Variation of Radon Gas Emanation with Altitude in Some Parts of Greater Accra

Peter Atta Amoah[1] Aba Bentil Andam[2] Paulina Ekua Amponsah[2, 3] Irene Nsiah – Akoto[4]

1. Ghana Atomic Energy Commission, Radiation Protection Institute,

P. O. Box LG 80, Legon – Accra.

2. Graduate School of Nuclear and Allied Sciences, University of Ghana, Legon

P. O. Box AE 1, Atomic - Accra.

3. Ghana Atomic Energy Commission, National Data Centre

P. O. Box LG 80, Kwabenya/ Accra.

4. Ghana Atomic Energy Commission, National Nuclear Research Institute,

P. O. Box LG 80, Legon – Accra.

*Email of the corresponding author: roq4eva@yahoo.com

Abstract

The study to ascertain the correlation between the concentration of radon gas (^{222}Rn) at a relatively higher altitude and that of the concentration at a lower altitude with seismic activity and geological formation was carried out at McCarthy Hill and GAEC using LR-115 solid state nuclear track detectors. A total of 180 track detectors were buried in a grid form at a depth of 75 cm covering an area of 576 sq. meters with intervals of 12 meters between the holes. The radon concentrations varied from 0.27 ± 0.04 kBq m^{-3} to 86.30 ± 2.94 kBq m^{-3} for Site A and 0.72 ± 0.04 kBq m^{-3} to 51.98 ± 1.75 kBq m^{-3} for Site B, whiles a variation from 1.22 ± 0.102 kBq m^{-3} to 123.23 ± 0.072 kBq m^{-3} was determined for Site C. Even though, all the three sites are located along the Akwapim fault zone, an anomaly of more than 5σ was observed at GAEC with a mean concentration of 37.39 ± 0.350 kBqm^{-3} whiles mean concentrations of 10.00 ± 0.126 kBqm^{-3} and 8.07 ± 0.069 kBqm^{-3} were obtained for sites A and B respectively at McCarthy Hill. The anomaly observed at G.A.E.C could be attributed to the geological setting of the landscape with respect to the altitude of the study area and its closeness to the Eastern Boundary fault compared to the study area at McCarthy Hill.

Keywords: radon concentration, altitude, correlation, LR-115, anomaly, Eastern Boundary fault.

1. Introduction

Radon (^{222}Rn), a gas with a half-life of 3.8 days, and long enough for it to be transported to the earth's surface from ores buried at considerable depths, provided the permeability of the overlying rock and soil is sufficiently high, is known to be present in all types of soil (IAEA, 1978). Though not much work has been done to analyze the variation of radon gas emanation at different altitudes with respect to different geological formations, the study of historical microseismic events which have occurred within the Greater Accra Metropolitan Area have been identified with localities close to the Akwapim fault zone and the Coastal boundary fault especially at their intersection. In recent times the occurrence of considerable and increasing number of radiation-induced hazards has made it imperative to investigate and ascertain the possible ways of mitigating these occurrences. With a spatial expansion of over three hundred percent (300%) and a population which has doubled since 1983, Accra, which is situated at $5^{o}30$ N, $0^{o}10$ W and close to the point where the Greenwich meridian and the equator intersect, has also experienced an immense increase in the number of houses being put up (Alotey et al. 2010). The Geological map of GAEC indicates that the landscape is mostly made of sand and clay, whiles that of McCarthy Hill is mostly of fault rocks.

