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Comparative Study on the Contribution of Asbestos and Gypsum Building Materials to Environmental Radioactivity and Its Radiological Implications

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Abstract

Building materials have been studied and found to contain trace amount of natural radionuclides. In order to estimate the radiological impact to the dweller, the level of radionuclides present in asbestos and gypsum building materials available in Nigeria market were carried out using a well shielded and calibrated gamma spectrometry. The results obtained shown that the natural radionuclides of ^{238}U, ^{232}Th, and ^{40}K are present in the building materials assayed, with activity concentration of 141.76 to 526.29 Bqkg^{-1}, 2.14 to 7.94 Bqkg^{-1} and 9.89 to 14.23 Bqkg^{-1} for the gypsum samples and 221.64 to 513.38 Bqkg^{-1}, 15.99 to 34.68 Bqkg^{-1} and 9.10 to 18.93 Bqkg^{-1} for the asbestos samples respectively. The average concentration obtained for samples are relatively lower than the worldwide average. The radiation hazard indices estimated are also lower than the international recommended values. Based on the results obtained, it can be concluded that the use of these materials in construction of dwellings may be considered safe for inhabitants and that the dwellers inside the buildings are not supposed to acquire any radiological complication in terms of radiation hazard.

Keywords: Asbestos; Gypsum Powder; Building materials; Radioactivity.

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1. Introduction

Throughout the history of life on Earth, humans are continuously expose to radiation with or without their consent, from radionuclides produced by cosmic ray interaction in the atmosphere and those from naturally occurring substances that are spatially distributed in the ecosystem. Materials derived from rock and soil contains natural radionuclides of the uranium (^{238}U), and thorium (^{232}Th) series and the radioactive isotope of potassium (^{40}K). Artificial radionuclides such as caesium (^{137}Cs) can also be present as a result of fallout from weapons testing [1]. Radiation exposure as a result of building materials has been divided into internal and external radiation exposure. This is because building materials have been found to contain various amounts of natural radioactive nuclides. The external exposure occurs through the emission of penetrating gamma rays. The internal exposure occurs through the inhalation of radon gas and their short-lived decay products. Radon and its progenies are constituents of the atmosphere, and their concentrations tend to be higher in confined buildings than in the open air. The air within a building contains radon which enters from outside, together with radon from the ground beneath and from the structure. As individuals spend more than 80% of their time indoors, the internal and external radiation exposure from building materials creates prolonged exposure situations [2]. Asbestos is a naturally occurring silicate with six varieties from two groups of minerals, namely the serpentine and amphiboles. It has notorious characteristics as a fibrous, solid, chemically non-reactive carcinogen. Because of its fibrous and crystalline characteristics, the product was successfully commercialized in the industrial age, and extensively used in the twentieth century. Historically, asbestos has been used in a diverse range of human activities, which include paintings, ceramic and pot making, lamp wicks, cigarette filters, gaskets, brake pads and other ancient artefacts with evidence suggestive of ancient Egyptian use as clothing to preserve the bodies of dead pharaohs [3-5]. Its high tensile strength, flexibility, resistance to chemical and thermal degradation, high electrical resistance, low electrical conductivity, and large surface area characteristics make it a cost-effective and commercially viable building material. Other several applications include, car break liners, gaskets, insulation and packing materials in industrial and maritime settings, such as refineries, chemical plants, naval ships, and energy plants [5-7]. However, the use of asbestos as a building material is illegal in many countries. As inhalation of asbestos fibres can lead to various serious lung conditions such as mesothelioma, asbestosis and cancer [8]. Authors in [9] further confirms the relationship between exposure to either forms of asbestos or their mixture and the increased risk of lung cancer and mesothelioma among workers and those living around asbestos factories and mines, as well as among individuals living with asbestos workers.Gypsum has been used as a building material for centuries and occurs naturally in sedimentary deposits from ancient sea beds. At present, most of the by-product of gypsum are employed in cement used in concrete for bridges, buildings, highways and many other structures such as plasterboard, partition systems and other building components that are part of human everyday life. The use of gypsum in plasterboard as interior design in modern buildings has been on the increase due to rapid structural and infrastructural development by government, individuals and private sectors at all levels. This is because the end product of the design beautifies the building. Furthermore, owing to the technological advancement, the use of gypsum plasterboard as interior decorations of buildings has outweighed the old way of interior design such as the use of bamboo tree, asbestos and others. Consequently, gypsum being derived from rocks contains various amounts of radioactivity. Reports have it that gypsum contains more natural radioactivity in form of radium than other building materials, but

