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SEASONAL VARIATION OF INDOOR RADON CONCENTRATION IN DWELLINGS OF ALEXANDRIA CITY, EGYPT

M. Abd El-Zaher*
Department of Basic and Applied Science, Faculty of Engineering, Arab Academy for Science & Technology, Alexandria, Egypt

*Corresponding author: mohamed.zaher@aast.edu, mohzaher400@hotmail.com

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Inhalation of radon (^{222}Rn) and daughter products are a major source of natural radiation exposure. Keeping this in view, seasonal indoor radon measurement studies have been carried out in 68 dwellings belonging to 17 residential areas in Alexandria city, Egypt. LR-115 Type 2 films were exposed for four seasons of 3 months each covering a period of 1 y for the measurement of indoor radon levels. Assuming an indoor occupancy factor of 0.8 and a factor of 0.4 for the equilibrium factor of radon indoors, it was found that the estimated annual average indoor radon concentration in the houses surveyed ranged from 45 ± 8 to 90 ± 13 Bq m^{-3} with an overall average value of 65 ± 10 Bq m^{-3}. The observed annual average values are greater than the world average of 40 Bq m^{-3}. Seasonal variation of indoor radon shows that maximum radon concentrations were observed in the winter season, whereas minimum levels were observed in the summer season. The season/annual ratios for different type of dwellings varied from 1.54 to 2.50. The mean annual estimated effective dose received by the residents of the studied area was estimated to be 1.10 mSv. The annual estimated effective dose is less than the recommended action level (3–10 mSv y^{-1}).

INTRODUCTION

Radon and its short-lived decay products are the most important contributors to human exposure to ionising radiation from natural sources. This contribution represents 50 % of the total dose[1]. This significant level of radon radiology implies the need to control it in the residence/or workplace. People spend of their time is spent within buildings; therefore, the measurement and limitation of radon concentration in buildings are important[2, 3]. Radon is a naturally occurring radioactive gas resulting from the radioactive decay of ^{226}Ra, the fifth daughter of ^{238}U. Radon decays with a half-life of 3.82 d into a series of short-lived daughter products out of which ^{218}Po and ^{214}Po emit high-energy alpha particles which are highly effective in damaging tissues. The fact that inhalation of radon daughters can cause lung cancer in human beings has been known since a long time ago[4, 5]. The following are the major radon sources for homes in the order of importance: soil below the building, building material, outside air and water from private wells. Soil subjacent to the building is by far the most important source of indoor radon[6, 7]. Measurements of radon ^{222}Rn in the indoor air of dwellings are continuously presented in many countries[8–10]. The numerous measurements of the activity concentrations of radon in different countries along with the epidemiological studies regarding the indoor radon and the risk of lung cancer have been published in recent years[11–13]. In Egypt, many research workers are engaged in the measurement of indoor radon levels in dwellings[14, 15], and in Egyptian tombs and temples[16–18], for the assessment and control of the health risk[19–24].

The present work represents a study for the indoor radon (^{222}Rn) concentration levels in dwellings of Alexandria city, Egypt, in the light of recommendations given by the International Commission on Radiological Protection (ICRP)[25]. This survey provides additional information about indoor radon concentrations in Egypt. Indoor radon survey of a total of 17 residential areas in Alexandria city was carried out. The measurements were carried out during the four different seasons. The surveyed area (Figure 1) is located in the north of Egypt, the city of Alexandria having the latitude and longitude of 31°13N and 29°58E, respectively. Bounded on the north by the Mediterranean sea, on the south by lake Mariot, on the east by Abu Qir bay and Edco and on the west by Matrouh. There are following four seasons in Alexandria: a cool and dry winter (December–February), spring (March–May), a hot and wet summer season (June–August) and autumn (September–November).

In this survey, radon levels were monitored using the solid-state nuclear track detector (SSNTD) technique, which is the most reliable technique for integrated and long-term measurement of radon concentration inside dwellings, and has successfully been used by many workers for indoor radon measurements in dwellings[26–28]. For health risk

