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*Original Article*

# Radiation Hazards Investigation of Jooshan Hot Spring in Kerman Province

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## Abstract

**Introduction:** Hot spring water is used for health and medical treatment. Hot spring water, when passing underground rocks, is contaminated with radioactive materials and water soluble sinter. Therefore, using Hot springs is associated with radiation hazards. There are Thorium (Th), Potassium (K), Uranium (U), and Caesium (Cs) as radioactive elements in sinter, soil, and water of hot springs.
**Materials:** First, the Th, K, U, and Cs activity in the sinter, soil, and water of Jooshan Hot Spring (30°09'38.7"N, 57°35'58.7"E) was measured by a CsI(Tl) detector. Then, using the radiation hazards equations, the amount of radiation hazards caused by radioactive elements in the sinter, soil, and Hot spring water was investigated.
**Results:** The XRD results indicated that the sinter composite of Jooshan Hot Spring is a combination of $CaCO_3$ and $SiO_2$ materials. The activity of Th, U, K, and Cs elements in the water, sinter, and soil of hot spring were 38.76, 11.07, 0, and 3.05, 45.8, 2.77, and 3.05 Bq/kg, and 26.42, 34.0, 0, and 12.19 Bq/kg, respectively. The radiation hazards of Jooshan Hot Spring using the radiation hazards equations was calculated.
**Conclusion:** Due to the activity of Th, K, U, and Cs, the radiation injuries or hazards, including $Da_{eq}$, $H_{in}$, and $H_{out}$ for the sinter, soil, and water were calculated to be less than the reported limit. Therefore, using Jooshan Hot Spring has not any radiation hazards.

**Keywords:** Hot Spring, Soil, Water, Radiation Injuries, Radioactive, Elements.

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## 1. Introduction

Kerman Province is one of the famous provinces for its hot springs distributed in the whole province zone [1]. One of the most important hot springs in Kerman is Jooshan hot spring (30°09'38.7"N, 57°35'58.7"E) near the Jooshan Village (30.123795852300823N, 57.609043174046725E). The water of this hot spring is used to treat various diseases [2]. Furthermore, the variation on radon gas in Jooshan hot spring water is also used to predict earthquake [3]. Various studies indicate that in addition to radon, the Th, K, U, and Cs radioactive elements are further present in the water, soil, and sinters of hot springs [4]. The aim of this research is the calculation of Jooshan Hot Spring radiation hazards by determining the $Da_{eq}$, $H_{in}$, and $H_{out}$ hazard equations. For this, the activity of radioactive elements in hot spring component should be measured.

The water of the hot spring zone penetrates into the underground layers and due to contact with hot volcanic crusts, it heats up and is transferred to the surface by pressure through the existing cracks. Some water-soluble materials are contaminated with radioactive elements. Different water passage pores likely emit radon gas due to the presence of $^{238}U$ and $^{232}Th$ series, which radon gas further dissolves in water when water passes through them. From the basement layers to the ground surface, the radioactive elements of various sediments and radon gas are dissolved in it. After the water reaches the surface and due to its cooling, the dissolved sediments in it settle around the spring. Due to the use of hot spring for medical treatment, it is possible to create radiation hazards caused by radioactive elements dissolved in water and moreover, the radioactive elements in the sediments and soil that is located in the bed of the spring and around it.

Water-soluble radon gas can be used to predict earthquakes in the area around the spring. Usually before the earthquake happens, many cracks are created in the faults around the spring, which reduces or increases the radon gas in the hot spring. By continuously monitoring the radon concentration in the hot spring, an earthquake of more than 3 Richter can be predicted between one week to 20 days [5, 6]. Likewise, by measuring the amount of radioactive elements in the water, soil, and sediments of the hot spring, the amount of hazards caused by these radioactive elements in its users can be calculated.

In this research, it is tried to collect samples of sediments, soil, and hot spring water by referring to Sirch hot spring in Kerman, and then using CSI (TL) scintillation detector to identify the amount of radioactive elements in the hot spring and calculate their specific activity. From the specific activity of each of the radioactive elements in each of the water, soil, and sediment samples of the spring, the amount of radiation hazards can be calculated using the hazard equations.