Known and measured properties of LR-115 together with the well established etching theory using "Huygens' principle" have been used to carry out detailed calculations for different types of exposure devices for indoor and outdoor soil measurements (Andriamanatena, 1997). The results obtained in different international intercomparisons on passive radon monitors have been analysed with the aim of identifying a suitable radon monitoring device for workplaces (Orlando et al. 2002). Severe environmental conditions (high temperatures, presence of water either in the vapour or liquid phase, presence of aggressive chemicals) may largely affect the detector response. However, the use of an additional radon source provides a way to overcome some of the difficulties previously pointed out, provided a careful laboratory calibration of the detector is carried out before hand (de la Cruz et al. 1986). With regard to the health risk to local inhabitants, it has been found that although some areas had been zoned as parkland, others had been heavily developed for residential purposes in a research done to estimate the health hazards of radon gas and carbon dioxide. This anomalous trend often corresponds to and usually elongated parallel to the Apennine mountain range, the controlling structural feature in central Italy. It was realized that many new houses had been built on ground which has radon values of more than 250 kBq m^{-3}. It was therefore recommended that land-use planners incorporate soil-gas and/or gas flux measurements in environmental assessments in areas of possible risk (i.e. volcanic or structurally active areas) (Beaubien et al. 2003). Extensive soil-gas surveys in sedimentary basins in Italy were performed to study the potential of some naturally occurring gases as indicators for concealed fracture zones, hydrocarbon and geothermal fluids. One conclusive result is a positive correlation between anomalously high values of radon and carbon dioxide in the soil-air over faults and that the highest Rn values are in contrast to the low Ra content of the underlying clayey rocks (Etiope and Lombardi, 1995). Soil radon surveys have been performed in a long term monitoring basis with SSNTD (LR 115 type II), in order to observe possible fluctuations due to high magnitude seismic events and volcanic eruptions. Five-year radon time series are available in stations located in an intense seismic zone located along the Pacific coast of Mexico. The series analyses have been performed as a function of the local seismicity and geological characteristics (Segovia et al. 1999). The method of neutron-activation analyses using SSNTD has been used for determination of the amount of fissile nuclides in hair. Mice-fluorineflogopite has been used as SSNTD (Malenchenko et al. 1995). Continuous studies of radon concentration changes in soils for the purpose of earthquake monitoring have been carried out in three Colombian districts and in the edifices of Galeras and Nevada del Ruiz volcanoes since 1995. In zones of active faulting, measurements of radon soil emissions between 1000 and 2500 pCi/L were recorded. In an intersection of two active geological faults, levels of 25000 pCi/L were measured (Garzon et al. 2003).

A preliminary study on geological fault location undertaken at Dunkonah and GAEC simultaneously produced concentration values from 10.2±0.5 to 23.0±0.7 kBq/m^3 for Dunkonah whiles the concentration values for NRWMC, GAEC ranged from 6.4±0.4 to 27.5±0.8 kBq/m^3 (Asumadu-Sakyi et al. 2011). Also in a joint survey with the Geological Survey Department, in 1979, the Ghana Atomic Energy Commission commenced a Track Etch orientation programme over the southern rim of the Voltaian basin. The survey area is located between longitudes $0^{o}30$ E and $0^{o}45$ E and latitudes $6^{o}30$ N and $6^{o}45$ N and covers the entire Field sheet 134, Abetifi S. E. (1: 62,500). The area is underlain by the Lower and Middle Voltaian sequences and at the southwestern corner, by Birimian schists and granites (Toutain and Baubron, 1998).

A study to ascertain the variation of radon gas levels with passing years in the Lake Bosomtwi area was conducted in 2007. The results obtained were compared with results from previous years and it came out clear that the year 2006 had the lowest average radon gas level of 99.95 $pCiL^{-1}$ or 3.70 $KBqm^{-3}$, with year 2001 having the highest of 167.2 $pCiL^{-1}$ or 6.19 $KBqm^{-3}$. The overall average radon gas level between the years 2001 to 2006 for the Lake Bosomtwi area was 130.94 $pCiL^{-1}$ and this value according to the United States' Environmental Protection Agency is within the range of 20 –200 $pCiL^{-1}$ which is considered greatly above average for residential structures (Badoe, 2007). For dry areas, Rn concentration depends on the area of the plane of fracture and its migration in the fracture system (Wu et al, 2003).

Useful information in determining potential drilling targets can be obtained by carrying out radon mapping of the area of interest. In principle, radon buried deep into the earth crust finds an easy passage to reach the surface through geological faults normally associated with geothermal sources (Whitehead, 1981). A recent review of geological and instrumental recordings by Amponsah (2002) in Ghana shows that earthquakes which have occurred in the past, are still liable to occur within the vicinity of the intersection of the Akwapim fault zone and the Coastal boundary fault (Amponsah, 2004). In another study by Amponsah (2002), the earthquakes that had occurred between the period of 1973 – 1997, had their magnitudes ranging from 1.0 to 4.8 on the Ritcher scale (Amponsah, 2002). Earthquakes have always been a source of terror and destruction for mankind. About 3.5 million deaths are known to have occurred in 38 major earthquakes from 342-1976 A.D (Badoe, 2007). The history of earthquakes in Ghana is being analysed with Northern Africa and the Middle East because of the similarity of occurrence of seismicity in Northern Africa and Northwest Africa. The historical record shows again and again that large earthquakes in the Hellenic arc can cause disproportionate damage round the southeast Mediterranean, especially in the Nile delta and Israel – presumably because of the particularly low attenuation in the oceanic crust in between (Ambraseys, 1994).

