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Indoor Radon Gas Levels in Selected Homes in the Greater Accra Region of Ghana

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Abstract: The aim of the study is to monitor indoor radon gas levels in dwellings in the Sakumono Estates and its environs in the Greater Accra Region of Ghana in order to assess the risk of exposure to the inhabitants, using the passive Solid State Nuclear Track Detectors (SSNTDs). The sampling and deployment of the detectors covered the predominant mode of dwelling structures, which are the flats, semi-detached, detached and cluster houses. The mean Radon concentration obtained was 10.18 Bq/m³, with an annual effective dose equivalent to the population determined to be 0.22 mSv/yr, assuming an occupancy factor of 0.5 for the modern estate dwellings and 0.3 for the cluster ("compound type") houses. The maximum recorded concentration was 18.60 Bq/m³ in a semi-detached building, followed by a concentration of 18.05 Bq/m³, recorded in a flat located on the ground floor. The annual effective dose equivalent to each type of housing unit has been calculated and given as 0.25 mSv/yr for flats, 0.25 mSv/yr for semi-detached houses, 0.23 mSv/yr for detached and 0.15 mSv/yr for the cluster houses. The Radon gas levels obtained may not pose any appreciable risk to the inhabitants on the basis that the levels were low. The excess life time risk of any member of the group suffering from Radon gas induced lung cancer is approximately 0.02%. The Radon gas levels were cross-checked with an active dosimeter (Radon Scout Plus) and an average concentration of 10 Bq/m³ was obtained. Mean values for flats, semi-detached, detached and cluster houses were 9.33, 10.86, 9.30 and 9.30 Bq/m³ with medians of 7.87, 9.86, 9.27 and 9.29 Bq/m³, respectively.

Key words: Dosimeter, LR-115, radon, risk, SSNTD, ventilation rate

INTRODUCTION

Radon is a naturally occurring radioactive gas which is a decay product of radium. It lies in the radioactive decay chain that begins with U-238 through a series to produce Ra-226 and subsequently Rn-222 gas and ending in Pb-206.

Uranium is particularly abundant in granite, shale and phosphate bearing formations. Thus, small amounts are dispersed throughout the earth's crust. This means radon may be found everywhere.

Radon being an inert gas seeps through cracks in the bedrock and soil before it finally escapes into the atmosphere in harmless levels. Radon gas can however enter buildings above such underground deposits through cracks in foundations, walls, household water usage, hollow concrete blocks and sump-pump openings. Once in a building, it can accumulate to high levels, especially in unventilated lower levels of homes and buildings.

Radon has a half-life of 3.82 days. It has four short lived decay products namely; Po-218, Pb-214, Bi-214 and Po-214 (Leonard, 1993) with the longest half life being that of Pb-214 which is approximately 29 min.

Exposure to high levels of radon gas through breathing air indoors increases the risk of lung cancer proportionally to the concentration and the period of exposure. When inhaled, radon gas flows quickly in and out of the lungs, almost never lingering enough to cause damage. The radon progeny, Po-218 and Po-214 which are solids tend to lodge in the bronchial trees where they emit "heavy" particles called alpha (α) (equivalent to a helium nucleus that is charged with a high mass).

Alpha (α) particles can cause more damage to tissues, because of their greater electrical charge and relatively large mass. Among the three emitted radiations, alpha (α) particles are the most harmful. The skin is often an effective barrier against alpha (α) particles owing to the fact that they can pass through only one or two cells before being brought to a halt. On the contrary, the lungs lack such a protective layer, and thus the particles can affect sensitive basal cells lining the bronchi when radon progeny (i.e. Po-218 and Po-214) become lodged in there.

Alpha (α) particles can damage the DNA in cell nuclei leading to uncontrollable cell reproduction and the growth of a cancerous tumour (Leonard, 1993).

In Ghana, some attempts were made between the late 80's and early 90's to study indoor radon exposure

