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Determination of radon concentration in drinking water of Taft Township and evaluation of the annual effective dose

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► ***Original article***

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ABSTRACT

Background: Radioactive substances are water chemical contaminants. In this study, the concentration of radon was measured in drinking water supplies of Taft villages (part of Dehshir-Baft fault located in central part of Iran) and also Shirkooh area with granite rocks (containing uranium). ***Materials and Methods***: This cross sectional research was conducted in fall 2013 and winter 2014 on the sources of drinking water and also drinking water network of Taft city of Yazd province. According to the measured radon levels; the annual effective absorbed dose was also calculated. ***Results:*** Minimum and maximum levels of radon gas were related to sample number 54 (0.88 BqL^{-1}) and number 31 (43.01BqL^{-1}). Range of radon concentrations was 1.88-43.01 BqL^{-1} in samples of wells in private homes, 0.88- 20.36 BqL^{-1} in supplier wells of public network of drinking water, 1.23-10.29 BqL^{-1} in aqueducts, 1.23-11.49 BqL^{-1} in water tap connected to the public network and 12.89 BqL^{-1} in one measured spring. The annual effective absorbed dose through drinking and breathing in an environment that this water is used ranged from 0.00 msv/y (sample No.54) to 0.11 mSv/y (sample No.31). ***Conclusion:*** Radon concentration was lower than the limit set by the Environmental Protection Agency of United States of America, in 82% of samples. Samples with high radon concentrations were located around Shirkooh area due to the presence of granitic rocks. Dehshir and Garizat villages located through Dehshir - Baft fault and the Radon concentration of these samples was less than the permissible limit, probably due to the inactive Fault.

Keywords: *Radon, drinking water, effective dose, Taft.*

INTRODUCTION

Radon comes from decay of uranium, thorium and radium found naturally on the earth surface. (1). Radon-222 (radon) and radon-220 (thoron) are the most common isotopes of radon (2). Radon does not have a great affinity for water and soil. Therefore it is easy to separate from water and soil molecules and inserts to air (3). Due to the wide range of uranium concentrations in soils and rocks, radon concentrations will vary (4). Total released radon from the Earth's landmass is 8.88×10^{19} Bq in a year (5). This gas is the main cause of lung cancer in some countries (6).

International Commission on Radiological Protection (ICRP) stipulates that available radio nuclides in water are absorbed much easier than radio nuclides in food (7). The amount of radon in groundwater is dependent on the concentration of radium in the aquifer layer (8). Rn-222 concentration of surface waters is generally very low (7). The Rn-222 inert gas (half-life 3.8 days) has low solubility in body fluids so unevenly spread throughout the body and converted into a series of short-lived elements,

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while alpha-particle irradiation. These elements are called radon daughters including Plutonium 218 (Po-218) and plutonium 214 (Po-214). Po-218 (half-life of three minutes) and Po-214 (half -life two-tenths of a second) are solid particles that are considered as biological effective hazards. These radioactive products are the result of inhalation and decay of radon in lung. After a while they decay and irradiate high-energy alpha particles that can damage DNA molecules and product free radicals. Due to this fact radon is introduced as one of the causes of lung cancer [9]. In addition to the respiratory system, the alpha particles of radon decay damage the gastrointestinal tract. Stomach cancer is one of the results. Radon is a bivalent element and similar to calcium. This explains why a major degree of it is absorbed into the bloodstream, concentrated in the bones and increases internal exposure rate [10].

Besides the health issues related to radon, changes in radon concentration of groundwater is one indicator for earthquake [11]. In most parts of Iran, the seismicity has been directly linked to the resurgence of active faults [12]. Depending on concentration measurement, environmental factors such as pressure, temperature, moisture and soil are potential factors that could affect the measured radon concentration [13].

A study conducted by Purhabib *et al.* in 2011 on radon concentrations in drinking water of Ramsar rivers, springs and wells [10]. Negarestani *et al.* in 2011 have performed a research about effective dose caused by radon gas of Joushan hot springs in Kerman Province [9]. Part of Dehshir - Baft fault passes west of Taft city and also Shirkooh granite area is located in this city and adjacent to the fault (two possible reasons for significant amounts of radon in water). Thus, it is likely that a significant radon concentration may exist in groundwater of this area. Several villages are located in study area with plenty of houses and villas. These buildings have private wells and use taken water immediately before release of radon gas. For this reason radon gas separation time from the water is short and evaluation of radon concentration in this region is necessary. Therefore by observing wells containing high radon concentrations water, permanent monitoring can be done and earthquake forecasted. Further, if radon concentration rate is higher than recommended levels, necessary measures must be taken to prevent physical damage during drinking and other purposes such as washing and bathing.

