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Evaluation of the Radiation Dose from Radon Ingestion and Inhalation in Drinking Water Sources of Mashhad

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Abstract: Radon and its radioactive progenies in indoor places are recognized as the main sources of public exposure from the natural radioactive sources. The tap water used for drinking and other household uses can increase the indoor radon level. In the present research drinking water samples were collected from various places and supplies of public water used in Mashhad city which has about 4 millions population. Then radon concentration has been measured by PRASSI system three times for each sample. Results show that about 75% of water samples have radon concentration >10 Bq L^{-1} which advised EPA as a normal level. According to measurements data, the arithmetic mean of radon concentration for all samples was 16.238±9.322 Bq L^{-1}. As well as the annual effective dose in stomach and long per person has been evaluated in this research. According to the advised of WHO and the EU Council, just 2 samples induced the total annual effective dose greater than 0.1 mSv $year^{-1}$.

Key words: Radon, effective dose, drinking water, PRASSI system, Mashhad city, Iran

INTRODUCTION

Radon (^{222}Rn) is a naturally occurring radioactive noble gas with a half-life of 3.82 days which is a member of the ^{238}U decay series (Somlai *et al*., 2007). Radon and its short-lived decay products such as ^{218}Po, ^{214}Pb, ^{214}Bi and ^{214}Po at indoor places are recognized as the main sources of public exposure from the natural radioactivity contributing to nearly 50% of the global mean effective dose to the public (Somlai *et al*., 2007; UNSCEAR, 2000). The type of soil, building materials and water used for drinking and other household uses can make variable contributions to the indoor radon level (Sohrabi, 1998). The available data indicate that the main source of the indoor radon is the soil underlying a building. However, certain building materials with high concentrations of radium and even domestic water with high concentrations of radon can make major contributions to indoor radon exposure (Kearfott, 1989; Li *et al*., 2006). The most important aspect of radon in high concentrations can be health hazard for humans mainly a cause of lung cancer (Folger *et al*., 1994; Khan, 2000). However, a very high level of radon in drinking water can also lead to a significant risk of stomach and gastrointestinal cancer (Zhuo *et al*., 2001; Kendal and Smith, 2002). Knowledge of the levels of radon in each source including household water, particularly water from groundwater sources is necessary to protect public from consequences of excessive exposure to radiation mainly from the risk of lung cancer.

In Iran, the household water is supplied from various sources. Due to the dry climate condition in the most parts of the country, drilled wells have provided the main section of drinking water used by public. In a few parts with high annual rain, surface water is the main source for public usages.

In a number of cities including Mashhad, both groundwater and surface water are the sources of household water. Domestic water of Mashhad the second big city of Iran after Tehran which has about 4 million fixed population and >12 million religion tourists and business persons is supplied from two Torogh and Kardeh dams and >84 deep wells drilled in and around the city. Depending on raining condition the contribution of groundwater to the supplied domestic water, particularly in summer season may increase.

Depending on geographical situation of a specified region in the city, domestic water may be supplied from groundwater, surface water or a mixture of them. In addition, there are a number of large reservoirs in various parts of Mashhad for the collection and distribution of treated surface water and groundwater in the city.

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In the present research results of radon measurement in 50 water samples, sources and tap water actually used for drinking and other household uses in Mashhad. Radon of water samples that have been measured using PRASSI system include a ZnS(Ag) scintillation detector.

MATERIALS AND METHODS

Water sampling: The water samples were collected in various points distributed in and around the city of Mashhad. Figure 1 shows the sampling sites. Water sampling has been done from each water supply including wells and surface water as well as from household water. The samples were collected from the head ports of active wells selected for sampling, rivers and surface water reservoirs as well as from domestic water taps of high consumption rates, using the standard procedure proposed by the USA Environmental Protection Agency, EPA (USEPA, 1991). In this procedure a plastic funnel was connected via a short plastic hose to the water tap. After the water flowed for several minutes, the flow rate was slowed down and the water was allowed to be collected in the funnel. Then, three 150 mL water samples have been collected from each source or region. The collected samples were transferred to the laboratory of Payame Noor University for analysis.