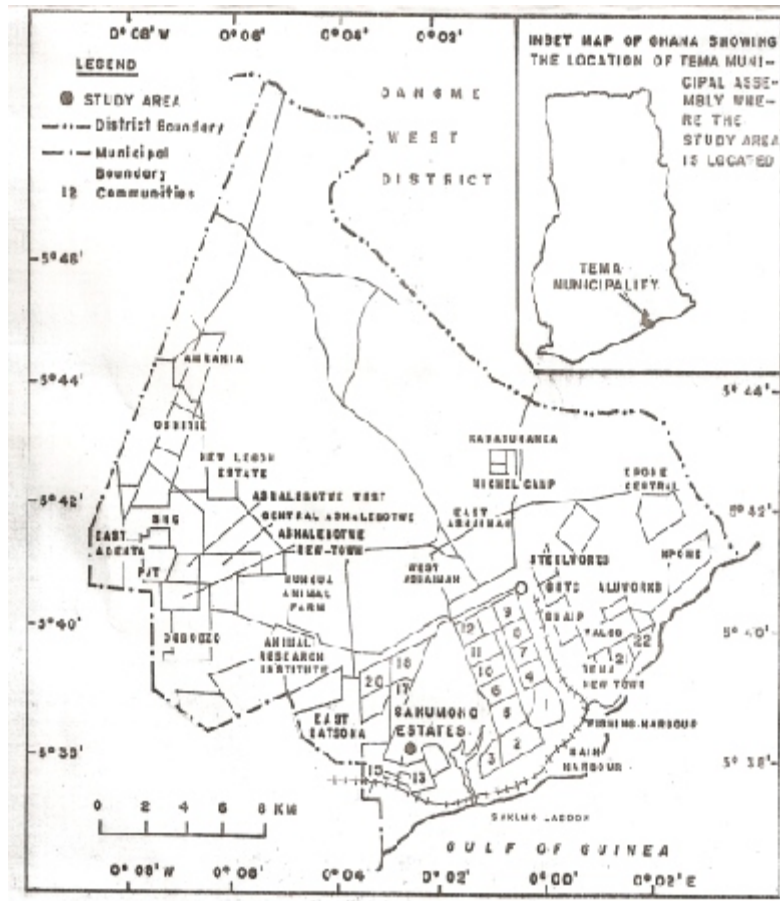


Fig. 1: Map of the study area

(Oppon *et al.*, 1990) around Dome village near Ghana Atomic Energy Commission (GAEC). These studies (Oppon *et al.*, 1990) showed that some houses around the Dome village and the residential area of the staff of GAEC exceeded the remedial action limit of 150 Bq/m^3 , with three of the houses exceeding the immediate action level of 400 Bq/m^3 as per the US E.P.A (Oppon *et al.*, 1990).

The problem associated with indoor radon accumulation is that; exposure to high levels or accumulated low levels for a long time increases chances of developing lung cancer. Additionally, building stocks being constructed in recent times in Ghana incorporate some western architecture (i.e., air-tight materials like aluminium cum glass doors and windows) which may be prone to indoor radon accumulation over a long period. There was therefore the need to monitor these houses for radon gas due to the changing trends in architecture. One can hypothesise some level of accumulation of radon in some of these indoor environments. Focus group discussions and interviews have also revealed that, the study area, where modern estate development began has not been monitored for indoor radon accumulation.

The lethal effect of radon gas is due to its cumulative nature, such that the risk keeps increasing year after year as exposure to radon gas continues. However, very little data exist on radon gas levels in dwellings, particularly in Ghana. Considering the skew of most building architecture towards the western style, with increasing use of air conditioners, this keeps majority of these indoor environments air-tight from natural ventilation and this invariably reduces the amount of air exchange rate.

One's chances of developing lung cancer from Radon exposure depend mostly on how much Radon is in one's home, how much time is spent indoors, and whether one smokes or have ever smoked, as radon gas acting together with smoking has a synergistic effect on cancer risk.

Ventilation and air-tightness of a building are important determinants of radon levels. Buildings constructed above ground level are known to influence the high incidence of radon gas accumulation, as radon gas concentration thins out with height of the building.

Basically, radon emanates from trace concentration of radium in the earth's crust. Indoor concentrations depend on the access of this radon gas to the building interior. Radon gas can enter directly from soil or rock in

the crust, via utilities such as water (and in principle, natural gas) that carry radon, or from crustal materials that are sometimes incorporated into building structures in the form of concrete, rock and brick (Nazaroff and Nero, 1988).

The relative significance of these pathways depend on the circumstances, but it has become clear that direct ingress from the soil, ordinarily dominates the higher indoor concentrations that have been observed in most homes (Nazaroff and Nero, 1988).

This research is intended to:

- Measure the radon gas concentration in dwellings, in order to assess the risk of exposure to indoor radon.
- Educate the public subsequently on the possible contribution of radon to the development of lung cancer.

Study area: Sakumono is an area located in the Greater Accra region of Ghana and very close to the coast of Gulf of Guinea on the Greenwich meridian (Fig. 1). It is also an area where modern estate development in Ghana began but the estate houses located in this community have not been monitored for possible indoor radon gas accumulation. It is against this backdrop that this monitoring exercise has been initiated in order to determine the level of exposure to radon gas.