offers significant technical and economic advantages. However, its use would increase the radiation doses to the public must especially, the interior designer working with gypsum powder and the retailer selling it. As these two end users are continuously exposed to radiation from these powders and the inhalation of the radiation may be hazardous to human health. Furthermore, the radiation dose to the occupants of a building where gypsum is used as part of the construction materials will depend on the amount of gypsum used, layout of the building, dimensions of components and structural elements, amount of time spent within the building and the positions of occupant [10-12].Reviewing the published reports available in literature, several studies have been conducted to assess the levels of exposure due to natural radiation as a result of different building materials products both locally and internationally [13-17]. However, there has been little or no comprehensive study undertaken on the contribution of gypsum and asbestos to environmental radioactivity in Nigeria. Thus, the study is aim at assessing and compare the radioactivity content of the gypsum and asbestos material available in Nigeria markets. This will help in determine the contribution of the radioactive element present in these materials used for interior decoration of building to the population exposure to radiation and to estimate the radiological impact to dwellers. Furthermore, knowledge of this study is useful in setting the yardstick and national guidelines for the use and management of these building material products.

2. Methodology

2.1 Sampling and Preparation

In order to have a good representative sampling of the asbestos and gypsum products, different local stores that prioritize sales of asbestos and gypsum building materials as major business were surveyed for sample materials. Nine (9) stores, each for the asbestos and gypsum were selected based on market value. In each of the selected store, nine (9) different gypsum powder products and asbestos used in building materials and readily available in Nigeria market were collected. In all, a total of eighteen (18) samples were collected for laboratory preparation. The gypsum powders obtained from the market were air dried at room temperature. The Asbestos samples were oven dried at 40°C for twenty-four hours in order to remove the moisture content. The dried samples were then pulverised into powder form and sieved through 2 mm mesh.The samples, 250 g each were packed inside a cylindrical polypropylene container that matches the geometry of the detector to be employed for gamma spectrometric analysis. The container had previously been washed, rinsed with distilled water and dried to avoid any contamination. Each packed sample was tightly sealed to avoid the possibility of gassing out of radon. The sealed containers were kept for a minimum period of four weeks which was sufficient time required to attain a state of secular radioactive equilibrium between radium isotopes and their respective daughters before their gamma spectrometry analysis.

2.2 Instrumentation and Measurement

The gamma spectrometry system employed consist of a 3 x 3 inch NaI(Tl) detector a product of Princeton Gamma Tech., USA. The detector is housed in a cylindrical lead shield to reduce the effect of background radiation. The detector was coupled to Gamma Spectacular (model GS-2000 Pro) multichannel analyser and further linked to a computer system. Data acquisition and analysis of gamma-ray spectra were achieved using

Theremino software. In order to derive a qualitative and quantitative relationship between the peak position in the spectrum and the corresponding gamma-ray energy, the spectrometry system was calibrated using the RSS8 gamma source set traceable to Spectrum Techniques LLC, USA and reference standard source consisting of known radionuclide activities. Prior to the sample measurement, an empty container was counted for 36000s so as to determine the background gamma-ray distribution count. The sealed samples after attaining a state of secular equilibrium were each placed on the detector for analysis one after the other. Each sample was then counted for the same period of time as that of the empty container. The characteristics of the radionuclides used to measure the activity concentrations of the sample are: 1460.0 keV (^{40}K), 1764.5 keV of ^{214}Bi (^{238}U), and 2614.7 keV of ^{208}Tl (^{232}Th). The samples activity concentrations A (Bqkg^{-1}) were determined using Equation (1):

$$A = \frac{C_{net}}{P_\gamma \times \varepsilon \times m \times t} \qquad (1)$$

where C_{net} is the net peak area, $P\gamma$ is the absolute gamma ray emission probability, ε is the full energy peak efficiency of the detector, t is the counting time, and m is sample mass. The mean activity concentration was then evaluated for each of the nine products assay.

2.3 Estimation of Radiological Parameters

The contribution of the primordial radionuclides identified in the samples to the absorbed dose rate due to external exposure (ADRA) was evaluated from the activity concentration of the radionuclides determined using Equation (2):

$$ADRA\ (\text{nGy}h^{-1}) = C_U A_U + C_{Th} A_{Th} + C_K A_K \qquad (2)$$

where C_U = 0.92, C_{Th} = 1.10, and C_K = 0.08 are the dose conversion factors and A_U, A_{Th} and A_K are the activity concentrations of ^{238}U, ^{232}Th and ^{40}K respectively [12,18].

