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Assessment of concentration and exposure doses due to radon by using CR-39 plastic track detectors in the dwellings of Saudi Arabia

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ABSTRACT

Indoor radon studies have been carried out in some dwellings of Jazan province, Saudi Arabia using CR-39 plastic track detectors. The study has been undertaken for the purpose of health risk assessments. The CR-39 detectors were placed in the bedrooms, guest rooms and living rooms, and exposed for one year. The annual average indoor radon concentration in dwellings varies from 18.2±5.5 to 41.4±10.4 Bqm^{-3} with a mean value of 31±6.6 Bqm^{-3}, which is well within the recommended action level. The seasonal variations of indoor radon reveal the maximum values in winter and minimum in summer. Mean concentrations amount to 27.4, 35.7 and 31.7 Bqm^{-3}in the living rooms, guest rooms and bedrooms, respectively. The lowest radon concentration (22.7±4.9 Bq m^{-3}) was found in Jizan, whereas the highest was found in Samtah (35.7±8.2 Bq m^{-3}). The annual estimated effective dose received by the residents of the studied area was found to vary from 0.47 ± 0.05 to 1.06 ± 0.14 mSv y^{-1} with the mean value of 0.80±0.08 mSv y^{-1}. The lifetime fatality risk is found to vary from 0.29 to 0.65%. The results have been compared with the results reported in other areas of the same country and in others countries. All the values of radon concentration, effective dose and fatality risk in all dwellings under test were found to be quite lower than the permissible value recommended by UNSCEAR and ICRP.

Keywords: Radon inhalation, effective dose, lifetime cancer risk, nuclear track detectors.

INTRODUCTION

Radon ($_{86}Rn^{222}$) is an inert naturally occurring radioactive gas produced by the decay of radium-226, resulting itself from the radioactive decay of ^{238}U. It has a half-life of 3.82 days and disintegrates by emission of alpha particles of energy 5.5 MeV. This gas (^{222}Rn) is produced in the soil and diffuses inside houses before it decays. However, radon gas is penetrating inside houses through the openings in the concrete basement structure; the concentration can reach high levels if air exchange is reduced.

Indoor radon levels are governed by different parameters such as atmospheric conditions, seasonal situations (different ventilation, different exhalation by soil), local geology, building features (types of building materials used, the height of the considered floor, orientation of the house) and the habits of the house occupants. Generally, the radon levels are different in different rooms of the same house [1].

Radon and its short-lived daughters are considered to be responsible for a significant dose to human beings, especially when they are in enclosed areas like caves, underground mines, poorly designed and badly ventilated houses. People generally spend most of their time in indoor areas, and therefore measurement of indoor radon level is very important. The measurement of radon concentration in the dwellings and in the environment has assumed ever increasing importance all over the world due to the fact that the inhalation of indoor radon and its progeny contribute a major fraction, nearly 60% of the total background radiation dose to the human being [2].

The health effects of radon are caused by its four radioactive decay products inhaled and deposited in the lungs causes damage as the emitted alpha particles strike the lung tissues, resulting in lung cancer in the long term [3-5]. The associated risk is the induction of lung cancer after 10–20 years of latency. In recent years the concern about this risk has grown and epidemiological studies have been conducted to assess the relation between radon exposure and lung cancer rate. The assessment of radiological risk related to inhalation of radon and its progeny is based mainly on the integrated measurement of radon [6-7].

For health risk assessment, indoor radon level measurements were carried out in a number of dwellings of Jazan province for a period of 1 year. 10 villages/towns and five houses in each village/towns were chosen for the present study. The annual exposure to the occupants, the annual effective dose received by the population and the lifetime fatality risk estimations have been assessed. The importance of this study is increased because limited work was carried out in this area.

