Available online at www.scholarsresearchlibrary.com

Scholars Research Library

Archives of Physics Research, 2013, 4 (3):42-50
(http://scholarsresearchlibrary.com/archive.html)

ISSN : 0976-0970
CODEN (USA): APRRC7

Evaluation of radiological hazard parameters in building materials used in a rural area of Ghana

[*1]Moses A. Addo, [2]Emmanuel O. Darko, [3]Chris Gordon and [1]Benjamin J. B. Nyarko

[1]National Nuclear Research Institute, Ghana Atomic Energy Commission, P. O. Box LG 80, Legon-Accra
[2]Radiation Protection Institute, Ghana Atomic Energy Commission, P. O. Box LG 80, Legon-Accra
[3]Institute of Environmental Science Studies, University of Ghana, P. O. Box LG 209, Legon-Accra

---

ABSTRACT

The measurement of specific activity due to Naturally Occurring Radioactive Materials (NORM) has been carried out in soil and Portland cement and its products available in two rural communities near Aflao, Ghana. The gamma spectra of the collected samples were obtained using HPGe detector and analyzed for the presence of ^{226}Ra, ^{232}Th and ^{40}K. In addition, the radon emanation coefficient and the corresponding mass exhalation rate of the samples were determined using the same instrumentation. The aim of the study was to find out whether the shift from the use of ingenuous soil to Portland cement in the construction of dwellings is more radiologically safe for inhabitants in the study area. Radiological parameters such as the radon emanation coefficient, the radon mass exhalation rate, the radium equivalent activity, the external and internal hazard indices, the indoor absorbed dose rate, and the annual effective dose were determined to assess the potential radiation hazards associated with the samples. The results were compared with reported data from other countries and safety guidelines from international recommendations. The study found out that the radium equivalent activity of the Portland cement and the raw materials of which it was composed was higher than reported data from other different countries whilst the soil values were lower compared to other published values. The variations and the large spread in data are a reflection of different geological origins of the building materials. However, the radiological hazard parameters assessed in the building materials under the current study were all found to be well below the acceptable limits of international guidelines. Therefore, it was concluded that the use of these materials in construction of dwellings is considered safe for inhabitants of the study area.

Key words: Gamma spectroscopy, Portland cement, indoor absorbed dose rate, radium equivalent activity, radon emanation coefficient

---

INTRODUCTION

Natural radioactivity of soil, rock and minerals, are the main sources of exposure to humans [1], and the associated external exposure due to the gamma radiation depend primarily on the geological and geographical conditions of the region and appear at different levels in the soil of each region [2]. It is now a common knowledge that raw and produced materials in the building sector such as cement, bricks, sand, tile, limestone, gypsum and others derived from rocks and soil contain mainly Naturally Occurring Radioactive Materials (NORM) of the uranium (^{238}U) and thorium (^{232}Th) series, and the radioactive isotope of potassium (^{40}K) [3]. In the ^{238}U series, the decay chain starting from radium (^{226}Ra) is radiologically the most important and, therefore, reference is often made to ^{226}Ra instead of

^{238}U [4]. The knowledge of natural radionuclides distribution and radioactivity level in soil and building materials play an important role in radiation protection measurement and geoscientific research [5].

The natural radiation level in building materials is a major cause of external and internal indoor exposure. Indoor radiological hazards to human health can be accessed from the determination of radioactivity levels in building materials [5]. Standards and national guidelines in the light of international recommendations are set for building materials to protect the global population from the radiological risk posed by these materials. The building materials which have been widely used in the assessment of natural radionuclides include, Portland cement, soil, gypsum, limestone, marbles, clinker, sand and ceramics [2, 6, 7, 8, 9, 10, 11, 12] . In setting standards and national guidelines in these materials, evaluation of some radiological parameters such as the radon emanation coefficient, the radon mass exhalation rate, the radium equivalent activity, the external and internal hazard indices, the indoor absorbed dose rate, and the annual effective dose have been employed for the purpose.

Cement as a building material is a source of large amounts of dust polluting the air with ^{226}Ra. The ^{222}Rn gas emanated from the ^{226}Ra may constitute a radiation hazard to both people working directly with the cement material and inhabitants of dwellings constructed with cement [13]. The fraction of ^{222}Rn that can diffuse through the building materials is known as the emanation coefficient or fraction of the material. The radon emanation coefficient (Rn_{EC}) is a very important radiological index used to evaluate the amount of ^{222}Rn emanated fraction released from the building raw materials and products containing naturally occurring radionuclides such as ^{226}Ra in radioactive equilibrium with its parents. The radon emanation coefficient of samples is calculated based on two γ-measurements. Based on these measurements, the radon emanation coefficient is calculated according to an expression adopted by Mujahid *et al*, [6].

