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Measurement and simulation of the effective annual dose and radiation hazards of Jooshan hot spring in Kerman province

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HIGHLIGHTS

- Calculating the U-238, Ra-226, Cs-137, Th-232, and K-40 activities in Jooshan hot spring.
- Calculating the Jooshan hot spring radiation hazards parameters.
- Calculating the effective annual dose of sediment, water and radon in Jooshan hot spring.
- All radiation hazards parameters and effective annual dose are less than permission level.

ABSTRACT

Hot springs are known as one of the hydrotherapy centers in the world and have been welcomed due to their healing properties. Due to the presence of radon and radioactive elements in hot spring sediments, water and soil, these components are radioactive. So far, the radiation hazards and the annual effective dose of hot spring components in the body organs have not been investigated in Iran. The purpose of this study was to calculate the amount of U-238, Cs-137, Th-232, and K-40 elements in soil, water, and sediments of Jooshan hot springs in the Kerman region. The presence of these elements causes radiation hazards and an effective annual dose in people who use these hot springs. In addition to the healing properties of hot springs, the high amount of radiation hazard and effective annual dose may cause cancer risk. Experimental results with the CsI(Tl) detector showed that the total activities of these elements in soil, water, and sediments of Jooshan hot spring were 95.26 ± 9.76, 52.86 ± 7.27, and 51.61 ± 7.18 Bq.kg^{-1}, respectively. The Jooshan hot springs radiation hazards were calculated using activity measurement of the radioactive elements in soil, water, and sediments which was less than the permission level. The result of the Monte Carlo simulation with the MCNPX code showed that effective annual dose of sediment, water, and radon in Jooshan hot spring are 5.43×10^{-6}, 3.00×10^{-3}, and 1.16×10^{-1} mSv.year^{-1} respectively, which is less than the effective annual dose (5 mSv.year^{-1}). The maximum time for treatment by hot spring water is considered equal to one year.

KEYWORDS
Hot springs
Effective dose
Radioactive elements
Activity
Sediments
Jooshan
Kerman

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1 Introduction

Due to the presence of radioactive elements in the components of hot springs, the study of radiation hazards is of particular importance. Also, because the water from these hot springs is used for agricultural and domestic purposes, it is necessary to estimate the dose in people living around and using these hot springs. Various quantities are considered for estimating radiation hazard quantities. One of these quantities is to calculate the risk of cancer, which should be calculated for hot springs. The soil, sediment and water (with and without radon) of hot springs may have Th-232, K-40, Cs-137, and U-238 radioactive elements, whose activity and also their radiation hazards should be investigated. The main goal of this study is to investigate the activity of radioactive elements in the sediment, water (with and without radon) and soil of the Jooshan hot spring to evaluate the effective annual dose in human organs. The kind of hot spring sediments are three main types: a) carbonate, b) silicon, and c) a combination

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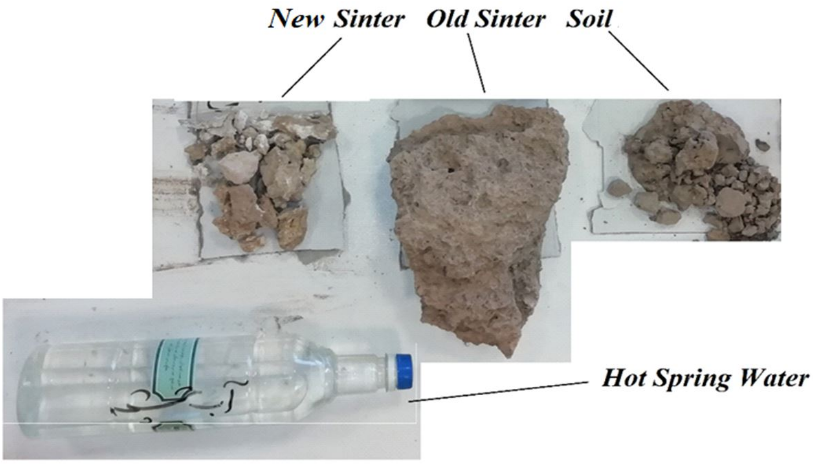

Figure 1: The sample of sediments, hot spring water and soil of the Jooshan hot spring.

of silicon and carbonate (Hamid et al., 2016). Some studies show that most sediments of hot springs are carbonate (Puryanti et al., 2022), and some of them are of the silicon type (Montazeri et al., 2011). Also, the both types of sediments in hot springs has been reported (Puryanti et al., 2022; Montazeri et al., 2011). The percentage of SiO_2 and $CaCO_3$ in these sediments is higher than all other elements (Hamid et al., 2016). In this research, it was tried to measurement of the kind of hot spring sediments using X-Ray Diffraction Analysis (XRD) techniques. Previously using X-ray fluorescence (XRF) techniques, the percentage of elements in the sediments of Jooshan hot springs has been investigated (Pourimani and Nemati, 2016). The results of this study can be used to estimate the hazards of other Irans hot springs. Also, the Tourism and Natural Resources Organization can use the results of this study to reassure tourists to make the best use of hot springs because of their healing properties. The activity of the Th-232, K-40, Cs-137, and U-238 radioactive elements in water and soil around the Black Sea hot springs of Turkey have been calculated (Rezaie Rayeni Nejad et al., 2020).