MATERIALS AND METHODS

Study was a cross sectional and conducted in autumn 2013 and winter 2014, on water resources and some of Taft villages drinking water network in Yazd province. Firstly, fault location, villages, fountains, aqueducts were identified by using geological and topographical maps and satellite photographs of the study area. Then they coincided by Arc Gis software and finally, sampling locations were identified on the map. 250 mm brown vials with Teflon caps were used for sampling. Sampling was conducted slowly so as not to create turbulence in water resources. The vial was filled with water below the water surface and the cap was placed screwed under the water. To avoid formation of bubbles, the sample vial was held upside down. For the sampling of well water, after opening the faucet water for ten minutes, a bucket was placed underwater and a tube placed in it. Water poured into the bucket with no elevation. The sample container was then inserted gently into the bucket and the cap was placed screwed under the water after filling. Samples were stored in composite containers with ice at temperatures below 4° C until transferred to laboratory. In less than 24 hours, solution radon concentration in water was analyzed by using RAD 7 electronic detector (product by Durridge Co., USA). Water temperature, electrical conductivity and pH of each sample was measured at each sampling site. Sampling and testing of this part of the research were based on methods described in book "Standard test methods for water and sewage" [14].

To ensure the accuracy of the test, according to the Environmental Protection Agency of

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United State of America (EPA), two samples of drinking water were taken from each site at same time. RAD7 device works according to alpha particles energy emitted by radon and Thoron [15]. The RAD method employs a closed loop aeration design in which the air volume and water volume are constant and independent of the flow rate [15]. The air circulates through the water and continuously extracts the radon until a state of equilibrium develops [15]. The RAD system reaches this state of equilibrium within about 5 min. This device has two glass bottles of 40 and 250 cc that two protocols (wat 40 and wat 250) are defined based on . In this study wat 250 protocol was used. According to this protocol, the first 5 minutes of bubble blowing was carried out automatically. During the bubble blowing phase, 94% of radon gas dissolved in water was removed and the pump stopped automatically after 5 min. The system waited for 5 min for gas to reach equilibrium. Alpha particles were then counted and the first reading done after 5 min. Actually, 15 minutes after the start of work, first reading was done. It meant radon concentration was measured during the four stages of the 5 min. Figure 1 shows the location of sampled water and central village name of Taft city (some sampling locations are shown superposed on the map due to proximity of them).

The average radon concentration in the water provided by the device is measured in terms of Bq/m^3but converted to Be/Lit. $A=A_0e^{(-0.693/T)t}$ formula which was used to apply for the effect of duration of sampling and testing on half-life of radon. In this formula, A is the average radon concentration in water samples (Bq/Lit) that is measured by Rad 7 devices, T is half-life of radon (3.8 days), t is duration of sampling until testing and A_0 is actual radon concentration of water samples [17].

Recommended parameters by UNSCER (United Nations Scientific Committee on the Atomic Radiation) in 2000 were used to calculate the annual effective absorption dose caused by inhalation and ingestion of radon. The annual effective dose caused by ingestion (drinking water containing radon 1Bq/Lit) was considered equivalent to 0.18 µSv / y. The annual effective dose due to inhalation corresponding to the concentration of radon 1Bq/Lit in tap water (Always, there is radon gas caused by evaporation and release of it in air surrounded water containing radon) was considered equivalent to 2.50 µSv / y. Thus, total annual effective absorbed dose rate from