The annual effective dose equivalent (AEDE) due to the radionuclides detected in the gypsum samples was estimated using Equation (3):

$$AEDE(\mu\text{Sv}y^{-1}) = ADRA \times I_f \times C_c \times T \qquad (3)$$

where ADRA is the absorbed dose rate due to external exposure, I_f is the indoor occupancy factor (0.8), C_c is the dose conversion coefficient (0.7 SvGy^{-1}) and T is the time of exposure for a year (8760 h) [20]. Radium equivalent activity (Ra_{eq}) is used to assess the different mixtures of environmental materials and hazards associated with radionuclide contained in the samples when used as part of building materials. The radium equivalent measured in Bqkg^{-1}was calculated using Equation (4), where A_U, A_{Th} and A_K are as already define.

$$Ra_{eq} = A_U + 1.43A_{Th} + 0.077A_K \qquad (4)$$

Activity concentration index (Iγ) is use to evaluate the gamma radiation hazard related to the radionuclide identified in the assay gypsum by-product. The activity concentration index takes into account typical ways and amounts in which the by-product gypsum material is used in a building and also for identifying whether a dose criterion is met. The Iγ was evaluated using Equation (5), as given by [18].

$$I_\gamma = \frac{A_U}{300} + \frac{A_{Th}}{200} + \frac{A_K}{3000} \leq 1 \qquad (5)$$

where A_U, A_{Th} and A_K are as already define for the activity concentrations of the radionuclide identified in the gypsum by-products.

The alpha index (I_α) was also estimated in this study. This parameter deals with the estimation of the excess alpha radiation due to radon inhalation originating from building materials. The alpha index was estimated using Equation (6):

$$I_\alpha = \frac{A_U}{200} \leq 1 \qquad (6)$$

where A_U is as already define. It was reported that, if the radium activity level in any building material exceed 200 Bqkg^{-1}, there is possibility that radon exhalation from the material could cause indoor radon concentrations Bqm^{-3} and otherwise, if the value is below 200 Bqkg^{-1}. The ICRP recommends an activity level of 200 Bqm^{-3} for radon in dwellings.

3. Results and Discussion

Tables 1 and 2 present the results obtained for the identified radionuclide and activity concentrations for each of the analysed gypsum and asbestos samples. The radionuclide detected are the singly occurring non series ^{40}K and decay series of ^{238}U, ^{232}Th, all of which belongs to the natural radionuclides. No artificial radionuclide was detected in all the assayed samples. The values obtained for the activity concentration in the gypsum samples range from 141.76 to 526.29 Bqkg^{-1} with an average value of 274.21 $\pm$ 5.34 Bqkg^{-1} for ^{40}K, 2.14 to 7.94 Bqkg^{-1} with an average value of 5.02 $\pm$ 0.23 Bqkg^{-1} for ^{238}U and 9.89 to 14.23 Bqkg^{-1} with an average value of 11.32 $\pm$ 0.49 Bqkg^{-1} for ^{232}Th. The values obtained for the activity concentration in the asbestos samples range from 221.64 to513.38 Bqkg^{-1} with an average value of 340.59 $\pm$ 4.21 Bqkg^{-1} for ^{40}K, 15.99 to 34.68 Bqkg^{-1}with an average value of 26.94 $\pm$ 0.56 Bqkg^{-1} for ^{238}U and 9.10 to 18.93 Bqkg^{-1} with an average value of 12.57 $\pm$ 0.53 Bqkg^{-1} for ^{232}Th. From the results obtained, it was observed that the activity concentration for the assayed samples varies for each of the product. More so, the mean activity concentration obtained for the asbestos samples is higher than that of gypsum samples as indicated in Figure 1. The variation may be attributed to the geological components which the gypsum and asbestos samples are made up. In all, the average values obtained for the identified radionuclides are lower than the recommended values. In addition, the results obtained are in agreement with literature reports on building materials [19]. The various radiological parameters estimated due to the activity concentrations of the identified radionuclides in the samples are presented in Tables 3 and 4. The estimated ADRA values range from 24.64 to 60.29 nGyh^{-1} with a mean value of 38.83 $\pm$ 1.18 nGyh^{-1} for gypsum while for the asbestos, the values range from 50.37 to 78.68 nGyh^{-1} with a mean value of 65.62 $\pm$ 1.38

$nGyh^{-1}$. The mean value obtained is lower than the 59 $nGyh^{-1}$ obtained by [1]. The estimated AEDE range from 0.12 to 0.30 $mSvy^{-1}$ with a mean value of 0.19 ± 0.01$mSvy^{-1}$ for the gypsum samples while the value range from 0.25 to 0.37 $mSvy^{-1}$ with a mean value of 0.32 ± 0.01 $mSvy^{-1}$. The mean AEDE value obtained is higher than the 70 μSvy^{-1} obtained by [20].