There are few reports on the calculation of the percentage of elements in the sediments of hot springs (Mehnati et al., 2022). The amount of radiation hazards caused by radioactive elements in the water of hot springs has been calculated (Dabayneh et al., 2008). There are also consecutive reports about the radiation hazards of rocks and soil around hot springs and other areas (Thabayneh, 2012). There are many reports for effective annual dose calculations using gas detectors above hot springs (Faweya and Babalola, 2010). The calculation of effective annual dose has been done by calculating the concentration of radon and radium in water and soil out of the hot springs (Huy and Luyen, 2006; Abel-Ghany et al., 2010; Alharbi et al., 2011). In 2018, Bahrami et al. calculated the percentage of radioactive elements in hot springs (El-Shershaby et al., 2006). In 2019, Bazargari et al. investigated and reported the radiation hazards caused by the amount of radioactive elements in the Khorasan hot springs (Faweya and Babalola, 2010). In 1998, De Vaniman et al. calculated the percentage of elements in the sediments of the Martian hot spring (Mehnati et al., 2022). This and other research show that the calculation of radiation hazards caused by soil, water and sediments of Jooshan hot spring is new and is an updated topic. According to the percentage of radioactive elements and using the equation of specific activity, the specific activity of radioactive elements in soil, sediments and water of hot spring components are calculated. According to the calculated specific activity and the corresponding radiation hazard equations, the amount of radiation hazards and the risk of cancer due to hot spring sediments and other components is calculated. Finally, by defining an adult male phantom approved by the Mird Committee and according to the radiation spectrum of each component of the Jooshan hot spring, the effective annual dose in different human organs can be calculated using the Monte Carlo n particle version X (MCNPX) code.

2 Materials and methods

2.1 Sampling and sample preparation

First, the soil, sediments and water of Jooshan hot spring and urban water of the Jooshan village were collected and each of them was divided into 5 packages with 100 g mass to calculate their gamma energy spectrum and activity. Figure 1 shows the sample of sediments, hot spring water and soil of the Jooshan hot spring.

2.2 XRD Analysis and gamma spectrum measurement of Jooshan hot spring components

The sediments and soil of Jooshan hot spring were kept in the laboratory for 1 week for drying. Then, 2 samples were sent to the laboratory to determine the type of sediments by the XRD techniques (Thabayneh, 2012; Montazeri et al., 2011). The gamma spectrum of other components was calculated using a CsI(Tl) scintillation detector (Fig. 2) at 8640 s and 672 V applied voltage in the nuclear physics laboratory of Graduate University of Advanced Technology to calculate the activity of Th-232, K-40, Cs-137, and U-238 radioactive elements.

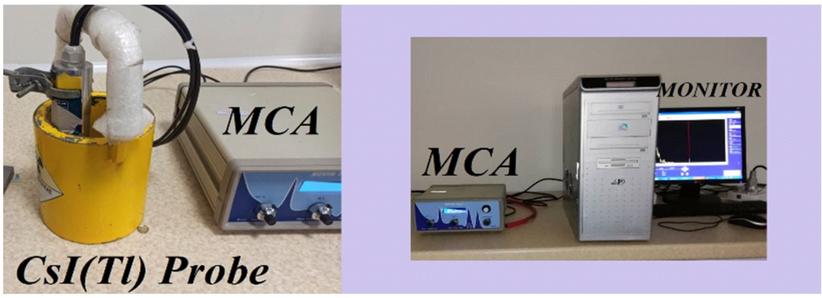

Figure 2: CsI(Tl) scintillation detector for activity measurement of Jooshan hot spring components.

2.3 Calibration of the CsI(Tl) detector

The output of the CsI(Tl) detector must be converted from channel number to MeV unit for activity calculation. In order to convert and calibrate the CsI(Tl) detector, three Co-60, Zn-65 and Cs-137 gamma sources was put in the shield cavity in front of detector. The Co-60 source with Compton edges at 0.854 MeV and X-ray peaks at 0.067 MeV, emits 2 gammas with energies of 1.17, 1.33 MeV, and has a sum peak at 2.5 MeV (Thabayneh, 2012). Also, the Zn-65 source has a peak at 1.11 MeV energy and the Cs-137 source has a peak at 0.66 MeV energy. For converting channel number to energy (MeV), By placing the above three sources separately front of CsI(Tl) detector, the number of channels corresponding to each peak has been determined. The calibration equation of the CsI(Tl) detector was obtained by fitting a nonlinear equation to output data with Origin software (Microcal Software, Inc.,Northampton, MA) as Eq. (1):

$$E\ (\text{MeV}) = 0.95 + 0.01282 \times Ch + 6.2763 \times 10^{-5.005} \times Ch^2 \tag{1}$$

The Ch is the channel number of CsI(Tl) detector and E (MeV) is the energy related to every channel number.

For calculation of the net count, the background radiation of laboratory and the empty shield in the same configuration, were calculated and subtracted from the total count. Then, using the calculated activity and the radiation hazard Eqs. (2) to (11), the amount of radiation hazards for Jooshan hot spring components are calculated.

2.4 Activity calculation

According to the gamma spectrum of Jooshan hot spring components that measured using the CsI(Tl) detector, the peaks count of the Th-232, K-40, Cs-137, and U-238 elements can be calculated and the activity of these elements can be obtained using Eq. (2) (Dabayneh et al., 2008):

$$A_s = \frac{N}{\varepsilon \times I \times m \times t \times 0.5} \tag{2}$$

where N is net count in the corresponding energy, ε is the detector efficiency, I is the gamma emission intensity, m is the soil sample mass (100 g), and t is the measurement time (8640 s).