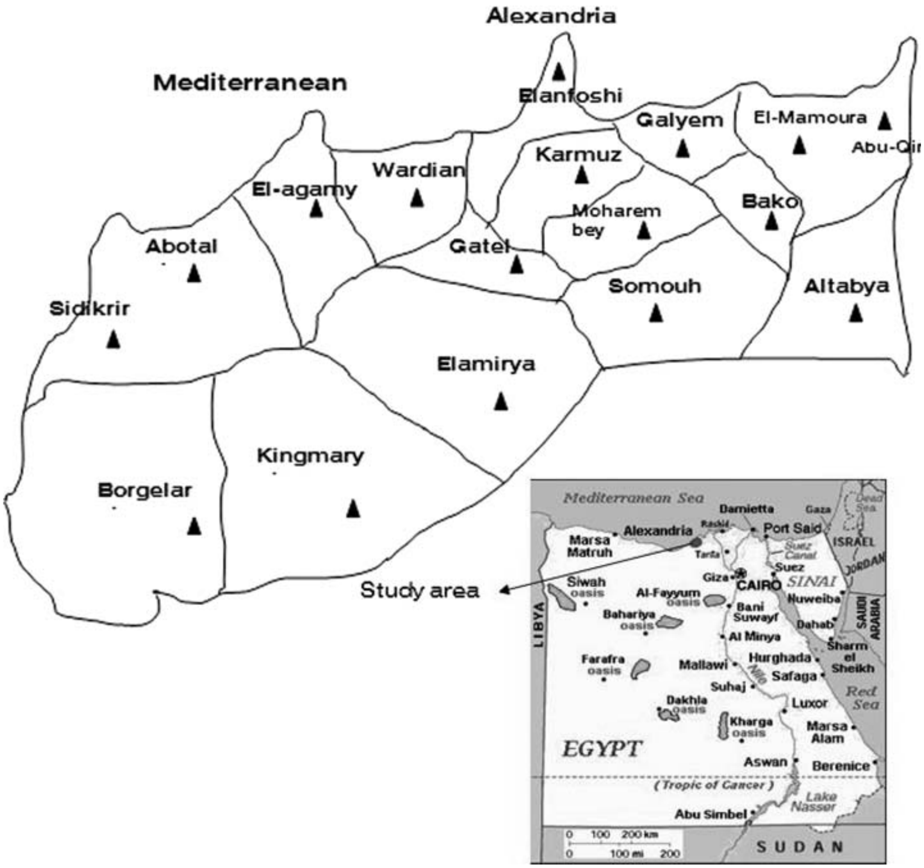

Figure 1. Map showing the locations of the studied areas in Alexandria (Egypt).

assessment, radon measurements were carried out for a period of 1 y in four consecutive 3-month periods (seasons). The annual exposure to occupants, the annual effective dose received by them and their lifetime fatality risk estimates have been assessed in the light of guidelines given by the ICRP[25].

THE CHARACTERISTIC OF DWELLING IN ALEXANDRIA

Most of the dwellings in the studied areas are concrete houses, which are partially ventilated. These houses were built using cement, sand bricks, dolomite and concrete. The walls of the dwelling were plastered with mortar of cement and sand. The floor material of these dwellings was made of approximately 2–4 cm thick concrete on the dolomite crush 3–4 cm thick over lain with 2 cm marble/ceramic tiles or gypsum. These materials are expected to contribute significantly to sources of indoor radon. Each house has rooms with common walls and some old houses are built of clay. The sizes of these houses and their rooms are different from area to area and also within the location.

MEASUREMENT TECHNIQUE

Published measurements of levels of radon and its decay products in homes have been made using several methods. Some measurements of the short-term values are called active methods and other measurements of the integrated values are called passive methods. In the present investigations, the passive technique (can technique) using the SSNTDs has been utilised for the comparative study of the indoor radon (^{222}Rn) level in the dwellings of Alexandria, Egypt. Radon activity concentrations were measured mainly using the passive closed-and-open can techniques (cylindrical can made of high grade plastic having diameter of 7 cm, height of 10 cm and thickness of 0.5 mm). Each can was equipped with a polymeric nuclear track detector LR-115 type II plastic

Table 1. Seasonal indoor radon level in the dwellings of different areas of Alexandria city, Egypt.

