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Measurement of Radon Concentrations and Their Annual Effective Dose Exposure in Groundwater from Qassim Area, Saudi Arabia

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ABSTRACT

Radon is a radioactive noble gas of a natural origin that may be found anywhere in soil, air and in different types of water. It is worthy to carry out the distribution of radon (^{222}Rn) activity concentration and their annual effective dose exposure in groundwater samples from Qassim area, Saudi Arabia. Radon concentrations were measured by using RAD7 an electronic radon detector connected to a RAD-H_2O accessory (Durridge Co., USA). The measured radon concentration ranges from 0.76 to 4.69 Bq L^{-1} with an average value of 2.8 Bq L^{-1}. The measured values of radon concentration are well in the range within the EPA's Maximum Contaminant Level (MCL) of 11.1 Bq L^{-1}. The total annual effective dose resulting from radon in groundwater of Qassim area were significantly lower than the (United Nations Scientific Committee on the Effects of Atomic Radiation UNSCEAR and World Health Organization WHO) recommended limit for members of the public of 1 mSv year^{-1}. The measured values for underground water from the study area suggest that the area is safe for farmers and there is no significant threat to the population as per as radon concentration is concerned.

Key words: Radon, RAD7 detector, annual effective dose, maximum contaminant level

INTRODUCTION

Research carried out in recent decades has shown that under normal conditions, more than 70% of a total annual radioactive dose received by people originates from natural sources of ionizing radiation, whereby 40% is due to inhalation and ingestion of natural radioactive gas radon ^{222}Rn and its decay products (UNSCEAR, 1993). Radon is a radioactive noble gas occurring in varying concentrations practically everywhere. It has three isotopes ^{222}Rn (Radon), ^{220}Rn (Thoron) and ^{219}Rn (actinone). Its most important isotope is ^{222}Rn, which is a product of decay of ^{238}U. The nuclei of ^{222}Rn have a half life of 3.824 days, decay by emitting α particle and generate radioactive progeny. Two of the ^{222}Rn descendents, ^{214}Po and ^{218}Po are α emitters and they contribute over 90% to the total radiation dose received due to radon exposure. Inhalation of indoor radon has long been recognized as a risk to health. The major sources of the indoor radon and its progeny are building materials, natural gas and underground-derived water supply (Kant *et al.*, 2010; Chougankar *et al.*, 2004). Radon and its daughters in the air can be inhaled as they decay some emit high-alpha particles as shown in Fig. 1.

In general, residential radon is regulated by an action level of radon concentration between 200 and 600 Bq m^{-3} based on ICRP recommendations (ICRP, 1993). Radon exposure may cause health risks in terms of cancer of human organs, mainly the stomach and lungs

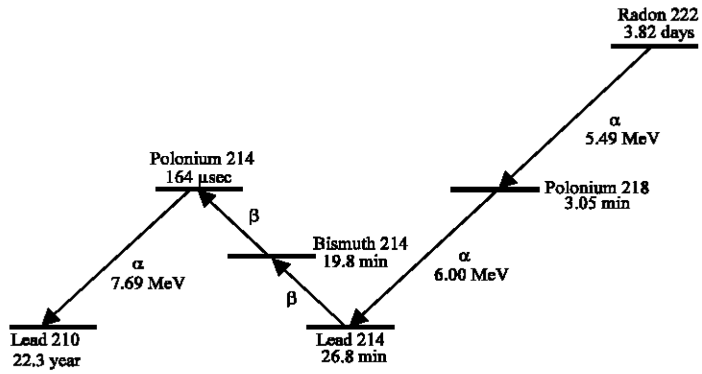

Fig. 1: Radon decay chain from radon 222 to lead 210

(Villalba *et al.*, 2006). Therefore, due to growing concern over the Airborne and waterborne/dissolved ^{222}Rn in underground waters, many studies have been conducted worldwide to measure the concentration levels of radon as well as to find out cost effective technologies for removing radon from underground water supplies (Cevik *et al.*, 2006; Erlandsson *et al.*, 2001). Hence, an attempt has been made for the first time in the current study areas by estimating radiogenic isotope radon (^{222}Rn) in the selected locations in the Qassim area. The present study was carried out with a view to bring awareness and concern among the people residing in these areas to save themselves from the radiological hazards due to ingestion of radon dissolved in underground water.

MATERIALS AND METHODS

Sampling: A total of 16 sampling points in Qassim area were selected for investigation. The wells were purged through pumping for 10 min to ensure sample quality. The depth of the Selected wells ranging from 12 to 600 m. All the water samples were collected in special glass bottles 250 mL capacity designed for radon in-water activity measurement ensuring minimum radon loss by degassing and without any air contact (Stringer and Burnett, 2004). This project was carried out between February to August 2012.