In Ghanaian rural communities, the uses of soil and sediment in the construction of buildings and dwellings have been a common practice. Likewise, cement and products have been used in the urban areas in the building industry and other infrastructural developments. However, gradually modernization is offering a shift from a sand based infrastructural development especially in the building sector in rural areas to a cement based situation. Ghana's housing deficit currently stands at more than 1 million with an annual delivery of only 40,000 being provided [13]. The country's cement industry is estimated to grow by over 8% every year for the next 20 years. This is because the demand for cement in the country is expected to increase as a result of increasing population and expansion of infrastructure [14]. There is therefore, the urgent need to accelerate research in the area of NORM to set regulatory limits for these materials in the building industry in Ghana.

For the purpose of this study, it is imperative to indicate that, for the past decade a cement factory (Diamond Cement factory Limited) has been operating in the Duta and Akprokploe rural communities near Aflao (border town) in the Volta Region of Ghana. Before, the advent of the cement factory in these rural communities, ingenious soil has been predominantly the material used in residential and other infrastructural developments for the citizenry in the area. At present the scenario is changing from soil based dwellings to cement based building developments by the people of the area. By this, national development is being improved and encouraged. From the radiological point of view, however, it is important to assess the radioactivity levels of these materials. The reason being that the radiation to which human are exposed to may increase if they live in houses or buildings constructed using materials where the radiation doses are above normal background level in the area.

The present investigation is aimed at verifying the radioactivity and dose rate levels of soil samples in the study area, and also samples of Portland cement from the Diamond Cement Factory as well as raw materials of which they are composed. Results of the study will provide useful data and information on radioactivity levels in these building materials in addition to whether these materials are safe for building purposes. Furthermore, it will provoke interest in having knowledge whether the shift from soil based to cement based construction of buildings is enhancing or depreciating human health radiologically.

MATERIALS AND METHODS

Sample Collection and Preparation

Building soil samples were collected from the 12 sites at a depth of 15 cm from the two communities of the study area using a soil corer. After removing grass, stone and the biological materials, the samples sieved through 250 μm then sun-dried and kept in plastic containers. In the cement factory the main raw materials used for the manufacture of cement are limestone, gypsum and clinker. The cement powder was of two types: ordinary Portland cement (OPC) and Portland limestone cement (PLC). Hence, the cement powder and its raw materials were sampled directly on three different occasions from the factory in separate containers. The samples were separately kept in plastic containers and kept in the National Reactors Research Center (NRRC) laboratory, Ghana Atomic Energy Commission (GAEC) pending analysis.

All the six different type of samples were oven dried at 110°C for 72 h and separately pulverized after which each was put together into composite samples after an exhaustive mixing. A set of 18 samples of the 6 different materials representing triplicates of each were prepared for the analysis. The homogenized samples were weighted and hermetically sealed-packed in plastic 450 ml marinelli containers. The containers with the same size and geometry were used for the reference materials for the efficient calibration of the detector system for the radioactivity measurement. The samples were filled to an indicated mark on the marinelli container and the mass determined by simple calculation after weighing respectively empty container in addition to a specific sample and the container alone. The samples were closed tightly to limit as far as possible escape of radon. Each marinelli container was analyzed after 4 weeks after ^{226}Ra and ^{232}Th secular equilibrium with their decay products was obtained using HPGe detector set-up and 8192 channel Multi-channel Analyzer (MCA). The detector was calibrated for absolute efficiency using mixed radionuclides gamma ray standard QCY4 solution (obtained from Physikalisch Technische Bundesanstalt PTB, Germany) supplied by the IAEA. Corrections for densities to the cement materials to be measured was made. The standard solution contains the following radionuclides with corresponding energies ^{241}Am (60 keV), ^{109}Cd (88 keV), ^{57}Co (122 keV), ^{139}Ce (1656 keV), ^{203}Hg (279 keV), ^{113}Sn (391.69 keV), ^{85}Sr (514 keV), ^{137}Cs (662 keV), ^{88}Yt (898 keV and 1836 keV) and ^{60}Co (1173 keV and 1333 keV).

Determination of Specific Radioactivity in Samples

The measurement of specific activity concentration of radionuclides in the samples under consideration was made using HPGe gamma-ray spectrometry system. The gamma spectrometry system was equipped with a high-resolution gamma ray spectrometry using HPGe detector Model GR 2518-7500L (Canberra Industries Inc.) coupled to a computer based PCA-MR 8192 MCA mounted in a cylindrical 90 mm thick lead shield and an internal volume of approximately 99.53 L. The detector is cooled by liquid nitrogen from vertically dipstick cryostat dipped in 35 L liquid nitrogen Dewar. The detector has a relative efficiency of 25% to NaI detector, 1.8 keV energy resolution at the energy peak of 1333 keV of ^{60}Co isotope, and a peak-to-Compton ratio of 55:1. The radionuclides were identified using gamma-ray spectrum analysis software, ORTEC MAESTRO-32.

