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Assessment of Equivalent Radium Activity and Annual Effective Dose Due to Building Materials in Côte D'Ivoire by Gamma Spectrometry: Cases of Cement

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Abstract

Radioactivity is a natural phenomenon present in the universe. So, because of human life solidarity with a habitat, we are permanently in contact, especially through building materials. The objective of this work is the determination of the used cement radioactivity level in the buildings in Côte d'Ivoire. Thus, samples of grey and white cement currently used on Ivorian territory were taken. In order to determine the radioactivity level of this cement, samples were analyzed by using gamma spectrometry chain which contains a NaI (Tl) scintillation detector designed by the German manufacturer LD-DIDACTIC, coupled to a multichannel analyzer (AMC) using a Cassy Lab software. Thus, the specific activity of the primordial radionuclides ^{226}Ra, ^{232}Th and ^{40}K, was able to be determined. The average values obtained are 29.66 Bq/kg, 34.88 Bq/kg and 178.424 Bq/kg respectively for ^{226}Ra, ^{232}Th and ^{40}K. All average values are below the limit values recommended by UNSCEAR. However, we evaluated the radiological parameters such as the equivalent radium activity and the annual effective dose in order to translate the specific activity in terms of harmfulness. Values obtained for these parameters are below those recommended by ICRP and UNSCEAR. These results show that the risk incurred by the use of these different brands of cement is low.

Keywords

Cement, Gamma Spectrometry, Equivalent Radiumactivity, Annual Effective Dose

1. Introduction

Building materials are objects to which we are accustomed and whose radiological impacts could be neglected. Yet these materials are made up of atoms like all existing materials in the universe. In addition, they can have different levels of radioactivity. Building materials cover a wide range of materials, especially from the processing of nature products. But radioactivity is a natural phenomenon that is defined as the spontaneous radiation emission by an atomic nucleus. Therefore, it is present in the raw material that allows the production of cement. However, the exposure to ionizing radiation from building materials is generally low to cause harm to men. But when this exposure exceeds the authorized annual dose this can have health disadvantages. In Côte d'Ivoire, radiological monitoring of materials used in construction is almost non-existent. This suggests a potential danger of exposure of populations to ionizing radiation emitted by elements contained in these materials. It is therefore important to analyze these materials because enormous quantities are used in the construction where we live and spend most of our time. The present work, therefore, highlights the radiological study carried out on cement used in Côte d'Ivoire using gamma spectrometry. Our work consists of two parts. The first part is material and method and the second is results and discussions.

2. Materials and Methods

2.1. Presentation of Samples

For this current work, we took cement samples from companies whose products are marketed in Côte d'Ivoire. These samples are:

- Sample of CEM II/B 32.5 R (CG1);
- Sample of CEM II/A-L 42.5 N (CB1);
- Sample of CPJ 35 R (CG2);
- Sample of CPJ 32.5 R (CG3);
- Sample of PCJ 32.5 R (CG4).

Samples taken were weighed and sealed during 30 days to reach the secular equilibrium between ^{226}Ra, ^{232}Th and their daughters.

2.2. Materials

A scintillation counter with a Thalium-doped NaI scintillation crystal (Diameter 38.1 mm and thickness 50.8 mm) [1] has been used. This detector designed by the German manufacturer LD Didactic has a resolution of 662 keV of about 7.5%. In order to constitute a measurement chain, the NaI crystal (Tl) was polarized by a high voltage generator (at 8.5 kV). At the output of the crystal, the analog signal is converted into a digital signal by the multichannel analyzer (AMC) to be transmitted to the Sensor-Cassy acquisition system. The collected information is carried out to the computer and appears as a spectrum. This equipment is located in the practical room of nuclear physics at the Felix Hou-

phouet Boigny University of Cocody.

2.3. Method

Analysis of the cement samples was performed using gamma spectrometry. However, its implementation requires two essential operations which are: the energy calibration and the determination of the detection efficiency.