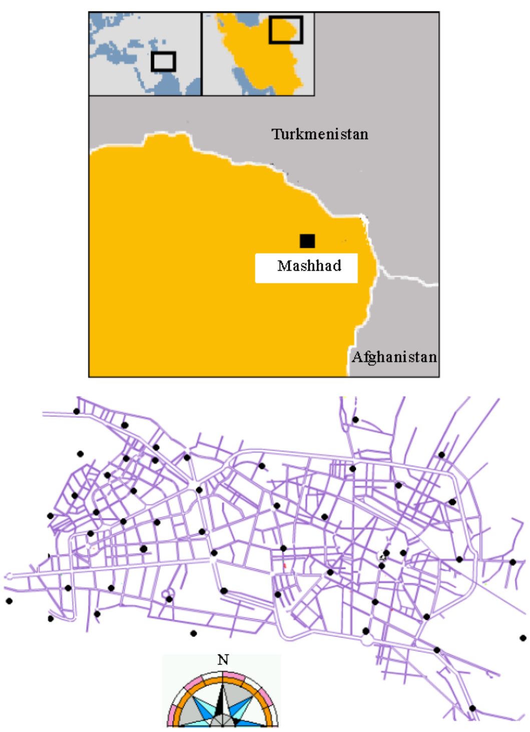

Fig. 1: (a) Mashhad location in Iran and (b) The map of Mashhad city and • shows the sampling sites

Radon measurement: The PRASSI (Portable Radon Gas Surveyor SILENA) Model 5S has been used for radon concentration measurement in the water samples which is particularly well suited for this type of measurement that must be performed in the closed loop circuit. Figure 2 shows the system set up of measurement including bubbler and drier column. PRASSI pumping circuit operates with constant flow rate at 3 L min^{-1} in order to degassing the water sample properly. The sensitivity of this system in continuous mode is 4 Bq m^{-3} during the integration time of 1 h.

To measure the content of radon in water, researcher consider V_{sample} = 150 mL of the water sample in bubbler and the PRASSI will read a concentration of:

$$Q_{PRASSI}\left[Bq\,m^{-3}\right] = \frac{A_{Rn}\left[Bq\right]}{V_{tot}\left[m^{3}\right]} \quad (1)$$

where, V_{tot} is the total volume of system equal 204×10^{-3} m^3 and A_{Rn} is the radon activity. It follows that the concentration of radon in water is:

$$Q_{Ra}\left[Bq\,m^{-3}\right] = \frac{A_{Rn}\left[Bq\right]}{V_{sample}\left[m^{3}\right]} = Q_{PRASSI}\frac{V_{tot}\left[m^{3}\right]}{V_{sample}\left[m^{3}\right]} \quad (2)$$

The average value of three measurements was considered as the radon concentration in the water sample.

RESULTS AND DISCUSSION

In the present research, a total number of 50 water samples from groundwater of deep wells, surface water of rivers, tap water samples were collected and analyzed for

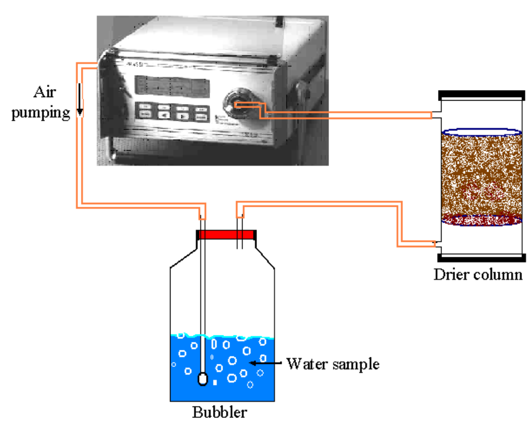

Fig. 2: The PRASSI system set up for radon measuring in the water sample

Table 1: Average radon concentration data and annual effective dose of different water sources per adult person