Recent recording of local earthquakes in southeastern Ghana has shown that almost all the activity occurs along the Akwapim fault zone, with little activity offshore. Evidence is presented that these events are typical of the historical pattern in which case the relative absence of activity offshore casts doubt on previous suggestions that the causative stress is due to continued movement along the Romanche fracture zone near the continental margin (Bacon and Banson, 1997). The main objective of this study is to analyze the variation in radon gas emanation with altitude and the possible mitigation of its effect in the study area and its environs. The other objectives are; determining the concentration of radon gas within the study area, thus ascertaining the safe use of the land, analyzing the relationship between the radon gas emanation and the altitude with respect to the geology of the study area, and also to add to the preliminary studies being done by the Physics Department, National Nuclear Research Institute (N.N.R.I) to undertake an earthquake zoning map being developed for the Greater Accra Metropolitan Area and the entire country.

2. The Study Area

A measurement of 24 m x 24 m was the size of the fields on which the holes of 75cm in depth and 20 cm in width were dug in a grid form at a separation of 12 meters for burying the detectors. In all, three field sites were prepared for the study. Two of the sites (sites A and B) are situated at McCarthy Hill with a separation of about 350 m between them and the other (site C) situated at Kwabenya (GAEC). The Geological maps of the two study areas are indicated in Fig.1 and 2.