Calibration is a tuning process that determines the energy range while eliminating measurement errors. It is, therefore, a prerequisite for any measure. This operation is intended to establish a relationship between the position of the peak in the spectrum and the corresponding γ line energy. For this work, a mixed source of americium (^{241}Am) and cesium (^{137}Cs) emitting respectively -peaks of energy at 59.54 keV and 661.66 keV have been used. Efficiency reflects the fact that all gamma photons emitted by sources are not detected. Then the detection efficiency noted ε is the efficiency of the detector used in the chain measurement. In this study, the efficiency curve was obtained using reference materials as sand containing a multi-photon radionuclide which is the ^{226}Ra [2] [3] of 5 kBq activity. After carrying out these operations, we determined the specific activity of the radionuclides like radium (^{226}Ra), thorium (^{232}Th) and potassium (^{40}K). ^{226}Ra was measured using the ^{214}Pb peak (351.93 keV) and the ^{214}Bi line (609.31 keV) [2]. For ^{232}Th quantification, we used the ^{212}Pb (238.63 keV) line and the ^{228}Ac (911.20 keV) line. For the ^{40}K, it was determined using its line emitted at 1460.83 keV. From these specific activities measured, we have been able to achieve the quantities that are the Equivalent Radium Activity and the Annual Effective Dose using the mathematical relationship below:

- The Equivalent Radium Activity noted Ra_{eq}

$$Ra_{eq} = A_{Ra} + 1.43 A_{Th} + 0.077 A_K \left(\text{Bq} \cdot \text{kg}^{-1} \right) \quad [4] \tag{1}$$

A_{Ra}, A_{Th} and A_K are the specific activities of ^{226}Ra, ^{232}Th and ^{40}K respectively.

- The Annual Effective Dose noted H_R (mSv·year^{-1}):

$$H_R = D \left(\text{nGy} \cdot \text{h}^{-1} \right) \times 8760 \left(h \right) \times 0.8 \times 0.7 \left(\text{Sv} \cdot \text{Gy}^{-1} \right) \times 10^{-3} \tag{2}$$

with $D \left(\text{nGy} \cdot \text{h}^{-1} \right) = 0.92 A_{Ra} + 1.1 A_{Th} + 0.08 A_K$;

D: is the absorbed dose rate given by UNSCEAR and EC;

8760 h: is the number of hours in a year;

0.8: is the weighting factor that implies that 80% of the time is spent inside a build in;

0.7: represents the conversion factor from an absorbed dose to an effective dose.

3. Results and Discussions

3.1. Specific Activity of ^{226}Ra, ^{232}Th and ^{40}K

In the present work the specific activity of ^{226}Ra, ^{232}Th and ^{40}K radionuclides

have been determined. This choice is mainly motivated by the fact that these three radionuclides are naturally present in the Earth's crust. Therefore, these radionuclides are also found in the cement whose basic constituents are clay and limestone. The concentrations of these radionuclides are shown in **Figure 1**.