The radioactivity measurement of the samples was made by placing them on the detector inside the lead shielding and spectrum was collected for accumulation. The same geometry was used to determine peak area of samples and references. Each sample was measured during an accumulating time for 36,000s. The activity concentrations were calculated based on the weighted mean value of their respective decay products in equilibrium. The gamma-ray lines of 295.2 (18.2), 351.9 (35.1) keV from ^{214}Pb and the 609.3 (44.6), 1764.5 (15.1) keV from ^{214}Bi were used to determine the activity concentration of ^{226}Ra. The gamma lines of 338.4, the 911.2 (26.6) keV from ^{228}Ac, the 727.3 keV from ^{212}Bi and 583.2 (30.6) keV from ^{208}Tl were used to determine the activity concentration of ^{232}Th. The activity concentration of ^{40}K was measured directly by its own gamma ray at 1460.8 (10.7) keV. The values inside the parentheses following gamma-ray energy indicate the absolute emission probability of the *gamma decay*.

The gamma-ray background around the detector inside the shielding was determined using an empty container under identical measurement conditions. This background was subtracted from the measured gamma-ray spectra of each sample before calculating the activity concentrations. The specific activity concentration, A_{Ei} of a radionuclide *i* and for a photopeak at energy E, is give by the analytical expression (1) [15]:

$$A_{Ei} = \frac{N_{Ei}}{\varepsilon_{Ei} T_c \gamma_d M_s} \qquad (1)$$

Where N_{Ei} is the net count for a sample at energy E, ε_{Ei} is the detector efficiency at energy E, T_c the counting live time, γ_d the gamma emission probability, and M_s the mass (dry weight) in kilogram of the sample.

Radon Emanation Coefficient and Radon Mass Exhalation

The radon emanation coefficient of samples was calculated based on two γ- measurements. The first measurement was carried out directly after sealing of samples, while the second measurement was carried out after attainment of secular equilibrium between radon and its short-lived decay daughters. Based on these measurements, the radon emanation coefficient was calculated according to the following expression (2) [13, 16]:

$$Rn_{EC} = \frac{N}{(N_o + N)} \qquad (2)$$

where, Rn_{EC} is the radon emanation coefficient, N_o is the net count rate of ^{222}Rn at the time of sealing the sample container, N is the net count rate of ^{222}Rn emanated at the radioactive equilibrium with ^{226}Ra and its progeny. Assuming that C_{Ra} is the concentration of ^{226}Ra (Bq kg^{-1}), λ_{Rn} is the decay constant ^{222}Rn (2.1× 10^{-6} per s), the mass exhalation rate E_x (Bq kg^{-1}.s) of ^{222}Rn was determined through the following equation (3):

$$E_x = C_{Ra} \times Rn_{EC} \times \lambda_{Rn} \qquad (3)$$

RESULTS AND DISCUSSION

Specific Activity Concentration of Building Materials

The minimum, maximum and average activity concentration of ^{226}Ra (C_{Ra}), ^{232}Th (C_{Th}) and ^{40}K (C_K) (in Bq kg^{-1}) together with statistical uncertainty (1σ) are presented for the different types of cement samples and their composite materials in addition to soil (used in building) in Table 1. The specific radioactivity of ^{226}Ra, ^{232}Th and ^{40}K in the analyzed building materials ranged from 13.46±0.84 to 72.32±1.67 Bq kg^{-1} with a mean of 38.34±1.41 Bq kg^{-1}, 10.56±0.83 to 30.32±0.52 with an average value of 23.12±0.93 and 235.07±3.28 to 524.13±4.54 Bq kg^{-1} with an average of 398.56±4.03 Bq kg^{-1} respectively. The activity concentrations were used to assess the radiological hazards of the building materials.

Table 1: Minimum, maximum and mean specific activities (Bq kg^{-1}) due to natural radionuclides from cement types and raw materials of which the products are composed as well as soil from the vicinity of the cement factory

Type of Materials	n	C_{Ra}			C_{Th}			C_K		
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Clinker	3	57.08 ±1.39	65.94 ±1.91	62.12 ±1.44	26.72±0.51	30.32±0.53	28.39±0.43	480.17±4.44	537.80±4.97	524.13±4.54
Gypsum	3	24.35± 1.25	30.30±1.51	27.57 ±1.47	10.56±0.83	13.14±0.81	11.96±0.91	235.07±3.28	292.54±4.08	266.33±3.94
Limestone	3	30.01± 1.20	37.27± 0.96	32.95 ±0.88	17.99±0.50	21.86±0.79	19.86±0.66	439.12±4.50	546.46±5.60	497.53±5.12
Cement (PC)	3	57.34±1.32	72.32±1.67	61.63 ±1.38	25.25±0.73	27.15±0.93	25.96±0.84	398.42±4.12	495.89±5.12	451.30±4.89
Cement (PLC)	3	47.81±1.62	59.50±1.70	54.35 ±1.92	21.27±0.71	26.35±0.84	24.04±0.66	419.41±4.69	521.94±5.84	476.87±5.03
Composite Soil	5	13.46±0.84	27.94±1.43	22.70±1.14	18.23±0.99	46.78±3.81	28.51±2.05	168.11±2.09	179.22±2.95	175.21±2.33

