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Radon exhalation rate from building materials used on the Garyounis University campus, Benghazi, Libya

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Abstract

Radon exhalation rates were measured from building materials on the Garyounis University campus by using the can technique, containing CR-39, to estimate the radiation exposure in the atmosphere. The radon concentration from brick walls, marble ledges, and ceramic floors was found to vary from 107.8 ± 3.6 to 277.9 ± 9.3 Bq m^{-3} with a mean of 172 ± 5.8 Bq m^{-3}, 100.0 ± 3.3 to 298.7 ± 10.0 Bq m^{-3} with a mean of 174.5 ± 5.8 Bq m^{-3}, and 87.0 ± 2.9 to 275.3 ± 9.2 Bq m^{-3} with a mean of 145.1 ± 4.9 Bq m^{-3}, respectively. The average radon exhalation rate from the brick walls and marble ledges showed approximately the same value, which was higher than that of the ceramic floors by more than 15%. The levels of radon concentrations caused by these construction materials in 15 work places were found to be relatively low, giving an annual exposure dose within the internationally recommended range.

Key Words: Radon exhalation rate; CR-39; Can technique; Building materials; Annual effective dose.

Introduction

Materials obtained from the earth's crust, such as building materials, may contain traces of ^{238}U and ^{232}Th. These radionuclides decay to radon (^{222}Rn), which is a radioactive gas with a half-life of 3.82 days. Prolonged exposure to radon may increase the risk of lung cancer (ICRP, 1978; Durani, 1993) because it delivers 55% of the total dose to the cells of the respiratory system (Deka et al., 2003). Due to the long half-life of radon gas, it can reach from the earth's crust or from the walls and floors of buildings into both outdoor and indoor air. In the case of indoor air, the risk of exposure to radon is higher, especially for buildings with poor ventilation systems, which may lead to a higher indoor concentration of radon. The International Commission on Radiological Protection (ICRP) (1993) recommended radon concentration value ranges of 500-1500 and 200-600 Bq m^{-3} for work places and dwellings, respectively; those concentrations do not pose a significant risk for workers.

In the last 20 years, more attention has been paid to the measurement of radon exhalation from building materials in many countries worldwide, including Great Britain (Abu-Jarad et al., 1980), Finland (Mustonen, 1984), Saudi Arabia (Al-Jarallah, 2001), Taiwan (Ching-Jiang et al., 1993), Greece (Savidou et al., 1996), and Turkey (Turhan, 2008). In light of this information, and due to the lack of radon exhalation studies from construction materials in Libya, it is very important to begin this preliminary study to measure the radon exhalation rates and annual effective doses in situations where construction materials are a significant source of radon in houses. This particular study, which will be the basis of a larger investigation in Libya, was carried out in various work places on the University of Garyounis campus. These work places were selected by taking into account the rate of occupancy and population.

Materials and Methods

A study of radon exhalation rates from building materials used on the campus of Garyounis University in Benghazi, in northeastern Libya on the Mediterranean Sea, was performed, as shown in Figure 1. Measurement of the time-integrated radon exhalation rate was carried out by placing an inverted cylindrical stainless steel can on the walls and floors of the sampled buildings. The contact between the cylindrical can and those sampled walls and floors was sealed with silicone sealant. This type of measuring method is called the sealed-can technique (Abu-Jarad et al., 1980; Fleischer et al., 1980; Somogyi et al., 1984). The detection system involves the use of plastic solid-state nuclear track detectors, SSNTDs of type CR-39, which were cut into small pieces, 1.5 cm × 1.5 cm. The CR-39 SSNTDs used in our study were purchased from Intercast Europe S.p.A., Parma, Italy. Each CR-39 detector was fixed onto the top center of the inverted can by means of adhesive tape, as shown in Figure 2. Once equipped with CR-39 detectors, the cans were properly labelled and mounted in 15 work places throughout the University of Garyounis campus. The selected work places included offices, teaching rooms, laboratories, and service rooms located on 3 different floors and in 7 different departments. Three cans were used in each work place. The first and second cans were installed vertically on the floor and the marble window ledge of the work place, respectively, while the third can was installed horizontally on the wall at a level identical to that of the window ledge, 1.25 m above the floor. The cans were mounted during the summer and left exposed for 90 days in order to obtain useful statistics. During this exposure time, the tracks of alpha particles from the decay of radon and its daughters that had entered the air volume of the cans were registered in the CR-39 SSNTDs. The SSNTDs were removed from the cans and etched chemically in a 6.25 M NaOH solution at 70 ± 1 °C for 8 h to display and enlarge the latent alpha tracks due to radon decay.