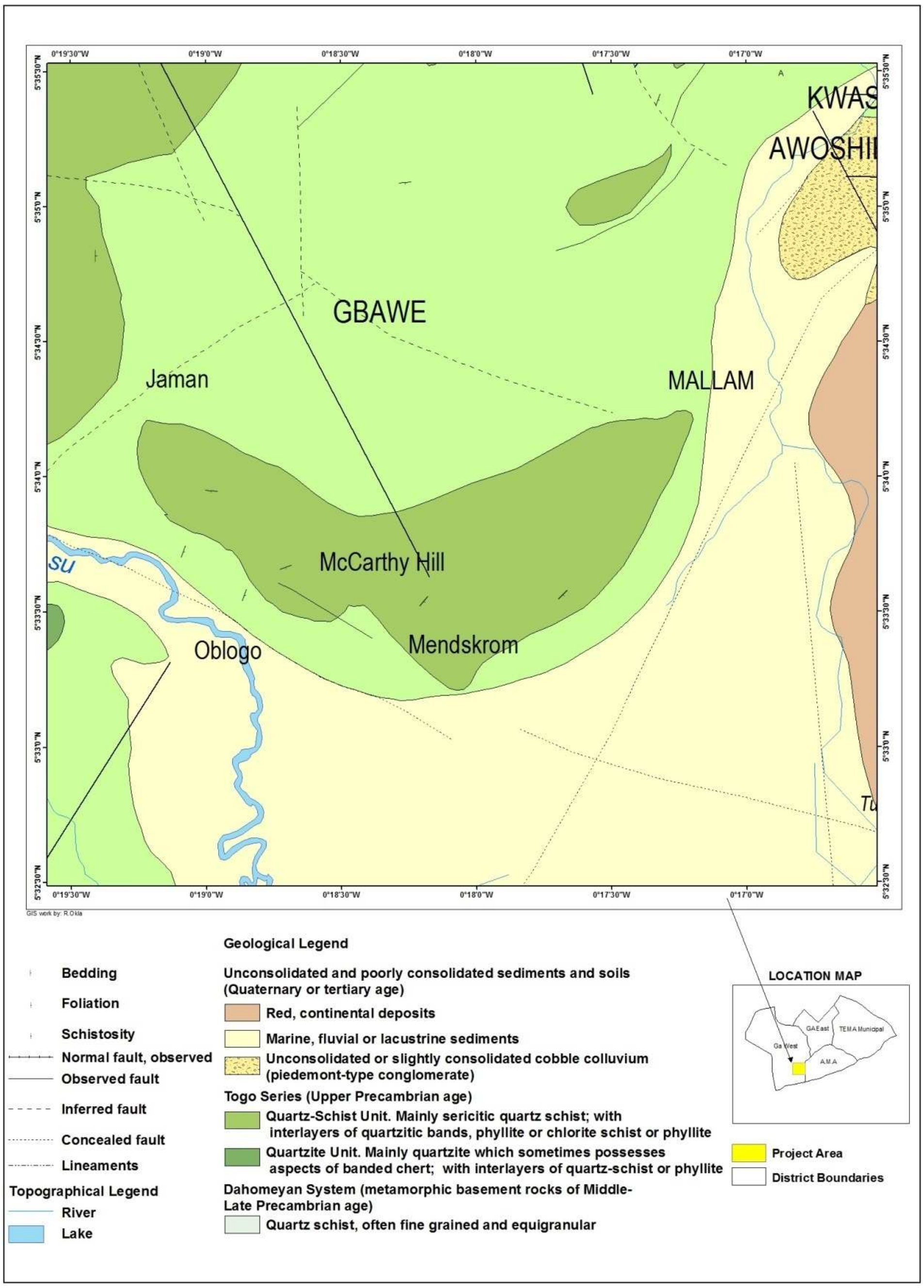

Fig.1 Geological Map of McCarthy Hill edited from Muff and Efa, 2006

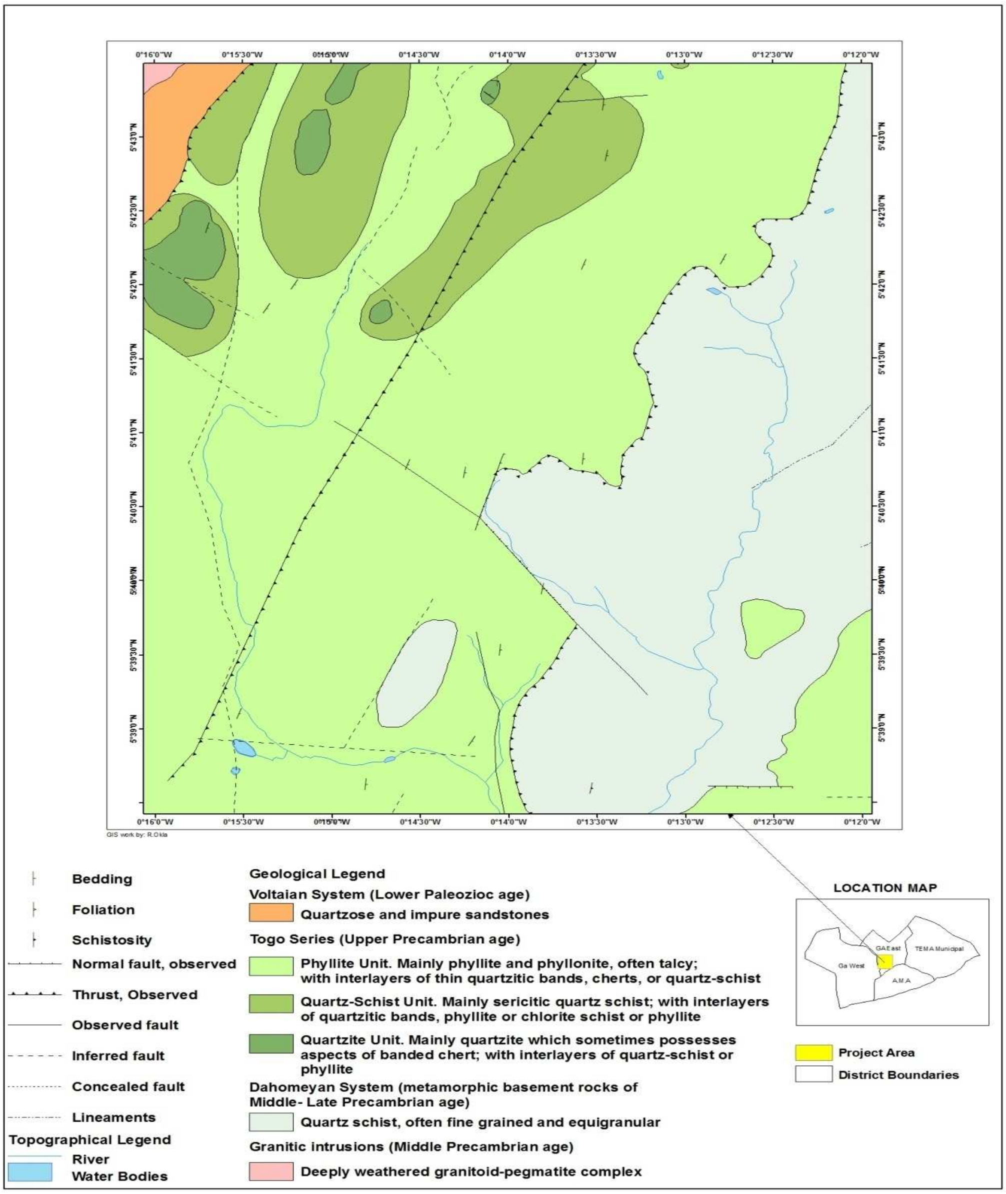

Fig.2 Geological Map of Kwabenya (GAEC), edited from Muff and Efa, 2006

3. Methodology

LR – 115 detectors were cut into sizes of 2 cm x 2 cm and stuck onto wooden corks using cellotapes. The corks were then fixed into Polyvinyl Chloride (P.V.C) tubes before they were buried at the site. The lengths of the P.V.C. tubes were approximately 25 cm, leaving the distance between the ground level and the top of the cork inside the hole to measure about 50 cm. After the detectors had been exposed for a

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period of two weeks, they were replaced with a new set at all the three sites (the same day). The irradiated detectors were then taken off the corks and then stored in small sized envelopes. 100 g of NaOH pellets was used with distilled water to produce a 2.5 M NaOH solution which was then stored in a conical flask. The etching bowl was filled to a level enough to cover the etchant fully, which had been poured into medium and small sized beakers to a level of about half – full. When the temperature of the etchant had reached 60 ^{o}C, the detectors were then dropped into the beakers containing the etchant for the etching process to begin. The process went on for a period of 1hr 20 mins for each set of detectors, through the etching process. After etching, the detectors were then removed from the solution and dropped into a bowl of water just enough to cover the etched detectors. The etched detectors were counted using the spark counter.

Before the spark counting of the exposed detectors was carried out, a quality control analysis was done using a standard alpha particle source (Cs – 137) in order to ascertain the reproducibility of the equipment. The track densities were determined using the expression in equation 1. The average number of counts used to determine the track densities refers to a value obtained from three consecutive counts on each detector. After the track density of the detectors had been evaluated, the corresponding radon concentration of the detectors was also determined. Where the calibration factor = 0.29 tracks cm^{-2}/KBqm^{-3}hrs for all the samples with an exposure time of 336hrs (two weeks).

