Artificial and Natural radioactivity measurements in the vicinity of Ghana Nuclear Research Reactor-1 (GHARR-1).

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Abstract. Radioactivity concentrations of ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs in soil and water samples around the Ghana Research Reactor-1 (GHARR-1) and the immediate surroundings have been investigated using gamma spectrometry. The primary aim of this study was to establish baseline radioactivity levels in the environs of GHARR-1. The average activity concentration in soil for ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs were 19.8 Bqkg^{-1}, 40.4 Bqkg^{-1}, 95.3 Bqkg^{-1} and 1.5 Bqkg^{-1} respectively. For the water samples the average activity concentration of ^{226}Ra was 2.15 Bql^{-1}, ^{232}Th was 0.61 Bql^{-1}, ^{40}K was 10.75Bql^{-1} and ^{137}Cs was 0.47 Bql^{-1}. The ^{226}Ra and ^{232}Th concentrations compare quite well with world averages, whilst the ^{40}K concentration was lower than the world average. The activity concentrations of ^{137}Cs observed in the samples are within the range of 'background' concentrations. The estimated average annual effective dose from external exposure to soil and ingestion of water samples was calculated to be 0.64 mSv. The estimated outdoor external gamma dose rate measured in air ranged from 10-430 nGyh^{-1} with an average value of 41 nGyh^{-1} which is lower than the worldwide average value of 60 nGyh^{-1}. In the case of the water samples, the average annual effective value was higher than the WHO guideline value of 0.1 mSvy^{-1}.

KEYWORDS: Radioactivity; Gamma Rays; Dose; Uranium; Thorium; Potassium.

1. Introduction

Radiation and radioactive materials occur naturally and are ubiquitous in the environment. It depends mainly on the local geology and geographical conditions and it is especially related to the rock types. Uranium (U), thorium (Th) and potassium (K) are the main elements that contribute to the natural radioactivity. Uranium and thorium are enhanced in radiogenic accessory minerals such as allanite, monazite, zircon, apatite, thorite etc., and K occurs in major minerals such as feldspar and mica [1, 2].

Studies on the levels of artificial and natural radionuclides have been reported in a number of published articles [3, 4]. These have helped in the formulation of guidelines for radiation protection of the worker, the general public and the environment. In addition, the study of the background level of ^{137}Cs in soil is important as it is the main source of inventory of radionuclides from nuclear fission into the food chain. Its presence in soil indicates that an area under study might have received some fallout radioactivity from past activities such as nuclear weapons testing [5]. The concentration of ^{137}Cs in surface soil from fallout ranges from 3.7 to 37 Bqkg^{-1}, averaging less than 14 Bqkg^{-1}. It has been reported that the 'background' ^{137}Cs in soils is estimated to be 4.81±2.96 Bqkg^{-1} [6]. For instance in Taiwan, levels of ^{137}Cs activity concentration in the range of 1.9-11.1Bqkg^{-1} has been reported [7], and a value of 6.5 Bqkg^{-1} was found in near surface soil around the research reactor in Bangladesh [8]. Other sources of artificial radiation are those used extensively in industry and medicine for the benefits of humanity and these could result in the exposure of people.

By far the largest contribution to the exposure of the population is from natural sources while exposure from artificial sources is largely due to the use of radiation and radioactive materials in medicine. Natural and artificial radionuclides may enter the food chain and expose man depending on the concentration levels in the environment. They can also be concentrated during their transfer through the environment resulting in higher exposures of some people.

The objective of this study was to obtain baseline data on environmental radiation and radioactivity in the vicinity of Ghana's Research first Reactor (GHARR-1) and the surrounding communities of the Ghana Atomic Energy Commission (GAEC). This study will help to establish a programme for periodic survey to find out if there has been any negative impact on the surrounding environment and to establish a baseline radioactivity data for comparison in the event of an emergency. Studies by Yeboah et al (2001) [9] concentrated on natural radioactivity in soils and rocks within the Greater Accra region of Ghana.