The etched tracks on the detectors were counted manually, using an optical microscope at 400× magnification. The area of one field of view was calculated by a stage micrometer and the track density was calculated in terms of tracks per cm^{-2}, accordingly. The background track density was determined by processing a virgin detector under the same etching conditions. The background was subtracted from the measured track density. In order to obtain realistic statistics of the tracks, 100 fields of view were selected randomly on the detector surface. The calibration factor of 0.239 ± 0.008 tracks cm^{-2}, obtained from an earlier calibration experiment for the CR-39 track detector (Saad, 2008), was used to compute the radon activity from the track density. The following subsections show how the radon exhalation rate from the building materials was calculated and give an explanation of the estimation of the annual effective dose.

Calculation of the radon exhalation rate

As mentioned before, if the inverted can is placed on the surface of a building material, e.g., a brick wall, marble ledge, or ceramic floor, the radon concentration in the can will vary with time and will reach equilibrium within approximately 70 h (Ching-Jiang et al., 1993). At the equilibrium state, the final activity of radon exhaled from each building material sample inside the can is as follows:

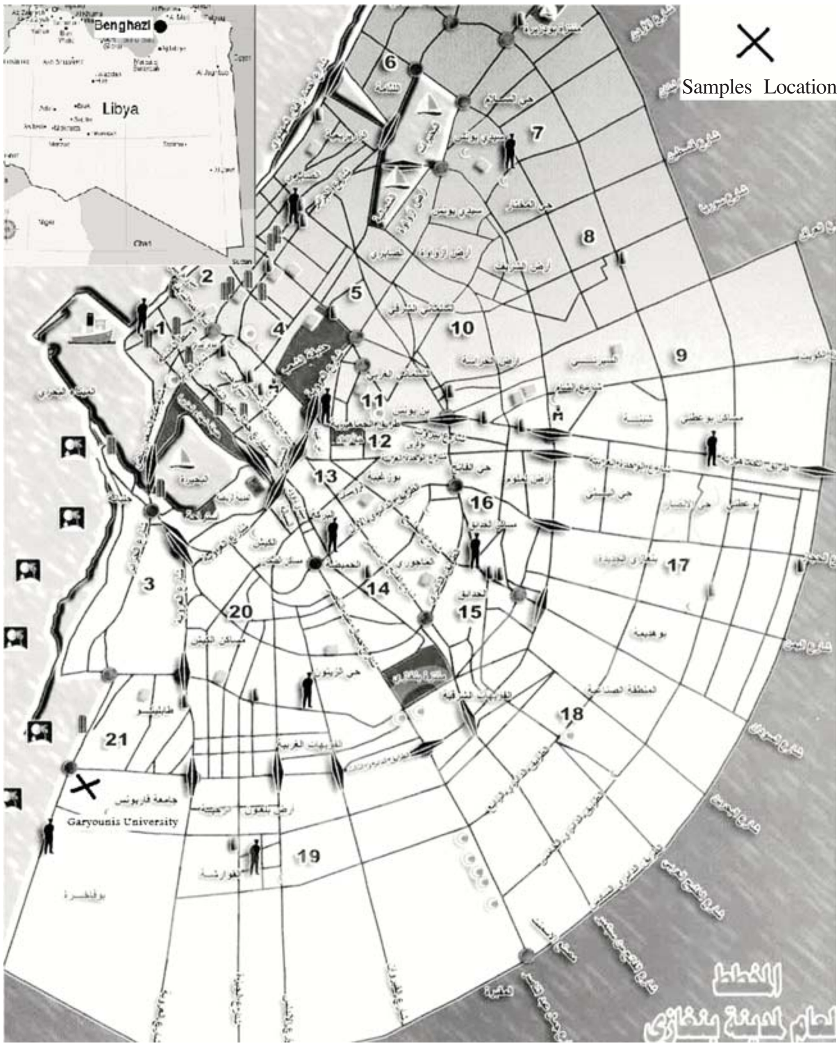

Figure 1. Map showing the area under study in Benghazi, Libya.