Laboratory measurements: ^{222}Rn measurement of ground water samples was carried out using a radon-in-air monitor RAD-7 (Durridge Co. Ltd) using RAD H_2O technique (Fig. 2) with closed loop aeration concept (Lee and Kim 2006). RAD H_2O technique employs closed loop concept, consisting of three components, (1) the RAD7 or radon monitor, on the left, (2) the water vial with aerator, in the case near the front and (3) the tube of desiccant, supported by the retort stand above as marked in Fig. 2a. Schematic representations of the radon-in-air monitor RAD-7 with RAD H2O given in Fig. 3. The radon activity was measured using a radon-in-air monitor (RAD7) coupled with a specially fabricated closed loop of aeration system that strip/free radon from the water. The sample bottles of 250 mL were connected to the RAD-7 and the internal air pump of the radon-monitor was used for re-circulating a closed air-loop through the water sample, purging radon from the water into the air-loop. The air was re-circulated through the water continuously to extract the radon until RAD-H2O system reaches a state of equilibrium. After reaching equilibrium between water, air and radon progeny attached to the PIPS detector, the radon activity concentration measured in the air loop was used for calculating the initial radon-in-water concentration of the respective sample. The RAD-7 allows determination of radon-in-air activity concentrations by detecting the alpha-decaying radon progeny ^{218}Po and ^{214}Po using a passivated implanted planar silicon detector (PIPS). The radon monitor (RAD-7) uses a high electric field above a silicon semi-

Fig. 2(a-b): Measurement apparatus RAD 7 (RAD H_2O User Manual), (a) Aerating a 250 mL water sample and (b) Aeration in progress. 1: Radon monitor, 2: Water vival with aerator, 3: Tube of desiccant

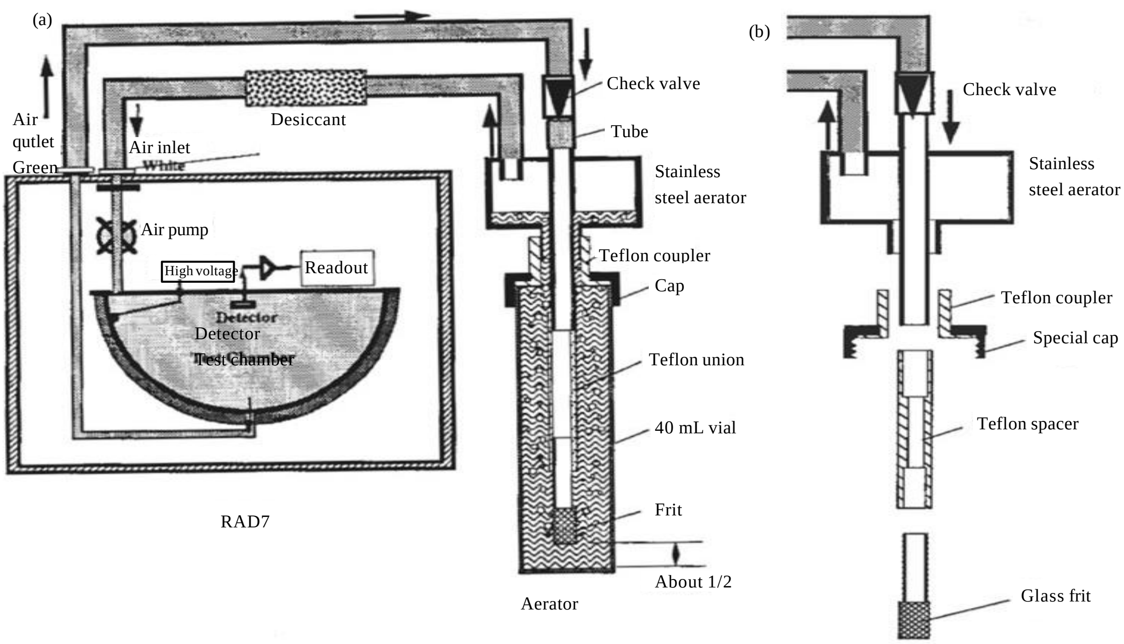

Fig. 3(a-b): RAD 7 instrument (a) Its schematic representation for measuring radon in water and (b) Aerator assembly

conductor detected at ground potential to attract the positively charged polonium daughters, ^{218+}Po ($t_{1/2}$ = 3.1 min; alpha energy = 6.00 MeV) and ^{214+}Po ($t_{1/2}$ = 164 μsec; alpha energy = 7.67 MeV), which are counted as a measure of ^{222}Rn concentration in air. At the end of the run (30 min after the start), the RAD7 prints out a summary, showing the average radon reading. The time elapsed for the sample collection and analysis corrected using the equation:

$$C = C_0\, e^{-\lambda t} \tag{1}$$

where, C is the measured concentration, C_0 initial concentration (to be calculate) after the decay correction and t is the time elapsed since collection (days), $\lambda = (0.693)/(t_{1/2}) = 0.181$, $t_{1/2} = 3.83$ days.

