.59±0.72 | 114.12±5.27 | 56.32±2.39 |
| S22 | 23.62±1.63 | 35.57±1.65 | 586.68±15.92 | 5.00±0.79 | 119.66±3.11 | 58.98±1.64 |
| S23 | 31.74±2.09 | 40.84±1.77 | 664.15±19.08 | 1.62±0.97 | 141.28±3.6 | 69.28±1.69 |
| S24 | 21.95±3.12 | 31.15±1.79 | 263.44±9.84 | 3.00±0.62 | 86.78±4.1 | 41.37±1.83 |
| S25 | 23.20±2.15 | 36.4±1.85 | 232.65±10.14 | 7.140±0.73 | 93.16±3.5 | 44.05±1.59 |
| S26 | 21.86±1.5 | 33.90±1.52 | 230.17±9.96 | 6.62±0.88 | 88.06±2.74 | 41.71±1.26 |
| S27 | 21.63±2.38 | 40.93±1.88 | 619.40±17.93 | 6.43±0.51 | 127.85±3.82 | 63.08±1.77 |
| S28 | 20.72±2.15 | 41.19±3.64 | 535.23±21.53 | 1.07±0.96 | 120.83±5.87 | 59.23±2.74 |
| S29 | 18.92±1.91 | 37.94±2.99 | 617.98±16.83 | 3.61±1.01 | 120.76±3.65 | 59.89±1.70 |
| S30 | 21.33±2.15 | 40.14±1.79 | 518.08±15.13 | 4.66±0.9 | 118.62±3.54 | 58.06±1.63 |
| S31 | 22.88±1.92 | 54.63±3.65 | 541.94±15.05 | 1.60±0.76 | 142.73±5.95 | 69.34±2.76 |
| S32 | 21.30±2.23 | 27.87±1.74 | 505.8017.31 | 1.31±0.67 | 100.10±3.6 | 49.39±1.68 |
| S33 | 23.03±2.47 | 35.03±1.69 | 517.00±16.16 | <1.49 | 112.93±3.67 | 55.35±1.69 |
| S34 | 22.51±2.36 | 54.27±3.65 | 585.00±16.5 | 3.92±0.49 | 145.16±5.86 | 70.81±2.71 |

**Table 3.** Radiological hazard of soil samples: $H_{in}$, $H_{ex}$, AEDE outdoor and indoor (mSv/y), AGDE (μSv/y), and ELCR

| Sample code | AEDE outdoor (mSv/y) | ELCR ($10^{-3}$) | $H_{in}$ | $H_{ex}$ | AGDE (mSv/y) |
|---|---|---|---|---|---|
| S1 | 0.06 | 0.21 | 0.37±0.02 | 0.30±0.02 | 0.38±0.02 |
| S2 | 0.06 | 0.21 | 0.37±0.03 | 0.29±0.02 | 0.34±0.02 |
| S3 | 0.06 | 0.21 | 0.38±0.02 | 0.29±0.02 | 0.35±0.02 |
| S4 | 0.07 | 0.24 | 0.42±0.04 | 0.33±0.03 | 0.39±0.03 |
| S5 | 0.07 | 0.24 | 0.40±0.03 | 0.32±0.03 | 0.41±0.03 |
| S6 | 0.05 | 0.17 | 0.28±0.02 | 0.23±0.02 | 0.28±0.02 |
| S7 | 0.05 | 0.17 | 0.32±0.03 | 0.24±0.02 | 0.29±0.02 |
| S8 | 0.08 | 0.28 | 0.46±0.03 | 0.38±0.02 | 0.48±0.02 |
| S9 | 0.07 | 0.24 | 0.41±0.02 | 0.34±0.02 | 0.42±0.02 |
| S10 | 0.07 | 0.24 | 0.40±0.03 | 0.33±0.02 | 0.41±0.02 |
| S11 | 0.06 | 0.21 | 0.33±0.03 | 0.26±0.02 | 0.33±0.02 |
| S12 | 0.06 | 0.21 | 0.38±0.03 | 0.30±0.03 | 0.35±0.03 |
| S13 | 0.06 | 0.21 | 0.37±0.03 | 0.28±0.02 | 0.33±0.02 |
| S14 | 0.07 | 0.24 | 0.39±0.03 | 0.32±0.03 | 0.39±0.03 |
| S15 | 0.07 | 0.24 | 0.40±0.03 | 0.33±0.02 | 0.41±0.02 |
| S16 | 0.06 | 0.21 | 0.33±0.02 | 0.27±0.02 | 0.32±0.02 |
| S17 | 0.06 | 0.21 | 0.37±0.02 | 0.29±0.02 | 0.34±0.02 |
| S18 | 0.09 | 0.31 | 0.54±0.03 | 0.43±0.02 | 0.53±0.03 |
| S19 | 0.08 | 0.28 | 0.48±0.03 | 0.38±0.02 | 0.48±0.02 |
| S20 | 0.08 | 0.28 | 0.44±0.04 | 0.37±0.03 | 0.46±0.03 |
| S21 | 0.07 | 0.24 | 0.37±0.04 | 0.30±0.03 | 0.39±0.03 |
| S22 | 0.07 | 0.24 | 0.39±0.02 | 0.32±0.02 | 0.41±0.02 |
| S23 | 0.08 | 0.28 | 0.47±0.03 | 0.38±0.02 | 0.48±0.02 |
| S24 | 0.05 | 0.17 | 0.29±0.04 | 0.23±0.02 | 0.28±0.02 |
| S25 | 0.05 | 0.17 | 0.31±0.03 | 0.25±0.02 | 0.29±0.02 |
| S26 | 0.05 | 0.17 | 0.30±0.02 | 0.24±0.01 | 0.28±0.02 |
| S27 | 0.08 | 0.28 | 0.40±0.03 | 0.34±0.02 | 0.43±0.02 |
| S28 | 0.07 | 0.24 | 0.38±0.04 | 0.33±0.03 | 0.40±0.03 |
| S29 | 0.07 | 0.24 | 0.38±0.03 | 0.32±0.02 | 0.41±0.02 |
| S30 | 0.07 | 0.24 | 0.38±0.03 | 0.32±0.02 | 0.47±0.02 |
| S31 | 0.08 | 0.28 | 0.44±0.04 | 0.38±0.03 | 0.47±0.03 |
| S32 | 0.06 | 0.21 | 0.32±0.03 | 0.27±0.02 | 0.34±0.02 |
| S33 | 0.07 | 0.24 | 0.37±0.03 | 0.30±0.02 | 0.38±0.02 |
| S34 | 0.09 | 0.31 | 0.45±0.04 | 0.39±0.03 | 0.48±0.03 |

