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Assessment of Radiological Hazard Indices of Building Materials in Ogbomoso, South-West Nigeria

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Abstract

This research study aims at assessing the radiological hazards indices of materials used for the construction of Ladoke Akintola University of Technology Teaching Hospital, a tertiary medical facility in Ogbomoso, South-West, Nigeria. The determination was sequel to the measurement of the radionuclide contents of the materials (Granite, Cement, Sand, and Concrete) used in the construction of the building, using a high-purity germanium detector gamma spectrometer. The natural radionuclides detected are traceable to the primordial series of ^{238}U and ^{232}Th as well as ^{40}K and traces of globally released ^{137}Cs. The specific activity values ranged between 27.79 and 30.65 Bq kg^{-1} with a mean of 29.22 Bq kg^{-1} for ^{238}U; while for ^{232}Th, the range was 16.69-22.73 Bq kg^{-1} with a mean of 19.71 Bq kg^{-1}. Relatively higher specific activity values were recorded in ^{40}K with a range of 132.76-276.42 Bq kg^{-1}, while the mean was 204.59 Bq kg^{-1}. However, a relatively low-specific radioactivity was obtained from ^{137}Cs with a range of 1.03-14.90 Bq kg^{-1} and a mean of 13.32 Bq kg^{-1}. All other values of other indicators were below the maximum permissible limit (MPL). The determination carried out prior to the building being occupied, showed no evidence of artificial radionuclide. Hence, the building materials may be considered safe for building construction and the values measured can therefore serve as reference for future measurement.

Keywords: gamma spectrometry, building materials, radiological risk assessment, radium equivalent, radionuclide concentration

1. Introduction

Radionuclides are heavy isotopes in the environment that are not stable. To be stable, these nuclides emit radiations or particles (Baxter, 1983). The radionuclides are present almost everywhere around us; in the Earth's crust, air, water, plants and so on. They may be naturally occurring or artificially produced (Beretka et al., 1985). A number of radioactive materials occur naturally in the earth itself. These radionuclides all have very long half lives and have been present in the earth since its formation (Martins & Harbinson, 1979). The examples include ^{238}U (half life 4.5×10^9 y), ^{232}Th (half life 1.4×10^{10} y) and ^{40}K (half life 1.3×10^9 y). Naturally occurring isotopes such as Uranium-238 and Thorium-232 are present in the earth's crust producing Uranium and Thorium daughters. Radium is found at low level in the soil, water, rocks, coal plant and food.

Several researchers have contributed immensely to the knowledge of radiation exposure from building materials. Among the reported some are the work of Farai and Isinkaye (2009), Xinwei et al. (2006), Farai and Ademola (2005), Sam and Abbas (2001). Having known that the concentrations of radionuclides are highest in mineral-based materials, such as stone, sand, bricks and cement, these materials invariably form the highest constituents of buildings in which man spends most of his time. As a result, it is pertinent to be aware of the level of radiation exposure to man from the building, especially the contribution of each of the aggregates making up the building. Data and reports on the exposure to radiation, emanating from public buildings such as hospital is very scanty if at all available in Africa, particularly Nigeria. This work is aimed at determination of activity concentrations of naturally occurring radionuclides in the building materials used in the construction of the teaching hospital of the Ladoke Akintola University of Technology, Ogbomoso, Nigeria. The samples were prepared for radio-assay to determine the radionuclide concentrations in them. The radiation hazard indices and radiation exposures to the occupants of this public building were subsequently determined from the radionuclide contents of the building materials. The study thus provides a pre-operational value and a yardstick to future evaluation of natural radiation exposure.

2. Materials and Method

Twenty samples of each of the building materials i.e. granite, cement, sand and concrete were collected at the construction site of the study area in Ogbomoso-Nigeria. After removing the stones and some grasses and leaves, the samples were dried in an oven at a temperature of 50 ºC for 24 hours to ensure that as much as moisture as possible was removed from the samples; they were then crushed to pass through 2 mm sieve to homogenize them. Representative samples were packed into polyethylene cylindrical containers of 95 mm diameter and 38mm height.

The granite and concrete samples were grinded and pulverised. The concrete sample was collected having ensured that it has cured, so as to ensure its independent nature of being affected by moisture. A 105 g of each of the prepared samples was obtained in a container, sealed and left for 28 days to attain secular equilibrium between radon and its decay products. Each of the samples, packed in 20 containers (giving a total of eighty samples) were later counted for 10 hours (36,000 s) using a gamma spectrometry system with NaI (TI) as the detector.