2. Material and methods

2.1 Description of the study area

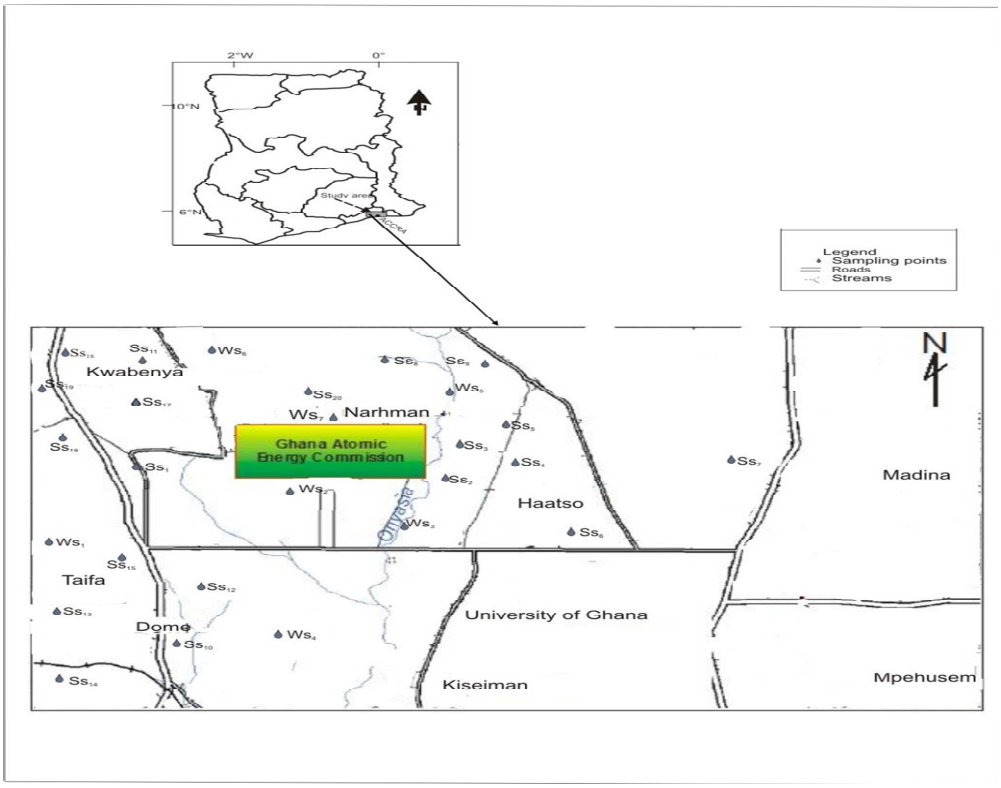
Ghana's first Research Reactor is installed at the site of GAEC. The study covered GAEC and its immediate surroundings up to 10 km from the main laboratories of the Commission. GAEC is located at the North-Western part of Accra, the capital city of Ghana at longitude 5^{o} 40' North and latitude 0^{o} 13' West. Figure 1 shows the location of GAEC and its surrounding communities where the study was carried out. GAEC has a number of nuclear facilities, which are used for research and training purposes for the socio-economic development of Ghana. These include a 30 kW miniature research reactor, 50 kCi gamma irradiator, a variety of radiation sources in storage at the Radioactive Waste Management Centre, sources for calibration in a Secondary Standard Dosimetry laboratory and a host of other sources used in the laboratory of GAEC. The GHARR-1 is also surrounded by a number of communities including; Dome, Kwabenya, Narhman, Haatso and Taifa. The main occupation of the inhabitants is farming. The predominant rock type of the GAEC and its environs is igneous rock with granite [9]. The rocks are composed of quartz-schists, metamicrogabbos forming dykes and sills [10].

2.3 Sample collection, preparation and analysis

Soil and water samples were collected within the site of the GAEC and the surrounding communities. Soil samples were taken around the GHARR-1 building and from farms around GAEC with a coring tool to a depth of about 5-20 cm into polyethene bags, labelled and transported to the laboratory for further preparation. The water samples were taken from fish ponds, streams, water hydrants, tap water and wells used for irrigation, domestic and other purposes within the study area. A total of 100 soil samples and 35 water samples were taken within the study area for analysis.