Sr. no.	Locations name	No. of houses studied	Radon concentration (Bq m^{-3}) June–August (summer) Maximum	Minimum	Average value ± SD	September–November (autumn) Maximum	Minimum	Average value ± SD	December–February (winter) Maximum	Minimum	Average value ± SD	March–May (spring) Maximum	Minimum	Average value ± SD	Annual radon concentration (Bqm^{-3})	Annual average dose mSv	Life-time fatality × 10	Winter/summer ratio
1	Abu-Qir	4	56	38	46 ± 8	71	52	61 ± 9	108	81	89 ± 13	82	56	68 ± 12	66 ± 11	1.13	0.87	1.93
2	El-Mamoura	4	71	55	63 ± 7	68	51	59 ± 8	114	85	97 ± 13	85	68	77 ± 8	74 ± 9	1.26	0.97	1.54
3	Altabya	4	53	32	40 ± 10	62	43	52 ± 10	105	86	95 ± 8	78	61	69 ± 7	64 ± 9	1.10	0.84	2.37
4	Galyem	4	47	23	33 ± 11	56	29	42 ± 13	91	61	77 ± 13	68	46	58 ± 10	53 ± 12	0.90	0.69	2.33
5	Somouha	4	36	22	29 ± 6	43	30	36 ± 6	82	56	70 ± 13	54	36	44 ± 8	45 ± 8	0.76	0.59	2.41
6	Moharembey	4	36	29	32 ± 4	46	32	39 ± 6	89	62	78 ± 12	58	34	46 ± 11	49 ± 8	0.83	0.64	2.43
7	Karmuz	4	38	19	29 ± 8	55	28	41 ± 12	75	56	63 ± 9	69	42	57 ± 12	48 ± 10	0.81	0.62	2.17
8	Elanfoshi	4	52	33	42 ± 10	66	42	53 ± 12	102	76	90 ± 12	81	53	69 ± 13	64 ± 11	1.08	0.83	2.14
9	Bakos	4	42	22	32 ± 9	64	38	52 ± 11	93	67	80 ± 12	78	39	58 ± 19	56 ± 11	0.95	0.73	2.50
10	Gatelanb	4	52	38	45 ± 7	65	51	57 ± 6	86	54	74 ± 15	71	42	57 ± 13	58 ± 10	0.99	0.76	1.64
11	Werdian	4	42	29	34 ± 6	52	38	45 ± 3	96	69	85 ± 12	66	41	53 ± 11	54 ± 8	0.93	0.71	2.50
12	El-agamy	4	66	41	51 ± 11	82	59	70 ± 11	118	96	103 ± 10	99	71	83 ± 12	77 ± 11	1.31	1.01	2.01
13	Sidikrir	4	82	52	67 ± 14	94	71	81 ± 10	134	97	115 ± 17	109	81	95 ± 12	90 ± 13	1.53	1.18	1.71
14	Abotalat	4	71	46	61 ± 12	59	41	49 ± 9	110	91	99 ± 9	96	66	81 ± 12	73 ± 10	1.24	0.95	1.62
15	Elamirya	4	66	54	56 ± 9	82	63	73 ± 10	114	84	99 ± 13	92	67	79 ± 12	77 ± 11	1.31	1.01	1.76
16	Kingmaryut	4	73	41	60 ± 15	91	72	81 ± 9	129	108	117 ± 10	102	86	91 ± 11	87 ± 11	1.49	1.15	1.95
17	Borgelarab	4	62	34	50 ± 13	71	43	58 ± 13	95	82	89 ± 6	78	62	69 ± 8	67 ± 10	1.14	0.87	1.78
Seasonal average				44 ± 9			56 ± 9			90 ± 12			68 ± 11		65 ± 10			

detector (which was purchased from Kodak France) each with a size of about (1.5×2 cm^2) fixed at its bottom. Alpha particles emitted by ^{222}Rn and its daughter products strike the detectors and leave latent tracks in it. Thoron ^{220}Rn is a radioisotope of ^{222}Rn, and has a half-life of 55.6 s. Owing to its short half-life, the concentration of thoron is usually much lower than that of radon in normal environments[29]. However, the recent report by UNSCEAR[30] reveals that the contribution from ^{220}Rn and its daughter products in the dwellings is in general ~10 % of that of ^{222}Rn and its daughter products. So this component can be neglected from the point of view of the inhalation dose particularly in an area which is not known for thorium mineralisation. A total of 68 houses were selected for this survey wherein 136 dosemeters were installed. All the dosemeters were suspended in the most frequently used room, the 'sitting room' of the dwellings of interest at a height of more than 2 m above the level of the ground (so that the detectors are not disturbed by the movement of the residents). The detectors were exposed during four consecutive seasons covering a period of 1 y. After the exposure time, the detectors from all cans were retrieved. For the revelation of tracks, the detectors were chemically etched in 2.5 N NaOH with an etching time of 90 min and etching temperature of 60°C in a water bath. The temperature was kept constant with an accuracy of ±1°C. After the etching period, the detectors were removed from the etchant and immediately washed with distilled water and then dried in air. After a few minutes of drying in air, the detector was ready for track counting. The etched tracks were counted using an optical microscope (Zeiss at ×400 magnification). The area of one field of view was calculated with a stage micrometer and the track density was calculated in terms of number of tracks per cm^{-2}. The correction was applied for the background alpha tracks in LR-115 plastic by subtracting the number of tracks observed in the unexposed detector. The number of tracks counted per unit area was then converted into radon concentration by applying the conversion factor for LR-115type II detectors in the can-technique dosemeters as 0.032 ± 0.002 tracks cm^{-2} d^{-1} per Bq m^{-3}. The calibration process for the dosemeters used in this survey was carried out at the radiation laboratory of the physics department in the faculty of science of the Alexandria University, Egypt[31]. Where four dosemeters (equipped at its bottom with LR-115 type II detectors) have been exposed to ^{226}Ra (radon source) of activity concentration 800 Bq m^{-3}, inside a chamber of 0.2 m^3 capacity. The resultant track density per unit of concentration is the calibration coefficient. The overall uncertainty in this calibration was estimated to be ±10 %.