4. Data Analysis and Results

The track densities of all the detectors were determined using the following expression:

$$\text{Track density} = \frac{\textit{average number of counts}}{\textit{area of field of view of electrode}} \;.............\textit{equation } 1.0$$

The average number of counts used to determine the track densities refers to a value obtained from three consecutive counts on each detector. The area of field of view was determined from the diameter (d) of the circular shape of the electrode using the expression: Area= $\frac{\pi d^2}{4}$ ………equation 2.0

where d = 0.8 cm. The unit of the diameter is left in cm because the unit of the calibration factor is T/cm^2/ KBqm^{-3}hrs; where T represents the number of tracks detected.

The determination of the minimum and the maximum concentration of all the three sites of the study area are illustrated below;

If the minimum average number of counts on the area of field of view which was identified with the 5th detector of the 1st batch = 13 counts and the area = $\frac{\pi\times(0.8)^2}{4}$ = 0.5027 cm^2

$\Rightarrow$ track density = $\frac{13}{0.5027}$ = 26 cm^{-2} as indicated in Table 4.1

Also, if the maximum average number of counts on the area of field of view which was identified with the 4th detector of the 6th batch = 4227.2

$\Rightarrow$ track density = $\frac{4227.2}{0.5027}$ = 8409 cm^{-2}

After the track density of the various detectors had been evaluated, the corresponding radon concentration of the detectors was also determined using the following relation:

$$\text{Concentration} = \frac{track\ density}{calibration\ factor \times exposure\ time} \text{ ....equation 3.0}$$

Where the calibration factor = 0.29 tracks cm^{-2}/KBqm^{-3}hrs for all the samples with an exposure time of 336 hrs (two weeks).

Mean ($\bar{x}$) = $\frac{\sum x}{n}$ ....equation 4.0; where $\sum x$ represents the summation of the values of the sampling data (counts) and n represents the number of sampling data.

Standard Deviation (error) = $\sqrt{\frac{\sum(x-\bar{x})^2}{n}}$ .... equation 4.0; where $\sum(x-\bar{x})^2$ is the summation of the square of variation or difference of each of the sampled values from the calculated Mean.

The Error analysis was also evaluated from the corresponding counts and average counts.