In the laboratory, the soil samples were air dried for a week and oven dried at a temperature of 105^{o}C for 4-5 hours until all the moisture in the soil samples had evaporated. The dried soil samples were ground into fine powder and sieved through a 2 mm particle size into 1 litre Marinelli beakers and hermetically sealed. The samples were stored for at least 30 days prior to analysis. Similarly, the water samples were collected into plastic bottles and acidified onsite with 1M HCL to prevent radionuclides adhering to the sides of the container. The bottles were filled to the brim without any head space to prevent trapping of CO_2 gas. In the laboratory, water samples were prepared into 1 litre Marinelli beakers and stored prior to measurements. The samples were not filtered prior to preparation and measurements. The pH of the water samples were measured insitu using a multi-parameter instrument, model pH/Cond 340i and serial number 05470077. The pH probe was calibrated using buffer solutions with 4.01 and 7.00.

Figure 1: Simplified map of GAEC showing sampling sites in the study area.



The method of the γ-ray analysis reported in published research works [11, 5] was adopted for this study. The gamma spectrometer used for the analysis consists of an ORTEC GEM Coaxial n-type HPGE gamma-ray detector with ORTEC Multichannel Analyzer (MCA) and MAESTRO-32 evaluation software for spectrum acquisition and processing. The gamma lines 609.31 and 1764.49 keV of ^{214}Bi was used to determine ^{226}Ra. The gamma lines 583.19 keV and 2614.53 keV of ^{208}Tl were used to determine ^{232}Th and that of ^{40}K was determined from the gamma line of 1460.83 keV. Cesium-137 (^{137}Cs) was determined from the gamma line 662.0 keV. The samples were counted for 36000 seconds (10 hours). The energy and efficiency calibrations were performed using mixed radionuclide calibration standard in the form of solid water, serial number NW 146 with approximate volume 1000 mL and density 1.0 g cm^{-3} in a 1.0 L Marinelli beaker. The standard was supplied by Deutscher Kalibrierdienst (DKD-3), QSA Global GmBH, Germany. Background measurements were made for the same period.

2.4 Calculation of the specific activity concentrations and the total annual effective dose.

The specific activity concentrations of ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs in Bqkg^{-1} for the soil and Bql^{-1} for the water samples respectively were determined using equation (1) [11] after decay correction.

$$A_{sp} = \frac{N_{sam}}{P_E.\varepsilon.T_c.M} \quad (1)$$

where; N_{sam} is net counts of the radionuclide in the sample after background corrections, P_E is gamma ray emission probability (gamma yield), ε is total counting efficiency of the detector system, T_c is sample counting time, M is the mass of sample (kg) or volume (l)

The total effective dose, E_T, was calculated by summing the individual equivalent doses due to external irradiation from the soil and ingestion of water using equation (8) according to ICRP publication 60 [12].

$$E_T = H_{\gamma,ext}(U,Th,K) + H_{ing}(w) \quad (2)$$

Where; $H_{\gamma, ext}$ (U, Th, K) is the annual external equivalent dose from external gamma radiation from the soil, $H_{ing}(w)$ is the annual equivalent dose from ingestion of Ra, Th and K in the water samples.

3. Results and discussion

Table 1 shows the results of the activity concentrations of ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs in the soil samples. The average value of the activity concentration of ^{226}Ra in study area was 19.8 Bqkg^{-1} in a range of 3.4-104.8 Bqkg^{-1}. For ^{232}Th, the average activity concentration was 40.5 Bqkg^{-1} in a range of 1.9-327.9 Bqkg^{-1}. The activity concentration of ^{40}K also varied in a range of 1.1-298.8 Bqkg^{-1} with an average value of 95.3 Bqkg^{-1}. For the man-made radionuclide ^{137}Cs, the average activity concentration was 1.5±1.1 in a range of 0.2-4.9 Bqkg^{-1}. The average activity concentrations of the natural radionuclides ^{226}Ra, ^{232}Th and ^{40}K in this study are lower than and in some cases compared well with the worldwide values for other countries [13]. The world average concentration of these radionuclides in soil samples are 35 Bq kg^{-1} (^{226}Ra), 45 Bq kg^{-1} (^{232}Th) and 420 Bq kg^{-1} (^{40}K) [13]. The highest value of 104.8 Bqkg^{-1} of ^{226}Ra was recorded in a soil sample, for ^{232}Th the highest value of 327.9 Bqkg^{-1} was recorded and the highest of ^{40}K value was 298.8 Bqkg^{-1}. The highest activity concentration of ^{137}Cs was 4.9 Bqkg^{-1} in soil. The value of ^{137}Cs compares well with results of similar studies reported in other countries [7, 8]. It also compares well with the background levels of ^{137}Cs in soils [6].