Table 1: Activity Concentrations ($Bqkg^{-1}$) for each assayed gypsum products

Sample Code	K-40	U-238	Th-232
GYP1	251.82 ± 5.20	6.94 ± 0.28	14.23 ± 0.56
GYP2	245.61 ± 5.13	5.80 ± 0.25	12.07 ± 0.51
GYP3	141.76 ± 3.90	2.47 ± 0.16	10.02 ± 0.47
GYP4	358.97 ± 6.20	4.75 ± 0.23	13.14 ± 0.54
GYP5	526.29 ± 7.51	7.94 ± 0.30	9.89 ± 0.46
GYP6	239.28 ± 5.06	3.46 ± 0.19	10.07 ± 0.47
GYP7	262.53 ± 5.30	6.31 ± 0.26	11.10 ± 0.49
GYP8	214.10 ± 4.79	5.39 ± 0.24	9.89 ± 0.46
GYP9	227.50 ± 4.94	2.14 ± 0.15	10.02 ± 0.47
RANGE	**141.76 – 526.29**	**2.14 – 7.94**	**9.89 – 14.23**
AVERAGE	**274.21 ± 5.34**	**5.02 ± 0.23**	**11.32± 0.49**

Table 2: Activity Concentrations ($Bqkg^{-1}$) for each asbestos products

Sample Code	K-40	U-238	Th-232
ASB1	298.06 ±3.48	26.35± 0.55	12.52± 0.56
ASB2	312.90± 4.03	34.68± 0.19	11.90± 0.27
ASB3	221.64± 2.77	23.92± 0.44	9.67± 0.67
ASB4	353.92± 5.02	15.99± 0.79	15.20± 0.50
ASB5	421.58± 6.51	26.49± 0.77	18.93± 0.64
ASB6	311.84±4.39	34.40± 0.25	11.67 ± 0.68
ASB7	513.38±4.42	25.53 ± 0.27	10.11± 0.52
ASB8	304.24±3.90	24.81± 0.86	9.10± 0.50
ASB9	327.78±3.38	33.48± 0.44	11.17± 0.50
RANGE	**221.64 – 513.38**	**15.99 – 34.68**	**9.10 – 18.93**
AVERAGE	**340.59±4.21**	**26.94± 0.51**	**12.57± 0.53**

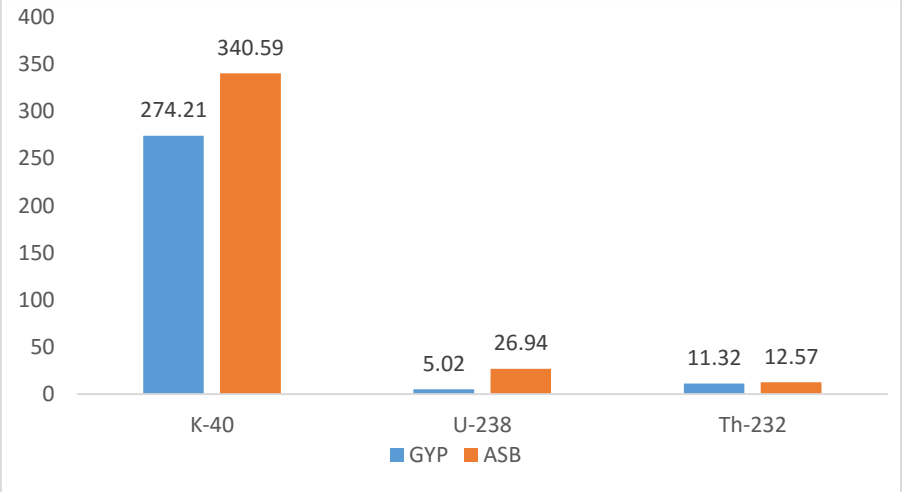

Figure 1: Comparison of the activity concentration ($Bqkg^{-1}$) obtained in the assayed gypsum and Asbestos samples.