Studied area

Jazan is one of the provinces of Saudi Arabia with a total population of 1.5 million peoples and area 13,457 km². The capital is the Jizan city. It stretches some 300 km along the southern Red Sea coast, just north of Yemen. The province Jazan is situated between 42°33′40″ east longitude and 16°53′21″ north latitudes (Figure 1). The weather in Jazan is hot in the summer and mild in the winter. The coastal regions of Jazan province are part of Tihamah, probably the hottest place in the country, with mean maximum temperatures ranging from 40°C in July to 31°C in January. High humidity from coastal lagoons makes the climate, even less bearable than it would be otherwise. Rainfall is extremely low at less than 75 millimeters (3 inches) per year [8].

Types of houses

Most houses in the study area are apartments and detached houses. These types of houses are concrete houses. The concrete houses are built using sand, cement, bricks, marble and concrete as constructional materials. In most of the houses the roofs are made concrete and are at a height of about 2.5-3.25 m above ground. Each house has two to four rooms with common walls and, in some cases, interconnected doors.

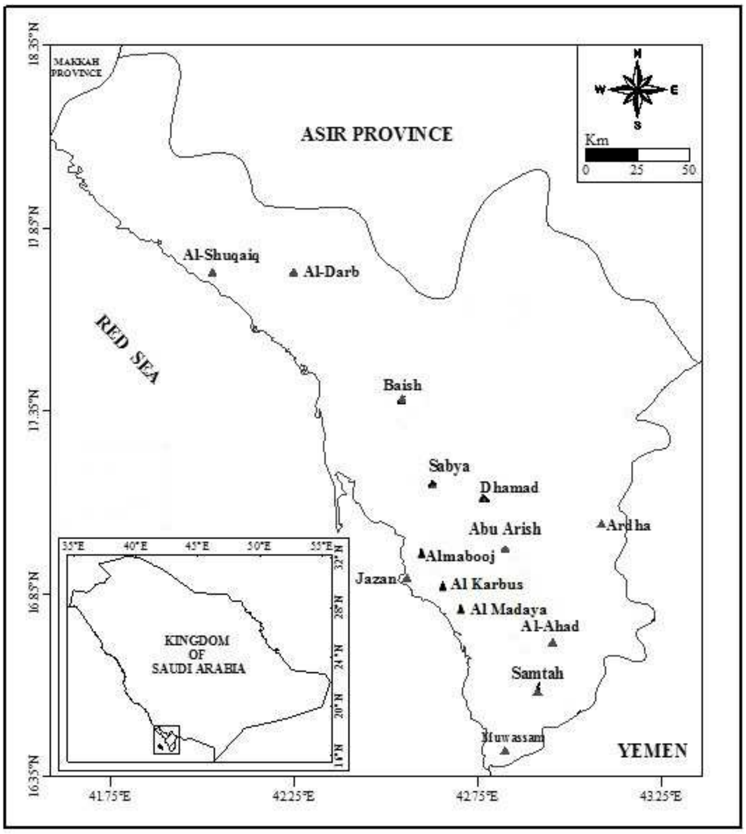

Fig. 1. The map showing the area surveyed during the present investigations

Selection of sampling sites
In order to conduct present indoor radon measurement survey, 50 houses were carefully selected. The choice of houses was based on our convenience, the willingness of the dwellers and its location within the studied area. CR-39 detectors were installed in bedroom, guest rooms and living rooms of each house.

MATERIALS AND METHODS

For indoor radon level measurements CR-39 nuclear track detectors (NTDs) were used (Intercast, Italy; 1,400 µm thick). Solid state track detector CR-39 is used widely in the field of health physics, such as for radon monitoring or neutron dosimetry. Alpha track detectors are not expensive, reliable and easy to use. The passive radon dosimeter geometry is a closed chamber into which radon diffuses [9]. The schematic diagram of the chamber is shown in Figure 2. The NTD has an area of 1.5×1.5 cm^2 which is fixed by double-stick tape in the dosimeter. The chamber has been covered fiberglass filter to allow the radon gas to pass and stop the aerosol and thoron (^{220}Rn, $T_{½}$ = 55.6 s) from entering the cup. The exposure time in all the cities was almost one complete year, from May 2013 to June 2014 in the dwellings at a height of 2 m above ground level and ~1 m below the ceilings and away from the walls so that the direct alpha particles from the building material of the dwellings did not reach the detector. The CR-39 NTDs were detached from all the collected dosimeters after 6 months and another fresh batch of detectors was installed in the same locations, and were chemically etched in 30% KOH, at 70°C for 6 h. The counting of tracks was done manually under an optical microscope. Radon concentration can be determined by counting the tracks in a given area. In order to obtain realistic statistics of the tracks, 100 fields of view were selected randomly on the detector surface. The individual error of radon measurements was estimated at less than 10%. The calibration process for the dosimeter of this type and dimensions was done in a previous work [10] in order to link the obtained track intensity with radon concentration.