**PC: Portland cement; PLC: Portland limestone cement*

The average concentration values are lower than the corresponding world mean values that are 50, 50 and 500 Bq kg^{-1}for ^{226}Ra, ^{232}Th and ^{40}K respectively [3]. Table 4.1 shows that ^{40}K is the largest contributor to the total activities due to all three radionuclides in raw materials of the Portland cements as well as the building soil. The activity concentration results show no significant difference ($p<0.05$) between clinker and ordinary Portland (PC) cement due to the three radionuclides. A situation which might account for this may be attributable to the higher percentage of clinker content in the PC product than in the PLC product.

A clear observation of the results indicated that the distribution of natural radionuclides in the analytical material samples is not uniform. These variations in activities are due to varying amounts of uranium, thorium and potassium-40 concentrations under the earth crust from where raw materials for particular building materials may be obtained. Therefore to compare the radioactivity concentration of any building material containing ^{226}Ra, ^{232}Th and ^{40}K, a common index is required to obtain the sum of radioactivities. The radium equivalent activity (Ra_{eq}) has been used for the purpose.

Radium Equivalent Activity (Ra_{eq})

The radium equivalent activity values for the building material samples were calculated using equation (4) [17]:

$$Ra_{eq} = C_{Ra} + 1.43C_{Th} + 0.432C_K \qquad (4)$$

Where C_{Ra}, C_{Th} and C_K are the specific activities of ^{226}Ra, ^{232}Th and ^{40}K, respectively in Bq kg^{-1}. In the definition of Ra_{eq}, it is assumed that 10 Bq kg^{-1} of ^{226}Ra, 7 Bq kg^{-1} ^{232}Th and 130 Bq kg^{-1} of ^{40}K produced equal gamma ray dose rate [7]. According to Turhan and Görbüz [3], the maximum value of Ra_{eq} in building materials and products must be less than 370 Bq kg^{-1} for safe use, ie to keep the external dose < 1.5 mSv y^{-1}.

The calculated values for the samples under the study are given in Table 2. From the results it can be observed that the mean lowest value is 142.44±4.47 Bq kg^{-1} was calculated in gypsum, while the highest value is 329.14±4.01 Bq kg^{-1} calculated in clinker. The Ra_{eq} results of the two types of Portland cement (PC and PLC) produced from the DIACEM factory compare favourably and are higher than their composed materials with the exception of clinker. Meanwhile, the soil samples Ra_{eq} results ranged from 112.15 to 172.26 Bq kg^{-1} with a mean of 139.16 ± 5.08 Bq kg^{-1}, indicating that they are lower compared to the other building materials.

Table 2: Radium equivalent (Ra_{eq}) activities and hazard Indexes ($H_{ex/in}$) and representative level index ($I_{\gamma r}$) of building materials obtained from the study area

Building materials	Radium Equivalent Activity (Ra_{eq})		Hazard Index (Ra_{eq})		Representative Level Index
	Range	Mean	H_{ex}	H_{in}	$I_{\gamma r}$
Clinker	302.72 – 341.72	329.14 ± 4.01	0.39	0.55	1.04
Gypsum	141.00 – 175.61	142.44 ± 4.47	0.17	0.24	0.45
Limestone	245.57 – 304.60	274.48 ± 4.04	0.27	0.35	0.74
Cement (PC)	265.57 – 325.38	293.71 ± 4.67	0.36	0.53	0.97
Cement (PLC)	259.41 – 322.66	294.76 ± 5.04	0.34	0.49	0.92
Composite Soil	112.15 - 172.26	139.16 ± 5.08	0.21	0.27	0.55

The growing worldwide interest in natural radioactivity exposure has lead to extensive survey in many countries. As a result, in some countries nationwide surveys have been carried-out to determine Ra_{eq} of soil samples and other building materials especially Portland cement.

Table 3a: Comparison of the activity concentrations and the radium equivalent activities (Raeq) of cement samples under the current study with those obtained in other selected published data.

Country	Specific Radioactivity (Bq.kg^{-1})			Ra_{eq} (Bq.kg^{-1})	References
	C_{Ra}	C_{Th}	C_K		
Bangladesh	62.3	59.4	328.9	172.8	Chowdhury *et al*, [18]
Brazil	61.7	58.5	564.0	188.8	Malanka *et al*, [19]
China	69.3	62.0	169.0	189.0	Zigiang *et al*, [5]
Egypt	78.0	33.0	337.0	151.0	El Afifi *et al*, [20]
Greece	92.0	31.0	310.0	160.0	Stoulos *et al.* [21]
India	37.0	24.1	432.2	104.7	Kumar *et al*, [22]
Ireland	66.0	11.0	130.0	86.0	Lee *et al*, [23]
Japan	35.8	20.7	139.4	125.6	Suzuki *et al*, [24]
Pakistan	26.1	28.6	272.9	87.9	Khan and Khan, [25]
Turkey	40.0	28.0	248.3	99.1	Turhan and Gùrbùz, [3]
Ghana	54.35 ±1.92	24.04±0.66	476.87±5.03	294.76 ± 5.04	Present Study

It has therefore become a normal practice to compare such survey results with other published data. Tables 3a and 3b compare the reported values of Ra_{eq} for Portland cement and soil samples obtained in other countries with those determined in this study.