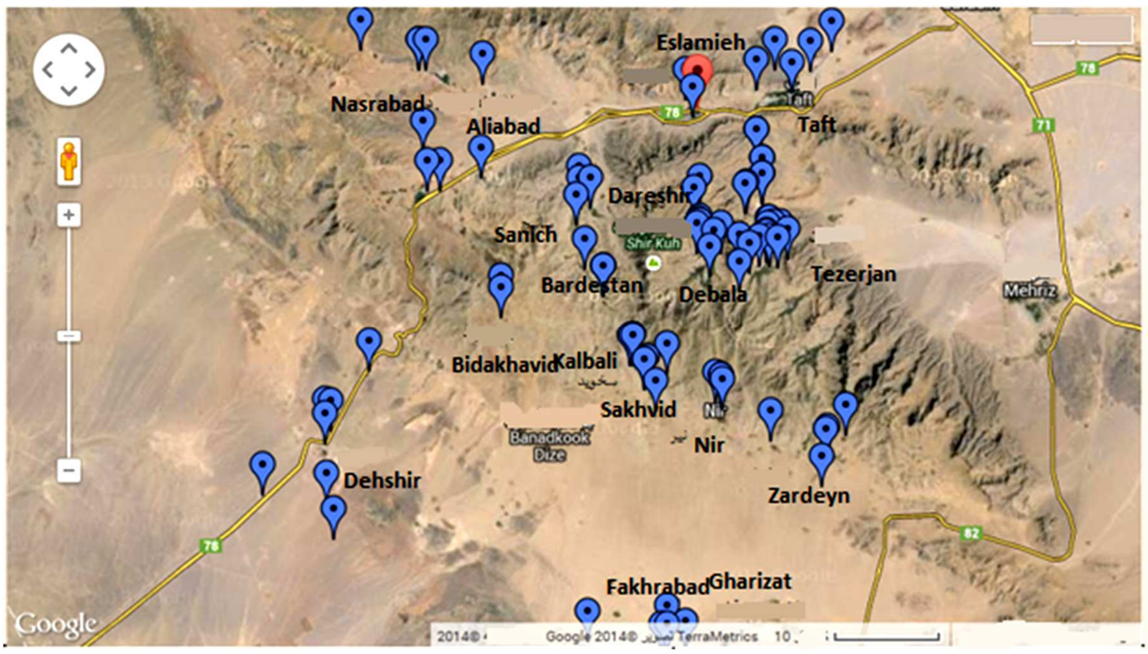

Figure 1. Location of sampled water and central village name of Taft city [16].

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inhalation and ingestion of radon in 1 Bq/Lit of water is equal to 2.68 μSv / y which annual effective absorbed dose was calculated by multiplying it to the radon concentration in each sample [18,19]. Annual effective absorption dose (μSv/y) =2.68A_0 (Bq/Lit)

RESULTS

Specifications of water samples including locations and geographical coordinates, type of sample resources (well, water tap, canals etc.), consumer population of sampled water, electrical conductivity and acidity, water temperature at the time of sampling, radon concentration of samples and annual absorbed dose for a middle aged person is given in table 1.

The minimum and maximum level of radon gas of sample was 0.88 BqL^{-1} (sample No. 54) and 43.01 BqL^{-1} (sample No. 31) respectively. Range of radon concentrations in samples of wells located in private homes ranged from 1.88 BqL^{-1} to 43.01 BqL^{-1}, wells that supplied public drinking water network showed radon concentration levels that ranged from 0.881 BqL^{-1} to 20.36 BqL^{-1}, aqueduct was 1.23 BqL^{-1}–10.29 BqL^{-1}, tap water connected to a public network was 1.23 BqL^{-1}–11.94 BqL^{-1} and the one measured spring was 12.89 BqL^{-1}. Based on radon levels in the samples, the annual effective absorbed dose through drinking and breathing was measured in environments where this water was used. The minimum amount was almost 0.00 mSv/y (sample No. 54) and the maximum amount was 0.11 mSv/y (Sample No. 31).

DISCUSSION

Permissible limit of dissolved radon of water recommended by the Environmental Protection Agency of America (EPA) is 11 Bq/L [11]. Radon concentration in %82 of total samples that are used as drinking water by people of villages in Taft Town, is lower than permitted limit recommended by the EPA. All water samples with higher radon concentrations than permissible limit was related to surrounding area of Shirkooh mountain as a result of the presence of granitic rocks containing uranium, thorium, radium etc. Radon concentration of Dehshir and Garyzat samples (located in direction of Dehshir – Baft fault) was lower than permitted limit. Inactivity of the fault could have been the reason, but the concentration of samples that were far from both Shirkooh mountain area and fault area was less than other samples. SPSS software (version 16) was used to data analysis. There was no significant relationship between radon concentration and electrical conductivity, radon concentration and pH, radon concentration and Temperature. Zareaee in 2009 investigated the natural radio nuclides of granite in Shirkooh mountain area. It was determined that the maximum value of the specific activity of radium which is the last element in the uranium decay chain and before radon [20]. It is thus clear that with an increase in the amount of radium in the granite of different parts of Shirkooh area, the radon levels of water increases too. According to the representative of the Geophysical Center of Tehran University in Yazd, an earthquake occurred strength of 2.5 on the Richter scale about 70 km from the sampling site at the geographical coordinates E: 54˙ 76 and N:31˙ 05at 14:11 (One day before sampling of samples No. 30 to 36 (2013/12/31, 10 am to 14 pm in Sakhvid area). Thus, high levels of radium in granite of Sakhvid and earthquake lead to increasing the radon levels in underground water sources in this area rather than other areas of Taft town.

