HIROSAKI UNIVERSITY

Radiation Environment and Medicine 2021 Vol.10, No.1 26–30

REM
Radiat Environ Med

Regular Article

Preliminary Survey Measurements of Radon in Egyptian Dwellings by a Passive Technique Using LR-115 Detectors

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Received 3 June 2020; revised 6 July 2020; accepted 17 August 2020

In the present work, a set of indoor radon levels were measured in 45 dwellings in 15 selected cities of Egypt. Radon concentrations were determined using time-integrated radon dosimeters (closed and bare) containing LR-115 solid state nuclear track detectors. Measurements were carried out for one year to obtain an unbiased estimate of the annual average. The main objective of this study was to assess the health hazard due to the indoor radon. The results showed that the radon activity concentration varied from 20.6 to 42.1 Bq m^{-3}, with an average value of 30.9 ± 7.3 Bq m^{-3}. These measured values are less than the recommended maximum value of 300 Bq m^{-3} for radiation protection of residents according to ICRP Publ. 126. Values of the indoor radon equilibrium factor F varied from 0.30 to 0.44, with an average value of 0.39 ± 0.03, which is almost equal to the value (0.40) proposed by UNSCEAR 2000 report. Calculated values of the indoor annual effective dose to residents in dwellings varied from 0.51 to 0.99 mSv, with an average value 0.75 ± 0.16 mSv. These values are lower the normal background level of 1.1 mSv y^{-1} quoted by UNSCEAR 2000 report and the recommended action level of 10 mSv y^{-1} as reported by ICRP Publ. 126. Thus, the present results have shown that radon concentration levels in the studied dwellings do not pose any significant health risk to occupants.

Key words: radon, LR-115 detectors, equilibrium factor, effective dose, Egyptian dwellings

1. Introduction

Radon has two main isotopes. Radon-222 (^{222}Rn, radon) is a radioactive decay product of radium-226, which is present in the earth's crust in varying concentrations. As radon is a gas, it is capable of movement from the soil to indoors. This movement is dependent on various factors such as the type of soil, building, and/or location. Radon-220 (^{220}Rn, thoron) is a radioactive decay product of radium-224 in the thorium-232 decay chain that is also present in the earth's crust. Both radon-222 and radon-220 can also be released from building materials to the indoor atmosphere. The indoor radon concentration can vary by several orders of magnitude from one building to another[1]. ^{222}Rn is the most important because of its longer half-life (3.86 d) and its longer diffusion length in air (3.16 m) compared to ^{220}Rn[2].

Radon tends to concentrate in enclosed spaces such as poorly ventilated dwellings[3, 4]. Indoor radon exposure has become a health concern in many parts of the world since it accounts for 60% of the total natural background radiation[4-6]. Radon is assumed to be an important cause of lung cancer after smoking[6-11]. The health concern

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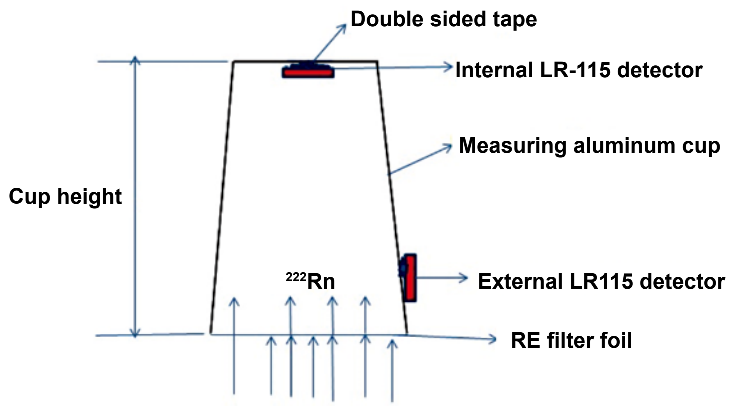

Fig. 1. Schematic diagram of the passive radon device.

Fig. 2. Map Showing the location of the studied cities in Egypt.

increases for persons who spend more than 80% of their time indoors in either the home or the workplace[12]. Radon concentrations in dwellings depend on a number of parameters such as building materials, geology, living environment, ventilation, climate and so forth[3, 13].