As shown in Tables 3a and 3b, the radioactivity in building materials varied from one country to another. It was important to point out that these values were not the representative values for the countries mentioned but for the regions from where the soil and composed material samples for the cement were collected. The comparison shows that the calculated mean Ra_{eq} for cement samples is higher than that calculated for all the countries used in the comparison. Clearly, for the soil samples, the result is the opposite as the mean Ra_{eq} is lower than what was calculated for all the countries.

Table 3b: Comparison of the activity concentrations and the radium equivalent activities (Ra_{eq}) of soil samples under the current study with those obtained in other selected published data.

Country	Specific Radioactivity ($Bq.kg^{-1}$)			Ra_{eq} ($Bq.kg^{-1}$)	References
	C_{Ra}	C_{Th}	C_K		
Bangladesh	42.0	81.0	833.0	517.31	Chowdhury *et al*,[18]
Belgium	26.0	27.0	380.0	228.77	UNSCEAR [26]
China	42.7	46.3	578.0	358.61	Zigiang *et al*, [5]
Egypt	16.7	19.4	262.0	157.63	Saleh *et al*, [27]
Greece	25.0	21.0	360.0	210.55	UNSCEAR, [26]
India	29.0	64.0	400.0	293.32	UNSCEAR, [26]
Iran	28.0	22.0	640.0	335.94	UNSCEAR, [26]
Japan	33.0	28.0	310.0	206.96	UNSCEAR, [26]
Pakistan	35.0	41.0	615.0	359.31	Tahir *et al*, [28]
Turkey	21.0	37.0	342.0	221.65	Karahan and Bayulken, [29]
Ghana	22.70±1.14	28.51±2.05	175.21±2.33	139.16 ± 5.08	Present Study
World average	35	30	400		UNSCEAR, 2000

Note: Only the activity concentrations of the three radionuclides were obtained from literature, the Ra_{eq} was computed under the current study.

For limestone and gypsum, the current results for Ra_{eq} were found higher than what was obtained from other countries like: Brazil (50.1Bq.kg^{-1} limestone and 18.1 Bq.kg^{-1} gypsum) [19]; Egypt (79.85 Bq.kg^{-1} limestone and 116 Bq.kg^{-1} gypsum) [4]; Italy (14±11 Bq.kg^{-1} limestone and 12±11) [30]; and Saudi Arabia (83 Bq.kg^{-1} and 107 Bq.kg^{-1}) [4].

Representative Level Index

In order to examine whether the samples merit limits of dose criterion, another radiation hazard index known as the representative level index ($I_{\gamma r}$) is used to estimate the level of γ-radiation hazards associated with the natural radionuclides in specific construction materials. The $I_{\gamma r}$ is defined by equation (5) [6].

$$I_{\gamma r} = \frac{C_{Ra}}{150} + \frac{C_{Th}}{100} + \frac{C_K}{1500} \quad (5)$$

For safe use of materials in the construction of buildings, $I_{\gamma r}$ should be less than unity. The calculated $I_{\gamma r}$ values for the studied geologic materials and product samples ranged from 0.45 to 1.04 with an average of 0.82±0.24 Bq.kg^{-1} (see last column of Table 2). It is clear that with the exception of clinker which is slightly higher than the criterion limit, all the samples are safe for use in respect of the representative level index assessment.

Radiological Hazard Indices

According to the International Convention on Radiological Protection (ICRP) [31], the upper limit of radiation dose arising from building materials is 1.5 mGyy^{-1}. To limit the external gamma radiation dose from building materials to this value, the external radiation index (H_{ex}) defined by Mujahid *et al* [6] as in equation (6) was used.

$$H_{ex} = C_{Ra}/370 + C_{Th}/259 + C_K/4810 \quad (6)$$

The value of this index must be less than unity for the radiation risk to be negligible [32]. For the maximum value of H_{ex} to be less than unity, the maximum value of Ra_{eq} must be less than 370 Bq.kg^{-1}. According to the calculation of H_{ex}, the values of H_{ex} for the studied samples ranged from 0.17 (gypsum) to 0.39 (clinker) which are indeed less than unity (see Table 4.2).