In another study was conducted by Purhabibi *et al.* regarding the presence of radon in rivers and water faucet of public network in Ramsar in 2011. It determined that the average radon of streams was 2.689 Becquerel per liter and the average amount of radon in drinking water was 3.404Becquerel per liter. Ramsar area has high exposure but since river water is in contact with air, radon will be released. Drinking water that was sampled from tap water sample had a low level of radon due to the long time it takes to extraction [10]. This result was consistent with results of this research.

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Table 1. Specification of water samples (including Address and geographical coordinates, type of sample resources: well, tap water, aqueducts and..., consumer population of sampled water, Electrical conductivity and acidity, water temperature at the time of sampling, radon concentration of samples and annual absorbed dose for a middle aged person).

Sample No	Source	Location	Lat (N)	Long (E)	Population (body)	EC(μs)	pH	T (°c)	Radon concentration ($Bq.L^{-1}$)	Annual effective dose Of adults (msv.y)
1	P H W	Baghestan	31.629′	54.124′	5	560	7.3	17	11.08	0.03
2	P H W	Baghestan	31.645′	54.157′	5	665	7.5	15	15.30	0.04
3	P H W	Dehebala	31.606′	54.127′	5	724	7.9	14	8.86	0.02
4	P H W	Janborazan	31.594′	54.122′	*	740	7.3	14	17.71	0.04
5	P H W	Shekhalishahe	31.615′	54.112′	5	600	7.2	13	11.62	0.03
6	A	Shekhalishahe	31.614′	54.113′	104	360	7.3	14	5.75	0.01
7	A	Arok	31.659′	53.996′	226	660	6.7	15	1.74	0.00
8	P H W	Dareheshir	31.649′	53.996′	5	680	7.9	14	3.86	0.01
9	A	Bahramabad	31.649′	54.007′	77	750	7.8	13	1.23	0.00
10	P H W	Sanich	31.636′	53.993′	226	800	7.6	14	9.29	0.02
11	P H W	Barddestan	31.577′	54.020′	5	660	7.1	13	4.79	0.01
12	P H W	Barddestan	31.578′	54.021′	5	780	7.6	12	6.32	0.01
13	P H W	Sanich	31.599′	54.001′	5	580	7.1	12	4.13	0.01
14	P H W	Tezerjan	31.617′	54.179′	5	570	7.6	14	5.10	0.01
15	P H W	Tezerjan	31.612′	54.179′	*	620	7.4	15	5.79	0.01
16	P H W	Tezerjan	31.606′	54.177′	*	695	7.4	12	4.52	0.01
17	P H W	Tezerjan	31.604′	54.178′	*	620	7.6	11	4.45	0.01
18	P H W	Tezerjan	31.602′	54.180′	5	700	7.4	13	10.83	0.03
19	P H W	Tezerjan	31.601′	54.188′	5	710	7.6	16	3.09	0.00
20	Tap	Baghiabad	31.613′	54.191′	108	410	7.4	10	1.64	0.00
21	P H W	Baghiabad	31.614′	54.184′	5	730	7.8	13	8.01	0.021
22	P H W	Baghiabad	31.616′	54.180′	5	790	7.3	15	12.79	0.03
23	P H W	Deheshir	31.413′	53.690′	5	2640	7.3	24	7.28	0.01
24	A	Deheshir	31.466′	53.756′	3173	1900	7.3	21	8.04	0.02
25	T	Deheshir	31.455′	53.750′	3173	1350	7.6	19	6.01	0.01
26	A	Deheshir	31.377′	53.759′	3173	1400	7.6	22	5.47	0.01
27	A	Deheshir	31.515′	53.792′	5	1300	7.2	19	8.90	0.02
28	A	Aliabad	31.663′	53.862′	5	570	7.4	19	5.78	0.01
29	P H W	Aliabad	31.663′	53.861′	5	1900	6.8	14	1.88	0.00
30	P H W	Kalbali**(sakhvid)**	31.520′	54.046′	5	701	7.3	22	5.30	0.01
31	P H W	Kalbali(sakhvid)	31.520′	54.045′	5	550	7.2	15	43.01	0.11
32	P H W	Kalbali(sakhvid)	31.521′	54.048′	5	815	7.4	15	23.37	0.06
33	A	Bedok(sakhvid)	31.520′	54.049′	33	645	7.3	15	5.85	0.01
34	P H W	Esterij(sakhvid)	31.502′	54.061′	5	710	7.7	15	12.16	0.03
35	P H W	Esterij(sakhvid)	31.500′	54.059′	*	738	7.8	16	18.55	0.05
36	P H W	Baghebid	31.482′	54.071′	5	570	7.6	16	25.90	0.07
37	P H W	Nir	31.487′	54.133′	5	740	7.6	14	11.79	0.03
38	T	Nir	31.487′	54.133′	1620	400	7.5	13	8.26	0.02
39	P H W	Chahak(nir)	31.457′	54.182′	5	920	7.6	16	10.42	0.02
40	P N W	Bidakhavid	31.562′	53.847′	125	520	7.6	14	2.60	0.00
41	P N W	Bidakhavid	31.552′	53.851′	125	550	7.3	16	8.20	0.02
42	P N W	Deheshir	31.501′	53.750′	3173	2500	7.3	20	6.62	0.01
43	P N W	Deheshir	31.497′	53.739′	3173	2110	7.4	19	8.38	0.02
44	P N W	Mirzamohamad	31.402′	53.702′	45	2400	7.1	13	5.64	0.01
45	P N W	Taft	31.666′	54.173′	15717	1040	7.3	15	20.36	0.05
46	P N W	Taft	31.653′	54.173′	15717	1802	7.1	13	14.57	0.03
47	P N W	Nasrabad	31.763′	53.841′	3821	1150	7.3	16	6.36	0.01
48	P N W	Nasrabad	31.763′	54.847′	3821	1145	7.5	15	10.60	0.02
49	P N W	Salehabad	31.751′	53.902′	185	2550	7.1	14	5.54	0.01
50	P N W	Beheshti	31.612′	54.133′	506	380	7.4	14	8.18	0.02
51	P N W	Shikhalishah	31.618′	54.113′	104	410	7.3	16	1.88	0.00