The scintillation detector, a 3×3 inch NaI (TI) detector coupled through a preamplifier to the Canberra S100 multi channel analyser, a product of Princeton Gamma Tech., USA was placed in a lead shield to reduce the effect of background radiation. Energy and efficiency calibrations of the detector were carried out using a standard source traceable to Analytical Quality Control Services (AQCS), USA; which contains ten radionuclides of γ-emitters with energies ranging from 59.54 to 1836 keV.

2.1 Radium Equivalent Activity

The exposure due to the γ radiation, defined in terms of the radium equivalent activity Ra_{eq} is given by equation (1) (Faheem et al., 2008; Beck, 1972):

$$Ra_{eq} = A_{Ra} + 1.43\, A_{Th} + 0.077\, A_K \leq 370 \quad (1)$$

According to this formula, 1 Bq/kg of ^{226}Ra, 0.7Bq/kg of ^{232}Th and 13 Bq/kg of ^{40}K yield the same γ ray dose. The radium equivalent activity for the material analyzed in this work was calculated and a highest value of 81.82 Bq/kg was obtained for sand. This value is much less that the upper limit of 370 Bq/kg. (UNSCEAR, 1988; UNSCEAR, 2000)

2.2 Dose in Air, Annual Effective Dose and the Corresponding External and Internal Indices

In order to evaluate the dose rate in air, Equation 2 was used as defined by (UNSCEAR, 1988; Hamzah et al., 2008).

$$D = \sum (A_x \times C_x) \quad (2)$$

Where A_x (Bq/kg) refers to the activity of ^{226}Ra, ^{232}Th and ^{40}K as calculated by Equation 1 and C_x (nGy/hour per Bq/kg) is the corresponding conversion factor. The C_x values used in this work are 0.427, 0.662 and 0.043 for ^{226}Ra, ^{232}Th and ^{40}K respectively. The annual effective dose equivalent due to the activity in the soil and building materials is calculated using Equation 3

$$E = T \times Q \times D \times Q_f \times 10^{-6} \quad (3)$$

Where the value of Q is 0.7 Sv/Gy/year for environmental exposure to γ-rays of moderate energy, T is time in hours in one year, i.e. 8760 hours, Q_f is the occupancy factor (0.8), and D is the dose rate given in Equation 2. The dose rate in air and the annual effective dose equivalent obtained are 30.15 nGy/hour and 0.29 mSv/year, respectively. The value for the annual effective dose rate in mSv/year adequately falls within the permissible dose equivalent limit of 1mSv/year (ICPR 60, 1990). The external hazards index (H_{ex}) and the internal index (H_{in}) was also determined using Equations 4 and 5 respectively (Papastefanou et al., 2005):

$$H_{ex} = \frac{A_{Th}}{259\ (Bq/kg)} + \frac{A_{Ra}}{370\ (Bq/kg)} + \frac{A_k}{4810\ (Bq/kg)} \quad (4)$$

$$H_{in} = \frac{A_{Th}}{259\ (Bq/kg)} + \frac{A_{Ra}}{180\ (Bq/kg)} + \frac{A_k}{4810\ (Bq/kg)} \quad (5)$$

Noteworthy, for radon and its short-lived progenies to produce negligible hazardous effects to respiratory organs from materials to be used in construction, both the external and internal hazard indices should be less than unity. Hence, the values of 0.18 and 0.25 for the external and internal hazard index, respectively were obtained, these values are much less than unity, indicating that the aforementioned hazardous effect due to the use of these materials is negligible as stipulated by OECD (1979).

Radon levels were not measured directly but an upper limit can be informed from the above guidelines. As the gamma dose rate is lower than 1 mSv/year, ^{226}Ra concentrations are unlikely to be high enough to cause indoor radon concentrations in excess of the 200 Bq/m^3 guidance level. In this regard, a number of models have been proposed in the literature.

3. Result and Discussion

The radionuclides found in the samples are the natural radionuclides ^{40}K, ^{238}U and ^{232}Th as well as the traces of globally released ^{137}Cs. The mean concentration of the radionuclides found in each of the samples assayed is presented in Table 1. The measurement showed that ^{40}K has the largest contribution to the specific activities in all the samples of the building materials assayed.