Table 3: Estimated radiological parameters for each gypsum products

Sample Name	ADRA ($nGyh^{-1}$)	AEDE ($mSvy^{-1}$)	Ra_{eq}	I
GYP1	42.17 ± 1.28	0.21±0.01	46.67±1.47	0.15
GYP2	38.26± 1.21	0.19±0.01	41.97 ± 1.38	0.09
GYP3	24.64± 0.98	0.12±0.01	27.72 ± 1.13	0.19
GYP4	47.54± 1.29	0.23±0.01	51.18 ± 1.47	0.25
GYP5	60.29± 1.38	0.30± 0.01	62.61 ± 1.54	0.13
GYP6	33.40±1.10	0.16±0.01	36.28 ± 1.25	0.16
GYP7	39.01±1.21	0.19±0.01	42.39 ± 1.37	0.13
GYP8	32.97±1.12	0.16±0.01	36.02 ± 1.28	0.12
GYP9	31.19±1.05	0.15± 0.52	33.99 ± 1.20	0.09
RANGE	24.64 – 60.29	0.12 – 0.30	27.72 – 62.61	0.09 – 0.25
AVERAGE	**38.83± 1.18**	**0.19± 0.01**	**42.09 ± 1.34**	**0.15**

Table 4: Estimated radiological parameters for each asbestos products

Sample Name	ADRA ($nGyh^{-1}$)	AEDE ($mSvy^{-1}$)	Ra_{eq}	I
ASB1	61.86 ± 1.41	0.30±0.01	67.21±1.62	0.32
ASB2	70.03± 0.79	0.34±0.01	75.79 ± 0.89	0.23
ASB3	50.37±1.37	0.25±0.01	54.81± 1.61	0.25
ASB4	59.74 ± 1.68	0.29± 0.01	64.97± 1.47	0.34
ASB5	78.92± 1.94	0.39± 0.01	86.02±2.19	0.31
ASB6	69.42± 1.33	0.34±0.01	75.09± 1.56	0.33
ASB7	75.68±1.17	0.37±0.01	79.52± 1.35	0.26
ASB8	57.17 ±1.56	0.28±0.01	61.25± 1.75	0.31
ASB9	69.31± 1.22	0.34± 0.01	74.69 ± 1.41	0.18
RANGE	50.37 – 78.68	0.25 – 0.37	54.81 – 86.02	0.18 – 0.34
AVERAGE	**65.62± 1.38**	**0.32± 0.01**	**70.93± 1.59**	**0.28**

The values obtained for Ra_{eq} range from 27.72 $Bqkg^{-1}$ to 62.61 $Bqkg^{-1}$ with an average value of 42.09 $\pm$ 1.34 $Bqkg^{-1}$ for the gypsum samples, while for the asbestos, the value range from 54.81 $Bqkg^{-1}$ to 86.02 $Bqkg^{-1}$ with an average value of 70.93 $\pm$ 1.59 $Bqkg^{-1}$. The mean values obtained show that the radiation dose expected to be delivered both externally and internally to the occupants where these samples are used as part of building material does not exceed 370 $Bqkg^{-1}$ for Ra_{eq} as the recommended value. The result obtained for the gamma radiation hazard related to the radionuclide identified in the assay gypsum and asbestos is far less than 1 as the recommended by [18]. Since, an average value of 42.09 $\pm$ 1.34 $Bqkg^{-1}$ and 70.93 $\pm$ 1.59 $Bqkg^{-1}$ was obtained for the radium activity level in the gypsum and asbestos samples respectively. This is far less than the 200 $Bqkg^{-1}$ recommended by [2] for any building material. The possibility that radon exhalation from the material could cause indoor radon concentrations is therefore lower.

4. Conclusion

A well shielded and calibrated NaI(Tl) gamma spectrometry system have been employed in studying the radionuclide contents and activity concentration in different brands of asbestos and gypsum building materials. The results obtained indicated that the natural radionuclides of ^{238}U, ^{232}Th, and ^{40}K are present in the materials. The activity concentration obtained for each identified radionuclide in the asbestos is higher than that of the gypsum products. However, it was observed that the average concentration obtained for both samples are found to be lower than the worldwide average. The various radiation hazard indices estimated were found to fall below the recommended values. Based on the results obtained, it can be concluded that the use of these materials in construction of dwellings may be considered safe for inhabitants and that the dwellers inside the building are not supposed to acquire any radiological complication.

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