5. Discussion of Results

The radon survey conducted has revealed positive anomalies which can be interpreted as being caused by the presence of active faults that have a higher porosity than surrounding soils. It can be deduced from geological studies that the higher porosity allows an increased flux of radon gas to reach the surface from several depths below. The average radon concentration and standard deviation (σ) are also presented. Radon concentration equal to or 2σ greater than, the mean value, are considered as radon anomalies. Whiles undertaking the study, possible correlation between microseismic events and the observed radon anomalies were assessed. Sites A and B of the study area (McCarthy Hill) is a hill landform with an altitude ranging between 111 m to 123 m across a rocky landscape. A detailed information of the altitudes is indicated in Table 2.0. The pattern of the radon gas concentration monitored at the three sites with their corresponding altitudes is indicated in Figure 3, 4, and 5

From Table 1.0 the radon concentrations obtained varied from 0.27 ± 0.044 kBq m^{-3} to 86.30 ± 2.940 kBq m^{-3} for Site A and from 0.72 ± 0.044 kBq m^{-3} to 51.98 ± 1.745 kBq m^{-3} for Site B, whiles a variation from 1.22 ± 0.102 kBq m^{-3} to 123.23 ± 0.072 kBq m^{-3} was determined for Site C.

Also as indicated in Table 1.0, the average soil radon-gas concentration of this study obtained for Site A is 10.05 ± 0.342 kBq m^{-3} and 8.05 ± 0.247 kBq m^{-3} for Site B, whiles an average value of 37.39 ± 0.350 kBq m^{-3} obtained for the study at GAEC.
Though McCarthy Hill has been noted to be more of an earthquake prone zone as compared to a location as GAEC, this study has been able to ascertain that, altitude and geological nature of a landscape has a

major contribution to the dependence of radon gas as a precursor for seismic activity. Considering the type of quartzite rocks embedded within the landscape of McCarthy Hill, one would expect that the fault rocks such as; cherty quartzite and metaquartzite will rather aid relatively higher emanation of the radon gas even though they are hard, resistant to weathering with good slope stability. Rather, the Quartz schist of Kwabenya (the location of GAEC) where the laterite soil also has good slope stability and also resistant to weathering, aids a much higher emanation of radon gas which has been proven from the relatively high concentration of radon gas, which was measured simultaneously with that at McCarthy Hill. This anomaly could be attributed to the altitude and also affirm the nature of radon gas as a precursor to seismic activity, which was experienced as an earth tremor at Kwabenya along the Akwapim fault line just about a week after the last set of detectors were taken off from the sites. Unfortunately, the epicenter and magnitude of this earth tremor is yet to be determined and confirmed from the Geological Survey Department (U.S.A), due to breakdown of equipment and unavailability of required software needed to process the data for the adequate information at the Geological Survey Department (Ghana). As indicated by Amponsah (2002) and also by Essel (1997) seismic activity is indeed related to deep-seated faults which are also active. Though unconfirmed, the surety and certainty of the recent seismic activity on the Eastern fault line, on 15th of February, 2011 is being related to earlier recorded data, since a number of the previously recorded seismic activities occurred very close to the geological location of the study area.

Table 1.0 Comparison of Minimum and Maximum concentration values with corresponding ranges of all the sites.

Soil-gas radon concentration (kBq m^{-3})	**Mean**	**Standard deviation**	**Minimum value**	**Maximum value**
Site A	10.05±0.34	8.72±0.35	0.27±0.04	86.30±2.94
Site B	8.05±0.25	5.65±0.19	0.72±0.04	51.98±1.75
Site C	37.39±0.35	12.75±0.53	1.22±0.10	123.23±0.07

Table 2.0 The Specific locations of the holes at the sites where the detectors were buried using the Earth's Geographical Positioning System of the Earth.

Hole	**Lat. (°)**	**Long. (°)**	**Altitude (m)**
1	5^{o}34N	0^{o}18W	117.0
2	5^{o}34N	0^{o}18W	117.2
3	5^{o}34N	0^{o}18W	118.0
4	5^{o}34N	0^{o}18W	123.2
5	5^{o}34N	0^{o}18W	121.0
6	5^{o}34N	0^{o}18W	121.8

Hole	Lat. (°)	Long. (°)	Altitude (m)
7	5°34N	0°18W	118.2
8	5°34N	0°18W	118.4
9	5°34N	0°18W	117.8
10	5°34N	0°18W	117.1
11	5°34N	0°18W	116.8
12	5°34N	0°18W	116.1
13	5°34N	0°18W	114.4
14	5°34N	0°18W	112.4
15	5°34N	0°18W	112.2
16	5°34N	0°18W	110.6
17	5°34N	0°18W	112.4
18	5°34N	0°18W	114.6
19	5°41N	0°13W	66.03
20	5°41N	0°13W	65.20
21	5°41N	0°13W	64.52
22	5°41N	0°13W	64.37
23	5°41N	0°13W	63.47
24	5°41N	0°13W	62.03
25	5°41N	0°13W	66.29
26	5° 41N	0°13W	65.22
27	5°41N	0°13W	62.91

