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Indoor Radon Levels and the Associated Effective Dose Rate Determination at Dome in the Greater Accra Region of Ghana

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Abstract: In this present work, the indoor radon concentration, the annual effective dose rate, the annual dose equivalent rate to the lung and the populace risk were estimated in sandcrete houses of Dome in Ghana using time-integrated passive radon detectors. LR-115 Type II Solid State Nuclear Track Detector (SSNTD) technique was used for the measurements were for a period of 3months. The mean annual effective dose rate and the mean annual equivalent dose rate to the lung in the studied area were (14.13±0.22) mSv/y and (3.74 E-07 ±3.50 E-06) Sv/y, respectively. The mean indoor radon concentration was (466.9±1.2) Bq/m^3. The odds ratio for the study at 95% confidence interval was 7 (CI 0.92-53.16). The indoor radon concentration has not only been found to vary considerably with the ventilation condition but also with the lifestyle of the people. The results obtained also give a correlation between indoor radon levels and the associated level of risk.

Key words: Annual effective dose, annual exposure, Ghana, LR-115 type II detector, odds ratio, radon concentration, (solid state nuclear track detector)SSNTD

INTRODUCTION

Radon is a naturally occurring odourless, colourless, tasteless inert gas which is imperceptible to our senses. It is produced continuously from the decay of naturally occurring radionuclide such as U-238, U-235 and Th-323. The radioisotope Rn-222, produced from the decay of U-238, is the main source (approximately 55%) of internal radiation exposure to human life (ICRP, 1993). Worldwide average annual effective dose from ionizing radiation from natural sources is estimated to be 2.4mSv, of which about 1.0 mSv is due to radon exposure (UNSCEAR, 2000). The measurement of radon in man's environment is of interest because of its alpha emitting nature. A certain fraction of the radon escapes into the air where, in the outdoors, it is quickly diluted and is of no further concern. However, in confined spaces such as homes and office buildings, radon can accumulate to harmful levels. Many environmental pollutants are classified as cancer-causing solely on the basis of laboratory studies using either animals or cell cultures. In the case of radon, there is direct evidence from human studies of a link between exposure to radon and lung cancer. For this reason radon has been classified by the International Agency for Research on Cancer, a branch of the World Health Organisation, as a Group 1 carcinogen. This places radon in the same group of carcinogens as asbestos and tobacco smoke.

Most of our time is spent indoors; therefore, the measurement and evaluation of radon concentrations in buildings are important (Risica, 1998; Hamori *et al.*, 2004) but in Ghana time spent indoors are less as compared to other countries in the world due to our climate. Worldwide measurements of radon activities in the indoor air of dwellings are continuously presented all over the world (Singh *et al.*, 2002; Iyogi *et al.*, 2003; Magalhaes *et al.*, 2003) including Ghana (Oppon *et al.*, 1990, Andam *et al.*, 2007; Quashie, 2009). The numerous measurements of the activity concentrations of radon in different countries along with epidemiological studies regarding the indoor radon and risk of lung cancer have been published in recent years (Papastefanou *et al.*, 1994; Bochicchio *et al.*, 1998; Field *et al.*, 2000). The main natural sources of indoor radon are soil, building materials (sand, rocks, cement, etc.,), tap water, natural energy sources used for cooking like (gas, coal, etc.,) which contain traces of U-238, the topography of the area, house construction type, soil characteristics, ventilation rate, wind direction, atmospheric pressure and even the life style of people.

The Solid State Nuclear Track Detectors (SSNTDs is an important tool in investigations concerning the presence of radon gas. Solid State Nuclear Track Detectors (SSNTDs) (Fleischer *et al.*, 1975) are insulating solids both naturally occurring and man-made.

In this present work, the technique of using the Solid State Nuclear Track Detectors (SSNTDs) has been

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Fig. 1: A map showing the study area Dome

utilized for the study of indoor radon level in dwellings of Dome in the Dome-Kwabenya area in the Ga-East district of Accra. The radon concentration is calculated from the track density. The annual equivalent dose rate to the lung received by the population is calculated based on guidelines given by the International Commission on Radiological Protection (ICRP) and United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). In this study, the inferential statistics tool, the odds ratio is used because currently it is one of the statistical methods for calculating risk. The odds ratio is one of a range of statistics used to assess the risk of a particular outcome (or disease) if a certain factor (or exposure) is present.

The main objective of this work was to assess the indoor radon concentration, the annual effective dose rate, the annual dose equivalent rate to the lung and the associated level of risk to the populace.

MATERIALS AND METHODS

The study was conducted at the Department of Physics, National Nuclear Research Institute of the Ghana Atomic Energy from March 2010 to May 2010.

