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Research Article

Assessment of Natural Radioactivity in Cements (Local and Imported) in Mali

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Abstract

Background: In this article, the radioactivity concentrations of U-238, Th-232 and K-40 (NORM) and radiological hazard parameters in different types of cements commonly used in Mali and available on the Malian market have been analyzed. The obtained values of NORM concentrations and radiological hazards in seven (07) cements samples will permit to the AMARAP to estimate the exposure (gamma rays) from the buildings and dwellings made by these cements. It will permit also to determine any over exposure (determinist effects which are an immediate tissue reaction due to the high exposition of ionizing radiation) and minimize as well the associated risk due to low doses (stochastic effects). *Materials and Methods*: The health impact due to the exposure of radionuclides from these cements was evaluated by the determination of specific activity of radionuclides U-238, Th-232 and K-40 using gamma spectrometry analysis. The radiological hazards such as Absorbed Dose Rate ($\dot{D}$) Annual Effective Dose ($\dot{E}$) Internal and External Dose indexes (H_{in} and H_{ex}) were evaluated in these cements samples. *Results*: The range of specific activities for U-238 vary from 21.77 ±1.50 to 145.31 ±7.70 Bq/kg, for Th-232 from 8.85 ±0.52 to 73.56 ±3.82 Bq/kg and for K-40 from 104.27 ±5.63 to 351.97 ±18.08 Bq/kg. The peak of U-238 wasn't detected only in one (01) sample (CIM04). The highest value of specific activity was reported in sample CIM07 (DANGOTE). The values of radiological hazard such as $\dot{D}$, $\dot{E}$, H_{in} and H_{ex} from this work were within the dose criteria limits given by international organizations (ICRP and UNSCEAR) and national standards. *Conclusion*: This study shows the analyzed cements do not pose any significant source of radiation hazard and are safe for use in the construction of dwellings even if the risk (stochastic effect) associated with low dose exists. Special attention and more analyzes must be done on them for more protection of public health.

Keywords

Buildings, Cement, Dwellings, Radiological Hazards, Specific Activity

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1. Introduction

All building raw materials and products derived from rock and soil contain various amounts of mainly natural radionuclides of the uranium (U-238) and thorium (Th-232) series, and the radioactive isotope of potassium (K-40), they are commonly called NORM (Naturally Occuring Radioactive Materials) [1]. Finding of levels for these radioactive elements in building equipment plays the prominent roles in the evaluation of public health indices, as most citizens kill 80% of their time indoors in either of living homes or working offices [2, 3]. Naturally occurring radiation sources in construction materials are means of external particle exposure sources in dwellings [4, 5]. Thus, Uranium, Thorium and their daughter products and 40K are important elements which played the predominant role to contribute a large part of energy dose received by people. The radiation is caused by gamma ray originating from NORM [6]. The internal radiation exposure, mainly affecting the respiratory tract, is due to the short-lived daughter products of radon which are exhaled from construction materials into room air [7]. Thus, the knowledge of radioactivity in building materials is important to estimate the radiological hazards on human health [8]. Building materials that contain high concentration of NORM in cements, have the potential to be carcinogenic when exposed to them. Therefore, monitoring of radioactive materials in cement is of primary importance from the view point of radiation protection in the environment [9].

This study has been initiated (general objective) in order to estimate the radioactivity level (NORM) in used cements by Malian population using gamma spectrometry technique. It will aim to assess radiological hazards on public health of exposure from external radiation (gamma rays) of buildings and dwellings made by these cements.

2. Materials and Methods

2.1. Sampling Process

Totally seven (07) brands of cements have been used in this study. Between them three (03) are manufactured in Mali (CMM, DIAMOND and CIMAF) and four (04) are imported (SAHEL, CIMASSO, SOCOCIM and DANGOTE). The samples have been directly collected in some hardware stores in Bamako city, see table 1 below for more details.