In addition to the external hazard index, radon and its short lived products are also hazardous to the respiratory organs. The external exposure to radon and its daughter products is quantified by the internal hazard index (H_{in}) defined by Krieger [9] as in equation (7).

$$H_{in} = C_{Ra}/185 + C_{Th}/259 + C_K/4810 \quad \textbf{(7)}$$

If the maximum concentration of radium is half than of the normal acceptable limit, then H_{in} would be less than one. For the safe use of material in the construction of dwellings, H_{in} should be less than one. The calculated values of H_{in} for the studied constructed building materials ranged from 0.24 to 0.55 Bq. Kg^{-1}. Once again all these values are less than unity. Therefore, the materials under the current test are safe for human health when used in the construction of dwellings.

Absorbed dose and Annal Effective Dose

The derived outdoor and indoor dose rates and annual effective dose are shown in Table 4. The outdoor absorbed dose rate in air at 1 m above the ground surface was calculated using the conversion factors given in UNSCEAR 1988 Report. It is observed that the range of outdoor dose was from 24.58 ± 1.33 to 67.86 ± 1.11± $nGyh^{-1}$ and the mean outdoor dose rate of the area was 48.71 ± 1.29 nGy h^{-1} which is lower than the world average value of 55 nGy h^{-1}. The conversion factors used to calculate the absorbed dose rates in outdoor air is given as in equation (8) [22]:

$$D_o = 0.462C_U + 0.604C_{Th} + 0.042C_K \qquad (8)$$

Table 4: Radiological parameters for building materials used in the study area

Building materials	Absorbed Dose Rate ($nGyh^{-1}$)		Annual Effective Dose ($mSvy^{-1}$)		Total Effective Dose ($mSvy^{-1}$)
	Outdoor (D_o)	Indoor (D_i)	Outdoor (H_o)	Indoor (H_i)	
Clinker	39.16 ± 1.11	130.31 ± 2.16	0.19	0.64	0.83
Gypsum	18.41 ± 1.40	59.83 ± 2.67	0.09	0.29	0.38
Limestone	32.95 ± 1.02	92.07 ± 1.95	0.16	0.45	0.61
Cement (PC)	34.63 ± 1.35	121.36 ± 2.58	0.17	0.60	0.77
Cement (PLC)	34.55 ± 1.50	114.62 ± 2.90	0.17	0.56	0.73
Composite Soil	24.58 ± 1.33	66.16 ± 3.49	0.12	0.33	0.45

The annual effective dose, D, from outdoor terrestrial gamma radiation using 0.2 as the outdoor occupancy factor and 0.7 Sv Gy^{-1} as the quotient of effective dose equivalent rate to absorbed dose rate in air. For indoor exposure, using an occupancy factor of 0.8, the annual effective dose was calculated (equation 9) implying that 20% of the time is spent outdoors, on an average, around the world.

$$D_i = 0.92C_{Ra} + 1.1C_{Th} + 0.080C_K \qquad (9)$$

The results of outdoor, indoor and total annual effective dose are shown in Table 4. The mean of the total (outdoor plus indoor) annual effective dose (D_T) from terrestrial radiation is found to be 0.67 mSv of which 0.48 mSv comes from indoor and 0.15 mSv from outdoor. The corresponding world average value is 0.41 mSv of which 0.34 mSv comes from indoor and 0.07 mSv from outdoor.

Radon Emanation Coefficient and Radon mass Exhalation Rate

Building materials can contribute to γ-ray dose rate through inhalation of ^{222}Rn and external irradiation by other radionuclides. The ^{222}Rn gas which emanates from the ^{226}Ra may constitute a radiation hazard to both people working directly with building materials and inhabitants of dwellings constructed with those cement. Measurements of the radionuclide concentrations are used to evaluate both indoor radon concentration and γ dose rate.

Exhalation of radon from these materials is of interest since the short-lived decay products of some radon isotopes are the greatest contributors to the lung dose from inhaled radionuclides. The most important isotope of radon is ^{222}Rn (radon, $t_{1/2}$=3.82 d) and belongs to the ^{238}U natural chain. ^{220}Rn (thoron, $t_{1/2}$=55s) is another isotope and belongs to the ^{232}Th natural chain. Essentially, the ^{220}Rn comes out from a thin external layer of the walls, due to the relationship of half-life time to diffusion rate (0.2–0.3md^{-1}). The entire wall, however, contributes to the ^{222}Rn concentration in indoor air. The irradiation levels are almost entirely due to ^{222}Rn, in the case of a room with infinitely thick walls.

The fraction of ^{222}Rn that can diffuse through the building materials is known as the emanation coefficient or fraction of the material. The radon emanation coefficient (Rn_{EC}) is a very important radiological index used to evaluate the amount of the ^{222}Rn emanated fraction released from the raw building materials and products containing naturally occurring radionuclides such as ^{226}Ra in radioactive equilibrium with its parents.

Table 5: Radon mass exhalation rates and radon emanation coefficient from the samples of building materials used in the study area.