Study area: The study area (Fig. 1) is located in the southern part of Ghana, precisely Greater Accra Region of Ghana and in the Dome-Kwabenya constituency. Dome was chosen for this study because previous research was done there in 1989 (Oppon *et al.*, 1990) which gave some results that needs to be re-investigated. Dome is situated between latitude 5º39′0″ North and longitude 0º13′48″ East (248 m of elevation).

Methodology: The LR-115 type II detectors were cut into rectangles and placed in specially made envelopes (Fig. 2) from cardboards. The detectors were hanged in the various bedrooms of the people in Dome at a height of 2 m from the ground level from December 2009 to March 2010. The sensitive lower surface of the detector was freely exposed to the emergent radon so that it was capable of recording the alpha-particles resulting from the decay of radon in the room. After the 3 months exposure, the detectors were subjected to chemical etching in a 2.5 M analytical grade sodium hydroxide solution at (60±1)ºC, for 90 min in a constant temperature water bath to enlarge the latent tracks produced by alpha particles from the decay of radon. After the etching, the detectors were washed with running cold water, then with distilled water. After a few minutes of drying in air, the detectors were ready for track counting. The detectors were first pre-sparked at 1200 V and sparked at 700 V thrice. After the sparking the replica sparks on the aluminized mylar were counted using a microfiche reader and a tally counter as shown in Fig. 3. The tracks were counted thrice for each detector and the average was calculated. The track densities were then converted into radon concentration by applying the calibration factor for LR-115 type II bare detector. The track density was calculated using the equation below:

$$\text{Track density } (\rho) = \text{Average number of sparks/Area of electrode} \quad (1)$$

Concentration of indoor radon gas in Bq/m^3 was calculated using the formula below:

$$\text{Concentration (kBq/m}^3) = \rho - \rho_B / \epsilon T(h) \quad (2)$$

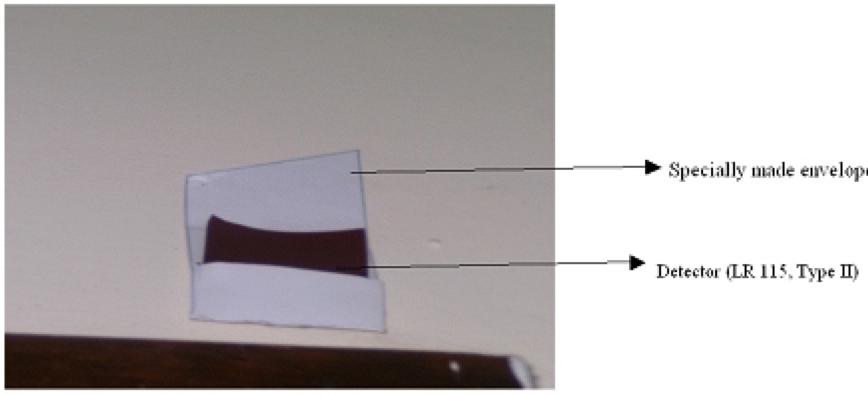

Fig. 2: A picture showing a detector placed in a participant's bedroom

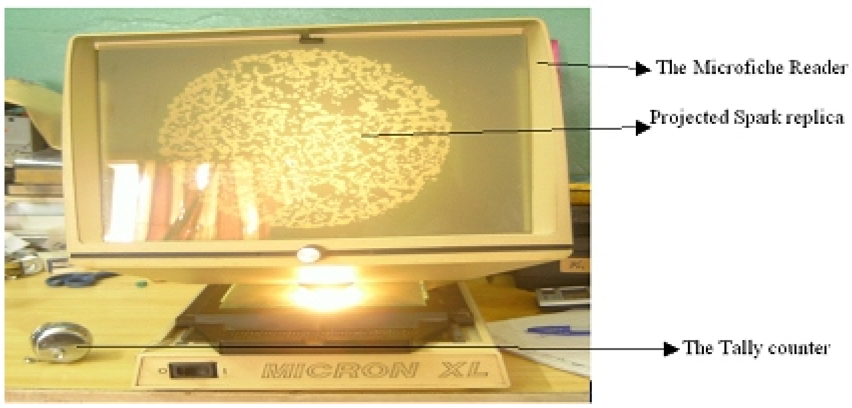

Fig. 3: The microfiche reader with a projected spark and the tally counter

where,
ρ is the track density
ρ_B is the background track density
ϵ is the calibration factor 1(Tracks.m^3 / cm^{2}kBq.h) of the LR-115 (Type II)
T(h) is the exposure time in hours.