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Table 1. Continued

Sample No	Source	Location	Lat(N)	Long(E)	Population (body)	EC(µs)	PH	T (˙c)	Radon concentration (Bq.L^{-1})	Annual effective dose Of adults (msv.y)
52	P N W	Baghiabad	31.603˙	54.152˙	108	700	7.5	15	2.40	0.00
53	P N W	Tezerjan	31.602˙	54.171˙	506	496	7.4	15	1.12	0.00
54	P N W	Banestan	31.581˙	54.152˙	10	740	7.5	16	0.88	0.00
55	P N W	Talezard	31.596˙	54.161˙	506	370	7.3	12	9.05	0.02
56	P N W	Taleasheghan	31.762˙	54.186˙	506	540	7.4	16	10.13	0.02
57	P N W	Layehosain	31.607˙	54.198˙	13	264	7.8	14	5.2	0.01
58	A	Darehyghol	31.462˙	54.254˙	65	421	7.1	12	4.17	0.01
59	T	Mirhashem	31.445˙	54.236˙	133	932	7.8	13	4.38	0.01
60	P N W	Zardeyn	31.420˙	54.231˙	2516	515	7.4	18	10.53	0.02
61	T	Zardeyn	31.442˙	54.235˙	2516	374	6.2	15	8.97	0.02
62	A	Nir	31.483˙	54.135˙	1620	640	7.6	17	4.78	0.01
63	A	Nir	31.489˙	54.128˙	1620	400	7.6	14	10.29	0.02
64	A	sakhvid	31.513˙	54.080˙	1747	264	7.8	14	9.18	0.02
65	T	Esterij(sakhvid)	31.500˙	54.060˙	1747	280	7.3	18	5.70	0.01
66	T	Taft	31.746˙	54.168˙	15717	895	7.4	20	8.14	0.02
67	T	Taft	31.744˙	54.202˙	15717	897	7.3	19	11.9	0.03
68	T	Taft	31.761˙	54.219˙	15717	735	7.1	18	6.53	0.01
69	Sp	Tamehr	31.738˙	54.100˙	1532	310	7.3	19	12.89	0.03
70	T	Eslamiya	31.738˙	54.108˙	1532	870	6.8	20	5.73	0.01
71	St	Eslamiya	31.724˙	54.106˙	1532	1460	6.8	19	1.53	0.00
72	P N W	Aliabad	31.674˙	53.514˙	2473	830	7.4	14	10.53	0.02
73	T	Aliabad	31.592˙	53.510˙	2473	720	7.3	19	9.46	0.02
74	P N W	Garizat	31.292˙	54.231˙	5558	650	7.8	15	7.04	0.01
75	P N W	Garizat	31.284˙	54.235˙	5558	730	7.6	13	10.77	0.03
76	P N W	Fakhrabad	31.297˙	54.135˙	329	610	7.4	16	5.45	0.01
77	P N W	Garizat	31.281˙	54.128˙	5558	710	7.7	15	1.54	0.00
78	P N W	Chahecham	31.281˙	54.080˙	11	780	7.2	18	10.78	0.03
79	P N W	Wells Ghorogh	31.612˙	54.060˙	72	410	6.9	13	7.84	0.02
80	P N W	Zayenabad	31.651˙	54.168˙	11	732	7.1	16	4.17	0.01
81	P N W	Mostofi	31.641˙	54.202˙	44	510	7.1	16	6.52	0.01
82	P N W	Mobarake	31.778˙	54.219˙	57	600	7.8	17	5.46	0.01