2.5 Radiation hazard equations

2.5.1 Absorbed dose rate in the air

The effects of gamma rays, which are a radioactive source in the environment, in general, according to the amount of the total absorbed dose of gamma rays in the air, D_r is expressed. The amount of D_r in the air at 1 m above the earth's surface is calculated through the measured activity of Th-232, K-40, Cs-137, and U-238 and the cosmic background radiation using semi-empirical Eq. (3) (Thabayneh, 2012; Faweya and Babalola, 2010):

$$D_r\ (\text{nSv.h}^{-1}) = 0.427 \times A_U + 0.662 \times 0.043 \times A_K + 0.03 \times A_C + 34 \tag{3}$$

2.5.2 Annual effective dose equivalent

The Annual effective dose equivalent (AEDE) received by people was calculated using the 0.7 Sv.Gy^{-1} dose rate conversion factor and internal and external occupancy factors of 0.2 and 0.8 of the calculated D_r values, respectively. Effective external annual dose (D_{out}), Effective annual internal doses (D_{in}), and the total effective annual doses (D_{tot}) is calculated according to the Eqs. (4) to (6) (Huy and Luyen, 2006; Abel-Ghany et al., 2010; Alharbi et al., 2011; El-Shershaby et al., 2006; Khezripour et al., 2022):

$$D_{out}\ (\text{mSv.year}^{-1}) = D_r \times 24 \times 365.25 \times 0.2 \times 0.7 \times 10^{-6} \tag{4}$$

$$D_{in}\ (\text{mSv.year}^{-1}) = D_r \times 24 \times 365.25 \times 1.4 \times 0.8 \times 0.7 \times 10^{-6} \tag{5}$$

$$D_{tot}\ (\text{mSv.year}^{-1}) = D_{out} + D_{in} \tag{6}$$

2.5.3 External radiation hazard indicators

In external and internal radiation hazard indices are respectively obtained using the Eqs. (7) and (8) (Mohammed and Ahmed, 2017; Veiga et al., 2006; Ertuğ et al., 2014):

$$H_{ex}\ (\text{Bq.kg}^{-1}) = \frac{A_U}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \tag{7}$$

$$H_{in}\ (\text{Bq.kg}^{-1}) = \frac{A_U}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \tag{8}$$

External radiation hazard index, H_{ex}, related to natural radionuclides Th-232, U-238, K-40 and in low risk mode should be less than or equal to one. The measured values of H_{in} should also be less than or equal to unity in low risk mode, which indicates a low concentration level of radon and its daughters for the respiratory organs of people living at home, less than 40 Bq.m^{-3}. For the safe use of a material in the construction of dwellings, the maximum value of (H_{ex}, H_{in}) must be less than unity.

2.5.4 Radioactivity level index

The radioactivity level index (I_γ) is generally used to assess the risk level of radionuclides in the human body when it is exposed to the annual effective dose (internal or external) caused by gamma rays of radioactive nuclides in nature. I_γ values can be calculated according to the semi-empirical Eq. (9) (Mahur et al., 2010; Beretka and Mathew, 1985; Jargin, 2014).

$$I_\gamma \ (\text{Bq.kg}^{-1}) = \frac{A_U}{150} + \frac{A_{Th}}{100} + \frac{A_K}{1500} \tag{9}$$

The evaluated values of I_γ should be less than or equal to 1 to ensure that the campus environment is generally safe or risk-free.

2.5.5 Excess lifetime cancer risk

The Excess Lifetime Cancer Risk(ELCR) is calculated by quantifying the threshold cancer risk using Eq. (10) (AI-Saleh and AI-Berzan, 2007; Ramasamy et al., 2009):

$$ELCR = D_{tot} \times D_L \times D_F \tag{10}$$

where D_L is the life expectancy (approximately 70 years) and RF is the risk factor (Sv^{-1}) this value is 0.05 according to ICRP report 60.

2.5.6 Radium equivalent activity

Radium equivalent activity, Ra_{eq}, in unit of Bq.kg^{-1}, is used to evaluate the risks of radiation for health, caused by the activity concentration of U-238, Th-232 and K-40 in the soil. The value of Raeq is obtained using Eq. (11) (Taskin et al., 2009; Ujić et al., 2010; Asano et al., 2001):

$$Ra_{eq} = A_U + 1.43 \times A_{Th} + 0.077 \times A_K \tag{11}$$

2.6 Jooshan hot spring effective annual dose calculation by MCNPX code

The MCNPX version of MIRD Phantom was used to calculate the effective annual dose in whole body. For this purpose, the MIRD phantom was placed in the water of Jooshan hot spring. To calculate the effective annual dose, the gamma source of Jooshan hot spring components must be defined in MIRD phantom. Three types of source were defined in this case. The first source is the gamma source that caused by sediments, which is a volume source distribution with a thickness of 1 cm under the feet of the phantom that the gamma spectrum of the sediments is taken from the data in Fig. 1. The second source is caused by the radioactive elements in the water of Jooshan hot spring that is a volume source distribution with dimensions of $3 \times 3 \times 3$ m^3 that is considered around the MIRD Phantom, that the gamma spectrum of the water inside the hot spring is taken from the data in Fig. 1. The third source is the gamma source caused by the gamma decay of radon in the hot spring, which is considered to be a volumetric source distribution with dimensions of $3 \times 3 \times 3$ m^3 around the MIRD phantom that the gamma spectrum of Radon and its progeny is obtained from Mansour bahmani et al research work (Mansour Bahmani et al., 2014). The radon is a volatile and come out as radioactive gas that concentration of it in Jooshan hot water was measured by rad7 detector (100 kBq.m^{-3} (Namvaran and Negarestani, 2013)). The average of transfer coefficient of radon from water to air is 8.8×10^{-5} (Council et al., 1999). Therefore, changing in radon concentration in water by transfer of radon from water to air is little and do not effect on radon concentration in water sample. Figure 3 shows a schematic of the MIRD phantom inside the Jooshan hot spring water.