The values of the specific activities presented in **Table 1** are below the limit values recommended by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) [4]. These limit values for building materials are 50 Bq·kg^{-1} for ^{226}Ra and ^{232}Th, and 500 Bq·kg^{-1} for ^{40}K. The specific activity values of ^{226}Ra range from 18.85 ± 1.68 Bq·kg^{-1} to 50.60 ± 2.26 Bq·kg^{-1} with an average of 29.66 Bq·kg^{-1}. The specific activities of other radioelements vary respectively from 22.94 ± 1.96 Bq·kg^{-1} to 41.82 ± 3.54 Bq·kg^{-1} for ^{232}Th with an average of 34.88 Bq·kg^{-1}, and from 111.10 ± 7.03 Bq·kg^{-1} to 309.74 ± 19.59 Bq·kg^{-1} for the ^{40}K with an average of 178.424 Bq·kg^{-1}. The specific activities of radionuclides are generally lower in CB1 white cement than grey cement samples (except for ^{40}K potassium where the minimum value corresponds to CG4 cement). This finding could be explained by the fact that white cement consists essentially of pure chalk and white clay (sedimentary rocks). While the grey cement contains pozzolana (volcanic rock). In fact, the natural radioactivity of soils and rocks is due to the presence of three long-lived natural radioelements: ^{238}U, ^{232}Th, ^{40}K and their daughters such as radium (^{226}Ra), which have a higher content in volcanic rocks (igneous rocks) than in sedimentary rocks.
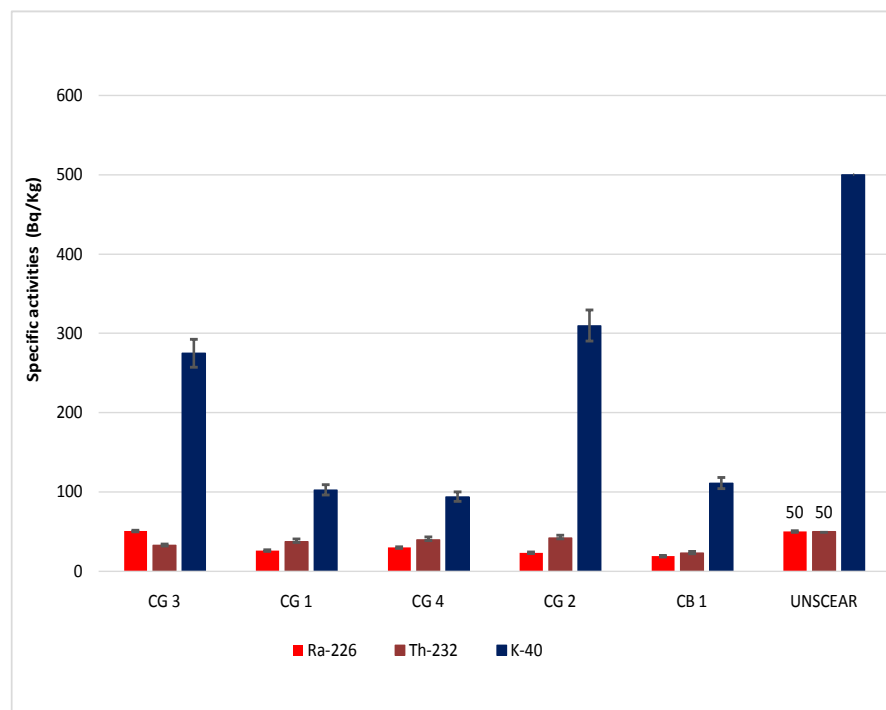

Figure 1. Comparison of specific activities of ^{226}Ra, ^{232}Th and ^{40}K in the samples.

Table 1. Comparison of specific activities of [226]Ra, [232]Th and [40]K in the samples.

	Type	A_{Ra} (Bq/kg)	A_{Th} (Bq/kg)	A_K (Bq/kg)
CG 4	Grey	29.72 ± 2.65	39.64 ± 3.54	94.00 ± 5.95
CG 3	Grey	50.60 ± 2.26	32.74 ± 1.46	274.73 ± 17.628
CG 2	Grey	23.19 ± 2.07	41.82 ± 3.54	309.74 ± 19.59
CB 1	White	18.85 ± 1.68	22.94 ± 1.96	111.10 ± 7.03
CG 1	Grey	25.96 ± 2.30	37.28 ± 3.33	102.55 ± 6.50
UNSCEAR	--	50	50	500

3.2. Equivalent Radium Activity Ra$_{eq}$

Equivalent radium activity was introduced to evaluate the radiation risks from [226]Ra, [232]Th and [40]K radionuclides in building materials. It is the most widely used index for radiological risk assessment and can be calculated using Equation 1 proposed by Beretka and Mathew [4]. It is a weighted sum of specific activities based on the assumption that 370 Bq·kg^{-1} of [226]Ra, 259 Bq·kg^{-1} of [232]Th and 4810 Bq·kg^{-1} of [40]K produce the same gamma radiation dose rate [4]. Any building material whose equivalent radium activity exceeds 370 Bq·kg^{-1} is not recommended and is considered as an unhealthy material [4]. The values of this factor are indicated and compared to the UNSCEAR [5] limit value of 370 Bq·kg^{-1} in Figure 2 and Table 2.

The equivalent radium activity ranges from 60.21 ± 5.02 Bq·kg^{-1} to 118.57 ± 5.70 Bq·kg^{-1} with 93.28 Bq·kg^{-1} average. These values are well below the value recommended by UNSCEAR (370 Bq·kg^{-1}). The values of equivalent radium activity were also compared to those obtained in other studies conducted in some countries as shown in Figure 3 and Table 3.