MATERIALS AND METHODS

Modern estate houses in Ghana are constructed from sandcrete blocks and are of different designs, with an average of two large windows per room. Some of these windows come with louver blades and wooden doors, whilst others have modern sliding windows also known as glazing and door fittings to aid ventilation. Various categories exist such as:

- Flats, which are mostly storeys with or without basements
- Semi-detached and detached houses uniquely designed by estate developers
- Bungalows

The traditional houses however, comprising the middle income homes and cluster (i.e., compound type) houses are constructed with sandcrete blocks and sometimes with mud bricks. The houses have small single windows for ventilation and thus a corresponding small air exchange rate (Oppon *et al.*, 1990). The study was however conducted between December 2007 and February 2008 in Sakumono and its environs in the Greater Accra Region of Ghana.

Radon dosimeter preparation and deployment: The alpha particle sensitive material used was the bare

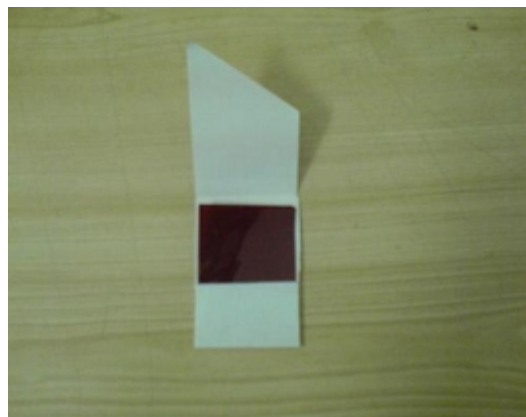


Fig. 2: LR-115 Detector with its holder

cellulose nitrate LR-115 type II. The detector materials (dosimeter) were cut out of a full size film with dimensions of 11.8 cm x 8.8 cm. These detectors were initially stored in between two sheets of paper in close contact with the sensitive side (concave surface) of the detector material. The dimension of the cut out detector is 5.8 cm x 4.4 cm, and made into two sections, namely, the exposed area and the background, which was shielded by a portion of the miniature envelope detector holder from the atmosphere.

The miniature envelope was designed with the following dimensions: full length being 9 cm, the folded length being 6 cm and the base of the envelope is 4.5 cm. The detectors were then placed in the envelopes, labelled and closed, ready for deployment in the homes as shown in Fig. 2.

The set of detectors were deployed in the selected homes in the study area. In the deployment exercise, each labelled envelope was coded with the house numbers and recorded for easy identification. The time and date of deployment was recorded. The Radon monitors were then left in the homes for a period of about one and half to two months, about which time it was expected that a good number of alpha particle tracks would have been registered in order to ensure good counting statistics.

Radon dosimeter collection: The radon dosimeters, after the exposure period, were retrieved from the various homes by following the coded records. The time and date of collection was recorded and were subsequently transported to the Solid State Nuclear Track Detection laboratory at Ghana Atomic Energy Commission for chemical etching. In all about forty (50) houses were mapped for monitoring, but only about thirty two (32) dosimeters were retrieved. This was due to the fact that some detectors were damaged or could not be found and retrieved.

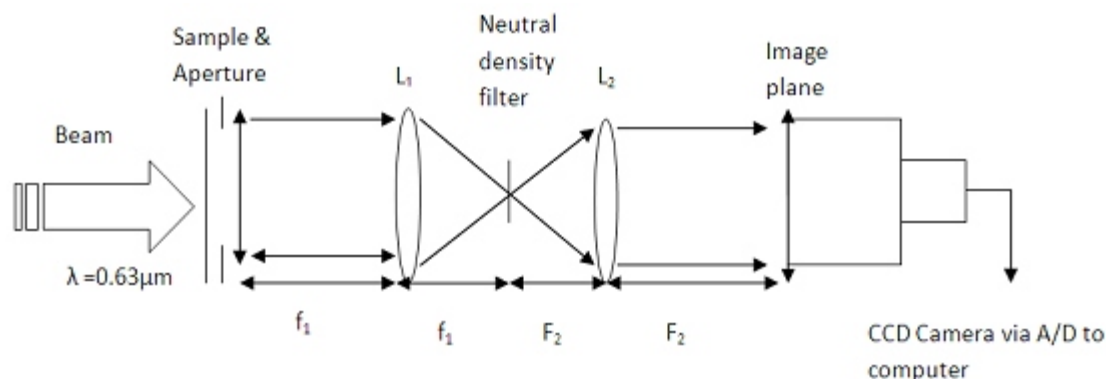


Fig. 3: A schematic diagram of the laser Fourier optical processor

Chemical etching of detectors: The bare LR-115 cellulose nitrate plastic detectors were then chemically etched in an aqueous solution of 2.5 M sodium hydroxide for 90 minutes at a temperature of 60°C in order to render the tracks visible.