There are two methods for calculation of the annual effective dose in MCNPX code: a) Dose calculation with f6 and f8 Tallies along with the necessary coefficients. b) Convert flux to dose with F4 Tally with DE and DF card. In this article, the first method is used to calculate the annual effective dose. Also, in MIRD phantom, the first method was used to calculate the annual effective dose. After defining the gamma spectrum of hot spring components in the MCNPX code of MIRD adult phantom, the effective annual dose in different human organs is calculated using tally F6. The unit of tally F6 is MeV.g^{-1}, which should be converted to Sv.

3 Results and discussion

3.1 Activity Calculation

For activity calculation of Th-232, K-40, Cs-137, and U-238 radioactive elements in the Jooshan hot spring components, the gamma spectrum of them must be calculated. The gamma spectrum results of background, sediments or sinter, soil and water that were obtained using the CsI(Tl) detector are given in Fig. 4.

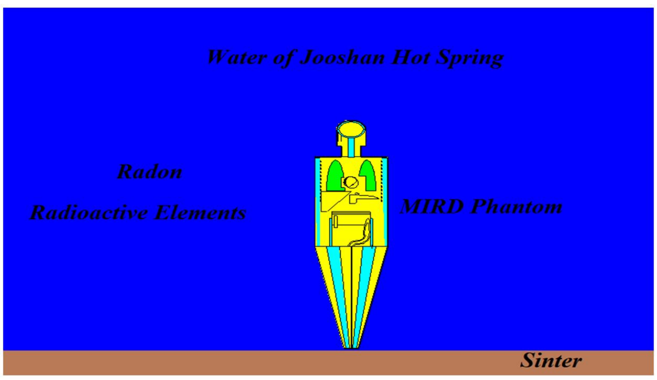

Figure 3: Schematic of the MIRD phantom inside the Jooshan hot spring water.

The results of measuring the activity of Th-232, K-40, Cs-137, and U-238 elements using Figure4 data are calcu-

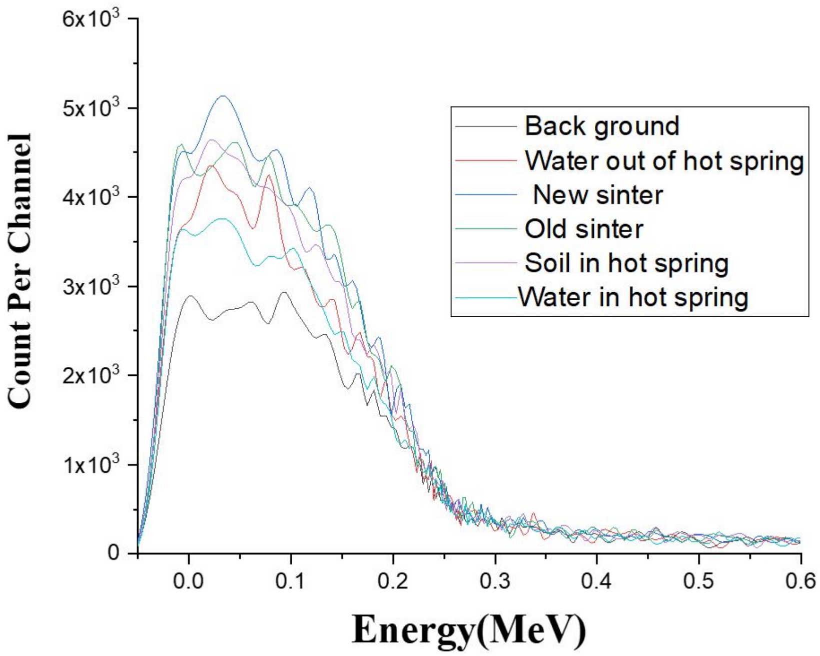

Figure 4: The gamma spectrum of background, soil, water, sinter, and water of Jooshan hot spring.

Table 1: Activities of Th-232, K-40, Cs-137, and U-238 elements in the Jooshan hot spring components.

Activity ($Bq.kg^{-1}$)	Hot spring water	Urban water	Sinter in hot spring	Sinter out of hot spring	Soil in hot spring	Permission Level (Ujić et al., 2010; Asano et al., 2001)
A_{Th}	38.75 ± 6.16	50.86 ± 7.02	45.8 ± 6.76	33.47 ± 5.77	14.09 ± 3.75	111
A_U	11.07 ± 3.32	24.91 ± 4.99	2.77 ± 1.66	19.38 ± 4.40	81.17 ± 9.00	78
A_k	0	0	0	0	0	1104
A_{Cs}	3.047 ± 1.74	0	3.04 ± 1.74	0	0	25
Total	52.86 ± 7.27	75.77 ± 8.70	51.61 ± 7.18	52.85 ± 7.26	95.26 ± 9.76	-
A_K/A_U	0	0	0	0	0	30.14
A_K/A_{Th}	0	0	0	0	0	100
A_U/A_{Th}	0.28	0.49	0.06	0.58	5.76	0.7
A_{Cs}/A_{Th}	0.078	0	0.06	0	0	-
A_{Cs}/A_U	0.27	0	1.09	0	0	-

lated and the results for hot spring components are shown in Table 1.