Table 1. *General informations.*

N°	Sample Code	Brand	Type	Point of collecte	Cordonnées GPS	
					Latitude	Longitude
1	CIM 01	Sahel	CEM II/B -M 32.5R	Quincaillerie Mamadou Sow (Banakabougou)	12.604972	7.946388
2	CIM 02	CIMASSO	Super CPJ 45	Quincaillerie Dembélé & Frères (Banakabougou)	12.605419	7.949907
4	CIM 03	CMM	CEM II/B -M 32.5R	Quincaillerie Mahamadou Coulibaly & Frères (Magnambougou)	12.608969	7.958727
5	CIM 04	Diamond	CPJ 35R	Quincaillerie Tériya (Magnambougou)	12.612972	7.957237
3	CIM 05	CIMAF	Super CPJ	Quincaillerie Zoulca-ADA (Banakabougou)	12.597626	7.936518
6	CIM 06	SOCOCIM	CEM II/B-M 32.5R	Quincaillerie Mahamadou Coulibaly & Frère	12.608969	7.958727
7	CIM 07	DANGOTE	CEM II/B-LL 35.5R	Quincaillerie Baby & Frères (Didiéni, cercle de Diema)	13.874852	8.083904

2.2. Sample Preparation

The samples were already collected in powder form, they have been prepared into geometries beakers type Marinelli (250ml). For each sample, the beaker has been filled, weighted using balance type (SARTORIUS TE2101) in order to calculated real mass of sample and sealed by adhesive tape. Samples have been stored for one (01) month for secular equilibrium time.

2.3. Specific Activity and Radiological Hazards

Specific activity

For gamma analysis, the specific activities of U-238 and Th-232 were assessed by averaging the peaks of different daughters for the U-238 and Th-232 series. The specific activity of K-40 was directly calculated in the spectrum. Specific activity $A_{s(E,i)}$ in Bq/kg, for a radionuclide *i* with a photopeak at energy E, was calculated by equation (1).

$$A_{s(E,i)} = \frac{N_{Ei}}{\varepsilon_E . t . \gamma_d . m} \quad (1)$$

Where $N_{E,i}$ is the net peak-area of *i* radionuclide at energy E, ε_E is efficiency at energy E, t is counting time (s), γ_d is the gamma emission probability, and m is the kilogram (kg)

Absorbed Dose Rate (Ḋ)

Ḋ is the symbol of absorbed dose rate, the unit is (nGy/h). It is due to the external exposure of gamma rays from NORM. Ḋ is calculated using equation 2 below.

$$\dot{D} = 0{,}462A_U + 0{,}604A_{Th} + 0{,}0417A_k \quad (2)$$

A_U, A_{Th} and A_K are specific activities in Bq/kg for U-238, Th-232 and K40. The values 0,462; 0,604 and 0,0417 are the conversion factors of radionuclides U-238, Th-232 and K-40 respectively [10].

Annual Effective Dose (Ė)

Ė is the symbol of annual effective dose, it is expressed in (mSv/year). According to the UNESCEAR 2008 report, a value of 0.7 (Sv/Gy) is the conversion factor (CF) from absorbed dose in air to effective dose received by adults. The values 0.8 and 0.2 are the values for Indoor occupancy factor (IOF) and outdoor occupancy factor (OOF) respectively. That means that 80% of the time is spent indoors and 20% is spent outdoors on average worldwide [10]. Ė is calculated using equation 3 below:

$$\dot{E}\ (\text{mSv. year}^{-1}) = D\gamma\ (\text{nGy/h}) \times 8760\ (\text{h/year}) \times CF \times IOF \text{ or } OOF \quad (3)$$

Internal and External Dose indexes

The external and internal living environment must qualify for healthy family. In order to keep the safety of the human health from the impact from radon and its progeny which may give rise to indoor radiation exposure [11].

H_{in} was calculated using equation 4 below.

$$H_{in} = \frac{A_U}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \leq 1 \quad (4)$$

H_{ex} was expressed using equation 5 below.

$$H_{ex} = \frac{A_U}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} < 1 \quad (5)$$

3. Results and Discussions

3.1. Results

Specific activity

Table 2 shows the specific activities of NORM into the seven (07) analyzed samples. The minimum detectable activity (MDA) for U-238, Th-232 and K-40 were 0,026; 0,027 and 0,021 Bq/kg, respectively.

