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Comparative assessment of natural radionuclide content of cement brands used within Nigeria and some countries in the world

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ABSTRACT

The gamma spectrometric analysis of different brands of cement used as building and construction material in Nigeria has been carried out in this study. Samples of 12 brands of gray Ordinary Portland Cement (OPC) and 5 brands of white cement of six samples each were collected and analyzed for their radiological content using gamma spectrometry method. The average value of ^{226}Ra, ^{232}Th, and ^{40}K for OPC is 30.2 ± 10.4 Bq kg^{-1}, 24.6 ± 7.1 Bq kg^{-1}, and 251.3 ± 27.6 Bq kg^{-1} respectively and the average value for the white cement is 41.9 ± 16.7 Bq kg^{-1}, 30.1 ± 9.4 Bq kg^{-1} and 340.2 ± 37.7 Bq kg^{-1} respectively. The total average content of ^{226}Ra, ^{232}Th, and ^{40}K for all the cement brand samples are 36.1 ± 13.6 Bq kg^{-1}, 27.4 ± 8.3 Bq kg^{-1}, and 295.8 ± 32.7 Bq kg^{-1} respectively. These values obtained are lower when compared to the world average values (^{226}Ra-50 Bq kg^{-1}, ^{232}Th-50 Bq kg^{-1} and ^{40}K-500 Bq kg^{-1}) for building materials. The estimated radium equivalent activities (Ra_{eq}), representative index (Iγ), average absorbed γ-dose rate (D), the annual effective dose rate (AEDE), annual gonadal dose equivalent (AGDE) external and internal hazard indices and the Excess life cancer risk (ELCR) were lower than the recommended safe limit and are comparable with results from similar studies conducted in other countries. The evaluated mean gonadal dose equivalents of three cement brand samples were found to be higher than the world average for building material while others are less than the world average. A comparison of the average activity values obtained in Nigeria cement and other countries of the world show that those countries with history of high radionuclide solid minerals have activity concentration far above that of Nigerian cement, while these values agreed with those obtained in other countries.

1. Introduction

Man and the biota are continuously irradiated by this ionizing radiation from many sources broadly classified as either natural or artificial. Most of the total radiation exposure of man and his environment come from natural sources (UNSCEAR, 2000). This natural radiation comes from two main sources: cosmogenic radionuclides (^{3}H, ^{14}C, etc.) and long lived primordial radionuclides and their daughters (^{40}K, ^{238}U, ^{235}U, and ^{232}Th). The amount of the cosmogenic radionuclides is basically constant because of equilibrium between their rate of creation by cosmic radiation and their radioactive decay (Mikhail, 2008). Although the amount of primordial radionuclide keeps decreasing slowly with time due to radioactive decay, quite a significant amount still remain in the earth crust today due to their long half lives. These natural (primordial) radionuclides are known to be distributed in rocks and soil across the earth in varying concentrations depending on the geography and geological formations. Higher radiation levels are associated with igneous rocks, such as granite and phosphate, whereas lower levels with sedimentary rocks.

The inhomogeneous distribution of these radionuclides in geological formations like soils and rocks suggests that man made products derived from these substances will contain traces of these radioisotopes whose concentrations will be dictated by the origin of the soil and rocks they are derived from. One of such materials derived from rocks is Portland cement. Portland cement is a major building material used worldwide; it is derived from mixing natural clay, limestone and gypsum at high temperature (Kpeglo et al., 2011). Cement when mixed with fine and coarse aggregate in the right proportion is used for making concrete block—a basic building material worldwide.

The use of cement as a basic building and construction material cuts across all social and economic strata in Nigeria. It is used (when mixed with other materials such as fine sand) majorly in making concretes, sand blocks and for floors, walls, bridges and even roof finishing. A random survey on the application of cements in building revealed that over 90% of structures used as homes, offices, and commercial centers in Nigerian urban areas are constructed majorly using cement as binding material for concrete blocks (Sam and Abbas, 2001). In rural areas where clay/mud blocks and other locally sourced materials are used, it

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is common to see walls and floors plastered using cement paste. Consequently, Nigeria yearly consumption of cement stood at 10 million tons (Farai and Ejeh, 2006), and has been on the increase due to rapid structural and infrastructural development by government at all levels and the rapid increase in population and the consequent need for more homes and public structures. About two decades ago, a large proportion of cements used in Nigeria is imported (Esubiyi, 1995) while lesser proportion comes from the local industries. Today, the number of local cement industries has swollen such that more than 70% of locally consumed cement is manufactured locally. Generally, the local producing companies are located in areas where the raw materials are obtained while the imported product comes majorly from Asian and European countries. Although the brand names of some of the cements may suggest that they are manufactured in Nigeria, research has shown that some local companies only package imported cement dust using different brand names (Avwiri, 2005). The diverse sources of these cements imply that their natural radionuclide content will vary. Many research conducted and completed all over the world (Esubiyi, 1995; El-Bahi, 2004; Khalid and Hasan, 2001, etc.), have shown that natural radionuclides are present in Portland cement in varying concentration from country to country. Due to the diverse application of cement in building constructions, it could account for the bulk of indoor background radiation exposure to the populace. Furthermore, the grain size of cement is such that it is aerodynamic (Esubiyi, 1995), which could easily pass through respiratory track, or get blown by air into food and water. Consequently, the presence of radionuclide in cement does not only pose potential external radiation hazard but could also cause internal radiological contamination as well.