Calculation the annual effective dose: Radon gas is the largest contributor to the collective exposition to natural radiation of the population in the world (IAEA, 1989; Nazaroff and Nero, 1988). The inhalation of short-lived decay products of radon (^{222}Rn) accounts on average about 50% of the effective equivalent dose on the human being (Kant *et al.*, 2010). The annual effective dose to an individual consumer due to intake of radon from drinking water is evaluated using the relationship (Alam *et al.*, 1999):

$$D_W = C_W\, CR_W\, DC_W \tag{2}$$

where, D_w is the annual effective dose (Sv year^{-1}) due to ingestion of radio-nuclides from the consumption of water, C_w concentration of ^{222}Rn in the ingested drinking water (Bq L^{-1}), CR_w annual intake of drinking water (L year^{-1}), DC_w is the ingested dose conversion factor for ^{222}Rn (Sv Bq^{-1}) (Somashekar and Ravikumar, 2010). For calculation of effective dose, a dose conversion factor of 5×10^{-9} Sv Bq^{-1} suggested by the United Nations Scientific Committee on the Effects of Atomic Radiation has been used (UNSCEAR, 1993). Annual effective dose due to intake of ^{222}Rn from drinking water has been calculated considering that an adult (Age> 8 year), on average, takes 730 L water annually (Cevik *et al.*, 2006). Following ingestion of ^{222}Rn dissolved in drinking water, annual effective doses (nSv year^{-1}) and effective doses per liter (nSv L^{-1}) were calculated.

RESULTS AND DISCUSSION

The measurements for radon concentration have been carried out for underground wells from Qassim area, Saudi Arabia, using RAD7 detector. Table 1 represents the overall radon concentration levels and their annual effective dose exposure. It can be seen that radon activity varies from 0.76 to 4.69 Bq L^{-1} with an average value of 2.8 Bq L^{-1}. The results of all samples are within the US Environmental Protection Agency Maximum Contaminant Level (MCL) of 11.1 Bq L^{-1} (EPA, 1991). Figure 4 shows comparison between the average values of radon in three cities in Qassim area. The spatial variations in radon concentration could be a function of the geological structure of the area, depth of the water source and also differences in the climate and geo-hydrological processes that occurs in the area. When the measured radon concentration values are compared with the allowed maximum contamination level for radon concentration in water (which is 11 Bq L^{-1}), proposed by USEPA (1991), it can be seen that present value are well below this recommended value .Also, when the measured values for radon concentration are compared with the European Commission Recommendations on the protection of the public against exposure to radon in drinking water supplies which recommends action levels of 100 Bq L^{-1} for public water supplies, it can be seen that the levels we measured were below these limits.

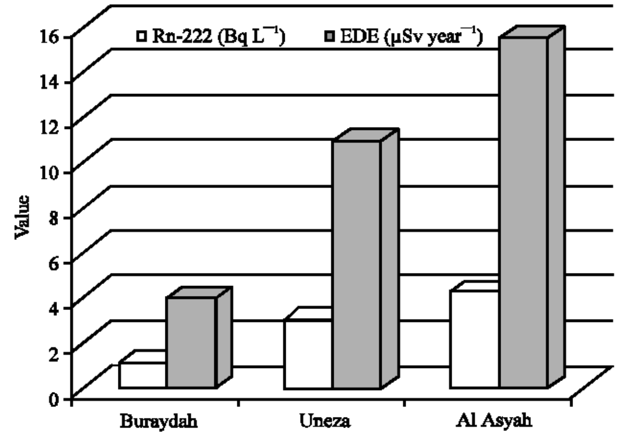

Fig. 4: Comparison between the average values of radon concentrations and annual effective dose (EDE) rate in three cities in Qassim area

Table 1: Radon concentration and their annual effective dose exposure in groundwater from Qassim area, Saudi Arabia