A temperature stabilized etching bath was filled with water. Three 250 mL beakers containing 2.5 M sodium hydroxide solution were put in the etching bath and covered to prevent the sodium hydroxide from evaporating during the etching period.

The etching bath was pre-set to a temperature of about 60°C and then allowed to attain equilibrium. The bath is such that, the thermostat cuts immediately it is at 60°C and stays at that temperature throughout the etching period.

The detectors were then taken out from the envelopes and hanged with strings at one of the edges. About three detectors were put into the etchant and allowed to stand for about 90 min. The detectors were rinsed in cold tap water for about 15 min, and hanged to dry at room temperature. They were then ready for counting.

Counting of etched tracks: The counting of the tracks registered on the detectors was done using an optical microscope (Bausch and Lomb) and the Optical-digital laser processor, developed at the Laser and Fibre optics Centre at the Physics department, University of Cape Coast, Ghana.

For the optical microscope, a magnification of 40 X was used in order to obtain a clearer view of the tracks. The detectors were stuck on a rectangular slide, and field views varied in order to count the impinging tracks horizontally, vertically and diagonally, after calibration with a graduated graticule.

In using the Laser Fourier optical processor, (Eghan *et al.*, 2007), as shown in Fig. 3, a helium-neon expanded laser beam of 15 mW and wavelength of 632 nm illuminates the etched LR-115 detector in its object plane. The tracks become diffracted and consequently appear as dark holes or spots in the image plane, which

were counted about four times and averaged. In order to have a smooth noise-free image, a background image of the laser beam, through the detector background that was etched was recorded and subtracted from the detector image that was exposed, in order to eliminate background noise. The instrument was calibrated using a straight rule with graduations in cm and mm. The CCD camera captures an area field of view of 1 cm x 0.7 cm per each field of view. Thus, with the chosen optical parameters for the set up, a detector track area of 0.7 cm² was covered per field, which fell within the image resolution of the camera being 1024x768 pixels. This was used to determine the track density of the tracks. The configuration was therefore flexible to image various detectors onto the CCD using the laser parallel beam for uniform track background illumination (Eghan *et al.*, 2007).

The calibration of the dosimeters, were done by comparison with a bare LR-115 detector whose calibration for Radon measurement is known and given as 1 T/cm²/KBqhr/m³ (Oppon, 1989).

The radon activity concentration can be estimated using the relation:

$$C = (\rho_E - \rho_B) / T \dots\dots\dots (3.1)$$

where

- C = radon activity concentration (Bq/m³)
- ρ_E = track density of the exposed area (T/cm²)
- ρ_B = track density of the measured background
- = efficiency of the detector/calibration factor (T/cm²/KBqhr/m³)
- T = time of exposure (h)

The track density (ρ) can also be estimated from the averaged counts and area of field of view counted at a time. This can also be arrived at with the relation:

$$\text{Track density } (\rho) = \frac{\text{Average Tracks counted under each field}}{\text{Area of view (cm}^2\text{)}}$$

RESULTS AND DISCUSSION

The results obtained in the indoor radon gas measurements, using etch-track detectors and evaluating with an Opto-digital imaging system are presented.

Figure 4 shows the radon gas concentrations in the blocks of flats at Sakumono estates. A radon gas concentration of 18.05 Bq/m^3 was determined on the ground floor. This was higher than the measurements in the upper floors on other blocks. There was slight variation in the radon gas concentration on the first, second and third floors measured on the various blocks as presented in Fig. 4. On the second floor of one of the blocks, the measured concentration was 6.02 Bq/m^3 . Radon gas concentrations however tend to decrease with increasing floors, hence the difference in concentrations recorded for the first floors on other blocks monitored.

The concentration of radon gas indoors is very complex, and can be affected by several parameters, such as natural radiation sources, microclimate, the structural design of the building, indoor air characteristics and the life-style of the inhabitants. From radon surveys reviewed, it was generally found that, radon gas concentrations are high on the ground level, since the major source is influx from the soil underneath and around the house.

The radon gas concentrations in the block of flats measured recorded similar results to some of the concentrations in the grounded houses, i.e., the semi-detached and detached. There was a slight variation in a block of flat located on the ground floor, recording about 18.05 Bq/m^3 , due to the fact that it was directly in contact with the soil which is a major source of radon gas. The radon gas concentrations in the upper levels and in apartments above the first floor were usually low, and this could be inferred from the subsequent values recorded for other floors in the flats. It could also be deduced that radon gas concentration thins out with height above the ground level, and it was assumed that there was some degree of saturation as the height of the building increases.