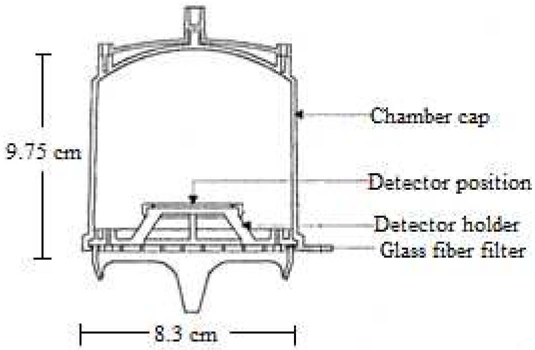

Fig. 2. Scheme of the BfS passive radon diffusion chamber

RESULTS AND DISCUSSION

The measurements were made in 50 dwellings in 10 villages/towns of Jazan province for a period of 1 year, during the two seasons: winter and summer. The results of these measurements are shown in Tables 1-3.

Table 1. The average indoor radon levels (Bqm^{-3}) recorded in towns/villages of the Jazan province

S.N	location	No of dwellings	Winter			Summer			Average annual Rn con.
			Min	Max	Mean value ±SD	Min.	Max.	Mean value ±SD	
1	Al karbus	5	20.3	41.2	33.3± 8.3	21.3	38.5	26.3±6.6	29.8±6.5
2	Baish	5	16.7	43.3	29.4±6.5	20.6	40.7	27.2±5.9	28.3±5.6
3	Almabooj	5	26.5	50.6	32.5±8.7	18.6	36.4	28.8±8.6	30.7±6.2
4	Samtah	5	23.9	47.3	37.7±11.3	24.4	42.9	33.6±10.1	35.7±8.2
5	Sabya	5	21.4	48.8	30.5±7.6	19.8	39.7	28.1±7.9	29.3±5.9
6	Jizan	5	20.4	33.5	27.2±6.3	13.4	28.3	18.2±5.5	22.7±4.9
7	Abu Arish	5	25.3	48.7	41.4±10.4	24.8	38.6	29.6±8.9	35.5±8.2
8	Al madaya	5	27.6	45.2	35.7±10.7	21.3	40.5	32.5±10.4	34.1±8.5
9	Al-Ahad	5	17.8	39.5	34.6±9.3	20.4	41.6	30.2±7.6	32.4±7.1
10	Dhamad	5	22.2	37.8	33.2±8.6	13.5	38.7	30.3±8.5	31.8±6.1
Mean									31.0±6.6

The range of indoor radon concentration varies from 22.7±4.9 in Jizan city to 35.7±8.2 Bqm^{-3} in Samtah village with the geometric mean value of 31 Bqm^{-3}. The ± values represent the standard deviation. The average annual indoor radon activity in all the villages of the study area is found to be in the range of the average values reported for the dwellings worldwide [2], but are smaller than those reported for Hafr Al-Batin [11] in Saudi Arabia. The difference in the values of indoor radon activity may also be due to the different ventilation conditions, the nature and type of building materials used during construction and the variation in the radioactivity content of the soil beneath the dwellings. The seasonal variations of indoor radon concentration in dwellings of different villages are given in Table 1. Figure 3 represents the frequency distribution of the annual average radon concentration levels among the 50 dwellings of the study area. The radon concentration values fall in the ranges 10–20, 20–30, 30–40, 40-50 and 50-60 Bq m^{-3} in 10, 36, 26, 22 and 6% of the houses.