Table 1: Average activity concentration of ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs in soil samples.

Location	Number of samples (n)	Activity concentration, Bqkg^{-1}			
		^{226}Ra	^{232}Th	^{40}K	^{137}Cs
GAEC	30	50.6±1.5 (5.9-104.8)	134.2±1.7 (1.9-327.9)	132.0±8.7 (1.1-298.8)	2.2±0.3 (0.8-4.9)
Haatso	15	14.7±1.1 (3.4-26.1)	31.8±1.7 (25.4-38.1)	118.2±5.5 (66.7-169.7)	1.6±0.3 (1.4-1.9)
Narhman	15	18.0±0.8 (14.3-22.5)	26.1±1.3 (23.4-28.3)	131.9±4.3 (52.8-260.8)	0.8±0.3 (0.3-1.3)
Dome	18	10.6±0.7 (7.5-13.6)	12.8±1.4 (12.4-13.1)	38.9±4.0 (23.4-54.4)	3.3±0.3 (1.7-4.9)
Kwabenya	15	11.1±0.9 (6.9-17.5)	17.2±1.5 (2.1-30.3)	84.8±4.6 (47.1-135.7)	1.0±0.2 (0.5-1.8)
Taifa	17	14.1±1.2 (9.6-20.2)	20.7±1.8 (15.1-25.7)	66.1±6.0 (50.2-88.9)	0.4±01 (0.2-0.6)
Average ± SD		19.8±15.3	40.4±46.4	95.3±38.4	1.5±1.1

Legend: GAEC-Ghana Atomic Energy Commission; SD-Standard deviation

Table 2 shows the results of the activity concentrations of ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs in the water samples in the study area. The average activity concentration of ^{226}Ra was 2.15 Bq l^{-1}, for ^{232}Th it was 0.61 Bq l^{-1}, for ^{40}K it was 10.75 Bq l^{-1} and for ^{137}Cs it was 0.47±0.38 Bql^{-1}. The corresponding annual effective dose due to all the radionuclides was 0.59 mSvy^{-1} which is about 6 times higher than the World Health Organisation (WHO) [14] recommended value of 0.1 mSvy^{-1} in drinking water. This high value could be attributed to geological and geochemical conditions of the study area. The previous study by Yeboah et al (2001) had established that the predominant rock type in the study area was granitic igneous rocks which are known to contain significant levels of NORM. Also the reasons for the high ^{232}Th concentrations in the water samples could be because they are underground water and also due to other geochemical conditions such pH and redox potential. The concentration of radionuclides in groundwater depends on the kind of minerals derive from the rock aquifers, the chemical composition of the water and the soil ion retention time [14].

Table 2: Average activity concentration of ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs in water samples.

Location	Type of water	pH	Activity concentration, Bql^{-1}				Annual effective dose, mSv
			^{226}Ra	^{232}Th	^{40}K	^{137}Cs	
GAEC	Fish pond	8.48	2.12±0.21	0.83±0.18	14.10±1.10	0.75±0.06	0.64
GAEC	Tap water	6.90	0.19±0.05	0.17±0.02	1.97±0.33	0.11±0.03	0.08
Dome	Tap water	7.80	1.79±0.15	0.22±0.06	7.32±0.60	0.30±0.01	0.44
Haatso	Stream	8.26	3.24±0.28	0.55±0.15	17.81±1.18	0.23±0.01	0.84
Taifa	Tap water	6.70	2.18±0.23	0.23±0.06	9.77±0.80	0.43±0.08	0.53
Kwabenya	Well water	7.28	2.76±0.25	0.49±0.16	10.17±0.92	0.24±0.05	0.69
Narhman	Well water	7.14	2.77±0.26	1.81±0.14	14.14±0.96	1.20±0.14	0.94
Average±SD		7.51±0.68	2.15±0.99	0.61±0.58	10.75±5.21	0.47±0.38	0.59±0.28