Indoor radon gas levels usually show a characteristic variation, depending on the level above the ground, with the basement or ground floors exhibiting the highest concentration (18.05 Bq/m^3) and the upper floors showing progressively lower concentrations. The third floor however, recorded a concentration of 8.59 Bq/m^3 which was higher than the first and second floors on other blocks. This may be due to the behavioural patterns of the dwellers. Additionally, the situation could be that the inhabitants on this floor had their rooms closed most of the time and as such dwell on minimal external ventilation. This tended to accumulate radon gas over time. These blocks of flats have an average of two large windows incorporated in their building design, and were therefore expected to have high air change rates, hence reduced radon gas levels. By comparing these values to

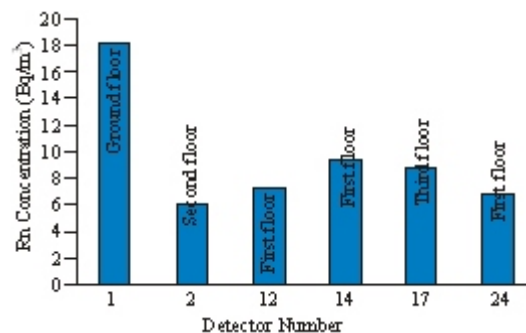


Fig. 4: Radon gas concentration in blocks of flats

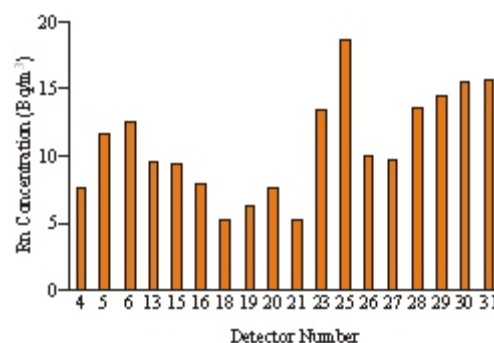


Fig. 5: Radon gas concentration in semi-detached houses

some literature, it could be inferred that there was no much deviation from what has been obtained in previous works (Nazaroff and Nero, 1988), that the block of flats monitored had an average of 1 and 3 Bq/m^3 for story buildings monitored around Kwabenya, Ghana Atomic Energy Commission staff flats. Average basement concentration comparable to the ground floor was reported as 17.4 Bq/m^3 , (Yeates *et al.*, 1972) while the first floor averages were 1.9 Bq/m^3 . Radon gas concentrations were reported, (Spitz *et al.*, 1980) where second floor radon concentrations were a factor of 3 lower than basement concentrations. Based on available data, there is essentially an agreement that radon concentration decreases with increasing story in buildings, especially for the second, first and ground floors in Fig. 4.

The mean radon gas concentration for the various blocks of flats was estimated to be 9.33 Bq/m^3 . This did not vary comparatively with those of the grounded houses. Also, the standard deviation of the mean determined for the block of flats was 4.44 Bq/m^3 , whereas those for the semi-detached, detached and cluster houses were 3.58 , 2.28 and 1.45 Bq/m^3 , respectively.

The radon gas concentrations in the semi-detached buildings monitored was presented in Fig. 5. This recorded a concentration of 18.60 Bq/m^3 among the various building stocks. It was followed by a concentration of 15.76 Bq/m^3 which was slightly lower than a concentration of 15.59 Bq/m^3 . The radon

concentration values determined in the semi-detached buildings varied from each other as presented in Fig. 5.

The concentrations of radon gas in the semi-detached houses monitored were not alarming, considering results of studies conducted on indoor radon gas concentration in the United States, which reported an average of 55 Bq/m^3 (Nero *et al.*, 1986), with about 1-3% of the homes exceeding 300 Bq/m^3 . It also indicated that, 7% of the single-family housing stocks had concentrations greater than the remedial action limit of 150 Bq/m^3 . About 18 semi-detached houses were monitored, which covered about 56% of the selected dwellings. The semi-detached type of building was the most predominant design that could be found within the study area. These have a single wall demarcating one single-family house from the other and have similar facilities. One would expect the radon gas concentration in the semi-detached houses to be similar, but the contrary was determined, as seen in Fig. 5. This may be due to the fact that, differences in radon concentrations in buildings exist mainly due to the ventilation rate and indoor characteristics. Thus, it may depend on the usage of air conditioners in some homes or generally the life style of the inhabitants. Additionally, it may also be due to the likelihood of some of the buildings sitting on radium bearing rocks, which were chief sources of radon gas underneath a particular building (Nazaroff and Nero, 1988). The concentrations determined may be attributed to the form of ventilation mechanism each one of these single-family semi-detached houses practiced. Meteorological factors such as wind velocity could also affect home ventilation and subsequently, a decrease in radon gas levels inside a particular building. In a similar survey conducted at Dome village (Nazaroff and Nero, 1988), in the Greater Accra region, the mean for the traditionally constructed houses was reported as 121 Bq/m^3 , of which about 9 houses exceeded the remedial action limit of 150 Bq/m^3 . Three of them exceeded the immediate action limit of 400 Bq/m^3 (USEPA, 2005).

