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Evaluation of Radon-222 Level in the Warehouses at Umm Al-Qura University

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Abstract. Radon (^{222}Rn), a daughter product of Ra in Uranium series, is a naturally occurring radioactive gaseous isotope. When radon isotopes are inhaled, it might damage the lungs if very excessive. The aim of this work is to assess ^{222}Rn activity concentration present inside 26 warehouses of Umm Al-Qura University using RAD 7 detector and to alert the workers, while working inside the warehouses. The highest ^{222}Rn concentration was 126.1±6.2 Bq/m^3 in the old storage 2 with AED (annual effective dose equal) to 3.18 mSv/y. The lowest was 8.3±0.98 Bq/m^3 in the organic chemicals storage with AED equal to 0.209 msv/y. The value of EP (Exposure to ^{222}Rn Progeny) and the PAEC (potential alpha energy concentration) was equal to in the range 0.0533 WLM/Y-0.0351 WLM/Y and 13.63-0.9 mWL respectively in the two warehouses. The value of CPPP (number of lung cancer cases per year per million people) was 57 in the old storage 2 warehouse, while the lowest value was found in Organic Chemicals Storage warehouse which was equal to 4. ^{222}Rn concentration in all the 26 warehouses is substantially below the limits set by US Environmental Protection Agency (USEPA), which recommends remediation at a maximum of 148 Bq/m^3 (4 pCi/L) but according ALARA high ventilation system is recommended in warehouses rooms.

Keywords: radon gas, RAD 7, indoor radon, warehouses, UQU

Introduction

Radon is a radioactive, colourless and odourless gas that is continuously released by natural sources of radiation present in rocks, soil and water (Hassan *et al*., 2022; Salim and Ebrahem, 2019; Al-Jarallah *et al*., 2003). There are three natural isotopes of radon: ^{219}Rn with $T_{1/2}$=3.96 s, ^{220}Rn $T_{1/2}$=56.6 s and ^{222}Rn $T_{1/2}$=3.823 days. All the natural radon isotopes are alpha radio-isotopes. Exposure to radon isotopes yields 50% of the total dose to the members of public from naturally occurring radiation sources. The USEPA sets a limit of 148 Bq/m^3 for ^{222}Rn action level (USEPA, 2012). Large scale ^{222}Rn research has primarily been conducted in the USA and Europe. In Saudi arabia's largest cities, indoor ^{222}Rn levels have also been measured. Even though Saudi arabia normally has low ^{222}Rn gas levels (Alaamer, 2012; Al-Saleh, 2007; Al-Jarallah *et al*., 2006; Abu-Jarad *et al*., 2003; Garawi, 1996; Abu-Jurad and Al-Jarallah, 1984). The concentration of ^{222}Rn gas in the open air is negligibly low and does not pose any health risk but when ^{222}Rn seeped into confined or poorly ventilated homes, buildings, tunnels and mines, it can build up and reach relatively high quantities, which would be of concern to human health. The most significant daughter products of ^{222}Rn due to its intake, in terms of getting radiation dose to humans, are the high energy alpha-emitting isotopes ^{218}Po and ^{214}Po. As the progeny are formed, they aggregate into clusters of approximately 1*nm* dia., referred to as the unattached fraction and associate with existing aerosol particles in the air to form attached fraction with larger particle sizes of 10 nm to >1 µm. Because ^{226}Ra and ^{232}Th concentrations in soil vary, radon concentrations and their progeny also do (Mao *et al*., 2023). Ground cover (including asphalt, structures and vegetation), altitude, grain size and porosity of the soil, temperature, atmospheric pressure, soil moisture, rainfall and snow cover, climatic conditions, seasons and other conditions all have an impact on the concentrations of ^{222}Rn in the air (Xie *et al*., 2024). Geographic location affects seasonal and nocturnal fluctuations in atmospheric ^{222}Rn concentrations. Ground level concentrations are at their highest in the fall and early winter seasons and at their lowest in the spring (Nunes *et al*., 2023). Because air

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temperature inversions are more likely to happen in the mornings, ^{222}Rn concentrations are often at their highest during that time of day. After daybreak, heating causes the inversion to burn off, which frees up more space for ^{222}Rn to climb through. In the late afternoon, ^{222}Rn concentrations are typically low. Although variations of >10 have been documented at few places, the normal diurnal change in concentration is within a factor of three to five. Outdoor ^{222}Rn level varies from 5-10 Bq/m^3. Whereas it can vary indoors from 10 Bq/m^3 to 10000 Bq/m^3.