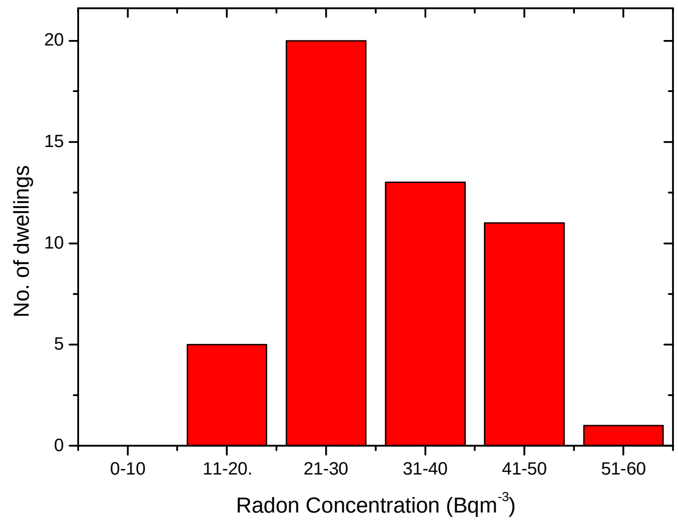

Fig. 3. Frequency distribution of indoor radon concentration (Bq m^{-3}) in dwellings of different villages/towns of the Jazan province

Table 2. Summary statistics of radon exposure (WLM y^{-1}), annual effective dose (mSv y^{-1}) and excess lifetime cancer risk (%)

Location	No of dwellings	Winter			Summer		
		Radon daughter exposure WLM y^{-1}	Effective dose (mSvy^{-1})	ELCR %	Radon daughter exposure WLMy^{-1}	Effective dose (mSvy^{-1})	ELCR %
Al karbus	5	0.15	0.85±0.09	0.52	0.12	0.67±0.07	0.41
Baish	5	0.13	0.75±0.07	0.46	0.12	0.70±0.08	0.42
Almabooj	5	0.14	0.83±0.10	0.51	0.13	0.74±0.07	0.45
Samtah	5	0.17	0.97±0.12	0.59	0.15	0.86±0.13	0.52
Sabya	5	0.14	0.78±0.08	0.48	0.13	0.72±0.06	0.44
Jizan	5	0.12	0.70±0.08	0.42	0.10	0.47±0.05	0.28
Abu arish	5	0.18	1.06±0.14	0.65	0.13	0.76±0.07	0.46
Al madaya	5	0.16	0.91±0.11	0.56	0.14	0.83±0.09	0.51
Al-Ahad	5	0.15	0.89±0.09	0.54	0.13	0.77±0.08	0.47
Dhamad	5	0.15	0.85±0.09	0.52	0.13	0.78±0.09	0.47
Average		0.15	0.86±0.08	0.53	0.13	0.73±0.07	0.44

The maximum value of radon concentration was observed during the winter season and minimum during the summer season. This was because all the dwellings were well air-conditioned by independent type air conditioners throughout the day because the temperature and humidity is high during summer. The operation of the air conditioner can increase the air exchange between the indoor and outdoor air through the pressure driven and hence reduce radon levels [12]. While in winter season the weather is moderate and the air conditioner is off most time, but the windows are closed all time because the presence some dust in air, so the ventilation was poor in winter.

Figure 4 shows the variation of radon concentrations for different types of rooms in the Jazan region. Guest rooms have a slightly higher radon concentration among others with an average of about 35.7 Bqm^{-3}, while a lower average concentration of about 27.4 Bqm^{-3} was found in living rooms. This may be because the guest rooms are normally less ventilated than the living rooms because they are closed most of the time to be ready for unexpected guests and to keep its expensive furniture away from dust. Bedrooms are less used than living rooms, but more used than guest rooms and therefore their average radon concentration falls in between.