During hot spring therapy, owing to the presence of radioactive elements, the time of using the hot spring is highly effective in the dose received and radiation hazards [5, 6]. This research aimed to investigate the radiation hazards of Jooshan Hot Spring due to the presence of radioactive elements. Furthermore, the sinter, water, and soil of the hot spring was collected. The compositions of the sinter were calculated using the XRD technique. The activity of radioactive elements in the hot spring water, soil, and sinter was measured using a CSI (Tl) detector [7]. By placing the activity of radioactive elements in radiation hazard equations, the radiation hazard caused by the water, soil, and sinter of Jooshan Hot Spring was investigated. Therefore, its operational method will be mentioned below.

## 2. Material and Methods

The main purpose of this study is to calculate the radiation hazards of Sirch hot spring in Jooshan village of Kerman province. To calculate the radiative hazards, first the activity of the elements in the components of the hot spring should be calculated, including sediments, water, and soil of the spring. Radiation hazards of each component of the hot spring are calculated by the hazards equations. Thus, first, the method of collecting samples of hot spring components is explained. Then, the method of calculating the activity of hot springs components will be described, and at the end, the equations related to calculating the radiative hazards of hot springs will be introduced.

## 2.1. Collecting samples of Jooshan hot spring components

With a little mountaineering, can be arrived to the Jooshan hot spring area, as depicted in Figure 1.

Initially, the soil around of the hot spring was collected and was divided to 5 packages with 100 g mass to calculate the soil activity. Then, the sediments of the hot spring were further collected. These sediments were kept in the laboratory for 1 week to remove water from them. After drying the sediments, 3 samples of them were divided into 100 g packages to calculate the activity of the Th, K, U, and Cs radioactive elements and determine the type of sediments by the X-Ray diffraction Analysis (XRD) [8, 3]. Likewise, 5 litters of hot spring water were prepared and was divided to 5 packages to calculate the Th, U, k, etc. as the radioactive elements displayed in Figure 2.

**Figure 1**. Zone of Jooshan hot spring area in Kerman

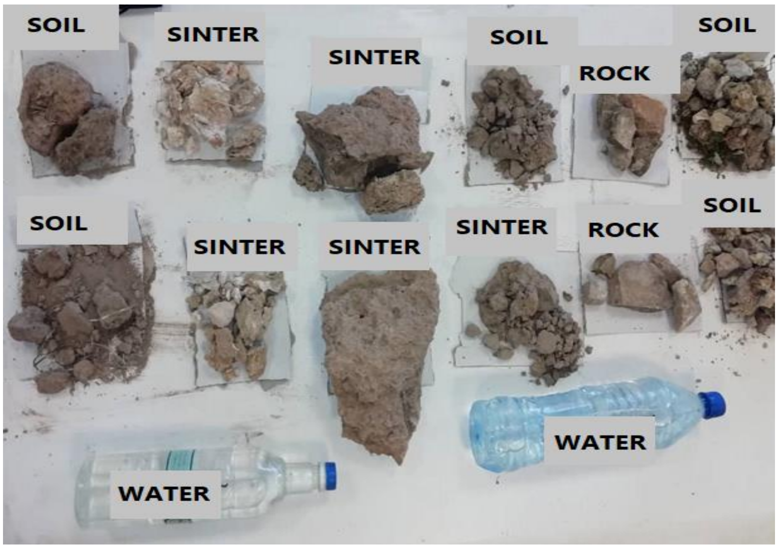

**Figure 2**. Jooshan hot spring component (soil, sinter, and water)

## 2.2. Calculating the specific activity of radioactive elements in Jooshan hot spring components

The special activity of each component of the hot spring is obtained from the Equation (1).

$$As = A/m \quad (1)$$

That As is the Specific activity of each radioactive element in unit of Bq/kg. A is the Sample activity in Bq unit and m is mass sample in kg unit. The mass of the samples is calculated using scales. The Specific activity of the samples is also calculated from Equation (2).