Materials and Methods

Study area. The study was designed to record ^{222}Rn levels in 26 warehouses with different areas (27.5-42 m^2), using a RAD-7 electronic radon and thoron monitor (RAD-7, Durridge Co-2009). Before each measurement, RAD-7 was purged for 10 min to discharge the remaining radon gas including thorium inside the RAD-7. After purging, the air inlet nozzle of the RAD-7 was positioned 0.8 m above the floor. The indoor radon concentration was continuously measured for 24 h, make a reading every 30 min, with 48 cycles, average radon concentration over the cycles are collected, each measurement is done at the center of the warehouse, there was no forced air-conditioning except natural ventilation through the entrance door opened and closed by workers in routine works. The measurement data were recorded and analyzed by using the program embedded already in RAD-7. In addition, these devices measure and track additional environmental parameters beyond the radon concentration such as relative humidity and temperature. The measurements have been carried out in the warehouses of Umm Al-Qura University in Makkah Al-Mukarramah, Kingdom of Saudi Arabia, during the period from 5th October, 2021 to 4th January, 2022.

RAD-7 radon monitor. The RAD-7 is a continuous ^{222}Rn monitor, which can measure various levels of ^{222}Rn concentration in the range of 0.1 pCi/L to 20,000 pCi/L (3.7 to 740,000 Bq/m^3) with the relative uncertainty of ±5% (RAD-7, Durridge Co-2009). The RAD-7 radon monitor employed in this study shown in Fig. 1a. The tubing used along with the desiccant of calcium sulfate to absorb the moisture. Schematic diagram of measurement chamber of the RAD-7 shown in Fig. 1b.

Radiological parameters. The annual effective dose (AED) in units (msv/y) were calculated by using the following equation (Hamidawi, 2012):

$$AED(msv/y) = C_{Rn} \times F \times H \times T \times D \quad \text{.....(1)}$$

where;

C_{Rn} is the radon concentration in Bq/m^3, F is the equilibrium factor and F=(0.4); H is the occupancy factor and H = (0.8) [UNSCEAR United Nations