Dose and risk estimate

The annual effective dose from radon (^{222}Rn) and average lifetime fatality risk have been estimated according to the ICRP[25]. ICRP assumes 80 % occupancy (7000 h y^{-1}) indoors and assuming an indoor equilibrium factor of 0.4 between radon and its decay products (moreover, ICRP[25] has recommended the use of 0.4 as the equilibrium factor if the measured values are not available), use of 0.4 for dwellings, the annual exposure at home to radon progeny per unit radon concentration of 1.56×10^{-2} (mJ h m^{-3}) per (Bq m^{-3}) and effective dose per unit exposure at home to radon progeny of 1.1 mSv (mJ h $m^{-3})^{-1}$. Under these circumstances, radon concentration of 1 Bq m^{-3} corresponds to an annual effective dose of 1.716×10^{-2} mSv. Also the dose in terms of working level month (WLM) was calculated. One WLM corresponds to the exposure of an individual to radon progeny of 1 WL concentration (2.08×10^{-2} mJ m^{-3}) for a duration of 170 h, which results in 1 WLM equivalent to 3.54 mJ hm^{-3}. The conversion factors of 3×10^{-4} WLM^{-1} and 3.88 mSv WLM^{-1}[25] are used for estimate the lifetime fatality risk and the annual effective dose, respectively.

RESULTS AND DISCUSSION

The annual average indoor radon (^{222}Rn) concentration levels have been measured in 17 residential areas (68 houses, 4 houses per each area) in Alexandria, Egypt, in each season of the year. The annual effective dose and average lifetime fatality risk for each area have also been estimated. The results obtained are summarised in Table 1. The yearly average indoor value in the studied areas varies from lowest radon concentration of 45 ± 8 Bq m^{-3} in Somouha region, and the highest value

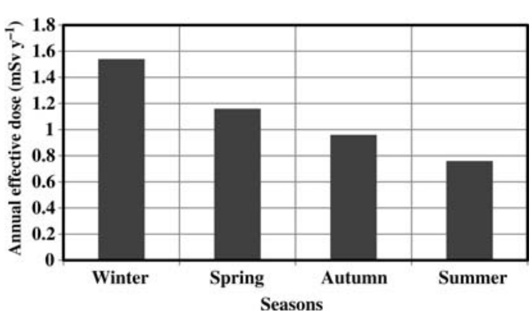

Figure 2. Comparison of the annual average effective dose in different seasons and for the 17 areas of the Alexandria city.

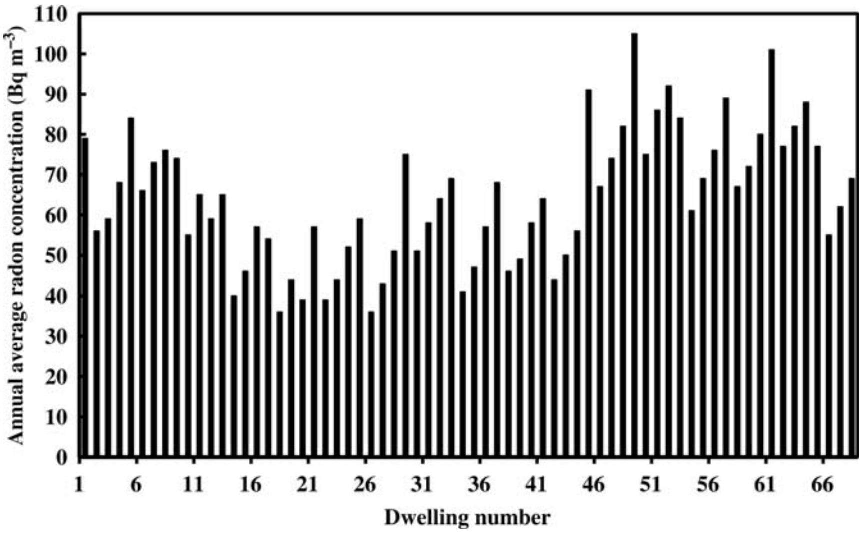

Figure 3. Annual average radon level in Alexandria city.