Sample No.	Location	^{222}Rn (PCi/L)	^{222}Rn (Bq L^{-1})	Annual effective dose rate (µSv year^{-1})	Annual effective doses per liter (nSv L^{-1})	Total annual effective dose rate (mSv year^{-1})
1	Buraydah	978±13	1.34	4.89	6.70	0.0049
2	Buraydah	934±17	1.28	4.67	6.40	0.0047
3	Buraydah	743±27	1.02	3.72	5.10	0.0037
4	Buraydah	554±32	0.76	2.77	3.80	0.0028
5	Buraydah	729±27	1.00	3.65	5.00	0.0037
Mean		787±23	1.08	3.94	5.40	0.0040
6	Uneza	1972±18	2.70	9.65	13.50	0.0097
7	Uneza	1786±32	2.44	8.90	12.20	0.0089
8	Uneza	2400±20	3.29	12.01	16.45	0.0120
9	Uneza	2318±21	3.17	11.57	15.85	0.0116
10	Uneza	2528±23	3.46	12.63	17.30	0.0126
Mean		2200±23	3.01	10.95	9.23	0.0110
11	Al Asyah	3421±32	4.69	17.12	23.45	0.0171
12	Al Asyah	3224±30	4.42	16.14	22.10	0.0161
13	Al Asyah	3297±33	4.52	16.51	22.60	0.0165
14	Al Asyah	3093±32	4.24	15.49	21.20	0.0155
15	Al Asyah	3239±33	4.44	16.22	22.20	0.0162
16	Al Asyah	2934±35	3.20	11.68	16.00	0.0117
Mean		3202±33	4.25	15.52	21.25	0.0155

The obtained results are far less compared to radon results obtained by Ramola *et al.* (1999), Borio *et al.* (2005), Landstetter and Katzlberger (2009). Ramola *et al.* (1999) has studied the measurements of radon for drinking water in the Dehradun City and it was found that radon concentration was varying from 27 to 154 and 26 to 129 Bq L^{-1}, respectively in hand pump and tube wells samples analyzed. Borio *et al.* (2005) has investigated the Radon and tritium measurements in drinking water in a region of central Italy (Umbria) using liquid Scintillation (L.S.) and Gamma Spectrometry (GS). Accordingly, the radon concentration was in the range of

4.63±0.41 to 65.7±9.2 Bq L^{-1} in the case of samples analyzed by LS and 8.54±3.49 to 69.3±0.2 Bq L^{-1} in few of the samples measured by means of GS. Health risks due to radon in drinking water in US has been studied by Hopke *et al.* (2000) under normal conditions and accordingly, the intake of radon from indoor and ambient air far surpasses the intake of radon from drinking water via both the ingestion and inhalation routes. The global average dose from the inhalation of radon and its decay products from all sources is approximately 1 mSv $year^{-1}$ (UNSCEAR, 2000; WHO, 1993) which is slightly less than half the total natural radiation exposure of 2.4 mSv $year^{-1}$ (UNSCEAR.,1988). In comparison, the average global dose from ingestion of radon in drinking water is relatively as low as 0.025 mSv $year^{-1}$ via inhalation and 0.002 mSv $year^{-1}$ from ingestion (UNSCEAR, 2000; WHO, 1993).

Hence, an attempt has been in the current study to estimate the total annual effective dose resulting from radon in the sampled groundwater and it was noticed that annual effective dose (EDE) and effective dose per liter (EDL) were varying with increase in radon concentration. The calculated annual effective dose (EDE) and effective dose per liter (EDL) were ranging from 2.77 to 17.12 μSv $year^{-1}$ and 3.80 to 23.45 nSv L^{-1}, respectively (Table 1). It was evident from Table 1 that the total annual effective dose resulting from radon in groundwater of Qassim area were significantly lower than the recommended limit 1 mSv $year^{-1}$ for the public (UNSCEAR, 2000; WHO, 1993).

CONCLUSION

The present study showed that the radon concentration in groundwater samples from Qassim area is well within the maximum contaminant level (MCL) value. The measured radon concentrations vary from 0.76 to 4.69 Bq L^{-1} with an average value of 2.8 Bq L^{-1} and will pose none serious health risks. Hence the study area is considered to be safe for the residents. Even the effective dose per liter and annual effective dose values were varying with respect to the increase in radon concentration and were significantly lower than the UNSCEAR and WHO recommended limit for members of the public of 1 mSv $year^{-1}$. These data must be regarded as preliminary and further extensive studies should be done on large scale by initiating further detailed investigation of whole command area completely for radon contamination, to increase awareness and mitigate possible hazards.

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