International Journal of Water Resources and Environmental Engineering Vol. 2(7), pp. 174-178, November 2010
Available online at http://www.academicjournals.org/ijwree
ISSN-2141-6613 ©2010 Academic Journals

Full Length Research Paper

Evaluation of the radiation dose from radon ingestion and inhalation in drinking water

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Accepted 13 August, 2010

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 million 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 gathered than 10 Bq/L 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. Similarly, the annual effective dose in stomach and lung per person has been evaluated in this research. According to the advice of WHO and EU Council, just 2 samples induced the total annual effective dose greater than 0.1 mSv/y.

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

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 (Somali 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 (UNSCEAR, 1993). 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 et al., 2002). Knowledge of the levels of radon in each source including household water, particularly water from groundwater sources, is necessary to protect the 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 most parts of the country, drilled wells have provided the main section of drinking water used by the 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 more than 12 million religion tourists and business persons, is supplied from two Torogh and Kardeh dams and more than 84 deep wells drilled in and around the city. Depending on the raining condition, the contribution of groundwater to the supplied domestic water, particularly in summer season, may increase. Depending on the geographical situation of a specified region in the city, domestic water may be supplied from groundwater, surface water or a mixture of

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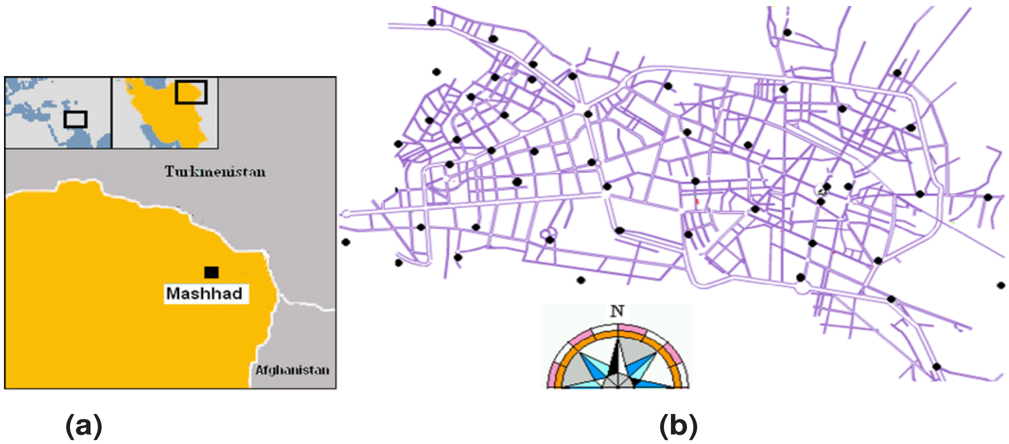

Figure 1. (a) Mashhad location in Iran, (b) The map of Mashhad city and ● shows the sampling sites.

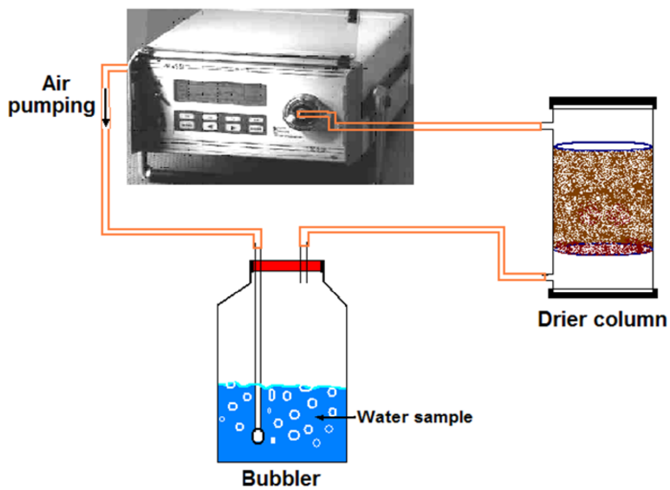

Figure 2. The PRASSI system set up for radon measuring in the water sample.

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.

In the present research results of radon measurement in 50 water samples, sources and tap water are actually used for drinking and other household uses in Mashhad. Radon of water samples that have been measured using PRASSI system includes 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; however, 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; EPA, 2006). 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 were collected from each source or region. The collected samples were then transferred to the laboratory of Payame Noor University for analysis.

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 a constant flow rate at 3 litters per minute in order to degas the water sample properly. The sensitivity of this system in a continuous mode is 4 Bq/m^3 during the integration time of 1 h.

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

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

where V_{tot} is the total volume of system equal to $2.4 \times 10^{-3}\ m^3$, and A_{Rn} is the radon activity. It follows that the concentration of radon in water is:

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

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 and tap water samples were collected and analyzed for radon concentrations. The third column of Table 1, presents 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, respectively. The arithmetic mean radon concentration of all samples was 16.238 ± 9.322 Bq/L. We must mention that we 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 till now, there is no specific national regulation for radioactivity concentrations in drinking water in Iran. When this is compared to the maximum contaminant level of 10 Bq/L for radon in public drinking water, suggested by the EPA (Folger et al., 1994), the radon concentrations in most of the drinkable water samples in Mashhad, are 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 (Zhuo et al., 2001). A number of investigators have reported much higher radon concentrations in public drinking water (Savidou et al., 2001; Al-Kazwini et al., 2003). Kusyk et al. (2002) has reported the mean value of 74 Bq/L for tap water and the mean value of 207 Bq/L for wells, in the southern part of Poland.

Evaluation of mean annual radon dose

The radon concentration of drinking water is an important issue from the dosimetry aspect, because more attention is paid to the control of public natural radiation exposure. Regarding radiation dose to the 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 report (UNSCEAR, 2000). For ingestion, the following parameters were used:

(i) The effective dose coefficient from ingestion equals 3.5 nSv/(Bq L);
(ii) Annual intakes by infants, children and adults are found to be about 100, 75 and 50 liters, respectively;
(iii) The annual effective doses, due to ingestion corresponding to 1Bq/L, would equal 0.35µSv/y for infants, 0.26µSv/y for children and 0.18µSv/y for adults.

For inhalation, the following parameters were used:

(i) Ratio of radon in air to radon in tap water supply is in the range of 4 to 10;
(ii) Average indoor occupancy time per person is about 7000 h/y;
(iii) Equilibrium factor between radon and its progeny is equal to 0.4;
(iv) 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 in tap water is 2.5 µSv/y. Therefore, waterborne radon concentration of 1 Bq/L causes total effective dose of about 2.68 µSv/y for adults. The mean annual effective dose per person for adults caused by different water samples are reported in Table 1.

The World Heath Organization (WHO, 1993) and the EU Council (EUC, 1998) recommend the determination of reference level of the annual effective dose received from drinking water consumption at 0.1 mSv/y 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 greater than 0.1 mSv/y.

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 that about 75% of samples actually used by people in Mashhad are greater than the EPA advised level, 10 Bq/L. Although, according to the advice of WHO and the EU Council, just 2 samples (No. 49 and 50) induced the total annual effective dose greater than 0.1 mSv/y. Therefore, there is a radon problem for these two sources, which require some action to reduce their radon level before public usage, such as

Table 1. Average radon concentration data and annual effective dose of different water sources per adult person (SW = Surface water; GW = Ground water; MW = Mixes of surface and ground water).

Water sample	Source or place of sampling	Average radon level (Bq/L)	Annual effective dose of adults (μSv/y)	
			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	(GW) Azad university	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	(GW) Manba ab hejab	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	(GW) Ershad boulevard	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

mixing with surface water in large reservoirs or aerate water in order to allow 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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