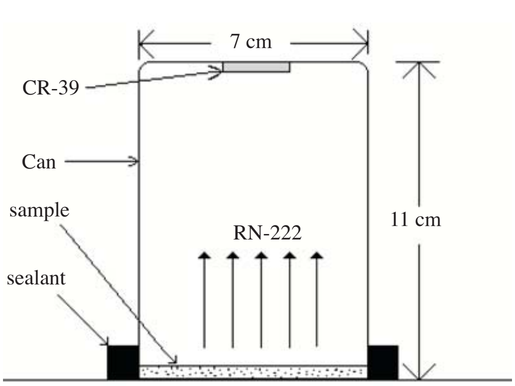

Figure 2. Schematic diagram of the sealed-can technique for measuring radon exhaled from a uranium-containing material by means of a CR-39 alpha-particle sensitive track detector.

$$A_t = A_0\left(1 - e^{-\lambda\, t}\right) \tag{1}$$

where λ is the decay constant of the radon and A_0 is the final value of the activity concentration. The radon exhalation rate per unit area of the building material sample E_a is calculated using the following formula (Mustonen, 1984; Barton and Ziemer, 1986):

$$E_a = A_0\, \lambda\, (V/F) \tag{2}$$

where $V$is the volume of the emanation can (0.423×10^{-3}m^3) and F is the total surface area of the building material sample (0.385×10^{-2}m^2;, which equals the cross-sectional area of the converted can.

Estimation of the annual effective dose

The radiation hazards of people's prolonged exposure to a high concentration of radon and its daughters in a room with an air ventilation rate of 0.5 h^{-1} were estimated. The risk of lung cancer from domestic exposure to radon and its daughters can be estimated directly from the effective dose equivalents. The radiation hazards of radon and its daughters were estimated from the radon exhalation rate of the building material samples. The contribution of indoor radon concentration from building material samples can be calculated with the following expression (Nazaroff and Nero, 1988):

$$C_{Rn} = \frac{E_x \times S_r}{V_r \times \lambda_v} \tag{3}$$

where

C_{Rn} = radon concentration (Bq m^{-3})
E_x = radon exhalation rate (Bq m^{-2}h^{-1})
V_r = room volume (m^3)
λ_v = air exchange rate (h^{-1})

In these calculations, the maximum radon concentration from the building materials was assessed by assuming the room to be a cavity with $S_r/V_r = 2.0$ m^{-1} and an air exchange rate of 0.5 h^{-1}. The annual effective dose equivalent, E_p, is then related to the average radon concentration C_{Rn} by the following expression:

$$E_P\left[WLM.y^{-1}\right] = \frac{8760 \times n \times F \times C_{Rn}}{170 \times 3700} \tag{4}$$

where C_{Rn} is in Bq m^{-3}; n is the fraction of time spent indoors; F is the equilibrium factor; 8760 is the number of hours per year; and 170 is the number of hours per working month. The values of n = 0.8 and F = 0.42 were used to calculate E_p. For radon exposure, the effective dose equivalents were estimated by using a conversion factor of 6.3 mSv/WLM (ICRP, 1987).

Results and Discussion

The locations of the radon dosimeters based on the CR-39 detectors on the university campus were arbitrarily selected. For various reasons, 4 dosimeters placed in a lecture hall, an office, and a laboratory were lost. As mentioned previously, the radon concentration levels were determined from the observed track densities by using the calibration factor of 0.239 ± 0.008 tracks cm^{-2}/1 Bq m^{-3} (Saad, 2008). Having determined the radon concentrations, the radon exhalation rates and annual effective doses were estimated accordingly; these values are given in Table 1.

Table 1. Radon concentration levels, radon exhalation rates, and annual effective doses from the 45 samples distributed among 15 locations on the university campus. Departments: P-physics, C-chemistry, G-geology, B-botany, Z-zoology, S-statistics, A-administrative. Sample type: W-brick wall, F-ceramic floor, M-marble ledge. Floor level: I-Ground Floor, II-First Floor, III-Second Floor.