Table 2. *Specific activity of NORM.*

Sample Code	Specific Activity (Bq/kg)								
	U-238			Th-232			K-40		
CIM01	119.09	±	6.39	67.72	±	3.63	184.05	±	9.62
CIM02	21.77	±	1.50	30.49	±	1.61	351.97	±	18.08
CIM03	87.77	±	4.46	27.20	±	1.40	173.86	±	8.87
CIM04	< 0,026			8.85	±	0.52	441.72	±	22.26
CIM05	26.00	±	1.90	20.13	±	1.08	279.04	±	14.41
CIM06	46.38	±	2.80	28.92	±	1.57	104.27	±	5, 63
CIM07	145.31	±	7.70	73.56	±	3.82	165.49	±	8.68
Mean Values	74.39	±	4.13	36.70	±	1.95	242.91	±	13.65
National Standard [12]	1000			1000			100000		

Comparison of our obtained specific activity with others works

The comparison was carried out using the mean values of NORM (U-238, Th-232 and K-340) in this work with others values of NORM in some countries. See table 3 for more details.

Table 3. *Comparison with others works around the world.*

Countries	Specific Activity (Bq/kg)			References
	U-238	Th-232	K-40	
China	119 ±14	36 ±18	444 ±163	[13]
Bangladesh	62 ±10	59 ±7	329 ±22	[14]
Turkey	34 ±4	15 ±2	220 ±13	[15]
Greece	111 ±17	19 ±3	244 ±30	[16]
Algeria	41 ±7	27 ±3	422 ±3	[17]
Egypt	36 ±4	43 ±2	82 ±4	[18]
Ghana	35 ±1	25 ±1	233 ±4	[19]
EUC	40	30	400	[20]
Mali	74 ±4	37 ±2	243 ±14	This study

EUC: European Union Commission

Radiological hazards

Absrobed dose rate, annual effective dose rate, internal and external dose indexes were expressed in table 4.

Table 4. *Absorbed and annual dose rates, internal and external dose indexes.*

Sample code	Specific Activity (Bq/Kg)			Hin	Hex	Ḋ (nGy/h)	Ė (mSv/y) Outdoor	Ė (mSv/y) Indoor
	U-238	Th-232	K-40					
CIM01	119,09	67,72	184,05	0,94	0,622	103,60	0,13	0,51
CIM02	21,77	30,49	351,97	0,31	0,25	43,15	0,05	0,21
CIM03	87,8	27,2	173,86	0,62	0,378	64,24	0,08	0,32
CIM04	< 0,026	8,85	441,72	0,13	0,126	23,77	0,03	0,12
CIM05	26	20,13	279,04	0,28	0,206	35,81	0,04	0,18
CIM06	46,38	28,92	104,27	0,38	0,259	43,24	0,05	0,21
CIM07	145,31	73,56	165,49	1,1	0,711	118,46	0,15	0,58
Valeur Moyenne	74,39	36,70	242,91			66,66	0,08	0,30

3.2. Discussions

The range of specific activities for U-238 vary from 21.77 ± 1.50 to 145.31 ±7.70 Bq/kg, for Th-232 from 8.85 ±0.52 to 73.56 ± 3.82 Bq/kg and for K-40 from 104.27 ± 5.63 to 351.97 ± 18.08 Bq/kg. None peak of U-238 wasn't detected only in sample (CIM04). More details are in table 1.

The lowest values of activity concentration for U-238 and Th-232 were reported in samples CIM02 and CIM04 where CIM04 (DIAMOND CEMENT) was the sample with less radioactive than others. The highest values of both U-238, Th-232 were reported in sample CIM07 (DANGOTE CEMENT). For K-40, the lowest and highest values were respectively for samples CIM06 (SOCOCIM CEMENT) and CIM02 (CIMASSO CEMENT).