AEDE: annual effective dose equivalent
AGDE: annual gonadal dose equivalent
ELCR: excess lifetime cancer risk

## Discussion

The specific activities of $^{226}$Ra, $^{232}$Th, and $^{40}$K, the natural radionuclides of soil samples, ranged from 18.92±1.91 to 43.11±2.69, 25.31±2.16 to 54.27±3.65, and 230.17±9.96 to 728.25±18.03 Bq/kg, respectively. The average values of specific activities of the mentioned radionuclides were calculated as 26.50, 37.93, and 470.34 Bq/kg, which for $^{226}$Ra is lower and for $^{232}$Th and $^{40}$K are slightly higher than the world average values (i.e., 30, 35, and 400). The specific activity of artificial radionuclide $^{137}$Cs varied from < 1.59 to 9.48 Bq/kg, revealing soil pollution by radioactive dust from other countries because in Iran there are not any nuclear facilities producing this radionuclide.

Since the Second World War, hundreds of nuclear weapons testing have been performed, and some nuclear reactor accidents such Chernobyl Reactor accident in 1986 caused pollution in many countries by radioactive dust, which transferred by atmospheric processes [21]. The level of pollution of $^{137}$Cs radionuclide is similar with other measurement in Markazi province [22, 23]. The average absorbed rate in air at one meter above the ground surface (56.54 nGy/h) was nearly the same as the corresponding world value (55 nGy/h) [1]. The mean value of radium equivalent of soil samples (116.58 Bq/kg) was slightly lower than the world mean value (131.69 Bq/kg), and for all samples are lower than acceptable value (370 Bq/kg) [24]. Therefore, the use of this soil in building materials is not a threat to the public health. The estimated annual effective dose equivalent varied from 0.05 to 0.09 mSv/y, which is lower than the acceptable value of 1 mSv/y [25].

The values of external and internal hazard indices ($H_{ex}$, $H_{in}$) ranged from 0.23 to 0.43 and from 0.23 to 0.54, respectively, which were lower than unity for the samples under investigation. Therefore the radiation hazard for the resident population in this region was insignificant [26]. The calculated values of AGDE are summarized in Table 3. The AGDE values varied from 0.28 to 0.48 mSv/y. Many of the values were near the world average value of 0.298 mSv/y [16].

**Table 4.** Comparison of specific activities of natural radionuclides of soil around fossil power plants of this study with some countries in Bq/kg

| country | $^{226}$Ra | $^{232}$Th | $^{40}$K | Reference |
|---|---|---|---|---|
| Iran | 26.5 | 37.93 | 470.34 | This study |
| Bangladesh (active soil) | 27.89 | 41.52 | 632.45 | [26] |
| Bangladesh (passive soil) | 32.82 | 56.01 | 777.41 | [26] |
| Nigeria (port Harcourt) | 49.9 | 5.51 | 437.9 | [27] |
| Serbia (TEK) | 48 | 58 | 680 | [28] |
| Serbia (TENT) | 26 | 30 | 410 | [28] |
| China( <1km) | 225 | 257 | 1571 | [29] |
| China(1~3 km) | 241 | 215 | 1265 | [29] |
| China(3~4 km) | 130 | 321 | 811 | [29] |

The values obtained for ELCR are summarized in Table 3. The obtained values varied from $0.17\times10^{-3}$ to $0.31\times 10^{-3}$ with a mean value of $0.23\times10^{-3}$ comparable to the mean world value of $0.29\times10^{-3}$, which is lower than the acceptable value of $10^{-3}$. Table 4 provides the results of measurement of specific activities of natural radionuclides of soil around power plants in different countries. Table 4 shows that the level of soil radioactivity in this study was at the same level as Bangladesh, Nigeria, and Serbia [26-28]. The level of radioactivity in soil in China was many times higher than those found in this study [28].

## Conclusion

The estimated average specific activity for $^{226}$Ra was less than the world average value, while the corresponding values of $^{232}$Th and $^{40}$K were higher. The radiological parameters calculated according to specific activities of the corresponding radionuclides in soil were within the acceptable range, and therefore, radiation exposure poses no significant risk to the resident population in the vicinity of the power plant.

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