Annual Effective Dose (μSv y^{-1})	Radon Exhalation Rate per Unit Area (Bq m^{-2}h^{-1})	Radon Concentration (Bq m^{-3})	Sample Code	Sample No.	Location
17.2 ± 0.6	0.146 ± 0.005	192.8 ± 6.5	PWI	1	i
10.5 ± 0.4	0.089 ± 0.003	118.2 ± 4.0	PFI	2	
14.9 ± 0.5	0.126 ± 0.004	166.2 ± 5.6	PMI	3	
10.6 ± 0.4	0.090 ± 0.003	119.5 ± 4.0	PWI	4	ii
8.5 ± 0.2	0.072 ± 0.002	94.8 ± 3.2	PFI	5	
24.9 ± 0.8	0.211 ± 0.007	279.2 ± 9.3	PMI	6	
14.6 ± 0.5	0.124 ± 0.004	163.6 ± 5.5	PWI	7	iii
20.9 ± 0.7	0.177 ± 0.006	233.7 ± 7.8	PFI	8	
11.2 ± 0.4	0.095 ± 0.003	126.0 ± 4.2	PMI	9	
22.8 ± 0.7	0.193 ± 0.006	254.5 ± 8.5	PWI	10	iv
14.5 ± 0.5	0.123 ± 0.004	162.3 ± 5.4	PFI	11	
18.5 ± 0.6	0.157 ± 0.005	207.8 ± 7.0	PMI	12	
11.9 ± 0.4	0.101 ± 0.003	133.8 ± 4.5	PWI	13	v
7.8 ± 0.2	0.066 ± 0.002	87.0 ± 2.9	PFI	14	
10.6 ± 0.4	0.090 ± 0.003	119.5 ± 4.0	PMI	15	
24.8 ± 0.8	0.210 ± 0.007	277.9 ± 9.3	PWII	16	vi
13.2 ± 0.5	0.112 ± 0.004	148.0 ± 5.0	PFII	17	
20.6 ± 0.7	0.175 ± 0.006	231.8 ± 7.8	PMI	18	
12.7 ± 0.5	0.108 ± 0.004	142.8 ± 4.8	PWII	19	vii
11.3 ± 0.4	0.096 ± 0.003	127.3 ± 4.3	PFII	20	
19.8 ± 0.7	0.168 ± 0.006	221.4 ± 7.4	PMII	21	
12.6 ± 0.5	0.107 ± 0.004	141.5 ± 4.7	PWIII	22	viii
9.5 ± 0.4	0.081 ± 0.003	106.5 ± 3.6	PFIII	23	
10.0 ± 0.4	0.085 ± 0.003	113.0 ± 3.8	PMIII	24	
11.6 ± 0.4	0.098 ± 0.003	129.9 ± 4.3	AWI	25	ix
9.4 ± 0.4	0.080 ± 0.003	105.2 ± 3.5	AFI	26	
9.9 ± 0.4	0.084 ± 0.003	110.4 ± 3.7	AMI	27	
13.7 ± 0.5	0.116 ± 0.004	153.2 ± 5.1	AWI	28	x
-	-	-	AFI	29	
-	-	-	AMI	30	
19.6 ± 0.7	0.166 ± 0.006	219.5 ± 7.3	CWII	31	xi
15.3 ± 0.5	0.130 ± 0.004	171.4 ± 5.7	CFII	32	
15.3 ± 0.5	0.130 ± 0.004	171.4 ± 5.7	CMII	33	
12.4 ± 0.5	0.105 ± 0.004	139.0 ± 4.7	GWII	34	xii
-	-	-	GFII	35	
26.7 ± 0.9	0.226 ± 0.008	298.7 ± 10.0	GMI	36	
-	-	-	BWI	37	xiii
24.5 ± 0.8	0.208 ± 0.007	275.3 ± 9.2	BFI	38	
12.5 ± 0.5	0.106 ± 0.004	140.2 ± 4.7	BMI	39	
19.1 ± 0.6	0.162 ± 0.005	213.6 ± 7.2	ZWII	40	xiv
13.1 ± 0.5	0.111 ± 0.004	146.7 ± 4.9	ZFII	41	
13.1 ± 0.5	0.111 ± 0.004	146.7 ± 4.9	ZMII	42	
9.7 ± 0.4	0.082 ± 0.003	107.8 ± 3.6	SWI	43	xv
9.9 ± 0.4	0.084 ± 0.003	110.4 ± 3.7	SFI	44	
9.0 ± 0.4	0.076 ± 0.003	100.0 ± 3.3	SMI	45	