Table 1 result was shown the A_U/A_{Th} ratio in water and sinter is less than the permissible level, but the A_U/A_{Th} ratio in hot spring soil is higher than the permissible level. This difference is due to the sinter and hot spring water arriving from "the inner layer of the earth" to earth surface. The A_{Cs}/A_{Th} ratio in water and sinter of hot spring is larger than in water. The Cs-137 radionuclide that is observed in water and sinter of the Jooshan hot spring may be contaminated due to atmospheric deposition of radioactive Cesium (Cs-137). The Cs-137 radionuclide is not naturally found in the environment and is normally distributed due to nuclear weapon tests or accidents in nuclear power plants (AI-Saleh and AI-Berzan, 2007; Ramasamy et al., 2009). This radionuclide distributes into the environment with radioactive dust through the atmospheric process and can penetrate the soil, thus causing pollution in surface and groundwater. The A_{Cs}/A_U ratio in Table 1 for sinter in Jooshan hot spring is equal to 1.09. This result has shown that the Cs-137 activity is comparable to U-238 activity.

3.2 Result of Jooshan hot spring Radiation Hazards

Calculations of radiation hazards include Ra_{eq}, D_r, D_{out}, etc. in each component of Jooshan hot spring according to Eqs. (2) to (10) were performed and the results were shown in Table 2.

As can be seen from Table 2, Raeq of soil in the Jooshan hot spring is higher than in other samples. According to calculations, D_r ($mSv.y^{-1}$) in urban water was higher than in the other samples. Dout ($mSv.y^{-1}$) in all components is less than D_{in}. The amount of D_{in} (mSv/y) and D_{tot} ($mSv.y^{-1}$) in urban water is higher than in all other samples H_{ex}, H_{in}, and I_γ in the soil of hot water were observed more than others. ELCR was observed in the urban water higher than in other. Urban water sample has the highest radiation hazards concerning the components of the hot spring, but if urban water is used only for swimming and hydrotherapy then the humans are at

Table 2: Jooshan hot spring radiation hazards.

Parameter	Radiation Hazards				
	Hot spring water	Urban water	Sinter in hot spring	Sinter out of hot spring	Soil in hot spring
Ra_{eq} (Bq.kg^{-1})	66.49	97.65	68.26	64.56	71.82
D_r (mSv.year^{-1})	64.47	78.312	65.59	62.56	66.39
D_{out} (mSv.year^{-1})	0.079	0.096	0.080	0.076	0.081
D_{in} (mSv.year^{-1})	0.44	0.54	0.45	0.43	0.45
D_{tot} (mSv.year^{-1})	0.52	0.634	0.53	0.50	0.53
H_{ex}	0.179	0.263	0.184	0.174	0.19
H_{in}	0.209	0.331	0.191	0.287	0.28
I_γ	0.461	0.674	0.476	0.437	0.491
$ELCR$	1.82×10^{-9}	2.22×10^{-9}	1.86×10^{-9}	1.77×10^{-9}	1.88×10^{-9}

risk. Drinking urban and hot spring water will not pose a risk to municipal water consumers. The only radiation hazard is from inhaling radon gas released from the water. People are more exposed to radiation hazards caused by drinking water. In a sample of old sediments, the amount of Hin was observed more than all the components of the Jooshan hot spring.

3.3 Effective Annual Dose Calculation

Using the MCNPX code, an adult human MIRD phantom was placed on the sediments of the hot spring and the effective annual dose was calculated with F6 Tally. With the F6 Tally command, the dose received in the organs of the body is calculated in MeV.g^{-1}. To convert MeV.g^{-1} to Sv.year^{-1}, the coefficient λ, introduced as Eq. (12) that is multiplied in the results of the F6 Tally.

$$\begin{aligned} D &= \lambda \times \mathrm{F6} \\ \lambda &= \eta.A.\rho.V.t.W_R.W_T \end{aligned} \tag{12}$$

In this equation, η is 1.6×10^{-10} for the conversion of MeV.g^{-1} to Gy. A is the specific activity of each sample which is equal to the total activity of Th-232, K-40, Cs-137, and U-238 in sediments (Bq.kg^{-1}). ρ is the density of sediment, which is equal to 2750 kg.m3^{-3}. The volume of sediment under the MIRD phantom is $V = 3 \times 3 \times 0.01$ m^3 = 0.09 m^3, W_R and W_T are radiation factors and tissue weight. The weight factor of W_R for gamma radiation is $W_R = 1$ and W_T or the tissue weight factors is chosen according of the ICRP report 103 (Khezripour et al., 2022). The calculation results of the effective annual dose of hot spring sediments in different body organs are shown in Table 3. This table indicated that the effective annual dose of the sediment sample of the Jooshan hot spring is $(6.64 \pm 0.07) \times 10^{-4}$ mSv.year^{-1} which is less than the permission level (5 mSv.year^{-1}). In the following, it will be mentioned how to calculate the annual effective dose of radioactive elements in water and the annual effective dose caused by gamma radiation in water.

To calculate the annual effective dose of radioactive elements in water, the format of Eq. (12) is used as Eq. (13).

$$D = \eta.A_s.\rho_w.V_W.t.W_R.W_T \times F6 \tag{13}$$

That As is the specific activity of radioactive elements in water, which according to Table 1 data (52.86 Bq.kg^{-1}).