Building materials	Radon Emanation Coefficient Rn_{EC} (%)	Radium Concentration C_{Ra} (Bq kg^{-1})	Mass Exhalation Rate E_x (µBq kg^{-1}.s)
Clinker	67.95 ± 3.8	62.12 ± 1.44	66.30 ± 1.20
Gypsum	52.28 ± 3.1	27.57 ± 1.47	30.30 ± 1.32
Limestone	50.83 ± 3.3	32.95 ± 0.88	47.70 ± 0.79
PLC	55.21 ± 3.4	61.63 ± 1.38	68.10 ± 1.24
PC	52.64 ± 3.3	54.35 ± 1.92	63.00 ± 1.72
Soil	42.70 ± 2.6	22.70 ± 1.14	20.40 ± 1.02
Mean	**53.60** ± 3.3	**43.55** ± 1.36	**49.30** ± 1.22

PC=Portland cement; PLC=Portland limestone cement

The radon emanation coefficient and mass exhalation rate of building materials under the current study have been shown in Table 5. The Rn_{EC} vary from 42.70 ± 2.6 to 67.95 ± 3.8% with the average value of 53.60 ± 3.3%, and a corresponding variation in E_x which ranged from 20.40 ± 1.02 to 66.30 ± 1.20 µBq kg^{-1}.s^{-1} with a mean of 49.30 ± 1.22 µBq kg^{-1}.s^{-1}. The lower and upper values occurred in building soil and clinker respectively. This variation in radon concentration confirms an earlier position that the uranium content in the earth crust is different at different locations.

The results indicated that the Rn_{EC} and E_x are relatively high. This has been supported by studies from other countries. For instance the mean results of 52.3% and 63.00 µBq kg^{-1}.s^{-1} for Portland cement in terms of Rn_{EC} and E_x respectively were higher than what was reported by Man and Yeung [10] for Turkey (0.5-29 %), Netherland (0.25-7.7 %), Hong Kong (2.0 %) and Hungary (7.8%). Likewise, the E_x of portland cement is higher than that reported by: Man and Yeung [10] for Hong kong (1.5 µBq kg^{-1}.s^{-1}); Mujahid *et al* [6] for Pakistan (2.25 ± 0.2 1.5 µBq kg^{-1}.s^{-1}).

CONCLUSION

Specific activities of ^{226}Ra, ^{232}Th and ^{40}K in building soil samples collected from rural communities in Aflao, Ghana, and samples of portland cement and raw composed materials (clinker, gypsum and limestone) obtained from Diamond Cement Factory (Ghana) Limited (DIACEM) located in the investigated communities have been measured using HPGe based gamma spectrometry technique. The Ra_{eq} values investigated were found to be normal and within worldwide ranges. However, some significant variations have been observed between the radioactivity contents of Portland cement products (OPC and PLC) and raw materials of which they were composed, both in the present study and in literature values for other countries of the world.

For limestone and gypsum materials, the results of Ra_{eq} were higher compared to values reported from other countries like, Egypt, Brazil, Italy and Saudi Arabia. Results from the building soil samples regarding Ra_{eq} were found to be lower compared to results from other countries. Likewise, the study took a position that the radon emanation coefficient and the corresponding mass exhalation rate of the materials under the current study were higher when compared to results from other studies in different countries. These variations and the large spread in data are a reflection of different geological origins of the building materials.

Studies of external and internal irradiation dose from the building materials, used in the construction of dwellings, are being carried out in order to estimate the indoor effective dose equivalent from the samples. The assessment of the radiological hazard parameters in terms of radium equivalent activity, internal and external hazard indices, indoor absorbed dose rate and the annual effective dose in the building materials were all found to be well below the acceptable recommended limits. Therefore, the use of these materials in construction of dwellings is considered safe for inhabitants of the study area according to OECD [32].

It is instructive to note that according to the current results, the radiation dose delivery from the building soil samples is less compared to the cementitious building materials. It can then be inferred that, the shift from the use of soil to a modernized form of construction of dwellings for this rural population means more radiological consequence for the inhabitants, notwithstanding the declaration of the modernized materials as safe according to the study.

The results may not reflect a real situation in that, the use of soil in the construction of dwellings in rural communities is radiologically safe. For more accurate understanding regarding this subject matter, more studies in the assessment of cement and processed products in the country and building soils should be undertaken. However, this study can be used as a reference for more extensive studies as the current results may serve as valuable information in this regard.

Acknowledgement
The authors would like to thank Carnegie Next Generation of Academic in Africa (CNGAA) for financing this work through the University of Ghana, Legon. The ethical support offered by the people Akporkloe is also acknowledged.