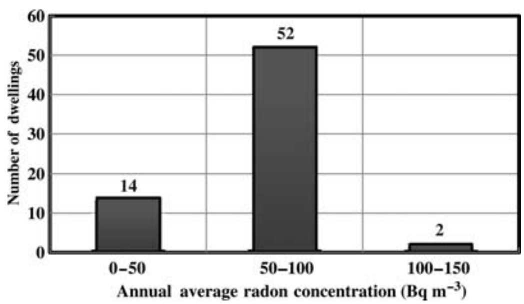

Figure 4. Frequency distribution of annual average radon concentration (Bq m^{-3}) in 68 Dwellings of 17 studied are of Alexandria city, Egypt.

of 90 ± 13 Bq m^{-3} was found in the Sidikrir region. These values are slightly higher than the average values reported for the dwellings worldwide of 40 Bq m^{-3}[32]. This may be due to the difference in the concentration of radioactive elements, viz. uranium and radium in the soil and building material of the study area However, these values are less than the lower limit of the range of the action level of (200–600) Bq m^{-3}, recommended by the ICRP[28]. The present values of indoor radon are slightly more than those in some other areas of Egypt[33].

The estimated annual effective dose received by the residents of the studied areas varies from 0.76 mSv (Somouha region) to 1.53 mSv (Sidikrir region) with an average of 1.10 mSv. From the measured indoor levels, the annual effective dose for each area in each season has also been calculated and shown in Figure 2. The estimated annual effective dose in different seasons is found to be higher in winter and lower in summer. In all the areas surveyed, the estimated annual effective dose is less than even the lower limit of the recommended action level (3–10 mSv). The lifetime fatality risk of the residents of the studied area varies from 0.6×10^{-4} to 1.2×10^{-4} with an average value of 1.10×10^{-4}.

The study of seasonal variations of indoor radon (^{222}Rn) concentration in 68 dwellings of 17 residential areas is given in Table 1. It is evident from the table that the maximum value of radon concentration is observed during the winter season and minimum during the summer season. This is because the doors and windows of the dwellings remain closed most of the time in winter compared with summer, and hence the ventilation is poor in winter. The winter to summer ratio of radon concentration has been computed for all 68 dwellings. This ratio of indoor radon ranges from 1.54 to 2.50 with an average of 2.04.

Figure 3 shows the distribution of the estimated annual average radon (^{222}Rn) concentration for all the 68 dwellings of the 17 residential areas studied in Alexandria. The annual radon concentration level for the dwellings ranges from 36 to 105 Bq m^{-3} with an average of 65 Bq m^{-3}. The difference in the values of indoor radon activity may be due to the different ventilation conditions, the nature and type of building material used during construction and the variation of the radioactivity level in the soil beneath the dwellings.

Figure 4 shows the frequency distribution of the estimated annual average radon concentration levels among 68 dwellings of the 17 residential areas studied in Alexandria. The radon concentration lies in the ranges 0–50, 50–100 and 100–150 Bq m^{-3} in ∼21, 76 and 3 % of the houses, respectively. In almost all the dwellings radon concentration is well below the action level (200–600 Bq m^{-3}) recommended by the ICRP[25].

CONCLUSIONS

The ^{222}Rn activities were measured in 68 indoor dwellings of Alexandria city, Egypt in 17 residential areas. The radon concentrations were measured over 1 y in each location. The radon dosemeters (LR-115 type II) were placed inside the dwellings for four consecutive seasons of 3 months each. The results of the present research work led to the following conclusions:

(1) It has been observed that the Sidikrir, Kingmaryut, Elamirya and Elagamy areas have relatively higher indoor radon levels when compared with other areas. The overall arithmetic mean of the present survey (65 ± 10 Bq m^{-3}) is higher than the world average values of the indoor radon levels (40 Bq m^{-3}). Nevertheless, present values are lower than the recommended action levels (200–400 Bq m^{-3}).
(2) The maximum value of the indoor radon (^{222}Rn) concentration is observed during the winter season, whereas the minimum concentration value has been observed in the summer season.
(3) The estimated annual effective dose in the studied area is less than even the lower limit of the recommended action level (3–10 mSv).
(4) The radon activity and the radon effective dose rate depend upon many factors inside the dwellings. Ventilation plays an important role as far as the problem of radio activity is concerned.
(5) There is a necessity for more detailed studies related to this subject in order to provide baseline information about the natural radiation of the radionuclides that exist in the building material used in Egypt and to establish an Egyptian code for these material.
(6) It is very important to improve the bad ventilation conditions, which play an essential role in the effective dose received by the residents, especially in winter.

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