Water sample	Source or place of sampling	Average radon level (Bq L^{-1})	Annual effective dose of adults (Sv $year^{-1}$)	
			Stomach	Lung
1	Haram Motahar (SW)	0.064±0.004	0.012	0.160
2	Boiling water of sample 50 (SW)	0.701±0.004	0.126	1.752
3	Mojtama abi sarzamin mojhaye (SW)	3.641±0.004	0.655	9.102
4	Anderokh village (SW)	5.195±0.004	0.935	12.988
5	Qaem hospital (SW)	5.262±0.004	0.947	13.155
6	Falahi boulevard (GW)	6.942±0.004	1.250	17.355
7	Manba abe Emamie (MW)	8.942±0.004	1.610	22.355
8	Qhanat Elahie (SW)	9.632±0.004	1.734	24.080
9	Koohsangi region (MW)	9.742±0.004	1.754	24.355
10	Vakilabad river (SW)	9.917±0.004	1.785	24.793
11	Bande-e Golestan (SW)	9.986±0.004	1.797	24.965
12	Hashemi boulevard (MW)	10.008±0.004	1.801	25.020
13	Rahahan region 1 (SW)	10.221±0.004	1.840	25.553
14	Gaz region (GW)	11.049±0.004	1.989	27.622
15	Reza shahr (MG)	11.2144±0.004	2.019	28.036
16	Mokhaberat region (GW)	11.427±0.004	2.057	28.567
17	Rastgari region (GW)	11.504±0.004	2.071	28.760
18	Mehregan hospital (GW)	11.614±0.004	2.091	29.035
19	Gaem square (GW)	12.403±0.004	2.233	31.008
20	Rahahan region 2 (MW)	12.554±0.004	2.260	31.385
21	Ferdowsi university of Mashhad (GW)	13.342±0.004	2.402	33.355
22	Azad university (GW)	13.475±0.004	2.426	33.688
23	Payame Noor university (GW)	13.542±0.004	2.438	33.855
24	End of Emamie (GW)	13.875±0.004	2.498	34.688
25	Manba ab hejab (GW)	14.357±0.004	2.584	35.892
26	17 Shahrivar square (MW)	14.442±0.004	2.600	36.105
27	Cheshme Ghasem abad (SW)	14.64±0.004	2.635	36.600
28	Andishe 19 (GW)	15.241±0.004	2.743	38.102
29	Toroq river (SW)	16.641±0.004	2.995	41.602
30	End of Andishe boulevard (MW)	16.656±0.004	2.998	41.640
31	Melat park (SW)	17.136±0.004	3.084	42.840
32	Ahmad abad street (MW)	17.136±0.004	3.084	42.840
33	Ershad boulevard (GW)	17.888±0.004	3.220	44.720
34	Tabarsi square (GW)	18.562±0.004	3.341	46.405
35	Ab square (GW)	18.704±0.004	3.367	46.760
36	Sad metri broad way (GW)	19.328±0.004	3.479	48.320
37	Seyed Razi boulevard (GW)	19.648±0.004	3.537	49.120
38	Emdadi hospital (GW)	19.744±0.004	3.554	49.360
39	Taghato-e-Andishe and Hesabi (GW)	20.416±0.004	3.675	51.040
40	Azadshahr (MW)	20.752±0.004	3.735	51.880
41	Emam Hosein square (GW)	21.984±0.004	3.957	54.960
42	Sajad boulevard (GW)	23.248±0.004	4.185	58.120
43	End of hejab (GW)	23.408±0.004	4.213	58.520
44	Bustan-e Reja (GW)	25.568±0.004	4.602	63.920
45	Danesh Amooz boulevard (GW)	25.76±0.004	4.637	64.400
46	Bargh square (GW)	29.088±0.004	5.236	72.720
47	Shaahed boulevard (GW)	31.024±0.004	5.584	77.560
48	Shohada square (GW)	34.208±0.004	6.157	85.520
49	Abutaleb street (GW)	40.992±0.004	7.379	102.480
50	Taghato-e-Hejab and Hesabi (GW)	49.088±0.004	8.836	122.720

SW = Surface Water; GW = Ground Water; MW = Mixes of surface and ground Water

radon concentrations. The 3rd column of Table 1, shows the mean radon concentration in each water samples. According to the data the minimum and maximum radon concentrations in samples are 0.064 and 46.088 Bq L^{-1}, respectively. The arithmetic mean radon concentration of all samples was 16.238±9.322 Bq L^{-1}. As the data shown in Fig. 3, the radon concentrations is about 75% for samples used by people in Mashhad which are greater than the EPA advised level, 10 Bq L^{-1}. Researcher must mention that they sorted the experimental data in ascending order. The main reasons for large differences of radon concentration in sample seems to be due to mixing of surface water with groundwater in proportions mentioned earlier and storage of the mixed water in large reservoirs before distribution.