The specific activities in this work are much lower than the Malian standard which are: 1,000 Bq/kg for U-238 and Th-232 and 100,000 Bq/kg for K-40.

The comparison with others works revealed the obtained results in this work are also closed to some results carried out around the world in cements, see table 3 for more details.

The absorbed dose rate ($\dot{D}$) of gamma external exposure from NORM was calculated using equation (2) and expressed in table 4. The range value of $\dot{D}$ varied from 23.77 to 118.46 (nGy/h) or almost 0.03 to 0.12 (µGy/h) respectively for CIM04 and CIM07. The obtained values of $\dot{D}$ (nGy/h) in this work (for gamma exposure) were less than the authorized limit for public leaving around facility using ionizing radiation (which is 0.5 µSv/h ≈ 1 mSv/y).

Annual effective dose rates ($\dot{E}$) were calculated using equation (3) and expressed in table 4 too. It was evaluated for internal and external exposure. The range values were 0.03 to 0.15 and 0.12 to 0.58 (mSv/y) respectively for external and internal exposure. External and internal values of $\dot{E}$ were also less than the authorized limit for public leaving around facility using ionizing radiation which is (1mSv/y ≈ 0.5µSv/h).

Both $\dot{D}$ (nGy/h) and $\dot{E}$ (mSv/y) were less than the world annual average doses and ranges of individual doses of ionizing radiation (which is 2.4 mSv/year) [10].

Internal and external dose indexes H_{in} and H_{ex} were calculated using equations (4) and (5), respectively presented in table 4. H_{in} and H_{ex} are the exposure due to internal and external radiation coming from radon isotopes and their short-lived decay products, which are particularly hazardous for the respiratory tract (primarily for the bronchi and lungs). In this work, the calculated values H_{ex} and H_{in} were respectively lower or at least equal to one (1) *excepted the* H_{in} *value of CIM07 which is slightly more than one (1.1).* That means the hazard of radiation originating from radon isotopes and its decay products remains insignificant and negligible.

4. Conclusion

The NORM were the analyzed radionuclides in this study. Therefore, the results of specific activity in cements samples were lower than the Malian standard [12] and approximatively closed to the results of some countries. The $\dot{D}$ and $\dot{E}$ were also under the authorized limit for the public and below than international limit for exposure of natural radionuclide [10]. Radiological hazards due to radon exposure were also insignificant based on the results of H_{in} and H_{ex}.

This study shows the analyzed cements do not pose any significant source of radiation hazards and they are safe for using in buildings and dwellings even if the risk (stochastic effect) associated with low dose exists.

Special attention and more analysis (investigations) must be done on them (especially on cement CIM07) for more protection of public health.

Abbreviations

AMARAP	Agence Malienne de Radioprotection
CF	Conversion Factor
DCST	Département Contrôle et Surveillance du Territoire
ICRP	International Commission on Radiological Protection
IOF	Indoor Occupancy Factor
ISA	Institut des Sciences Appliquées
NORM	Naturally Occurring Radioactive Materials
OOF	Outdoor Occupancy Factor
USTTB	Université des Sciences des Techniques et des Technologies de Bamako
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation.

Author Contributions

Adama Coulibaly: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing

Fatoumata Dite Niaber Nafogou: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Writing – original draft, Writing – review & editing

Binefou Kone: Conceptualization, Funding acquisition, Software, Supervision, Validation, Visualization

Aly Ag Mohamed Dicko: Conceptualization, Funding acquisition, Resources, Supervision, Validation, Visualization

Oumou Camara: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Methodology, Resources

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Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] A. Eštoková, L. Palaščáková, Study of Natural Radioactivity of Slovak Cements (2013).

[2] P. A. Kumara, P. Mahakumara, A. Jayalath, C. P. Jayalth, Estimating natural radiation exposure from building materials used in Sri Lanka, J. Radiat. Res. Appl. Sci. 11, 350–354 (2018).

[3] European Commission (EC), Radiological protection principles concerning the natural radioactivity of building materials. Directorate – general environment, nuclear safety and civil protection, Radiat. Protect. 112, 1–16 (1999).