The average equivalent radium activity for grey cement samples (101.55, in this work) is lower than that obtained in Algeria, Australia and India. But this activity is higher than those obtained in Lebanon, Tunisia, Ghana and Nigeria. Regarding white cement, the equivalent radium activity is higher than that measured in Tunisia and lower than that of Cuba and Lebanon.

3.3. Annual Effective Dose H$_R$

The effective dose is a protection quantity expressed in millisievert (mSv). It allows taking into account for an individual the effect of ionizing radiation on the whole organism from equivalent doses weighted in all tissues and organs of the body. The annual effective dose noted H$_R$ (mSv·year^{-1}) is defined from this quantity. It is evaluated by equation 2 given by the European Commission (EC) and the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSEAR) [11]. For this quantity, the limit value recommended by the ICRP is 1 mSv·year^{-1} for the public.

Measurements on cement samples yielded annual effective dose values

ranging from 0.252 ± 0.021 mSv·year⁻¹ to 0.513 ± 0.021 mSv·year⁻¹ with 0.427 mSv/year average. We also note that grey cement values remain the lowest. **Table 4** and **Figure 4** illustrate these results.

These values are below the limit value set at 1 mSv/year by the ICRP (**Table 5** and **Figure 5**).

It is noted that the annual effective dose for grey cement samples (0.427 in this work) is higher than that obtained in Ghana, Tunisia and Egypt. But this dose is lower than that obtained in Turkey. For white cement, the annual effective dose is roughly equal to that measured in Tunisia and Ghana.
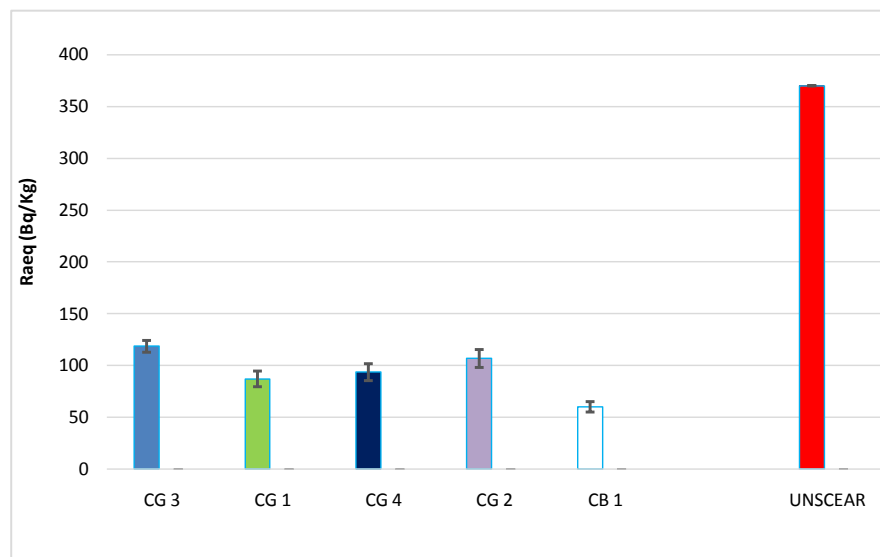