ANNUAL EFFECTIVE DOSE RATE

In order to estimate the annual effective dose rate received by the population, one has to take into account the conversion co-efficient from the absorbed dose and the indoor occupancy factor. According to the UNSCEAR (2000) report, the committee proposed 9.0 x 10^{-6} mSv/h per Bq/m^3 to be used as a conversion factor, 0.4 for the equilibrium factor of Rn-222 indoors and 0.8 for the indoor occupancy factor. Calculating the annual effective dose to the population, the equation below is used (ICRP, 1993). At a certain radon concentration C_{Rn} in Bq/m^3, the annual absorbed dose, D_{Rn} is usually expressed in the unit of mSv from the following relation below:

$$D_{Rn}\,(mSv/y) = C_{Rn}.D.H.F.T \qquad (3)$$

where,
C_{Rn} is the measured Rn-222 concentration (in Bq/m^3),
F is the Rn-222 equilibrium factor indoors (0.4),
T is the indoor occupancy time 24 h ×365 = 8760 h/y
H is the indoor occupancy factor (0.4), and
D is the dose conversion factor (9.0×10^{-6} mSv/h per Bq/m^3).

Now to calculate the annual equivalent dose and effective dose, one has to apply a tissue and radiation weighting factors according to ICRP, 1991. The equivalent dose is the radiation- weighted absorbed dose. The radiation weighting (W_R) factor for alpha particles is 20 as recommended by ICRP, 1991. With the effective dose, a tissue weighting (W_T) factor is applied. According to ICRP, the tissue weighting factor for lung is 0.12. The annual effective dose is then calculated according to the equation below:

$$H_E\,(mSv/y) = D_{Rn}.W_R.W_T \qquad (4)$$

where,
D_{Rn} = Annual Absorbed dose
W_R = Radiation Weighting Factor for Alpha Particles, 20
W_T = Tissue Weighting Factor for the Lung 0.12

It is, however, apparent that the time spent by individuals in the home varies widely globally. The occupancy factor of 0.8 (ICRP, 1993) over estimates the excess lung cancer risk in the tropical regions but may be valid for the inhabitants of the cold climate zone. In the tropical regions, people spend most of their time in open air and only go indoors to sleep at night. In this present study, the occupancy factor that was used for the annual absorbed dose calculation will be 40% (0.4).

The indoor occupancy factor used was calculated, based on the fact that dwellers spend only about 9 hours indoors out of the 24 h in a day.

In the case of the annual equivalent dose to the lungs, the radon content of the lung air has to be taken into account, which results in the equation below according to UNSCEAR:

$$H_{lungs}\,(Sv) = 8 \times 10^{-10}\, \chi_{Rn,air}\, Bq/m^3 \qquad (5)$$

The odds ratio:
Calculating the odds-ratio for a set of data is fairly straight-forward. A contingency table was constructed as shown in Table 1.

In calculation:
Odds of cases (The probability of the event occurring)

$$= A\times(A+B)/B\times(A+B) = A/B \qquad (6)$$

Odds of control (The probability of the event not occurring)

$$= C\times(C+D)/D\times(C+D) = C/D \qquad (7)$$

The odds ratio is calculated by dividing the Odds of Cases by the Odds of Control, thus the probability of the event occurring to the probability of the event not occurring:

$$\text{Odds ratio: } AD/CB \qquad (8)$$

RESULTS AND DISCUSSION

Table 2 and 3 gives a summary of the results of the track densities, indoor radon concentration levels, the annual effective dose rate and the annual dose equivalent rate measured in 20 different houses in Dome for the present study where the observation were taken from December, 2009 to March, 2010. The houses were selected at random situated at different areas, at least half a kilometre away from each other in the town. The average number of tracks per unit area was taken from the mean of the individual number of tracks per unit area. The present survey shows that the indoor radon concentration obtained varied from (278.09 to 740.12) Bq/m^3 with an overall mean value and standard error of (466.89±1.24) Bq/m^3 which is within the recommended ICRP action level of 200-600 Bq/m^3 (ICRP, 1993) . The lowest value concentration was found to be 278.09Bq/m^3, whereas the highest concentration was found to be 740.12Bq/m^3. The annual effective dose from the corresponding measured radon concentration in the different houses has been calculated using Eq. (4), which varies from (8.42 to 22.41) mSv/y with a mean value and standard error of (14.13±0.22) mSv/y which is above the recommended ICRP intervention level of (3-10) mSv/y (ICRP, 1993). The highest value was observed in the house of