[4] F. B. Masok, P. L. Masiteng, R. D. Mavunda et al., Measurement of radioactivity concentration in soil samples around phosphate rock storage facility in Richards Bay, South Africa, J. Radiat. Res. Appl. Sci. 11, 29–36 (2018).

[5] N. Damla, U. Cevik, A. I. Kobya et al. Radiation dose estimation and mass attenuation coefficients of cement samples used in Turkey, J. Hazardous Mater. 176, 644–649 (2010).

[6] T. Abate, Radioactivity and health risk assessments in cement samples commonly used as construction materials in the case of South Gondar Zone, Ethiopia, (June 2022).

[7] K. Khan, H. M. Khan, Natural gamma-emiting radionuclides in Pakistani Portland cement, Applied Radiation and Isotopes 54, 861-865 (2001).

[8] A. El-Taher, S. Makhluf, A. Nossair, A. S. Abdel Halim, Assessment of natural radioactivity levels and radiation hazards due to cement industry, Applied Radiation and Isotopes 68, 169-174, (2010).

[9] A. B. D Elghany, A. M. Abdel-Monem, M. A. El-Samad, Assessment of Natural radioactivity and Associated Radiiation Hazards in some Egyptian and Yemenian Cement Samples (2013).

[10] United Nations Scientific Committee on the Effects of Atomic Radiation. Sources and effects of ionizing radiation [Internet]. UNSCEAR; (2008).

[11] A. K. Ademola, O. P. Ademola et al., Assessment of natural radioactivity levels in cement samples commonly used for construction in Lagos and Ogun State, Nigeria, Nucl. Radiat. Phys. 102, 44416–44420 (2017).

[12] Décret N°2014-0931/P-RM, Fixant les Règles Relatives à la Protection contre les Rayonnements Ionisants à la Sûreté et la Sécurité des Sources de Rayonnements Ionisants. In English: [Fixing relatives rules to protection against ionizing radiation, safety and security of ionizing radiation sources in Mali] (31 décembre 2014).

[13] X. Lu, S. Chao, F. Yang, Determination of natural radioactivity and associated radiation hazard in building materials used in Weinan, China. Radiat Phy Chem. https://doi.org/10.1016/j.radphyschem.2014.02.021 (2014).

[14] M. I. Chowdhury, M. N. Alam, A. K. S. Ahmed, Concentration of radionuclides in building and ceramic materials of Bangladesh and evaluation of radiation hazard. J Radioanal Nucl Chem. https://doi.org/10.1007/BF02388016 (1998).

[15] O. Baykara, S. Karatepe, M. Dogru, Assessments of natural radioactivity and radiological hazards in construction materials used in Elazig, Turkey. Radiat Meas. https://doi.org/10.1016/j.radmeas.2010.08.010 (2011).

[16] H. Papaefthymiou, O. Gouseti, Natural radioactivity and associated radiation hazards in building materials used in Peloponnese, Greece. Radiat Meas. https://doi.org/10.1016/j.radmeas.2008.03.032 (2008).

[17] D. Amrani, M. Tahtat, Natural radioactivity in Algerian building materials. Appl Radiat Isot. https://doi.org/10.1016/S0969-8043(00)00304-3 (2001).

[18] M. Y. Shoeib, K. M. Thabayneh, Assessment of natural radiation exposure and radon exhalation rate in various samples of Egyptian building materials. J Radiat Res Appl Sci. https://doi.org/10.1016/j.jrras.2014.01.004 (2014).

[19] D. O. Kpeglo, H. Lawluvi, A. Faanu, A. R. Awudu, P. Deatanyah, S. G. Wotorchi, C. C. Arwui, G. Emi-Reynolds, E. O. Darko, Natural radioactivity and its associated radiological hazards in Ghanaian cement. J Environ Earth Sci 3(2): 160–166, (2011).

[20] Commission European Radiological protection principles concerning the natural radioactivity of building materials. Radiat Prot 112: 1–16, (1999).