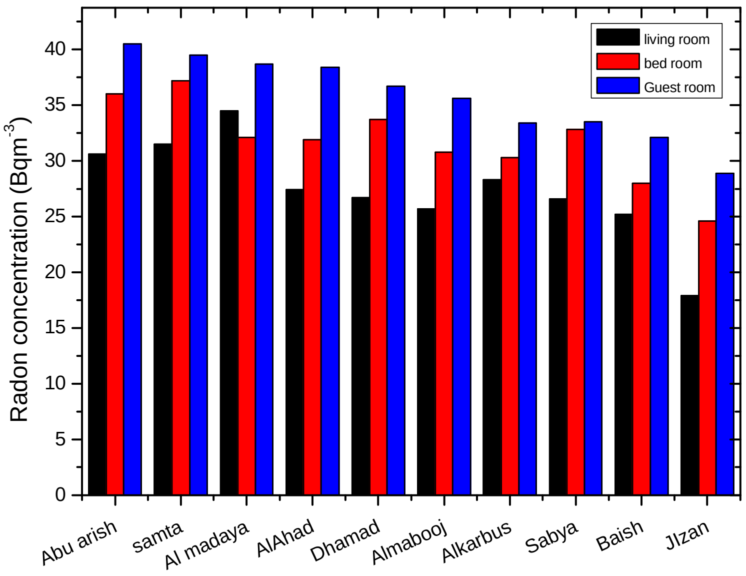

Fig. 4. Distribution of average radon concentration (Bq m^{-3}) in living, bed and guest rooms at Jazan province

For clarity, these values are also mentioned in Table 3. The average radon concentration in living rooms, guest rooms and bedrooms of the ten villages is within the world average of 40 Bq m^{-3}. Average radon levels, keeping the occupancy factor in view, were also calculated, and the results obtained are shown in table 3.

Table 3. Indoor radon concentration for different kinds of rooms in Jazan province

Kind of room	Min. con.	Max con.	Average (Bqm^{-3})	Indoor occupancy*	WLM y^{-1}	ELCR%	Effective dose (mSv)
Living room	17.9	50.6	27.4	0.42	0.064	0.22	0.37
Bedroom	19.6	53.3	31.7	0.34	0.060	0.21	0.35
Guest room	19.6	55.2	35.7	0.05	0.010	0.03	0.057

**Under the assumption that on average, the people in the investigation area stay in bedrooms for 8 h, in living rooms for 10 h and in guest rooms for one hour.*

Radiation Dose Estimation

The exposure to radon daughters in the Jazan dwellings can be calculated on the basis of the measured radon concentration using the following equation and EPA methodology [13].

$$E_R = C_R \times F \times n \times (2.7 \times 10^{-4}) \times \frac{8760}{170} \quad (1)$$

where E_R is exposure to radon daughters in WLM /y, C_R is the radon concentration in Bq m^{-3}, 2.7×10^{-4} is the factor for the conversion of radon concentration to the WL per Bq m^{-3}, F is the equilibrium factor (0.4 for indoor), n is the occupancy factor, 8760 indicates total hours in the year, and 170 indicates the total working hours per month.

The annual effective dose due to radon in the dwellings has been estimated using the following formula [14]:

$$D_E = E_R \times DCF \quad (2)$$

where, D_E is the annual effective dose (mSv y^{-1}) due to radon daughters, E_R is the exposure to radon daughter in WLM y^{-1} as per equation (1) and DCF is the dose conversion factor (mSv per WLM). For the determination of effective doses in the dwellings, the dose conversion factor of 5.75 mSv per WLM [2] has been used.

The excess lifetime cancer risk (ELCR) due to radon exposure of the population in the dwellings was determined using the following equation based on the methodology described in EPA report [13].

$$ELCR = E_R \times T \times F_R \quad (3)$$

where, E_R is the exposure to radon daughter in WLM y^{-1} as per equation (4), T is the average life time expectancy, that is about 67 years in Saudi Arabia and F_R is the risk coefficient factor for exposure to radon in equilibrium with its progeny. Based on the recommendations of ICRP, the F_R is taken as 5×10^{-4} per WLM [15].