By relating the concentrations of an earlier work to the results obtained in this research for the modern estate houses in the study area, with an overall mean of 10.18 Bq/m^3 , it was evident that the modern estate houses were about a factor of 10 lower in radon levels than the traditionally constructed houses measured earlier (Oppon *et al.*, 1990). Consequently, this displays the importance of construction materials for the modern buildings in either elevating or reducing indoor radon gas concentration. Thus, buildings constructed with concrete together with proper sealing against radon ingress routes often tend to have lower concentrations (Qiu *et al.*, 2005).

Figure 6 illustrates the radon concentrations determined for the detached houses. This type of building within the study area comprised plush apartments that mostly used air conditioners. Some of the building designs have glazing windows (i.e., aluminium cum glass)

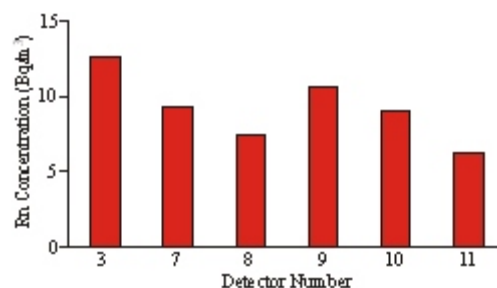


Fig. 6: Radon gas concentration in detached houses

and doors incorporated. The radon gas concentrations determined were thus illustrated in the Fig. 6. A radon gas concentration of 12.70 Bq/m^3 was determined, which was followed by a concentration of 10.76 Bq/m^3 . A concentration of 6.33 Bq/m^3 was also recorded. This concentration was quite low and may be due the indoor air characteristics, which may have had some influence on the indoor concentration.

There was no significant variation in the concentrations recorded for the detached houses compared to the semi-detached houses in Fig. 5. The detached type of building found in the study area ranged from a moderate to huge plush apartments, with insulating walls and use of air conditioning. This invariably reduced air changes with the exterior and was expected to produce high radon concentrations. But the contrary was determined as illustrated in Fig. 6. The radon gas concentrations ranged from 6.33 to 12.70 Bq/m^3 . These quite low concentrations may be due to the coastal influences on the air change rate experienced within the entire study area. Between December and February, when most of the detectors were deployed in these houses, the hamattan haze was highly prevalent. This might have resulted in some inhabitants reducing the use of air conditioners and rather resorted to natural ventilation thereby reducing accumulated radon gas levels. By comparing this to the concentrations determined for the semi-detached buildings, it could be deduced that detached buildings in the study area were built with more space for natural ventilation than the semi-detached buildings. The mean radon concentration was 9.30 Bq/m^3 and a median of 9.27 Bq/m^3 was determined for the detached buildings.

Figure 7 showed the concentrations recorded in the cluster houses. The cluster houses comprised the “compound houses”, which house several families, unlike the semi-detached and detached houses. This type of building is common in Ghana. Radon gas concentration of 10.33 Bq/m^3 was determined in one house and a concentration of 8.27 Bq/m^3 was also determined in another cluster house. The results were illustrated by Fig. 7.