The V_w is the volume of the hot spring water minus the volume of the phantom. The volume of the hot spring is $3 \times 3 \times 3$ m^3 = 27 m^3 and the volume of the phantom is equal to 0.076 m^3. The w is the density of water (1000 kg.m^{-3}). Then the V_w is 26.924 m^3. The rest of the coefficients and calculations are the same as sediment coefficients and calculations of Equation 13 will be as Eq. (14).

$$\begin{aligned} D &= 1.6 \times 10^{-10} \times 26.924 \times W_T \times F6 \times 86400 \\ &\times 365 \times 52.86 \\ &= 7.19 \times 10^{10} \times W_T \times F6 \end{aligned} \tag{14}$$

After calculating F6 in different organs using the MCNPX code, the results related to the annual effective dose caused by the water of the hot springs are shown in Table 4. To calculate the annual effective dose of radon in water, the format of Eq. (13) is used as follows (Eq. (15)):

$$D = \eta.A_R.t.W_R.W_T \times F6 \tag{15}$$

where A_R is radon activity ($A_R = C_R \times V$). C_R is radon mean concentration in the Jooshan hot spring (100 kBq.m^{-3} (Mansour Bahmani et al., 2014)) and $V = 27 - 0.076 = 26.924$ m^3 is hot spring water volume minus phantom volume according to Eq. (13) data. The rest of the coefficients and calculations are the same as sediment coefficients and calculations of Eq. (15) will be as follows.

$$\begin{aligned} D &= 1.6 \times 10^{-10} \times 100 \times 10^3 \times 26.924 \times 1 \times W_T \\ &\times F6 \times 86400 \times 365 \\ &= 1.36 \times 10^4 \times W_T \times F6 \end{aligned} \tag{16}$$

After calculating F6 in different organs using the MCNPX code, the results related to the annual effective dose caused by the radon in the Jooshan hot spring are shown in Table 4.

In Table 4 the effective annual doses of sediments, radon and water of Jooshan hot spring were shown. The radon effective annual dose of radon in the water of hot spring is higher than the hot spring water and sediment. The effective annual dose of hot spring water in body organs is lower than other. Table 4 results show that the effective annual dose in the skin is higher than other sensitive organs. In the hot spring water sample, the highest effective annual dose is observed in the lungs and then the

Table 3: Effective annual dose of hot spring sediments in different body organs.

Tissue	F6 tally (MeV.g^{-1})	Tissue weighting factor	Effective dose (Sv)
Lungs	1.44 E -11	0.12	5.12 E -08
Skin	1.36 E -10	0.01	4.04 E -08
Liver	1.53 E -11	0.04	1.82 E -08
Stomach	1.87 E -11	0.12	6.67 E -08
Bladder And Content	2.43 E -11	0.04	2.88 E -08
Gonads	5.91 E -11	0.08	1.40 E -07
Brain	7.08 E -12	0.01	2.10 E -09
Esophagus	8.78 E -12	0.04	1.04 E -08
Colon And Content	1.85 E -11	0.12	6.57 E -08
Bone Marrow	4.51 E -11	0.12	1.60 E 07
Thyroid	5.53 E -12	0.04	6.57 E -09
Bone Surface	6.19 E -11	0.01	1.84 E -08
Kidneys	2.11 E -11	0.015	9.37 E -09
Pancreas	1.34 E -11	0.015	5.96 E -09
Spleen	1.80 E -11	0.015	8.00 E -09
Thymus	1.56 E -11	0.015	6.94 E -09
Adrenals	1.21 E -11	0.015	5.40 E -09
Gall Bladder	1.62 E -11	0.015	7.21 E -09
Heart	1.22 E -11	0.015	5.43 E -09
Small Intestine	1.54 E -11	0.015	6.84 E -09
Effective Annual Dose =(6.64 ± 0.07)E-07 Sv.year^{-1}= (6.64 ± 0.07)E-04 mSv.year^{-1}			

Table 4: Effective annual dose of radon, sediment and water of Jooshan hot spring for sensitive organs.

Organs	Effective annual dose (mSv.year^{-1})		
	Sediment	Water	Radon
Lungs	5.12 E -05	1.10 E -03	4.06 E -02
Skin	4.04 E -05	1.30 E -04	3.68 E -03
Liver	1.82 E -05	3.09 E -04	1.20 E -02
Bladder and content	6.67 E -05	3.08 E -04	1.14 E -02
Gonads	2.88 E -05	6.13 E -04	2.82 E -02
Brain	1.40 E -04	9.07 E -05	3.48 E -03
Kidneys	2.10 E -06	1.61 E -04	4.22 E -03
Pancreas	9.37 E -06	1.32E-04	3.81 E -03
Gall bladder	5.96 E -06	1.09 E -04	4.09 E -03
Heart	7.21 E -06	5.33 E -05	4.49 E -03
Effective annual dose in sensitive organs	5.43 E -06	3.00 E -03	1.16 E -01

testes. The effective annual dose of radioactive elements in sediment and radon in sensitive organs is lower than the annual permission limit. In this research, the maximum time per year for using of hot spring water for water treatment is considered equal to one year.

3.4 Comparison of result with other research

In other researches similar present study, from many hot spring in Iran, the samples were collected. Then the count per channel was measured by the High Purity Germanium (HPGe) gamma detector. The activity and the radiation hazards was calculated with similar formulas that used in present study (Pourimani et al., 2015; Mohebian and Pourimani, 2019). But the gamma detector in present study was CsI(Tl) detector. In other researches, the effective annual dose was measured by RDS -110 survey meter (Pourimani et al., 2015; Mohebian and Pourimani, 2019) or by measuring the radon activity that replace in effective annual dose formula (Hashemi and Negharesani, 2011). But in present study, the count per channel was measured by CsI(Tl) detector and the effective annual dose was calculated by MCNPX version of MIRD phantom. Table 5 are shown the comparison of many works and activities done in Iran with Present study.