Using Eqs 1−3, radon daughter exposure, effective dose and corresponding lung cancer risk in the dwellings in the study area have been estimated and summarized in Table 2. The average value of exposure rate to radon daughters is lower than the values reported from other regions in the Saudi Arabia [16]. The values of annual effective doses thus calculated for radon inhalation by the inhabitants were found to vary in the range 0.47–1.06 mSv with a mean of 0.85±0.08 and 0.73±0.07 mSv in winter and summer, respectively. Overall mean effective dose for the studied area was found as 0.80 ± 0.07 mSv y^{-1}. The effective dose and the excess lung cancer risks estimated from 50 dwellings surveyed are presented in Table 2. According to UNSCEAR [2], the worldwide average dose due to inhalation of radon and its decay product is 1.15 mSv y^{-1}. Therefore, the dose received by population investigated in the Jazan region of Saudi Arabia lies below the worldwide average dose limit.

To estimate the annual effective radon doses in different room types, it is necessary to partition the indoor occupancy factor among them. Table 3 shows this partitioning as well as the annual effective radon doses. The minimum value of the annual radon dose was in guest rooms and the maximum value was in living rooms. These results reverse the average radon concentration results because the indoor occupation factor plays an important role in determining the annual radon dose.

The mean excess lung cancer risk estimated by this work was found to range between 0.28 and 0.65% with an average value of 0.49%. The average of Excess Lifetime Cancer Risk (*ELCR*) is very small as compared with the estimated risk of 1.3% due to a radon exposure of 148 Bq m^{-3}(action level of EPA) for the entire population [13].

Table 4. The comparison of mean radon concentrations in indoor air samples, annual effective dose and Excess lifetime cancer risk with different countries

S. No.	Country	Mean Radon concentration (Bqm^{-3})	H (mSv y^{-1})	ELCR%
1	India [17]	132.84	2.27	0.18
2	India [18]	60.57	1.15	0.89
3	UK [19]	20	-	-
4	Sudan [20]	49	1.3	1.04
5	Jordan [21]	39	0.99	-
6	Jordan [22]	36.3	0.92	-
7	Nigeria [23]	257	6.5	-
8	Egypt [10]	46	1.74	0.68
9	Pakistan [24]	82	2.06	-
10	Saudi Arabia(Hafr Al-Batin) [11]	21	-	-
11	Saudi Arabia(Khafji) [11]	40	-	-
12	Saudi Arabia (Jeddah) [16]	36	0.61	0.47
13	Saudi Arabia(Riyadh) [25]	24.68	0.62	-
14	Saudi Arabia (Present study)	30.80	0.79	0.44

A comparison of the current results with data reported for other parts of the world is made in Table 4. Comparison with the international data suggests that the average measured indoor radon concentration values for Jazan are higher than those reported for the UK (20 Bq m^{-3}) and KSA - Hafr Al Batin (21 Bq m^{-3}) [19, 11]. On the other hand, indoor radon concentration values obtained from the current survey are less than the values reported for some other parts of the world like India (133 Bq m^{-3}), Nigeria (257 Bq m^{-3}) and Pakistan(138 Bq m^{-3}) [17, 23, 26].

CONCLUSION

In the present study, we have measured the values of radon levels in the indoor environment of some dwellings of Jazan province in Saudi Arabia. Annual effective dose has also been calculated for the occupants of these dwellings. It has been observed that province Jazan has relatively higher indoor radon levels as compared to the other provinces (Riyadh, Hafr Al-Batin) as measured by other research groups. Overall arithmetic mean of the present survey (31.0 ± 6.6 Bq m^{-3}) is lower than the typical global indoor radon level, (40 Bq m^{-3}). The maximum value of the indoor radon concentration is observed during the winter, whereas minimum concentration value has been observed in the summer season. The maximum values were found in guest rooms and minimum values were found in living rooms. The annual effective dose received by the residents in the study area is less than even the lower limit of the recommended action level (3–10 mSv). The ventilation conditions of the dwellings play an important role in order to decide the values of indoor radon concentration and effective dose. The ELR due to indoor radon is within the limits and does not pose any serious threat to the occupants. Consequently, the relative lung cancer risk from radon exposure is low in these buildings and they can be considered safe when the hazardous health effects of radon are concerned.

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