The WHO guideline values of ^{226}Ra, ^{232}Th and ^{137}Cs in drinking water are 1.0, 1.0 and 10 Bq l^{-1} respectively [15]. The results show that, the average activity concentration of ^{226}Ra is about 50 % higher than the WHO guideline value whilst that of ^{232}Th is also about 40 % lower. The higher activity concentration of ^{226}Ra as compared to ^{232}Th could be attributed to its higher solubility due to geochemical factors than the latter. For ^{137}Cs the average activity concentration slightly exceeded the guideline value. In general however, the concentrations of the ^{226}Ra are higher than that of ^{232}Th as expected due to the low solubility of thorium. Also the pH of the water samples varied from 6.70-8.48 with an average value of 7.51. The range of the pH values are within the WHO recommended values in drinking water [15].

The results of the outdoor external gamma dose rate measured in air at 1 meter above the ground and the absorbed dose rate due to soil activity concentrations as well as their corresponding annual effective doses are shown in Table 3. For the air measurement, the values ranged from 10-430 nGy h^{-1} with an average value of 41 $nGyh^{-1}$ and annual effective dose of 50 μSvy^{-1}. The average gamma dose rate from the soil activity concentrations was 38 $nGyh^{-1}$ with corresponding annual effective dose of 46 μSvy^{-1}. The average absorbed gamma dose rate for the air measurement and for the soil activity concentrations are lower than results reported for other countries from similar studies [13].

Table 3: Comparison of the average outdoor gamma absorbed dose rates measured in and that calculated from soil activity concentrations as well as their corresponding annual effective doses.

Location	Number of readings	Range of absorbed dose rate in air, $nGyh^{-1}$	Average absorbed dose rate, $nGyh^{-1}$		Average annual effective dose, µSv	
			Measured in air	Calculated from soil	Measured in air	Calculated from soil
GAEC	20	30-430	112.22	109.95	137.7	134.9
Haatso	10	10-110	34.83	30.92	42.7	37.9
Narhman	15	20-90	32.34	29.54	39.7	36.3
Dome	15	10-80	18.31	14.22	22.5	17.4
Kwabenya	12	10-100	23.12	19.04	28.4	23.4
Taifa	9	20-90	24.98	21.77	30.7	26.7
Average		10-430	40.97	37.57	50.28	46.10

Figure 1 shows the map of the communities surrounding GAEC where the sampling was carried out for this study and the type of samples indicated with different symbols. Figure 2 is a plot of the activity concentrations of the radionuclides in various communities. The ^{226}Ra and ^{232}Th activity concentrations are higher in GAEC than the other communities which confirm the previous study by

Yeboah et al., 2001 where higher activity concentrations were reported. The activity of concentration of ^{137}Cs is fairly uniform in the study area as shown in Figure 2 which shows that there have not been any significant releases of the radionuclide into this area. Figure 3 also shows a comparison of the activity concentrations of the radionuclides in the water samples. The activity concentrations of ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs in the water samples are variable from the various communities. The results also show that GAEC recorded the lowest values as compared to the other communities.

Figure 2: Specific Activity of soil samples collected from different locations.