Table 5 data was shown the maximum activity of Th-232 in Jooshan hot spring is larger than Mohallat, Arak, Hormozgan and Chabahar hot springs. The minimum activity of K-40 in Jooshan hot spring is smaller than mohallat, Arak, Hormozgan and Chabahar hot springs. The maximum activity of Cs-137 in Jooshan hot spring is larger than Mohallat, and is smaller than Arak, Hormozgan and Chabahar hot springs. The maximum of radium equivalent in Jooshan hot spring larger than Arak and Chabahar hot springs. The ELCR in Jooshan hot spring is smaller than Arak hot spring. The effective annual dose of Jooshan hot spring is smaller than Hormozgan hot spring. Also the effective annual dose that was calculated by measuring of radon concentration in Jooshan hot spring is 6×10^{-5} mSv.year^{-1} (Council et al., 1999) that is smaller than 6.64×10^{-4} mSv.year^{-1} calculated by using the MCNPX code in the present study.

Table 5: The comparison of other works and activities in Iran with present study.

Region of hot spring	A_{Th} (Bq.kg^{-1})	A_K (Bq.kg^{-1})	A_{Cs} (Bq.kg^{-1})	Ra_{eq} (Bq.kg^{-1})	$ELCR$	Effective Annual Dose (mSv.year^{-1})	Reference
Mohallat	26.29	137.33	3.53	-	-	-	(Pourimani et al., 2015)
Arak	11.3-35.86	257.82-605.5	1.28-3.36	88.35	0.18	-	(Mohebian and Pourimani, 2019)
Hormozgan	2.52	11.8	-	-	-	42	(Dabbagh et al., 2006)
Chabahar	20	450	42.92	86.79	-	-	(Hosseini et al., 2014)
Jooshan (Present study)	14.09-50.86	0	0-12.19	64.56-01.32	2.22E-09	6.64E-04	-

4 Conclusions

In order to estimate the radiation hazards of Jooshan hot spring in Kerman province, the samples of hot spring components (soil, hot spring water, and sediments) were collected. Then the type of sediments and the activity of hot spring components were obtained by XRD technique and CsI(Tl) detector. The results of XRD technique showed that the type of the sediments of Jooshan hot spring is composite of calcareous-silicate. The activity of Cs-137, K-40, U-238, and two Th-232 elements in hot spring sediments is 45.80, 2.77, 0, and 3.05 Bq.kg^{-1} respectively. The activity of radioactive elements in hot spring sediments is more than the other components. Also, the effective annual dose caused by the hot spring sediments (6.64×10^{-4} mSv.year^{-1}) is less than the global limits.

The radiological hazards caused by ionizing radiation emitted from Th-232, K-40, Cs-137, and U-238 radionuclides on the population living in the region were assessed by estimating the radiological parameters such as absorbed gamma dose rate outdoors and the corresponding annual effective dose rate from external exposure, annual effective dose rate from radon and excess lifetime cancer risk. The results revealed that there are no significant radiological hazards for the human population because the average values of radiological parameters are less than the recommended limitations. The simulation and experimental result show that the effective annual dose, radiation hazards parameters of hot spring components and radon in hot spring are less than annual permission and radiation hazard limitations.

The reason for difference in activity, the calculation of annual effective dose and radiation risks of the different parts of Jooshan hot spring is due to the examined samples that have three different origins: a) sediments, water and soil inside the spring b) rock, soil and water outside the spring and c) sediments outside the spring from areas that are dry and hot water does not exit from them. The results of the present study show that the sediments, water and soil inside the hot spring for a) origin have different radioactive elements compared to the b) and c) origins. The reason is that hot water passes through the underground layers and dissolves some sediments with radioactive elements in it and deposit in hot spring after cooling of water.

Conflict of Interest

The authors declare no potential conflict of interest regarding the publication of this work.

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References

Abel-Ghany, H. et al. (2010). Natural activities of u-238, th-232, and k-40 in manganese ore. *American Journal of Environmental Sciences*, 6(1):90–94.

AI-Saleh, F. and AI-Berzan, B. (2007). Measurements of natural radioactivity in some kinds of marble and granite used in Riyadh region. *Journal of Nuclear and Radiation Physics*, 2(1):25–36.

Alharbi, W., Alzahrani, J., and Abbady, A. G. (2011). Assessment of radiation hazard indices from granite rocks of the Southeastern Arabian Shield, Kingdom of Saudi Arabia. *Aust J Basic Appl Sci*, 5(6):672–682.

Asano, T., Sato, K., and Onodera, J.-i. (2001). United nations scientific committee on the effects of atomic radiation 2000 report. *Japanese Journal of Health Physics*, 36(2):149–158.

Beretka, J. and Mathew, P. (1985). Natural radioactivity of Australian building materials, industrial wastes and by-products. *Health physics*, 48(1):87–95.

Council, N. R. et al. (1999). Risk assessment of radon in drinking water.

Dabayneh, K. M., Mashal, L., and Hasan, F. (2008). Radioactivity concentration in soil samples in the southern part of the West Bank, Palestine. *Radiation Protection Dosimetry*, 131(2):265–271.

Dabbagh, R., Ghafourian, H., Baghvand, A., et al. (2006). Discovery of the second highest level of radioactive mineral spring in Iran. *Journal of Radioanalytical and Nuclear Chemistry*, 269(1):91–94.