Several techniques have been used to measure indoor concentrations of radon and its progeny. Solid state nuclear track detectors (SSNTDs), such as LR-115 and CR-39, have been widely used for the measurement of time-integrated radon levels under different conditions[3, 13]. LR-115 detectors have high sensitivity, low cost, are easy to handle and retain a permanent record of the detected alpha tracks. Such detectors also compensate for the effects of seasonal and diurnal fluctuation of radon activity concentrations due to physical and geological factors as well as meteorological factors[3].

In Egypt, many research workers are engaged in the measurements of indoor radon levels in dwellings using LR-115 and CR-39 SSNTDs[14-27].

The aims of the present study were to determine the radon decay equilibrium factors and indoor radon levels in dwellings of 15 selected cities of Egypt and to calculate the annual effective doses to residents from indoor radon and progeny.

2. Materials and Methods

The passive measurement device was a diffusion cup of aluminum 3.5 cm in radius and 11 cm in length equipped with LR-115 type II film (Kodak Pathé, France), numbered and attached with double adhesive side by side at the top center of the inverted cup. The cup was closed using a 50 μm PE filter. Another LR-115 detector was fixed outside the cup (bare detector) as shown in Figure 1. This device was used for simultaneous estimation of radon activity concentration and the equilibrium factor[3]. The detection system was calibrated at the National Institute for Measurements and Standards (NIS), Cairo, Egypt[28, 29].

A total of 180 measuring cups were used to measure indoor radon levels in 15 Egyptian cities shown in Figure 2, measured at three dwellings in each city and using four cups in each dwelling. As reported in scientific literatures, the radon concentration in the indoor air vary with building ageing, high above the ground, ventilation pattern, architectural style of building, the meteorological conditions such as temperature, barometric pressure and wind speed as well as the variation of living habits of the occupants[3, 13], Due to these factors, the studied dwellings were select with nearly with the same construction and ventilation conditions to minimize the number of variables affecting radon concentrations. The dwellings under study were chosen in the Egyptian National Social Housing Project. This project exists in all cities in Egypt with a unified engineering and architectural style. These dwellings were made of reinforced concrete, cement and red bricks, all on the ground floor. The cups were placed at a height of 2 m above the floor and were distributed in both living rooms and bedrooms. The period of the survey was one year. After the exposure time, the detectors were removed and etched in a freshly prepared NaOH solution: 2.5 M at 60 ℃ for 2 h[3]. The track densities were determined by means of an optical microscope of magnification 600X. Background track densities were subtracted from the tracks of exposed detectors, and the average radon concentration values were determined.

The track density recorded on the internal detector ρ_i which related to the radon activity concentration C (Bq m^{-3}) in the following way:

$$C = \frac{\rho_i}{K \cdot \eta \cdot t} \tag{1}$$

where K is the attenuation factor of radon transport through the membrane which can be determined by the method reported by Hafez and Somogyi[30], η is the calibration coefficient of the measuring system in terms of α-tracks cm^{-2} day^{-1} per Bq m^{-3} radon and t is the exposure time.

The equilibrium factor F between radon and its short-lived daughters can be determined by the following empirical formula

$$F = aR - b\,, \tag{2}$$

where a and b are fitting parameters, $R = \frac{\rho_e}{\rho_i}$, for values $1.2 < R < 3$, and ρ_e is the track density recorded on the external (bare) detector. Recently the values of the above-mentioned fitting parameters were found to be $a = 0.5$ and $b = 0.53$ as given by Planinić *et al.*[31]

The annual effective dose (E: mSv y^{-1}) for radon and its progeny was calculated using conventions published in UNSCEAR[4] using the following equations:

Table 1. Annual radon activity concentration(C), annual equilibrium factor (F) and annual effective dose (E) calculated inside houses of selected cities of Egypt