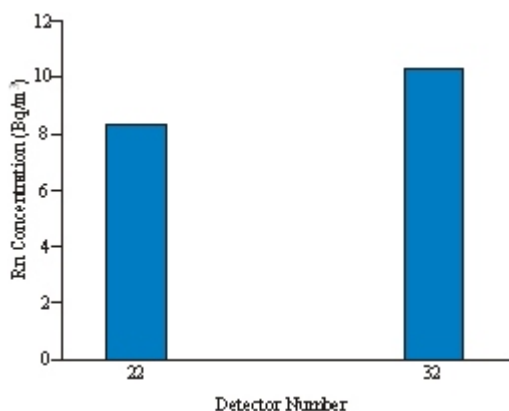


Fig. 7: Radon gas concentration in cluster houses

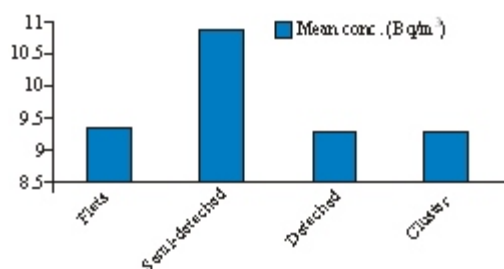


Fig. 8: Mean Radon concentration in the various housing stocks

The concentrations for the cluster houses did not deviate so much from what pertained in the modern estate houses in the area. Two separate cluster houses (i.e., compound houses) were monitored for their radon gas levels and a mean concentration of 9.30 Bq/m^3 was estimated. It was suspected that this type of building would have a higher level of radon gas because of their closeness. The cluster houses have an average of one to two windows per room, relatively smaller in size and have lower volume to surface ratio when compared to the detached and semi-detached houses. The concentrations obtained, even though quite low, were reflective of the average concentration exhibited by other building stocks. It was inferred from the survey that, the buildings were relatively new and were constructed and probably sealed, with hardly any cracks and crevice for radon gas to seep through to the interior. It may also be due to the coastal influences on the air change rate. This was characterised by strong breezes from the sea which is close to the study area and as such the cluster houses would experience much favourable ventilation conditions in the rooms, which tended to reduce the radon levels.

Figure 8 illustrated the mean concentration of the of houses monitored. Mean radon gas concentration of 10.86 Bq/m^3 was recorded for the semi-detached houses, followed by mean concentration of 9.33 Bq/m^3 recorded in the blocks of flats as in Fig. 8. The mean radon

concentration for both detached and cluster houses were similar, i.e., 9.30 Bq/m^3 . Their medians were close, i.e., 9.27 Bq/m^3 for the detached houses and 9.29 Bq/m^3 for the cluster houses. The detached and the cluster houses have different architectural designs, and one would expect a difference in their radon gas concentrations, but that did not occur. This may be attributed to the prevailing weather conditions at the time of deployment of the dosimeters. Due to the breezy nature of the entire area, it could be deduced that the air in a particular house was constantly being changed, owing to differences in temperature and pressure indoors and outdoors.

The mean radon gas concentration for the entire area was determined to be 10.18 Bq/m^3 . This mean concentration was lower than a reported mean indoor radon concentration of 40 Bq/m^3 (UNSCEAR, 1993) by a factor of four, (Steck *et al.*, 1999) and a factor of three lower than the newly reported average concentration of 39 Bq/m^3 . The outdoor mean radon gas concentration was reported as 10 Bq/m^3 (UNSCEAR, 1993). Comparing this value with the mean value of 10.18 Bq/m^3 for the present work; it implied that the indoor concentrations were considerably low. This could be deduced as being within tolerable limits, as no single measured concentration approached the remedial action limit of 150 Bq/m^3 , set by the United States EPA. The results demonstrated that, radon gas concentration was low in the Sakumono estates and its environs, due partly to the coastal influences on the air exchange rate and also due to the fact that, the climatic conditions that prevail in Ghana allow buildings to be ventilated for long time periods. The results were also consistent with previous observations in a survey conducted on Cypriot buildings and dwellings (Christofides and Christodoulides, 1993). In an attempt to cross-check the results that were obtained using the bare detectors (LR-115) in the measurement, an active Radon measuring instrument (Radon Scout Plus) was employed. Three test houses were randomly chosen within the study area and their radon gas concentrations measured, for a period of about 24 to 48 h each. The average concentration obtained for the test houses was 10 Bq/m^3 . The average was comparatively similar to the mean concentration of 10.18 Bq/m^3 estimated for the area.

Of the 32 houses monitored, 41% of the houses had indoor radon values above 10 Bq/m^3 , but below the world mean value of 39 Bq/m^3 (UNSCEAR, 2000). However, about 59% of the houses had concentrations below 10 Bq/m^3 , with none of the houses recording concentrations approaching the remedial action level and thus did not require any intervention.

Figure 9 illustrated the annual effective doses received in each type of buildings monitored. A dose of 0.25 mSv was determined for the blocks of flats as shown in Fig. 9. A similar dose was determined for the semi-detached houses. The lowest dose determined was in the

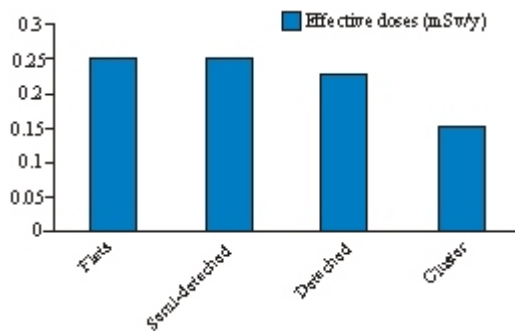


Fig. 9: Effective doses received in the various housing stocks

cluster houses. The doses corresponded to the mean concentration determined for the types of houses.