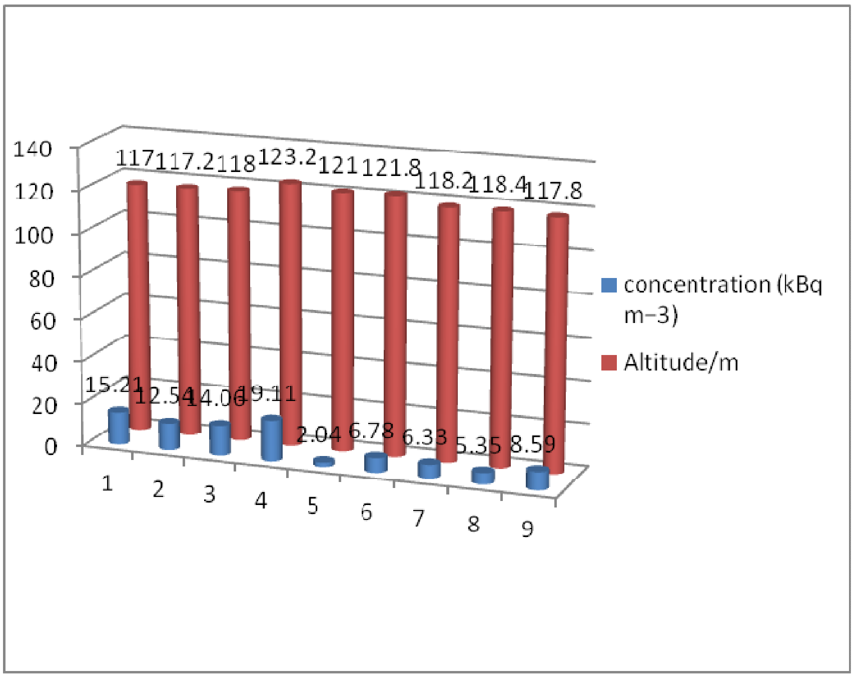

Fig.3 Comparison of radon gas concentration to the various corresponding altitudes for Site A

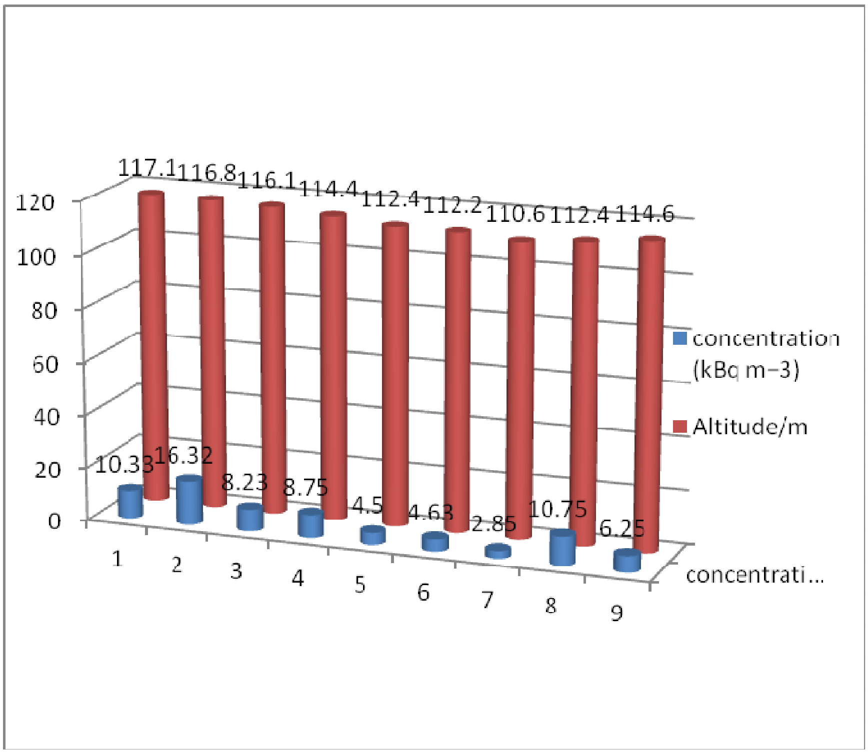

Fig.4 Comparison of radon gas concentration to the various corresponding altitudes for Site B