City	C (Bq m^{-3}) Min.–Max. (Mean ± S.D)	F ± S.D.	E (mSv)
Alexandria	6–68 (42.2 ± 13.3)	0.37 ± 0.03	0.98
Asuite	7–52 (21.7 ± 10.0)	0.41 ± 0.03	0.56
Aswan	5–53 (28.0 ± 10.7)	0.44 ± 0.05	0.78
Cairo	3–97 (25.9 ± 12.1)	0.43 ± 0.04	0.70
Hurghada	11–62 (33.7 ± 11.4)	0.42 ± 0.03	0.89
Luxor	7–52 (31.5 ± 9.9)	0.41 ± 0.03	0.81
Marsa Matruh	12–77 (40.8 ± 13.4)	0.36 ± 0.02	0.93
New valley (Kharga)	8–48 (25.7 ± 8.8)	0.37 ± 0.03	0.66
North Sinai (Arish)	11–38 (20.6 ± 5.9)	0.39 ± 0.03	0.51
Port Saied	13–37 (23.3 ± 5.7)	0.41 ± 0.03	0.60
Qena	19–59 (40.0 ± 8.4)	0.30 ± 0.02	0.76
Safaga	13–65 (37.9 ± 10.9)	0.39 ± 0.03	0.93
Siwa Oasis	11–69 (39.4 ± 12.0)	0.40 ± 0.03	0.99
South Sinai (Sharm El-Sheikh)	10–41 (23.0 ± 7.0)	0.35 ± 0.02	0.51
Suez	14–46 (29.9 ± 6.7)	0.37 ± 0.02	0.70
Average	30.9 ± 7.3	0.39 ± 0.03	0.75 ± 0.16

$$E = C \times F \times O \times T \times D \tag{3}$$

where C is the average radon concentration (Bq m^{-3}), F is the equilibrium factor, O is the occupancy factor (assumed to be 0.8), T is hours in a year (8760 h y^{-1}) and D is the dose coefficient (9 nSv Bq m^{-3} h^{-1}).

3. Results and Discussion

The calibration coefficient η for LR-115 detector obtained from the calibration experiment was 0.036 ± 0.006 α-tracks cm^{-2} d^{-1} per Bq m^{-3} of radon[28, 29]. This value was used to estimate the radon activity concentration C with the help of equation (1). From the measured track densities ρ_i and ρ_e and using equation (2) the equilibrium factor F was calculated. Using equation (3), the effective dose values to dwelling residents were calculated based on the annually mean value of both radon activity concentration and equilibrium factor inside the dwelling. The results of the annual indoor radon activity concentration C, the annual equilibrium factor F and the annual effective dose E are presented in Table 1.

The annual radon activity concentration C inside the studied dwellings varied from 20.6 to 42.1 Bq m^{-3}, with an average value of 30.9 ± 7.3 Bq m^{-3}. These results showed that the annual radon activity concentration was low due to good ventilation because the windows were kept open most of the time. The indoor average radon concentration in the dwellings of the study were found less than action level of 300 Bq m^{-3}, 100 Bq m^{-3} and 148 Bq m^{-3} as

Table 2. The comparison of mean radon concentration *C* from other studies in Egypt using the cup technique with LR-115 or CR-39 detectors

City	*C* (Bqm^{-3}) Min.–Max. (Mean)	Reference
Alexandria.	1–6	14
	33	15
	38.62–120.39 (75.6)	24
	45–90 (65)	25
Asuite.	3–14	14
Cairo, Alexandria, Demiette and Roseta.	3–47	16
Cairo, Alexandria, Ismalia, Sohag and Aswan.	11.8–46.8 (24.7)	21
Cairo.	2–11	14
	18–62 (39)	17
	22.95–59.32	20
	50.8–81.29	22
El-Dabaa	24–77 (54)	26
Qena.	19–59 (40)	23
	21.60–41.61 (33.69)	27
Sers Ellian.	15–98 (52)	18
Sinai.	4–15	14
Teta, Minoufya	78–133	19
15 cities of Egypt.	30.9 ± 7.3	Present work

recommended by ICRP Publ. 126[1)], WHO[5)] and EPA[11)], respectively. The mean value of radon concentration throughout this study in agreement with the average worldwide value of 40 Bq m^{-3} reported by UNSCEAR[4)]. It is evident from Table 1 that there is a variation in the values of concentration of indoor radon. This variation may be attributed to the variety of living style of the inhabitants, the different air exchange rate with the outdoor in the different rooms depending on their pattern of use, the construction materials and the environmental conditions.