$$As = N/(t.\ I\gamma.\varepsilon.m) \quad (2)$$

In Equation (2), ε is the total gamma count efficiency of the CsI (Tl) detector, Iγ is the probability of the gamma emission of Th, K, U, and Cs radioactive elements and t is the time of irradiation that assumed 900 s to increase the accuracy of activity. To calculate the activity of each Th, K, U, and Cs radioactive elements the amount of N count for each of these elements should be specified. Because each of the above elements has its own characteristic gamma, the amount of gamma particle count in each of the energies should be determined according to the radiation spectrum of each of these samples. Likewise, the total gamma count efficiency of measuring device is different for each of the radiative gammas related to the elements.

The gamma spectrometer is a CSI (Tl) scintillator whose the total gamma count efficiency is indicated for each of the Th, K, U, and Cs radioactive elements according to its characteristic gamma in Table 1. CSI (Tl) scintillation detector for gamma measurement should be calibrated that was calibrated with $^{60}$Co source.

After measuring the number of gamma counts related to each of the Th, K, U, and Cs radioactive elements in each of the samples of sediments, water, and soil of the Jooshan hot spring and by placing in the Equation (2), the specific activity can be calculate.

**Table 1.** The total gamma count efficiency of the CsI (Tl) detector (ε) and the probability of the gamma emission (Iγ) of the Th, K, U, and Cs elements

| Element | Probability of the Gamma Emission (Iγ) | Total Gamma Count Efficiency (ε) |
|---|---|---|
| $^{232}$Th | 43.5 | 0.88 |
| $^{238}$U | 19.2 | 0.68 |
| $^{238}$U | 35.1 | 0.55 |
| $^{232}$Th | 30.58 | 0.3 |
| $^{137}$Cs | 87.5 | 0.25 |

## 2.3. Calculation of Jooshan hot spring components radiation hazards

In order to calculate the radiative hazards of each of the components of the hot spring, the amount of specific activity Th, K, U, and Cs radioactive elements should be calculated and placed in the equations 3-11 as hazards Equation [1-28] [7-23].

$$Ra_{eq}=A_U+1.43\times A_{Th}+0.077\times A_k \quad (3)$$

$$Dr=0.43A_U+0.66A_{Th}+0.043A_K+0.03A_C+34 \quad (4)$$

$$D_{out}=D_r\times 24h\times 365.25d\times 0.2\times 0.7\times 10^{-6} \quad (5)$$

$$D_{in}=Dr\times 24\times 365.25\times 1.4\times 0.8\times 0.7\times 10^{-6} \quad (6)$$

$$D_{tot}=D_{out}+D_{in} \quad (7)$$

$$H_{ex}=A_U/370+A_{Th}/259+A_K/4810 \quad (8)$$

$$Hin=Au/185+A_{Th}/259+A_k/4810 \quad (9)$$

$$I\gamma=Au/150+A_{Th}/100+A_k/1500 \quad (10)$$

$$ELCR=D_{tot}\times D_L\times RF=D_{tot}\times 70\times 0.05\times 10^{-6} \quad (11)$$

Equation 3 reveals an equation that can be used to obtain the equivalent activity of $Ra_{eq}$ radium. Equation 4 depicts an equation that can be used to obtain the $D_r$ or absorbed dose in the air. Equation 5 indicates an equation that can be used to obtain $D_{out}$. Equation 6 indicates an equation that can be used to obtain $D_{in}$. Equation 7 displays an equation that can be used to obtain $D_{tot}$. Equation 8 indicates an equation that can be used to obtain $H_{ex}$. Equation 9 depicts an equation that can be used to obtain $H_{in}$. Equation 10 shows an equation that can be used to obtain $I_\gamma$. Equation 11 shows an equation that can be used to obtain Excess Lifetime Cancer Risk (ELCR).

## 3. Results and Discussion

Figure 3 presents the XRD results of the detection of molecular compounds in the sinter of Jooshan Hot Spring.