As may be seen in Table 1, radon concentration levels from the brick walls were found to vary from 107.8 ± 3.6 to 277.9 ± 9.3 Bq m^{-3}, with an average value of 172 ± 5.8 Bq m^{-3}. The radon concentrations from the marble ledges were found to vary from 100.0 ± 3.3 to 298.7 ± 10.0 Bq m^{-3}, with an average value of 174.5 ± 5.8 Bq m^{-3}. Finally, the radon concentrations from the ceramic floors were found to vary from 87.0 ± 2.9 to 275.3 ± 9.2 Bq m^{-3}, with an average value of 145.1 ± 4.9 Bq m^{-3}. These results showed that the marble ledge samples yielded the highest average radon concentration values, while the ceramic floor samples produced the lowest values. However, the average values of radon concentrations from the brick wall, marble ledge, and ceramic floor samples were all below the internationally recommended ICRP action level range for work places, 500-1500 Bq m^{-3}.

Overall, the mean value of radon concentrations from the ceramic on the ground floor was higher than that on the first and second floors. This is because the radon gas that emanated from the soil would have had a better opportunity of flowing to the ground floor rather than the first or second floor through common pathways, such as cracks and pipes entering the work places. Additionally, the mean values of radon concentration due to ceramic flooring were lower than those from the brick walls and marble ledges. Therefore, the ceramic flooring samples will contribute less to indoor radon if used with a very good insulating material to stop radon from diffusing into the environment. The little difference between the values of radon concentration from the marble ledges and brick walls may be due to the fact that the plaster and paint on the walls work as good insulating material to reduce radon concentration, or it might be that both of the materials have approximately the same uranium content. However, both will contribute more to indoor radon.

In Table 1, the results obtained for the radon exhalation rate per unit area of the 3 analyzed building materials are given. The areal radon exhalation rates ranged from 0.082 ± 0.003 to 0.210 ± 0.007 Bq m^{-2} h^{-1} with a mean value of 0.130 ± 0.004 Bq m^{-2} h^{-1} for the brick walls; from 0.076 ± 0.003 to 0.226 ± 0.008 Bq m^{-2} h^{-1} with a mean value of 0.132 ± 0.004 Bq m^{-2} h^{-1} for the marble ledges; and from 0.066 ± 0.002 to 0.208 ± 0.007 Bq m^{-2} h^{-1} with a mean value of 0.110 ± 0.004 Bq m^{-2}h^{-1} for the ceramic floors. It should be noted that the measured radon exhalation rates of the marble ledges and brick walls were approximately the same, whereas both were higher than that of the ceramic floors by a factor of 1.20 within a very small uncertainty. This is attributed to good insulation material between the ceramic flooring and the soil below the buildings.

It is very important to find radon emanation potential in the university buildings in order to have an estimate of the radiation risk to the inhabitants. Thus, the estimation of the annual effective dose expected to be received by the workers due to radon and its daughters was based on calculations from the radon exhalation rate. Minimum, maximum, and mean annual effective doses were found to be 9.7 ± 0.4, 24.8 ± 0.8, and 15.3 ± 0.5; 9.0 ± 0.4, 26.7 ± 0.9, and 15.6 ± 0.5; and 7.8 ± 0.2, 24.5 ± 0.8, and 13.0 ± 0.5 μSv y^{-1} from the brick walls, marble ledges, and ceramic floors, respectively. The effective doses from the brick walls were almost equal to those from the marble ledges, and both were a little bit higher than those from the ceramic floors in all studied work places on the university campus. The values of annual effective doses reported in the present study conform to the internationally recommended range.

Conclusion

Radon concentration levels from building materials used on the University of Garyounis campus were calculated using the can technique. The radon concentration levels, the areal radon exhalation rates, and the annual effective doses in work places on the Garyounis University campus were determined to assess the radiological hazards from the Libyan building materials. The results showed that the brick walls and marble ledges contain approximately the same level of radon concentrations, while the ceramic floors contain the lowest level. The lower radon activity in the ceramic floors is due to good insulation material between the ceramic flooring and the soil below the buildings, or it might be due to the low radioactivity of the ceramic raw material itself. The radon concentration levels and the annual effective doses are, on average, below the action level recommended by the ICRP (1993) and ICRP (1987), respectively. The present work shows that the building materials do not pose a significant radiation hazard, and thus the use of these materials in the construction of the university campus is considered to be safe for staff and students.

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