REFERENCES

[1] M. Abusini, K. Al-ayasreh, J. Al-Jundi, *Radiat. Prot. Dosim*., **2008**, 128, 213–216
[2] M. Faheem, S. A. Mujahid, K. Matiullah, *Radiat. Measurement*. **2008**, 43, 1443–1447
[3] F. Turhan, G. Gűrbűz, Radiation Protection Dosimetry, **2008**, 129, 391- 396
[4] A. El-Taher, *Rom. Journ. Phys*., **2012**, 57 (3–4), 726–735
[5] P. Zigiang, P., Y. Yin, G. Mingqiang, *Radiat. Protect. Dosim*., **1988**, 24, 29-35
[6] S. A. Mujahid, A. Rahim, S. Hussain, M. Farooq, *Radiation Protection Dosimetry*, **2007**, 130 (2), 206- 212.
[7] J. Beretka. P. J. Matthew., *Health Phys*., **1985,** 48, 87 – 95
[8] H. M. Khan, K. Khan, M. A. Atta, F. Jan, *J. Chem. Soc. Pak.*, **1994**, 16, 183.
[9] R. Krieger, *Betonwerk Fertigteil techn*., **1998,** 47: 468
[10] C. K. Man., H. S. Yeung, *J. Radioanal Nucl. Chem.*, **1998**, 232 (1-2), 219-222
[11] N.K. Ahmed, *J. Environ. Radioact*., **2005**, 83, 91-99.
[12] S. Righi, L. Bruzzi, L., *J. Environmental Radioactivity*, **2006,** 88, 158-170
[13] D.O.,Kpeglo, H. Lawluvi, A. Faanu, A.R. Awudu, P. Deatanyah, S. G. Wotorchi, C. C. Arwui, G. Emi-Reynolds, E. O. Darko, E.O., *Research Journal of Environmental and Earth Sciences*, **2011,** 3(2): 160-166
[14] MWRWH (Minister of Water Resources, Works and Housing)., "Report Statement by the Minister of Water Resources, Works and Housing on the STX Housing Project. Retrieved from the internet on February 23, 2010 on http://www.dailyguideghana.com/index.housing
[15] H.L. Beck, J. Decompo, J. Gologak, "In situ Ge (ii) and NaI(Tl) gamma ray spectrometry". In: Otoo *et al*, 2011. *Research Journal of Environmental & Health Sciences*, **2011**, 3 (3): 261-268.
[16] S. Turhan, H. Yuce, L. Gűndűz, S. Sahin, M. Vural, A. Parmaksiz. B. Demircioglu, *Appl. Radiat. Isot.*, **2008**, 65, 350-354.
[17] K. N. Yu, Guan, Z. J., Stokes, M. J., Young, E.C.M., *Journal of Environmental Radioactivity*, **1992**, *17*(1), 31–48
[18] I. M. Chowdhury, M. N., Alam, A. K. S. Ahmed, *J. Radioanal. Nucl. Chem*., **1998**, 231 (1-2), 117-122
[19] A. Malanca, V. pessina, L. Dallara, *Radiat. Protect. Dosim.* , **1993**, 48, 199-203
[20] E. M. El Afifi, M. A. Hilal, S. M. Khalifa, H. F. Aly, *Radiat. Meas.*, **2006**, 41, 627-633
[21] S. Stoulos, M. Manolopoulou, C. Papastefanou, *J. Environ. Radioact*, **2003**, 69, 225-240
[22] V. Kumar, T. V. Ramachandran, R. Prasad, *J. Radioanal. Nucl. Chem*., **1999**, 266 (3), 93-96
[23] E. M. Lee, G. Menezes, E. C. Fich, *Health Phys*., **2004,** 86, 378-383
[24] A. Suzuki, T. Lida, J. Moriizumi, Y. Sakuma, *Radiat. Protect. Dosim.*, **2000**, 90, 437-443
[25] K. Khan, H. M. Khan, *Radiat. Protect. Dosim.*, **2001**, 114, 533-537
[26] UNSCEAR **(**United Nations Scientific Committee on the Effects of Atomic Radiation), Report of UNSCEAR to the General Assembly", United Nations, New York, USA. ,**2000**, 111–125
[27] I. H. Saleh, A. I. Hafez, N. H. Elanany, H. A. Motaaweh, N. A. Naim, *Turkish J. Eng. Environ. Sci.*, **2007**, 31, 9-17
[28] S. N. A. Tahir, K. Jamil, J. H. Zaidi, M. Arif, M. Ahmed, S. A. Ahmed, *Radiat. Prot. Dosim* ., **2005**, 113 (4), 421-427
[29] G. Karahan, A. Bayulken, A., *J. Environmental Radioactivity***, 2000**, 47, 126-130
[30] S. Rizzo, M. Brai, S. Basile, S. Bellia, Hauser S., *Appl.Radiat. Isot.*, **2001,** 55, 259–265.
[31] ICRP (International Convention on Radiological Protection) (**1993**). Protection against radon-222 at home and at work. Annals of the ICRP Publication, **1993**, 65, 23(2), 1-45
[32] OECD (Organization for Economic Cooperation and Development), Report by a Group of Experts of the OECD Nuclear Energy Agency, Paris, France, **1979**, 22