The annual equilibrium factor F varied from 0.30 to 0.44 with an average value of 0.39 ± 0.03, which is almost equal to the value (0.40) adopted by the UNSCEAR[4)].

The calculated annual effective doses per dwelling varied from 0.51 to 0.99 mSv, with an average value of 0.75 ± 0.16 mSv. These values were lower the typical background levels of 1.1 mSv y^{-1} by UNSCEAR[4)], and were less than the recommended action value of 10 mSv y^{-1}, as recommended by ICRP Publ. 126[1)].

These measurement results and calculated annual effective doses infer that all dwellings under investigation are safe and not harmful regarding human exposures to radon and progeny in breathing air. Table 2 presents a comparison of the current results with data reported for Egypt. Table 2 shows the variance in the results of radon concentrations due to the different time periods for measurements, as well as the different building and living conditions in these dwellings.

4. Conclusions

In this study, 45 dwellings in 15 cities of Egypt were studied to determine indoor radon concentrations over a period of one year. Measurements were made using LR-115 solid state nuclear track detectors in an inverted cup configuration. All radon activity concentrations were found to be less than the action level recommended by international scientific radiation protection organizations. In all cases, the calculated effective doses were less than the action levels recommended by ICRP Publ. 126 of 10 mSv y^{-1}. These results showed that all occupants of these dwellings are not exposed to unsafe exposures to radon and progeny. These important measurement results and calculated effective doses confirmed that exposures to radiation from indoor radon and progeny in these Egyptian residences places are less than typical backgrounds (world-wide), and therefore do not represent any significant threat to human health. The results of this work have contributed important data to the overall radiological assessment program and radon radioactivity map of Egypt.

Regarding published radiological studies, the analysis of population exposures to ^{220}Rn and its decay products in a greater is not trivial, and the evaluation of ^{220}Rn and its decay products in a greater number of dwellings and dwelling types has not been fully studied in Egypt. Therefore, it is recommended that further studies be conducted to assess the indoor ^{222}Rn and ^{220}Rn concentrations in Egyptian dwellings.

Acknowledgements

The author would like to thank Dr. Darrell Fisher, a past president of the Health Physics Society, for his valuable contributions in this work. Also, the author thanks the residents of the dwellings under study for their cooperation throughout the measurement period.

Conflict of Interest

The author declares that he has no conflict of interest.

References

1. ICRP. Recommendations of the International Commission on

Radiological Protection: Radiological Protection against Radon Exposure, ICRP Publication 126. Ann ICRP 43. Oxford: Pergamon Press; 2014.