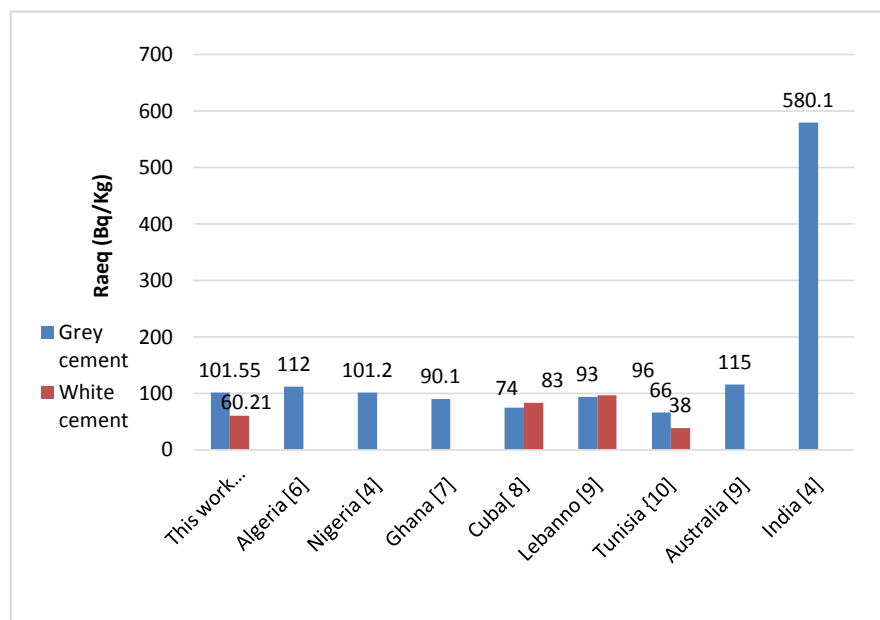**Figure 2.** Comparison of equivalent radium activity (Raeq).

Figure 3. Comparison of equivalent radium activity with other countries' studies.

Table 2. Comparison of equivalent radium activity.

Samples	Type	Ra$_{eq}$ (Bq/kg)
CG 4	Grey	93.64 ± 8.17
CG 3	Grey	118.57 ± 5.70
CG 2	Grey	106.84 ± 8.64
CB 1	White	60.21 ± 5.02
CG 1	Grey	87.16 ± 7.56
UNSCEAR		370

Table 3. Comparison of equivalent radium activity with other countries' studies.

Countries	Ra$_{eq}$ (Bq·kg^{-1})	References
Algeria	112	Amrani D. et Tahtat M. (2001) [6]
Nigeria	101.2	Olarinoye, I. Oyeleke (2013) [4]
Ghana	90.1	Kpeglo *et al.*, (2011) [7]
Cuba	74*; 83**	Brigido Flores O. et *col* (2008) [8]
Lebanon	93*; 96**	Kobeissi M. A. et *col* (2008) [9]
Tunisia	66*; 38**	FatenTurqui (2010) [10]
Australia	115	Kobeissi M. A. et *col* (2008) [9]
India	580.1	Olarinoye, I. Oyeleke *et al.* (2013) [4]
Cote d'Ivoire	87.16* - 118.57* (101.55)* 60.21**	This work

*Grey cement; **White cement; ( ) Average.

Table 4. Comparison of annual effective dose.

Samples	Type	H$_R$ (mSv/year)
CG 4	Grey	0.385 ± 0.033
CG 3	Grey	0.513 ± 0.021
CG 2	Grey	0.451 ± 0.036
CB1	White	0.252 ± 0.021
CG 1	Grey	0.358 ± 0.031
CIPR	--	1

Table 5. Comparison of H$_R$ values with other studies results.

Countries	H$_R$ (mSv·an^{-1})	References
Turkey	0.5*; 0.3**	Turhan S *et al.* (2008) [12]
Ghana	(0.21)*	Kpeglo *et al.*, (2011) [7]
Tunisia	(0.27)*; 0.16**	FatenTurqui (2010) [10]
Egypt	0.09	El Alfifi M.E. et *al.* [13]
Cote d'Ivoire	0.358* - 0.513* (0.427)* 0.252**	This work