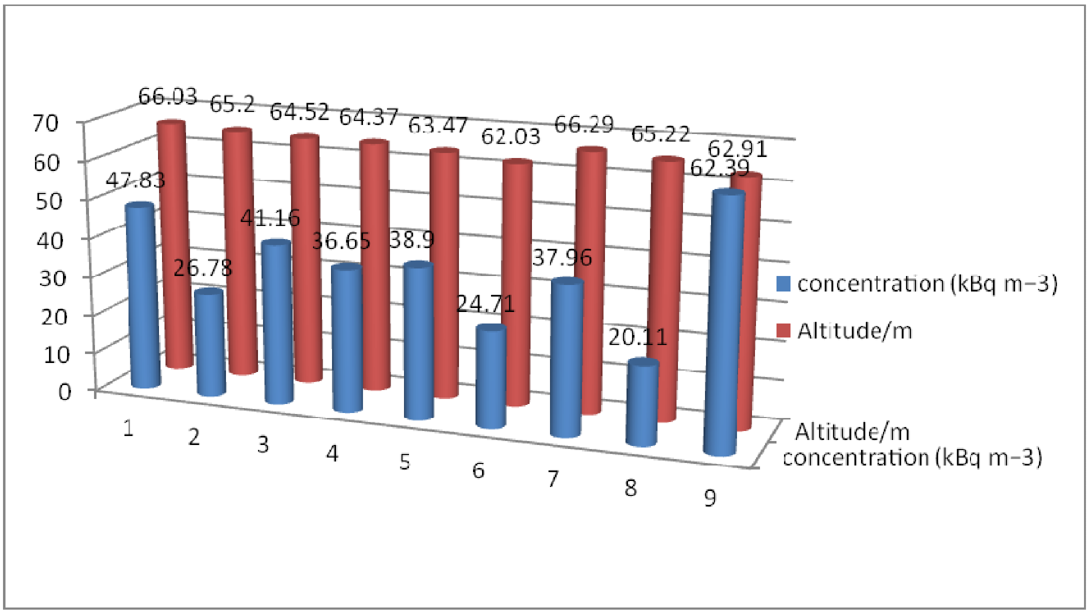

Fig.5 Comparison of radon gas concentration to the various corresponding altitudes for Site C

6. Conclusions

The radon gas concentrations at depths of 75 cm were monitored in Accra at McCarthy Hill and the grounds of Ghana Atomic Energy Commission (GAEC), Kwabenya simultaneously, from November, 2010 to February, 2011. Even though there was no officially recorded seismic activity during the study period, some deductions on anomalies in radon concentration can be made from this study. Radon concentrations measured in the latter part of January and in February explains the high value of the standard deviation from the results, especially at GAEC. At GAEC, an anomaly of more than 5σ was observed. This anomaly could be compared to the fact that; McCarthy Hill has been observed, as indicated on the Environmental and Engineering Geology Map of Greater Accra Metropolitan Area, to be less closer to the Western Boundary Fault as compared to the landscape of the Ghana Atomic Energy Commission which is almost within the path of the Eastern Boundary Fault. The study area of McCarthy Hill is actually much closer to concealed faults as indicated on the Geological Map in fig. 1. A further comparison can be made with a study undertaken to ascertain the variation of radon gas levels from 2001 to 2006 at Lake Bosomtwi in the Ashanti Region. From the results, it came out clear that 2006 had the lowest average radon gas level of 3.70 $KBqm^{-3}$ whilst the highest value of 6.19 $KBqm^{-3}$ was obtained for 2001(Badoe, 2007). Though the study undertaken in Accra did not take much time as it was in Ashanti Region, it can still be noted that areas in Ghana where there are no fault lines give relatively little allowance to radon gas emanation. Although the radon measurements were not correlated with recent measured seismic events, the result of this study has ascertained the usefulness of using such data for setting the range of normal soil-air radon variations above which, the values obtained could be considered anomalous. Thus, considering the consecutive batches of radon concentration monitored, it can be realized that after a longer period of data collection, much more precise results with respect to the correlation between radon gas emanation and seismicity must be expected. The anomalous radon gas levels measured can also provide evidence of probable radon response to earthquake activity in the region, and also indicate possible application of radon measurements as a useful predictive tool for assessing and monitoring fault systems within active seismic zones in the Greater Accra region and possibly the entire country.

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