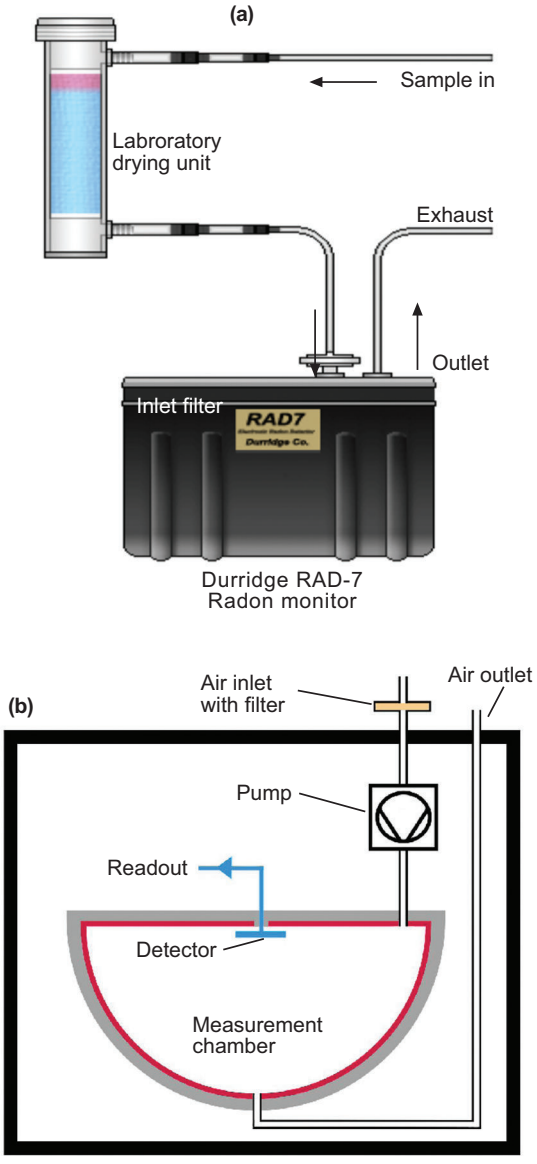

Fig. 1. (**a**) The RAD-7 Professional electronic radon detector. (**b**) Schematic diagram of measurement chamber of the RAD-7.

Scientific Committee 2000; T is the time in one year in hours and T= (8760 h/y); D is the dose conversion factor [D = 9*10^{-6} m Sv / (Bq.h/m^3)].

Exposure to ^{222}Rn Progeny (EP) in term of WLM/Y units were calculated using the following equation (Salim and Ebrahiem, 2019):

$$EP\ (WLM/Y) = \frac{8760 \times n \times F \times C_{Rn}}{170 \times 3700} \quad \text{.....(2)}$$

n is the fraction of time spent halls and n=0.8; where the number of hours per year is 8760 and is the number of hours per working month 170 (Kitson *et al*., 2019).

The potential alpha energy concentration (PAEC) in units (WL) was calculated by using the following equation (Ismail and Jaafer, 2010):

$$PAEC\ (WL) = (F \times C_{Rn})/3700 \quad \text{.....(3)}$$

The number of lung cancer cases per year per million people in each AED (CPPP) were calculated by using the following equation (Najam, 2018):

$$CPPP = AED \times (18 \times 10^{-6}\ mS/v.y) \quad \text{.....(4)}$$

Results and Discussion

The ^{222}Rn levels measured in the interiors of all warehouses at Umm Al-Qura University (Table 1). The most elevated normal the ^{222}Rn concentration (C_{Rn}) in warehouses was found in the old storage 2 warehouse which was 126.1 Bq/m^3, while the least normal the ^{222}Rn

Table 1. Radon gas measurements inside Umm Al-Qura University warehouses

Site	Mean (Bq/m^3)	SD	AED m Sv/y	EP WLM/Y	PAEC (mWL)	CPPP/ 10^6
Radioactive chemicals storage (educational purposes waste sources)	23.1	2.06	0.5828	0.0977	2.50	10
Glassware storage 1	21.9	1.39	0.5525	0.0926	2.37	10
Glassware storage 2	16.3	2.77	0.4112	0.0689	1.76	7
Glassware storage 3	18.4	3.45	0.4642	0.0778	1.99	8
Inorganic chemicals storage	18.8	1.92	0.4743	0.0795	2.03	9
Acids storage	15.4	1.84	0.3885	0.0651	1.66	7
Salt chemicals storage	15.2	2.42	0.3835	0.0643	1.64	7
Dangerous chemical storage	15.7	1.93	0.3961	0.0664	1.70	7
Organic chemicals storage	8.3	0.98	0.2094	0.0351	0.90	4
Glassware storage 4	89	3.96	2.2454	0.3764	9.62	40
old storage 1	54.6	4.44	1.3775	0.2309	5.90	25
old storage 3	35.4	3.81	0.8931	0.1497	3.83	16
old storage 4	14.8	1.97	0.3734	0.0626	1.60	7
old storage 5	33.4	3.88	0.8426	0.1412	3.61	15
old storage 6	11.2	1.41	0.2826	0.0474	1.21	5
RLUFAS Storage	14.5	1.16	0.3658	0.0613	1.57	7
old storage 2	126.1	6.2	3.1814	0.5333	13.63	57
FAS Storage1	36.6	2.56	0.9234	0.1548	3.96	17
FAS Storage 2	37.6	2.54	0.9486	0.1590	4.06	17
FAS Storage 3	31.3	1.86	0.7897	0.1324	3.38	14
FAS Storage 4	40.4	2.03	1.0192	0.1708	4.37	18
FAS Storage 5	43.2	1.81	1.0899	0.1827	4.67	20
FAS Storage 6	48.7	2.37	1.2286	0.2059	5.26	22
FAS Storage 7	73.7	3.81	1.8594	0.3117	7.97	33
FAS Storage 8	40.9	2.54	1.0319	0.1730	4.42	19
FAS Storage 9	38.2	2.97	0.9637	0.1615	4.13	17
Average	**35.49**		**0.8953**	**0.1501**	**3.84**	**16**
The limit values of ICRP (17)	**300**		**7.6**	**1.3**	**32**	**136**
The limit values of UNSCEAR (18)	**300**		**8**	**1.3**	**32**	**135**