Unfortunately up to now, there is no specific national regulation for radioactivity concentrations in drinking water in Iran. Compared to maximum contaminant level of 10 Bq L^{-1} for radon in public drinking water suggested by the EPA (Folger *et al*., 1994), the radon concentrations in

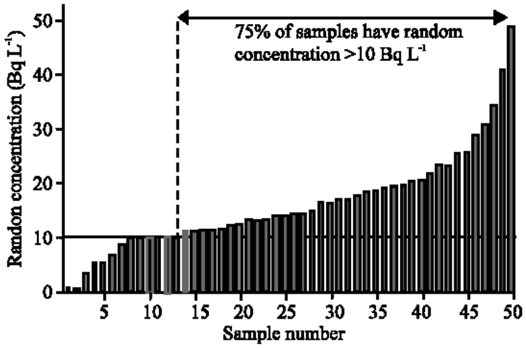

Fig. 3: Radon concentration for various samples of drinking water

most of the drinkable water samples in Mashhad, is significantly higher. In addition, the EPA requires that action be taken to reduce radon levels above an alternative maximum contaminant level of 150 Bq L^{-1} (Zhuo *et al*., 2001). A number of investigators have shown much higher radon concentrations in public drinking water (Savidou *et al*., 2001; Al-Kazwini and Hasan, 2003). Kusyk and Ciesla (2002) has been shown the mean value of 74 Bq L^{-1} for tap water and mean value of 207 Bq L^{-1} for wells in southern of Poland.

Evaluation of mean annual radon dose: The radon concentration of drinking water is an important issue from dosimetry aspect because more attention is paid to control of public natural radiation exposure. Regarding radiation dose to public due to waterborne radon, it is believed that waterborne radon may cause higher risk than all other contaminants in water (Vitz, 1991). Radon enters human body through ingestion and through inhalation as radon is released from water to indoor air. Therefore, radon in water is a source of radiation dose to stomach and lungs. The annual effective doses for ingestion and inhalation were calculated according to parameters introduced by UNSCEAR (2000). For ingestion the following parameters were used:

- The effective dose coefficient from ingestion equals to 3.5 nSv/(Bq L)
- Annual intakes by infants, children and adults of about 100, 75 and 50 L, respectively
- The annual effective doses due to ingestion corresponding to 1 Bq L^{-1} would equal to 0.35 μSv $year^{-1}$ for infants, 0.26 μSv $year^{-1}$ for children and 0.18 μSv $year^{-1}$ for adults

For inhalation the following parameters were used:

- Ratio of radon in air to radon in tap water supply is in the range of 4-10
- Average indoor occupancy time per person is about 7000 h $year^{-1}$
- Equilibrium factor between radon and its progeny is equal 0.4
- Dose conversion factor for radon exposure is 9 nSv/(Bq.h m^3)

The annual effective dose due to inhalation corresponding to the concentration of 1 Bq L^{-1} in tap water is 2.5 μSv $year^{-1}$. Therefore, waterborne radon concentration of 1 Bq L^{-1} causes total effective dose of about 2.68 μSv $year^{-1}$ for adults. The mean annual effective dose per person for adults caused by different water samples are shown in Table 1.

The World Heath Organization and the EU Council recommend the determination of reference level of the annual effective dose received from drinking water consumption at 0.1 mSv $year^{-1}$ from these three radioisotopes: ^{222}Rn ^{3}H, ^{40}K (Somlai *et al*., 2007). So, 2 samples (No. 49 and 50) induced the total annual effective dose >0.1 mSv $year^{-1}$.

CONCLUSION

The results of this study well indicate that the radon concentrations in public drinking water samples of Mashhad are mostly low enough and below the proposed concentration limits. Measuring radon results show about 75% of samples actually used by people in Mashhad are greater than the EPA advised level 10 Bq L^{-1}. Although, according to the advised of WHO and the EU Council just 2 samples (No. 49 and 50) induced the total annual effective dose >0.1 mSv $year^{-1}$. Therefore, there is a radon problem for these two sources and requiring some action to reduce their radon level before public usage such as mixing with surface water in large reservoirs or aerate water in order to allowing some radon removal from the water. It is evident that if the wells are to be the only water supply for some parts of Mashhad, the required remedial action should be taken to reduce radon concentrations consumed by people.

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