Table 1: A contingency table for the odds ratio

	Cases	Controls	Total
Exposed	A	B	A+B
Non-exposed	C	D	C+D
Total	A+C	B+D	

Table 2: Radon concentration, annual effective dose and the annual equivalent dose rate to the lung in the environment of dome

No.	Radon concentration (Bq/m^3)	Annual effective dose (mSv/y)	Annual equivalent dose to the lung (Sv/y)
15B	493.36	14.94	3.94686E-07
19B	422.22	12.78	3.37778E-07
17B	284.26	8.61	2.27407E-07
1B	337.96	10.23	2.7037E-07
25B	369.87	11.20	2.95894E-07
4B	452.47	13.70	3.61975E-07
11B	558.64	16.91	4.46913E-07
6B	515.74	15.61	4.12592E-07
24B	602.47	18.24	4.81975E-07
10B	597.22	18.08	4.77778E-07
18B	394.14	11.93	3.15309E-07
8B	469.44	14.21	3.75556E-07
3B	415.12	12.57	3.32099E-07
2B	740.12	22.41	5.92099E-07
16B	438.41	13.27	3.50725E-07
21B	278.09	8.42	2.22469E-07
13B	519.44	15.73	4.15556E-07
5B	568.52	17.21	4.54815E-07
23B	317.08	9.60	2.53664E-07
20B	563.16	17.05	4.50526E-07
MEAN±SE*	466.9±1.2	14.13±0.22	3.73E-07±3.50E-05

*: SE (standard error) = δ/√N; δ = SD (standard deviation); N = no. of observations

Table 3: Average track density (Exposed), average track density (Background), average final track density and radon concentration

Number	Average track density (Exposed)	Average track density (Background)	Average final track density
15B	1521.33	432.00	1089.33
19B	1552.67	640.67	912.00
17B	1124.00	510.00	614.00
1B	1331.33	601.33	730.00
25B	1408.00	591.33	816.67
4B	1336.67	359.33	977.33
11B	1627.33	420.67	1206.67
6B	1533.33	419.33	1114.00
24B	1526.67	225.33	1301.33
10B	1474.00	184.00	1290.00
18B	1152.00	300.67	851.33
8B	2306.67	1292.67	1014.00
3B	1186.00	289.33	896.67
2B	1852.67	254.00	1598.67
16B	1352.67	384.67	968.00
21B	1024.00	423.33	600.67
13B	1584.67	462.67	1122.00
5B	1630.67	402.67	1228.00
23B	1022.00	306.67	715.33
20B	1583.33	299.33	1284.00

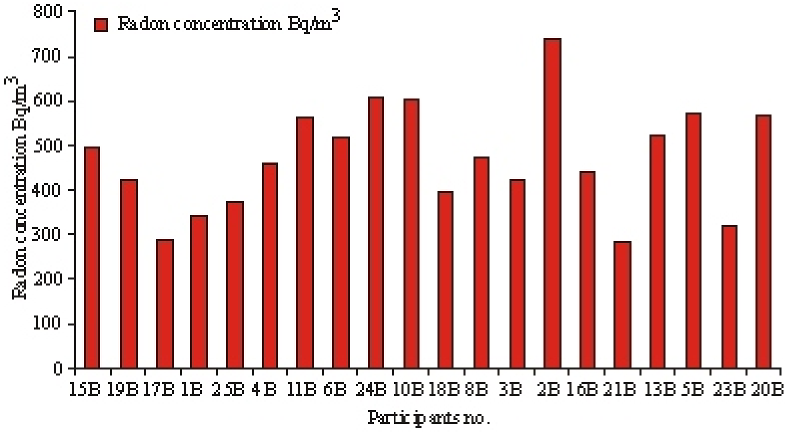

Fig. 4: A bar chart of participant's number and their corresponding indoor radon concentration

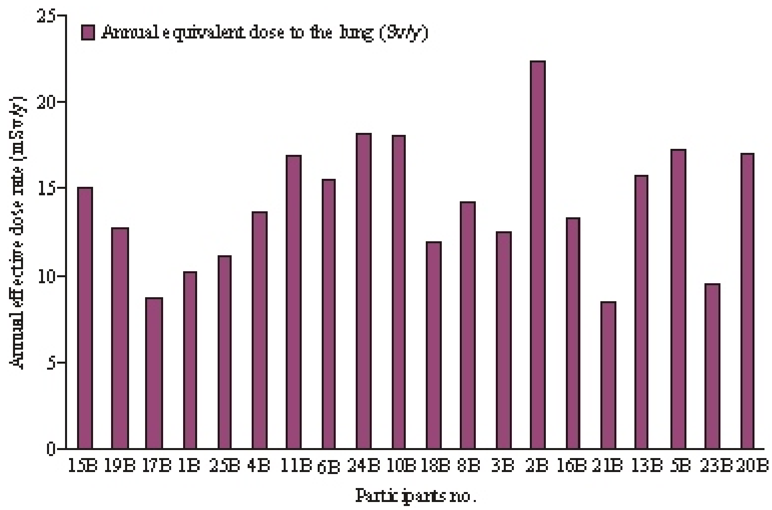

Fig. 5: A bar chart of participant's number and their corresponding annual effective dose rate