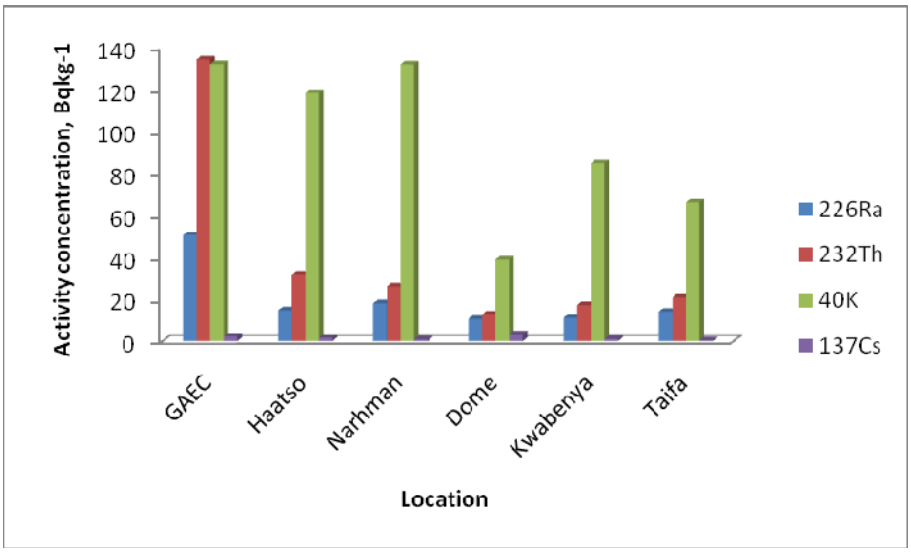
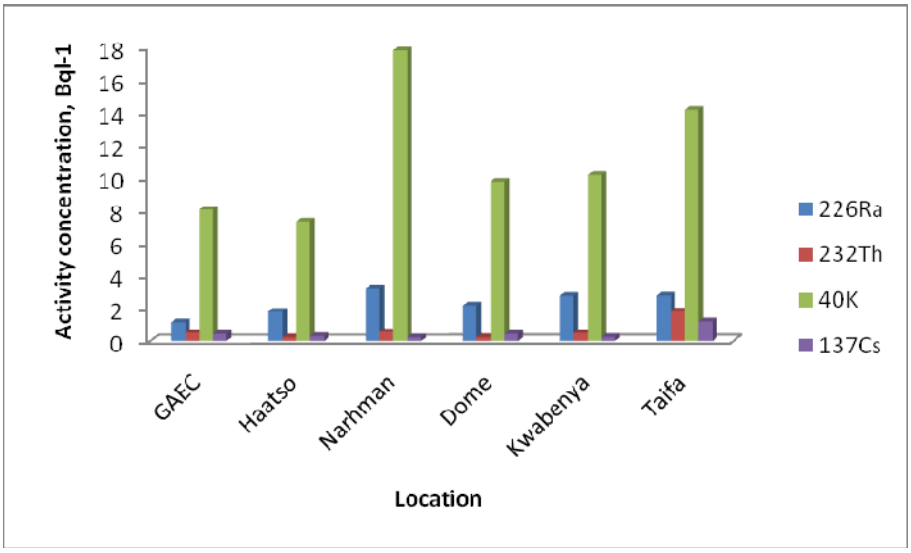


Figure 3: Specific Activity of water samples collected from different locations.



The total annual effective dose including contribution from ingestion of water and external irradiation due to U, Th and K in soil was calculated to be 0.64 mSv y^{-1}. From radiation protection point of view, the calculated doses from might not pose any radiological health hazards to the public within and around GAEC since these doses are below the recommended public annual dose limit of 1 mSv. It is also an indication that, the Research Reactor (GHARR-1) and the other radiation facilities within the GAEC are not impacting negatively on the immediate surroundings.

4. Conclusion

Assessment of the levels of natural and artificial radionuclides within GAEC and its immediate surroundings has been carried out. The estimated annual effective doses from exposure to the natural radionuclides in the soil and water samples were found to be 0.05 mSv and 0.59 mSv respectively. The levels in the water samples were about 6 times higher than that of the European Union and WHO guidance levels. The activity concentration of the radionuclides in the soil, however, compared quite well with the world average. Even though the estimated average annual effective dose for the water samples is higher, it is still lower than the ICRP recommended public dose limit of 1 mSv per year for practices. Also, the average activity concentrations of ^{137}Cs in the soil compared well with literature for similar studies and below the WHO guideline values in drinking water. These results will further serve as a baseline data for future studies.

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