The radon dose estimates were based on the dose conversion coefficient recommended by the International Commission on Radiological Protection (ICRP), that an exposure to 20 Bq/m³ of radon gas in a typical indoor condition will give rise to an annual effective dose equivalent of 1 mSv (ICRP, 1981). Taking into account an occupancy factor (average amount of time spent at home) of 0.5, it meant the inhabitants in the modern estate building spent about 12 h/day indoors due to the provision of basic amenities under one roof. The occupancy factor for the cluster houses was 0.3, (i.e., occupants spent averagely about 8 hours at home). Assuming the occupancy factor for most typical African homes averaged to be about 8 h/day. This may be different in some cases.

Based on these considerations, the radiation dose due to the radon gas concentration in the blocks of flats was 0.25 mSv/yr by proportion to the International Commission on Radiological Protection recommendations. For the semi-detached houses, the dose was 0.25 mSv/yr, which was not disparate from that received in the flats. However, there was a slight difference in the dose received in the detached and cluster houses. The dose for the detached was determined to be 0.23 mSv/yr and that of the cluster houses was estimated to be about 0.15 mSv/yr. By considering the respective doses received by the occupants, it could be estimated that, the indoor radon gas contribution to the general population dose per year, to the non-radiation worker in Sakumono was 0.22 mSv/yr. The doses determined were shown in Fig. 9.

In order to assess the life time risk of the inhabitants, resulting from the exposure to Radon-222 gas, the length of the latent period, followed by lung tumour expression has to be quantified. Other factors to consider are the age and sex of the subjects, synergistic effect with other pollutants (such as cigarette smoke) and the integrated amount of exposure (Nazaroff and Nero, 1988). Assessment of risk at lower levels of exposure such as

0.22 mSv is often difficult, considering the life expectancy for the average Ghanaian woman to be about 59 years and man, about 56 years. The total risk over an individual's life time of premature death from radon induced lung cancer is a build up from the effective dose of 0.22 mSv received each year. This was about a factor of four lower than the annual effective dose limit of 1 mSv/y proposed by the International Commission on Radiological Protection (ICRP, 1981).

A person exposed to radon progeny from birth at the rate of 1 mSv/y would accumulate an additional life time risk of approximately 0.1% of developing lung cancer as a result. Since the average exposure level of 0.22 mSv determined was very low, the excess life time risk of any member of the group developing radon induced lung cancer would be approximately 0.02%. Taking into account the reduced effectiveness of exposure in the age range 50-70 years (Nazaroff and Nero, 1988), because of latency, and other competing causes of death, the life expectancy for the average Ghanaian, i.e., 59 for women and 56 for men indicated that the overall risk in proportion to the dose was minimal.

CONCLUSION

Airborne radon gas concentration in dwellings in most countries is the major contributor to the annual effective dose equivalent to the population (Nero *et al.*, 1986; Clarke and Southwood, 1989). Considering the measurements of the radon gas levels determined, in relation to the objectives of the research, an annual effective dose equivalent to the Sakumono community of 0.22 mSv/yr was obtained. This indicated that, the levels did not pose any appreciable risk to the home dwellers, as the effective dose equivalent to the population was about 2 to 3 times lower than the 1 mSv recommended by the ICRP.

The indoor radon concentration results obtained for the various dwellings illustrated by Fig. 4-9, showed a considerable correlation with the ventilation conditions in each of the dwelling. It may also partly be related to the fact that, the newly built estate houses have been properly constructed and sealed with hardly any cracks for radon gas to seep through to the interior.

Deductively, the results showed that the radon gas levels were within acceptable limits and fell below the remedial action limit of 150 Bq/m³ (USEPA, 2005), and World Health Organization value of 200 Bq/m³ for general applications (WHO) (Department of Environment, 1995). These are internationally acceptable levels for safety, and it could then be concluded that, the results could be a basis upon which future comparisons can be made. As the mode of construction of the buildings were similar within the study area, the radon gas concentrations obtained was negligible, even though it served the hypothesis that some amount of radon gas could be found in these dwellings.

Since the total risk over an individual's life time of premature death from radon gas induced lung cancer was a build up from the effective dose equivalent of 0.22mSv per year, the excess life time risk of any person dying, which was approximately 0.02% may not be alarming.

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