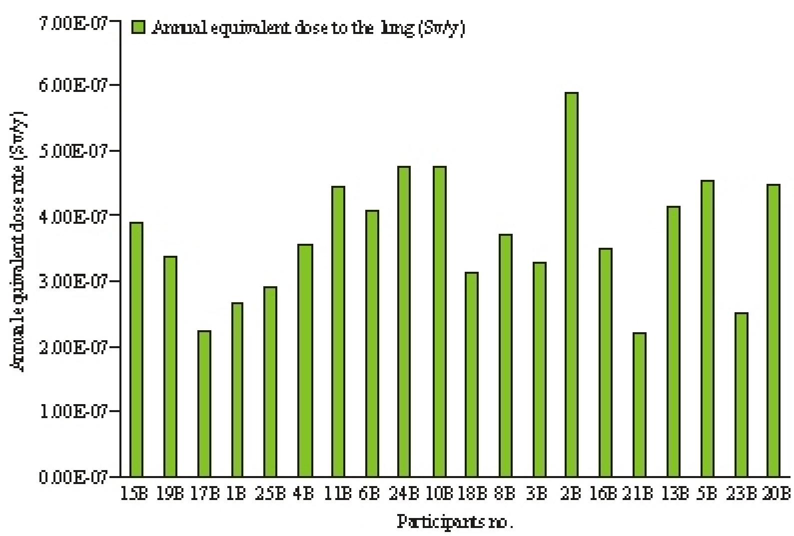

Fig. 6: A bar chart of participant's number and their corresponding annual equivalent dose rate to the lungs

participant number 2B with an indoor radon concentration of 740.12 Bq/m^3 and an annual effective dose rate of 22.41 mSv/y. The high radon concentration level in 2B is due to poor ventilation, lifestyle and the accumulation of dust in the room due to the closeness of the house to the roadside which are usually considered as important sources of radon in buildings. The lowest value was found in the house with number 21B with an indoor radon concentration of 278.09Bq/m^3 and an annual effective dose of 8.42 mSv/y which is probably due to adequate ventilation. Although most of the indoor radon concentration is within the ICRP action level, all the values are higher than the reference level set by the USEPA for the USA, thus 148 Bq/m^3 (USEPA, 2004) and almost three times the new reference level (100 Bq/m^3) set by WHO (WHO, 2009) and ICRP 2007, Also, the average value is higher than the world average radon concentration of 40 Bq/m^3.(UNSCEAR, 2000). From the statistical error on track counting, the statistical uncertainty on the track density was about 10%.

The results of the study indicate that radon concentrations in most of the rooms investigated were significantly high. Although the houses were constructed mainly from the same skeletal building materials (concrete and cement blocks), the finishing materials used in such compartments differ from room to room. Another factor explaining the high levels of radon these compartments are the poor ventilation status due to the relatively narrow openings. Windows are opened only when dwellers are in the house and since most of the dwellers are traders, they leave the house early and come back late in the night. Also, most of the houses in the present study areas serve as both living rooms and bed rooms for the residents. This could also account for the high radon concentration levels since most of the residents valuables are kept in one room making the room non-spacious for inflow of air. The various dwellings and their corresponding radon concentrations, annual effective dose rate, annual dose equivalent to the lungs are represented graphically in Fig. 4, 5 and 6.

CONCLUSION

This work assesses the indoor radon concentration in 20 houses at Dome. The radon activities were measured from December 2009 to March 2010 in each location. The results of the present research led to the following conclusions: the mean radon concentration for the three months period was (466.9±1.2) Bq/m^3 with a range of (278.09-740) Bq/m^3. The mean annual effective dose rate and the mean annual equivalent dose rate to the lung in the studied area were (14.13±0.22) mSv/y and (3.74 E-07±3.50 E-06) Sv/y, respectively. All studied dwellings recorded concentrations above the recommended action level (ICRP, 1993). It is concluded that the poor ventilation, the season and the lifestyle of the people raise the accumulation of radon gas to a risky level for the people. Measurement obtained stresses the need for a more extended survey on radon risk all over the country.

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