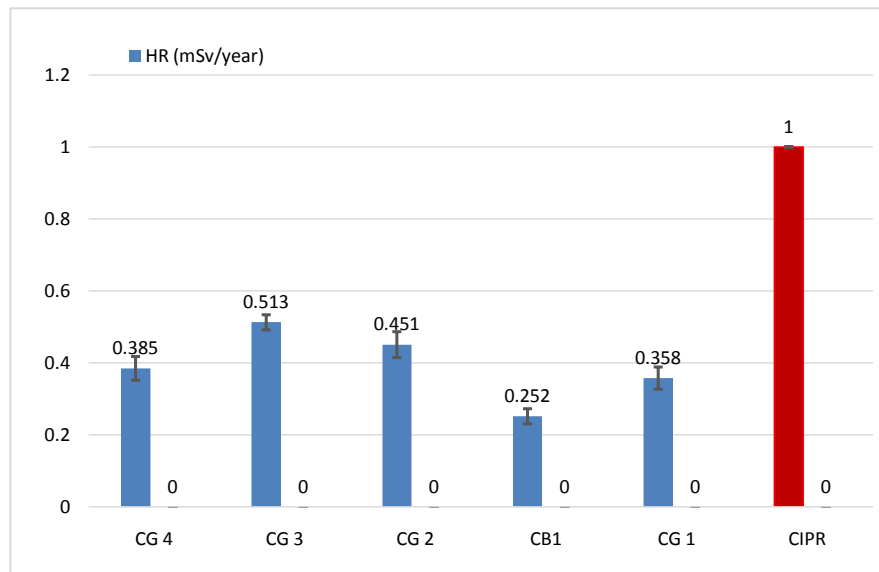*Grey cement; **White ciment; ( ) Average.

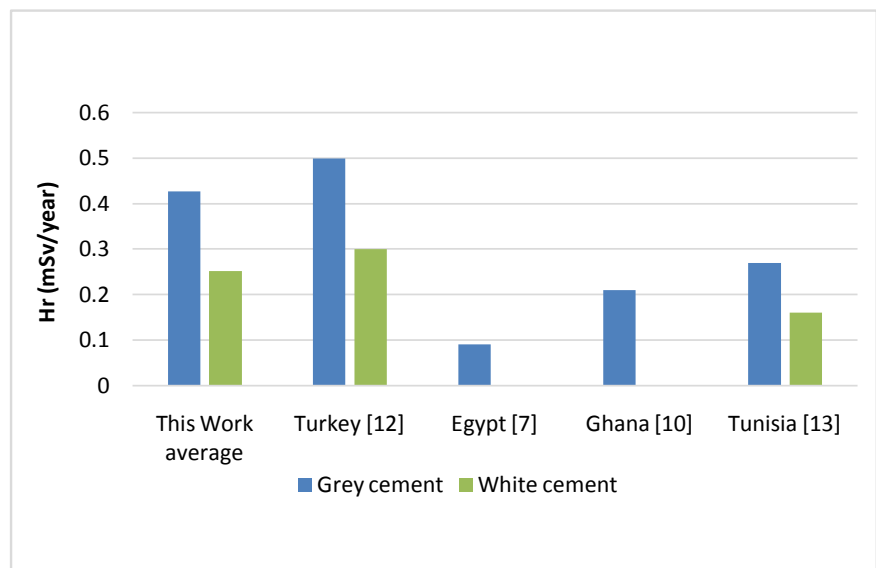**Figure 4.** Comparison of annual effective dose.

Figure 5. Comparison of H_R values with other studies results.

4. Conclusion

The present work is devoted to the determination of radioactivity levels of the building material that is cement. The study was carried out on the grey cement samples of various companies very present in the construction and the white cement of one company. The purpose is to evaluate the radioactivity of these samples. So samples were sealed in polyethylene packaging to prevent contamination during 30 days in order to reach secular equilibrium. Then they brought into contact with the German manufacturer LD-DIDACTIC scintillation counter for analysis. The analysis of the samples made it possible to determine the specific activities whose average values are 29.66 Bq·kg^{-1} for the ^{226}Ra; 34.88

Bq·kg^{-1} for the ^{232}Th; 178,424 Bq·kg^{-1} for the ^{40}K. These average values are all below the limit values recommended by UNSCEAR. From these specific activities, we carried out the radiological study by determining the quantities that are the equivalent radium activity Ra$_{eq}$ and the annual effective dose H$_R$. The average values for each of these parameters are well below the values recommended by UNSCEAR, the ICRP and below the averages measured in some countries. This means that the radiological risk (relative to the unit of mass) incurred by the populations is low. In addition, it appears generally that white cement is less radioactive than grey cement. However, it would be appropriate to increase the number of white cement samples. So that it will be representative and we can confirm or deny the finding report. In perspective we plan to increase the number of samples and extend this study to other building materials such as sand, gravel, plaster.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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