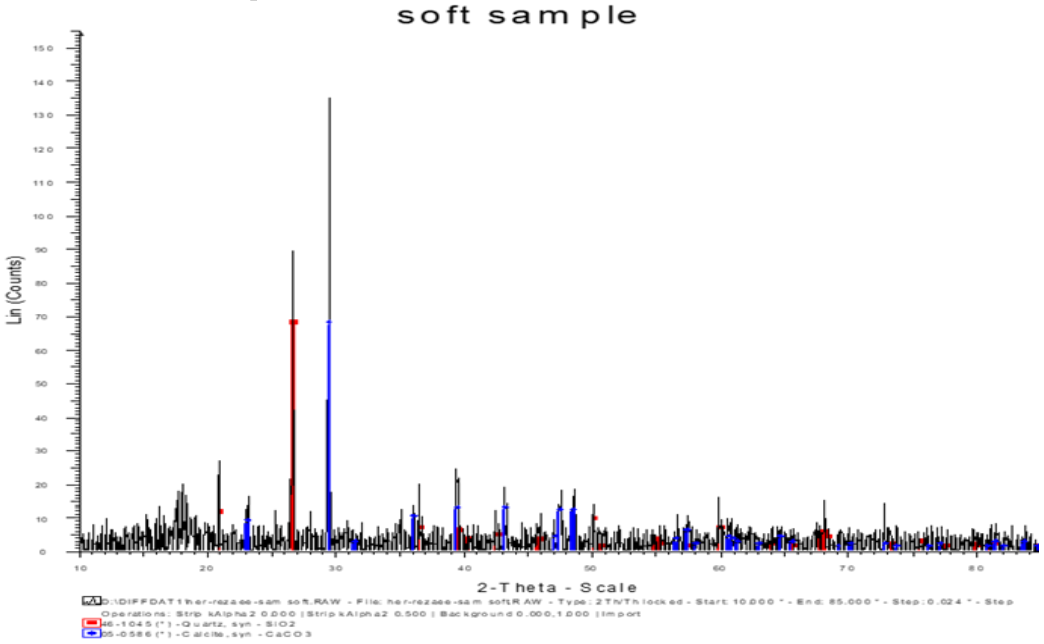

**Figure 3**. Jooshan Hot Spring sinter compositions using the XRD technique

The type of the sinter of hot springs is generally either CaCO3, SiO2, or CaCO3-SiO2 type [24]**.** The results of this study indicate that the sinter of Jooshan Hot Spring of CaCO3-SiO2 type is according to Figure 2. Table 2 depicts the results of measuring the activity of Th, K, U, and Cs elements using a CSI (Tl) detector in the sinter, water, and soil of hot springs.

**Table 2.** The activity of Th, K, U, and Cs elements in the sinter, water, and soil of Jooshan Hot Spring in Kerman

| | **Activity Bq/kg** | | |
|---|---|---|---|
| **Elements** | **Water** | **Sinter** | **Soil** |
| $A_{Th}$ | 38.76 | 45.80 | 26.42 |
| $A_U$ | 11.07 | 2.77 | 34.04 |
| $A_k$ | 0 | 0 | 0 |
| $A_{Cs}$ | 3.05 | 3.05 | 12.19 |
| Total | 52.88 | 51.65 | 72.62 |

## 4. Conclusion

The results show that the sinter type of Sirch hot springs is CaCO3- SiO2 type. Most of the sediments of springs have been reported as CaCO3 or SiO2 types [21]. A small number of sinter type hot springs in the world have been reported as CaCO3-SiO2 type [21]. Studies reveal most of the hot springs have contaminated to the Th, Cs, U, etc. radioactive elements [25]. The amount of radioactive elements observed in the components of hot springs depends on the type of faults and the soil of the area around the spring. Due to the mountainous nature of the around Kerman Sirch hot spring, there is a possibility of contaminating surface water that has penetrated into underground rocks to Th, U, k, etc. radioactive elements in faults. The calculated activity of Th, U, k, radioactive elements in soil, water, and sinter of Sirch Kerman hot spring that are mentioned in Table 1, show that these elements are present in the faults around the spring. The study of radioactive elements in the hot springs of Iran [4] also shows the presence of radioactive elements in the faults around the Iranian hot spring. Comparison of the Th, U, Cs, etc. activity of hot spring elements in Iran and the world [25] shows that the activity of Jooshan hot spring radioactive elements is less than other hot springs.