El-Shershaby, A., El-Bahi, S., El-Dine, N. W., et al. (2006). Assessment of natural and man-made radioactivity levels of the plant leaves samples as bio-indicators of pollution in Hebron District. *Arab J Nucl Sci Appl*, 39(2):231–242.

Ertuğ, F. P., Şingirik, E., Büyüknacar, H. S., et al. (2014). Pharmacological profile of a nitric oxide donor spermine NONOate in the mouse corpus cavernosum. *Turkish Journal of Medical Sciences*, 44(4):569–575.

Faweya, E. and Babalola, A. (2010). Radiological safety assessment and occurrence of heavy metals in soil from designated waste dumpsites used for building and composting in Southwestern Nigeria. *Arabian Journal for Science and Engineering*, 35(2):219.

Hamid, B., Mohammad Bagher, A., Mohammad Reza, B., et al. (2016). Review of sustainable energy sources in Kerman. *World Journal of Engineering*, 13(2):109–119.

Hashemi, S. and Negharesani, A. (2011). Effective dose rate of radon gas in jooshan hot spring of kerman province. *Journal of Kerman University of Medical Sciences*, 18(3):279–285.

Hosseini, A. et al. (2014). The effect of soil radioactivity in pollution. *Journal of Community Health Research*, 2(4):286–292.

Huy, N. Q. and Luyen, T. (2006). Study on external exposure doses from terrestrial radioactivity in Southern Vietnam. *Radiation Protection Dosimetry*, 118(3):331–336.

Jargin, S. V. (2014). On the genetic effects of low-dose radiation. *J Environ Occup Sci*, 3(4):199–203.

Khezripour, S., Zarei, N., and Rezaie, M. (2022). Estimation of granite radiation hazards of Deh Siahan village in rafsanjan city. *Journal of Instrumentation*, 17(08):T08011.

Mahur, A., Kumar, R., Mishra, M., et al. (2010). Study of radon exhalation rate and natural radioactivity in soil samples collected from East Singhbhum Shear Zone in Jaduguda U-Mines Area, Jharkhand, India and its radiological implications.

Mansour Bahmani, M., Moussavi, A. H., Vakili, A., et al. (2014). The daily radon dose in body organs caused by drinking milk and water. *Journal of Radioanalytical and Nuclear Chemistry*, 301:653–657.

Mehnati, P., Jomehzadeh, A., and Doostmohammadi, V. (2022). Measurement of ra-226, th-232, k-40 and cs-137 concentrations in sediment samples and determination of annual effective dose due to these radionuclides in vicinity of hot springs in Kerman Province. *International Journal of Radiation Research*, 20(1):223–228.

Mohammed, R. and Ahmed, R. (2017). Estimation of excess lifetime cancer risk and radiation hazard indices in southern Iraq. *Environmental Earth Sciences*, 76:1–9.

Mohebian, M. and Pourimani, R. (2019). Measurement of radioactivity levels and health risks in the surrounding soil of shazand refinery complex in Arak, Iran, using gamma-ray spectrometry method. *Iranian Journal of Medical Physics*, 16(3):210–216.

Montazeri, H., Abbasnejad, A., and Negarestani, A. (2011). Continuous radon monitoring in the jowshan hot spring as an earthquake precursor, se iran. *Geochemical Journal*, 45(6):463–472.

Namvaran, M. and Negarestani, A. (2013). Measuring the radon concentration and investigating the mechanism of decline prior an earthquake (Jooshan, SE of Iran). *Journal of Radioanalytical and Nuclear Chemistry*, 298:1–8.

Pourimani, R., Gheisari, R., Zare, M. R., et al. (2015). Radioactivity concentration in sediment and water samples of hot springs of Mahallat and soil samples of their neighboring environs. *Environmental Studies of Persian Gulf*, 2(1):24–31.

Pourimani, R. and Nemati, Z. (2016). Measurement of radionuclide concentration in some water resources in Markazi Province, Iran. *Iranian Journal of Medical Physics*, 13(1):49–57.

Puryanti, D., Putra, A., Nova, E. F. S., et al. (2022). Mapping of hot spring sintered sediment materials around Mount Talang, Solok Regency, West Sumatera. In *AIP Conference Proceedings*, volume 2524, page 050002. AIP Publishing LLC.

Ramasamy, V., Suresh, G., Meenakshisundaram, V., et al. (2009). Evaluation of natural radionuclide content in river sediments and excess lifetime cancer risk due to gamma radioactivity. *Research Journal of Environmental and Earth Sciences*, 1(1):6–10.

Rezaie Rayeni Nejad, M. R. et al. (2020). Investigation of the relationship between of the radon concentration variation in Reyhanshahr hot spring and earthquakes with d/r¿ 0.5 in that zone. *Iranian Journal of Radiation Safety and Measurement*, 8(4):267–274.

Taskin, H., Karavus, M., Ay, P., et al. (2009). Radionuclide concentrations in soil and lifetime cancer risk due to gamma radioactivity in Kirklareli, Turkey. *Journal of Environmental Radioactivity*, 100(1):49–53.

Thabayneh, K. (2012). Natural radioactivity levels and estimation of radiation exposure in environmental soil samples from Tulkarem Province–Palestine.

Ujić, P., Čeliković, I., Kandić, A., et al. (2010). Internal exposure from building materials exhaling rn-222 and rn-220 as compared to external exposure due to their natural radioactivity content. *Applied Radiation and Isotopes*, 68(1):201–206.

Veiga, R., Sanches, N., Anjos, R., et al. (2006). Measurement of natural radioactivity in Brazilian beach sands. *Radiation Measurements*, 41(2):189–196.