Symbols: A: Aqueduct, P H W: Private home wells, A D W: Agriculture and drinking water wells, T: Tap, P N W: public network wells, St: storage, Sp: Spring.

In 2005, Alirezazadeh measured radon levels in groundwater and surface water sources in Tehran. An average radon level of surface water was 2.5 Becquerel per liter and the average radon levels of groundwater was 46.4 Becquerel per liter. Remarkably, after extraction and mixed with surface water and with regard to long time that consumers reaches water, the radon rates were significantly decreased [19].This was consistent with results of this research.

In the study by Tabassum Nasir *et al.* in 2012 about the effective dose caused by radon in drinking water in Karachi, Radon concentrations in all samples were less than recommended levels by US-EPA (11Bq/Lit)[7], this result being consistent with the bulk of results obtained in this study.

In 2013 Malakootian *et al.* measured the concentrations of 222Rn in drinking water resources, in villages surrounding ‘‘Rafsanjan fault’’. In that study 14.2 % of total samples (8 samples of 56 samples) radon concentrations are above recommended limits by EPA. In this research 18 % of total samples (15 samples of 82 samples) radon concentrations are above recommended limits by EPA. Almost that result was consistent with results of this research [21].

A study was conducted in 2014 in Iran by Malakootian and colleague on the sources of drinking water and also drinking water network of Mehriz villages of Yazd province. In that study radon concentrations in 2 samples of 38 samples are above recommended limits by EPA. Samples with high radon concentrations were located in granitic rocks area, that result was consistent with results of this research [22].

In 2005 Bozarjmehri *et al.* measured gamma background radiation in 8 city of yazd province, the maximum value was in taft city, it's cause was expressed the existence uranium in the granite of the Shirkooh region ,that is located in this city [21]. This was consistent with results of this research [23].

In 2014, Malakootian *et al.* measured radon levels in39 drinking water springs and Qanats in Kouhbanan active fault zone. In six out of water samples, radon levels was more than proposed emission by EPA. In this research the Radon concentration of samples in villages are located through Dehshir–Baft fault is less than the permissible limit. Inactivity of the fault could have been the reason [24].

In this study, radon concentration is measured. According to World Health Organization guidelines (regarding drinking water quality) the annual effective absorbed dose values of all radio nuclides that enter the body through drinking water should not be more than 0.1mSv in a year [25].

CONCLUSION

Radon concentration was lower than the limit set by the Environmental Protection Agency of United States of America, in 82% of samples that can be used as drinking water by people in village of Taft town. Samples with high radon concentrations were located around Shirkooh area due to presence of granitic rocks containing uranium, thorium, Radium. Dehshir and Garizat villages located through Dehshir–Baft fault and the Radon concentration of these samples was less than the permissible limit, probably due to the In active Fault. The annual effective absorbed dose through drinking and breathing in an environment that this water is used ranged from 0.002 mSv/y (sample No.54) to 0.11 mSv/y (sample No.31). Of the whole sample, the effective absorbed dose of sample No. 31 was higher than annual limit declared by the WHO (0.1 mSv/y).

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Conflicts of interest: *none to declare.*

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