concentration (C_{Rn}) was found in the organic chemicals storage which was 8.3 Bq/m^3 (shown in Fig. 2), while it was with total average dose of 35.49 Bq/m^3. This variation due to natural ventilation through the entrance door opened and closed by workers in routine works and geological variation of warehouses room, where the warehouses spread on around one square Km. The highest value of exposure to ^{222}Rn progeny (EP) was found in the old storage 2 warehouse which was equal to 0.533 WLM/Y, while the lowest value of Exposure to ^{222}Rn progeny (EP) was found in the organic chemicals storage warehouse which was equal to 0.0.035 WLM/Y, with an average value 0.15 WLM/Y, which is higher than the recommended range (1-2 WLM/Y). The highest value of potential alpha energy concentration (PAEC) was found in the old storage 2 warehouse which was 13.63 mWL, while the lowest value of potential alpha energy concentration (PAEC) was found in the organic chemicals store warehouse which was 0.9 mWL with an average value 3.8 mWL, which is less than the recommended value 32 mWL. Also from it can be noticed that the highest value of the annual effective dose (AED) was found in the old storage 2 warehouse which was equal to 3.18 m Sv/y, while the lowest value of the annual effective dose (AED) was found in the organic chemicals store warehouse which was equal to 0.209 m Sv/y with an average value 0.895 m Sv/y. Finally, it can be noticed from Table 1 that the highest value of lung cancer cases per year per million people (CPPP) was found in the old storage 2 warehouse which was equal to 57, while the lowest value of lung cancer cases per year per million people (CPPP) was found in organic chemicals storage warehouse which was equal to 4, with an average value 16.

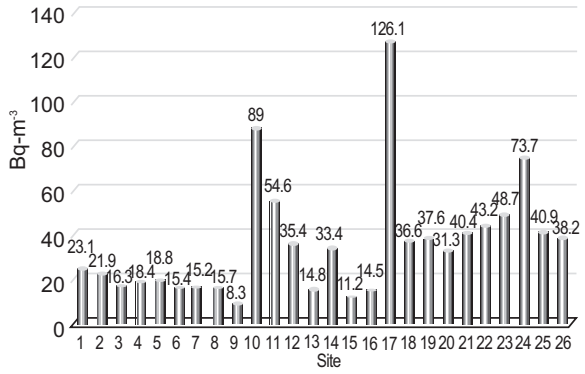

Fig. 2. Mean radon concentration in Bq/m^3

Conclusions

The ^{222}Rn concentration in the indoor warehouses of Umm al-Qura University is substantially below the limits of ^{222}Rn by the US Environmental Protection Agency. But due to natural ventilation through the entrance door opened and closed by workers, there are differences in ^{222}Rn concentration levels. However, according to ALARA, wearing masks and reducing the time in the closed places is recommended to minimize the amount of ^{222}Rn gas exposure. The implementation of a proper ventilation system or even taking benefit of the natural air exchange by opening windows and door occasionally can avoid accumulation of radon, thus the high ventilation system recommended in warehouses rooms.

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