Table 1. Mean concentration of radionuclides in samples of building materials

Sample	^{40}K (Bq.kg^{-1})	^{238}U (Bq.kg^{-1})	^{232}Th (Bq.kg^{-1})
Granite	132.76(54.23)*	27.79(9.57)	19.83(6.43)
Cement	201.45(45.42)	30.65(11.76)	20.65(9.54)
Sand	276.42(67.90)	28.08(6.99)	22.73(9.87)
Concrete	175.85(28.68)	27.87(9.56)	16.69(6.99)

*Values in parentheses are the standard deviations of mean of the each of the measurement in the samples.

Note Standard deviation, $S = [\sum(X-M)^2/n-1]^{1/2}$. Where X, M and n are individual values, mean and sample size respectively.

The activity concentration of ^{40}K was found to range from 132.76 to 276.42 Bq.kg^{-1} with an average of 204.59 Bq.kg^{-1}. The mean radionuclide concentration obtained for the ^{238}U range from 27.79 Bq.kg^{-1} to 30.65 Bq.kg^{-1} with an average of 29.22 Bq.kg^{-1}. For the ^{232}Th, the range is from 16.69 Bq.kg^{-1} to 22.73 Bq.kg^{-1} with an average of 19.71 Bq.kg^{-1}. However, a relatively low-specific radioactivity was obtained from ^{137}Cs with a range of 1.03-14.90 Bq.kg^{-1} and a mean of 13.32 Bq.kg^{-1}.

Table 2. Values of the radiological indices

Samples	Ra_{eq}(Bq.kg^{-1})	H_{ex}	H_{in}	D_{in}(nGy.h^{-1})	$H(eff)_{in}$(mSv.y^{-1})
Granite	66.33	0.18	0.25	58.01	0.28
Cement	75.65	0.2	0.29	67.03	0.33
Sand	81.82	0.22	0.29	72.95	0.36
Concrete	65.24	0.18	0.25	30.15	0.29

The radiological indicators frequently used to assess the gamma radiation hazard to human from environmental samples were thereafter calculated using the expressions defined by Beretka and Mathew (1985), for the radium equivalent (Ra_{eq}). The external and internal hazard indices H_{ex} and H_{in} respectively were calculated using the expression of UNSCEAR 2000. Furthermore, the absorbed dose rate in indoor air, D_{in} (nGyh^{-1}) and the effective dose rate, H_e (mSv.y^{-1}) were estimated using the definitions reported by Papastefanou *et al*. (2005). These values are presented in Table 2.

Table 3. Comparison of mean Raeq equivalent activity ($Bq.kg^{-1}$)

Material	*Nigeria (2010)	Algeria (1999)	Malaysia (1996)	Zambia (1995)	Australia (1985)	Germany (1981)	Sweden (1979)	UK (1977)
Granite	66.33	58	-	24	115	322	114	59
Cement	75.65	112	188	79	115	70	-	-
Sand	81.82	28	136	135	70	59	-	19
Concrete	65.24	101	138	63	15	41	7	44

* This is the present study area (Ladoke Akintola University of Technology Teaching Hospital, Ogbomoso-Nigeria).

Similarly, Table 3 compares the reported values of radium-equivalent activities for selected building materials, obtained in other countries with those determined in this study. As shown in this table, 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 samples were collected (Amrani et al., 2001).

The values of the radium equivalent and the dose rate were found to be highest in sand with respective values of 81.814 $Bq.kg^{-1}$ and 72.950 $nGy.h^{-1}$. These values are however below the recommended limits of 370 $Bq.kg^{-1}$ and 84 $nGy.h^{-1}$ respectively given for radium equivalent and the dose rate above (UNSCEAR, 1988, 1993, 2000; OECD, 1979).

Also, the effective dose rate, external and internal hazard indices all revealed values that are within unity which is the recommended limit for building materials. As an index of the artificial radionuclide monitor, a region on the spectrometer defined for ^{137}Cs recorded the traces of globally released ^{137}Cs. Hence, artificial radionuclides are detected in the samples assayed.

4. Conclusion

The radiological indices of some building materials in Ogbomoso, South Western Nigeria have been determined from the radionuclide concentrations of the materials used in the construction of the building structures. Values of these radiation hazard indicators were however found below the recommended limit. This determination, revealing no artificial radionuclide can serve as a baseline for future assessment as the determination has been carried out at a period in which the facility is pre-operational. Also, the study concludes that the usage of the materials extracted from the study area may be safe for building constructions as they pose no significant radiation exposure to occupants.

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