2. Singh B, Singh S, Virk HS. Radon diffusion studies in air, gravel, sand, soil and water. Nucl Tracks Radiat Meas. 1993;22(1-4):455–8.
3. Durrani SA, Ilic R. Radon Measurements by Etched Track Detectors: Applications in Radiation Protection, Earth Sciences and the Environment. 1st ed. World Sci: Singapore; 1997.
4. UNSCEAR. Report to the General Assembly with Scientific Annexes. United Nations Scientific Committee on the Effect of atomic Radiation. New York, United States: United Nations; 2000.
5. WHO. Handbook on indoor radon: a public health perspective. Geneva, Switzerland: World Health Organization; 2009. p. 94
6. ICRP. Recommendations of the International Commission on Radiological Protection: Lung cancer risk from radon and progeny and statement on radon, ICRP Publication 115. Ann ICRP 40. Oxford: Pergamon Press; 2010.
7. NRC. Health Effects of Exposure to Radon: BEIR VI. Washington, DC: The National Academies Press; 1999.
8. IAEA. Protection of public against exposure indoors to radon and other natural sources of radiation. Vienna: International Atomic Energy Agency; 2015;SSG-32:1–5.
9. Gaskin J, Coylo D, Krewki D. Global estimate of lung cancer mortality attributable to residential radon. Environ Health Prospect. 2018;126(5):057009.
10. UNSCEAR. Report to the General Assembly with Scientific Annexes. United Nations Scientific Committee on the Effect of atomic Radiation. New York, United States: United Nations; 2019.
11. EPA. Overview EPA's state indoor radon grants: 2019 Activities. Environmental Protection Agency: Wexford; 2020.
12. UNSCEAR. Report to the General Assembly with Scientific Annexes. United Nations Scientific Committee on the Effect of atomic Radiation. New York, United States: United Nations; 1993.
13. IAEA. National and Regional Surveys of Radon Concentration in Dwellings, Review of Methodology and Measurement Techniques. Vienna: International Atomic Energy Agency. 2013;AQ-33:1–13.
14. Kenawy MA, Morsy AA, Kotb MA, Osman A, El-Haag A. International workshop on radon monitoring in Radioprotection Environmental Radioactivity and Earth sciences;1989 Apr 3-14; International Centre for Theoretical Physics (ICTP), Trieste (Italy): IAEA; 1990.
15. Hafez AF, El-Katib AM, Kotb MA. Proceedings of the Regional Symposium on Environmental Studies; 1990 May 15-17, Alexandria, Egypt: 1990.
16. Hassib GM, Amer HA, Hussein MI, Piesh E. The application of nuclear track detectors for alpha energy discrimination and radon measurement in Egyptian dwellings. German – Egyptian Cooperation Scientific Research and Technology Development, Burean. Forschungszentrum Jülich Zentralbibliothek: 1995.
17. Maged AF and Borham EA. Study of the radon emitted from various building materials using alpha track detectors. Radiat Meas. 1997;28(1-6):613–7.
18. Maged AF, Ashraf FA, El-Behay AZ. Radon levels measured at building sites and in sub-soil in Delta. Radiat Meas. 1997;28(1-6):599–602.
19. El-Sersy AA. Radon level determination in natural samples using alpha-tracks and gamma spectroscopic methods [dissertation]. Physics Department, Faculty of Sciences, Egypt: El-Minoufiya University; 2000.
20. Kenawy MA, Morsey AA, Hugely TM, Abdel-Ghany HA. radon concentrations in different locations in Cairo city using CR-39 detector. Proceeding of the Sixth Radiation Physics Conference; 2002 Oct 27-30; Assiut, Egypt: 2002.
21. Abdel-Naby A, Morsy AA. radon levels in several cities in Egypt namely Cairo, Alexandria, Ismalia, Sohag and Aswan. Proceeding of the Sixth Radiation Physics Conference; 2002 Oct 27-30; Assiut, Egypt: 2002.
22. Abdel-Ghany HA. Variability of radon concentrations in different compartments of dwellings in Egypt. Environ Med. 2005;15(4):153–6.
23. Hussein AS. Radon concentrations in some Egyptian dwellings using LR115 detectors. Proceeding of the VIII Radiation Physics & Protection Conference; 2006 Nov 13-15; Beni Suif – Fayoum, Egypt: 2006.
24. Abdel-Zaher M, Fahmi NM. Studying the variation of radon level in some houses in Alexandria City, Egypt. Proceeding of the IX Radiation Physics and Protection Conference; 2008 Nov 15-19; Cairo, Egypt: 2008.
25. Abdel-Zaher M. Seasonal variation of indoor radon concentration in dwellings of Alexandria city, Egypt. Radiat Prot Dosim. 2011;143(1):56–62.
26. Hussein AS. Indoor radon concentration measurements at the site of the first nuclear power plant in Egypt. Radioprotection. 2014;49(3):201–3.
27. Harb S. Measurements level of radon-222 in some houses by using SSNTDS in Qena City, Egypt. Proceeding of the 9th Conference on Nuclear Particle Physics; 2015 Oct 11-15, and Luxor-Aswan, Egypt: 2015.
28. Hafez AF, Hussein AS. Radon activity concentrations and effective doses in ancient Egyptian tombs of the Valley of the Kings. Appl Radiat Isot. 2001;55:355–62.
29. Hussein AS. Measurements of environmental alpha-activity using CR-39 and LR-115 plastic nuclear track detectors [desertation]. Physics Department, Faculty of Science, Egypt: Alexandria University; 2003.
30. Hafez AF, Somogyi G. Determination of radon and thoron permeability through some plastic by track technique. Nucl Track Radiat Meas. 1986;12(1-6):697–700.
31. Planinic J, Radolic Z, Faj Z, Suveliak B. Radon equilibrium factor and aerosol. Nucl Instrum Meth A. 1997;396:414–7.