Radiation hazards have also been calculated using the hazard equations for Jooshan-Kerman hot spring. The results of these hazards are presented in Table 3.

The sinter of Jooshan Hot Spring, like some hot springs in the world, has radioactive elements, including Cs, Th, U, and K [26, 27]**.** The total activity of these elements in the water, sinter and soil of Jooshan Hot Spring was 52.88, 51.65, and 72.62 Bq/kg, respectively. The amount of radioactive elements in the sinter is more than that in the hot spring soil and water. Using the results in Table 3, the radiative hazard of different spring components, including sinter, water, and soil can be obtained according to Equations 1-8. Table 3 presents the results of the calculations.

**Table 3.** The results of the radiative hazards of the sinter, water, and soil of Jooshan Hot Spring

| | **Radiation Hazards** | | |
|---|---|---|---|
| **Radiative Hazards** | **Water** | **Sinter** | **Soil** |
| **$Ra_{eq}$(Bq/kg)** | 66.49 | 68.26331 | 71.83 |
| **$D_r$(nGy/y)** | 64.47 | 65.59357 | 66.39 |
| **$D_{out}$(nGy/y)** | 0.08 | 0.080488 | 0.08 |
| **$D_{in}$(nGy/y)** | 0.44 | 0.450733 | 0.46 |
| **$D_{tot}$(nGy/y)** | 0.52 | 0.531221 | 0.54 |
| **$H_{ex}$** | 0.18 | 0.184319 | 0.19 |
| **$H_{in}$** | 0.21 | 0.1918 | 0.29 |
| **$I_\gamma$** | 0.46 | 0.476462 | 0.49 |
| **ELCR** | 1.83E-09 | 1.86E-09 | 1.88E-09 |

Radiation hazards, including $Da_{eq}$, $D_r$, $D_{tot}$, $H_{in}$, $H_{ex}$, $H_{in}$, $I_\gamma$, and ELCR for the sinter, soil and water of Jooshan Hot Spring were less than the annual limits. To estimate the radiative hazards of Jooshan Hot Spring in Kerman, first various samples of sinter, soil, and water hot springs were collected. Second, the chemical composition of sinter with XRD technique, finally the amount of $Da_{eq}$, $D_r$, $D_{tot}$, $H_{in}$, $H_{ex}$,$H_{in}$ $I_\gamma$, and ELCR radiation hazards of sinter, soil, and water of hot spring were obtained. The results demonstrate that the sinter of Jooshan Hot Spring is of the calcareous-silicate type. The activity of Th, U, K, and Cs elements in the sinter of hot springs is 45.80, 2.77, 0, and 3.05 Bq/kg, and the activity of all radioactive elements in the sinter is 51.8 Bq/kg. The activity of Cs, Th, U, and K elements in the spring sinter is less than that in the water and soil. The amount of radiation hazards for the sinter, soil, and spring water is less than the limited level. The results of this study indicate that the use of Jooshan Hot Spring in Kerman is allowed, and there are no significant radiation hazards.

## Declarations

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. The authors declare that there is no conflict.

## Authors' contributions

Mahmoud Abdoulahpour and Mohammad Reza Rezaie designed and simulated this study and Saeed Mohammadi analyzed the data. Mahmoud Abdoulahpour and Neda Zareie proceeded to the data quality control and the manuscript drafting. Neda Zareie revised the final version.

## Consent for publications

All authors agree to have read the manuscript and authorize the publication of the final version of the manuscript.

## Conflict declaration

The authors declare that there is no conflict.

## Conflict of interest

None of the authors have any conflict of interest to declare.

## Availability of data and material

Data are available on request from the authors.

## Funding/Support

Not applicable.

## Ethics approval and consent to participate

Because the simulation of this study, it does not need an Ethics approval and consent to participate form.

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