Some works have been done in Nigeria on building materials including cements without indication of brand name and their acceptability and covering the entire country (Avwiri, 2005; Esubiyi, 1995; Farai and Ejeh, 2006; Ibrahim, 1999). Thus, one is not sure about the nature and the distribution of the cement referred to in those works. In this study, the natural distribution of the cement brands considered is emphasized using the Nigeria map for the first time. Furthermore, this work considered brands that make up of more than 96% of those presently used in Nigeria including those used as tile adhesive. This work would serve as indicator of the indoor and outdoor radiation exposure of Nigerian people due to cement.

In the light of the diverse application of cement in Nigeria building construction industries and the fact that an average Nigerian spends about 80% of their time indoors, the knowledge of radiological content and associated hazard from cement is thus a necessity. The aim of this study is therefore to quantify the natural radionuclide content of cements available in local market in Nigeria and estimate the potential radiological hazard to the dwellers of buildings constructed from such cements and compare them with values obtained in other parts and countries of the world. The data from this study may be used by the Nigerian authority for the development and implementation of radiation protection guidelines for the use and management of cements in the country. The data in this work could also assist builders in Nigeria in considering radiological factor when making choices for cements rather than the traditional factors of cost and availability. Moreso, the data obtained in this study will add to the world data base of radioactivity content in cement as a building/construction material.

2. Materials and method

2.1. Site description

In order to collect cement brand samples that represent a fair proportion of major cement brands used in Nigeria, a survey was carried out. The survey includes visiting major cement factory, re-bagging site, suppliers' stores and sites where buildings were under construction throughout the six geopolitical zones in Nigeria. The survey revealed that the acceptability of a particular brand of cement is dictated by its availability and cost. The availability of a particular brand in a region is closely related to the proximity to the manufacturer or distributor and the cost of all local packaged cement brands is almost the same.

2.2. Sample collection

The survey revealed that 12 gray cements and 5 white cements used as tile adhesive are generally used in different parts of Nigeria. The color of each of the brands is given in Table 1. The cement brands and the places in Nigeria where they are mostly used are shown in Fig. 1. Six samples of each brand of the 17 brands totaling 102 samples were collected from major suppliers, factories, re-bagging site and building/road construction sites. The samples were collected into clean plastic containers, sealed, marked and transported to the laboratory.

2.3. Sample preparation and analysis

The samples of cements collected from construction site and major distributors and factories in locations across the country where they are mostly found were collected for radioactivity measurement. Each sample was air dried and pulverized into powdered form. 200 g of each powdered sample was put in a cylindrical polystyrene container and sealed with tapes to prevent radon permeability and left for more than four weeks in order to allow for radon and its short lived progeny to reach radioactive equilibrium. After this period, the radioactivity measurement was carried out for 7 h using a 7.6 cm × 7.6 cm NaI(Tl) detector with a resolution of 8% at 662 keV and housed in 10 cm thick lead shield to reduce background gamma radiation. The power supply and the data acquisition of the energy spectra were achieved by using an integrated spectroscopy system from Bicron. The system utilized SAMPO S100 software package from Canberra. The energy calibration of the detector was performed using IAEA standard point sources (^{109}Cd, ^{57}Co, ^{137}Cs, ^{54}Mn, and ^{22}Na) of gamma energy range between 83 keV and 1275 keV being the energy range of the radionuclide to be identified. To simulate the cement samples, 200 g of IAEA-375 reference soil was used. The radioactivity concentrations of ^{226}Ra were determined from the photopeaks of 609.32 keV (^{214}Bi), 1120.20 keV (^{214}Bi) and 352.6 keV (^{214}Pb) and that of ^{232}Th from 969.3 keV (^{228}Ac) and 583.78 keV (^{208}Tl) while the radioactivity of ^{40}K was determined from 1460.3 keV photopeak following the decay of ^{40}K as shown in Fig. 2. The background spectrum measured under the same conditions for both the standard and sample measurements, was used to correct the calculated sample activities concentration in accordance with Arogunjo et al. (2005), Kabir et al. (2009) and Zarie and Al Mugren (2010). The activity concentrations (C) in Bq kg^{-1} Bql^{-1} of the radionuclides in the samples were calculated after decay correction using the expression:

$$C_s = \frac{N_{Ey}}{\varepsilon_{Ey} \times M_s \times t_c \times P_\gamma} \left(\mathrm{Bqkg}^{-1}/\mathrm{Bql}^{-1}\right) \quad (1)$$

where C_s = Sample concentration, N_{Ey} = net peak area of a peak at energy, ε_{Ey} = Efficiency of the detector for a γ-energy of interest, M_s = Sample mass, t_c = total counting time, P_γ = Emission probability of radionuclide of interest.

2.4. Quality control and assurance

Energy calibration and efficiency calibration of the spectrometer system were performed every two months using the standard reference radionuclide sources and the reference soil. The samples of 10% were selected at random for replicate analysis (n = 3) and the relative standard deviations of results were found as <3.4%. It is therefore indicated that the detector system is relatively stable, and the results are reliable (Gang et al., 2012).