

Assessment of Radionuclide Activity and Radiological Hazard Indices in Cement Used for Construction in Benue State, Nigeria

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Abstract- *This study assessed natural radionuclide activity and associated radiological hazards in selected cement types used for construction in Benue State, Nigeria. Four cement samples—Ordinary Portland Cement (OPCT), White Portland Cement (WPCT), Portland Pozzolana Cement (PPCT) and Rapid Portland Cement (RPCT)—were analysed by gamma-ray spectrometry using a NaI(Tl) detector. Activity concentrations of U-238, Th-232 and K-40 were determined and used to evaluate absorbed dose, activity concentration index, annual effective dose equivalent, external hazard index, internal hazard index and radium equivalent activity. U-238 ranged from 9.79 ± 2.61 to 29.65 ± 5.11 Bq/kg, Th-232 from 1.03 ± 0.06 to 5.07 ± 0.59 Bq/kg, and K-40 from 64.11 ± 42.48 to 230.32 ± 20.08 Bq/kg. All measured radionuclide concentrations were below the reference values adopted in the source study. Mean external and internal hazard indices were both 0.12, while mean radium equivalent activity was 155.24 Bq/kg, below the 370 Bq/kg criterion. The results indicate that the sampled cement types are within the radiological safety limits applied in this study under normal construction use.*

Index Terms- *Building materials, Cement, Gamma-ray spectrometry, Natural radioactivity, Radiological hazard*

I. INTRODUCTION

Natural radioactivity is an inherent component of the human environment and arises principally from terrestrial radionuclides, cosmic radiation and radionuclides incorporated into construction materials. Naturally occurring radioactive materials may contain members of the uranium and thorium decay series and potassium-40, and their concentrations vary with geology and raw-material origin [1], [2]. Because people spend substantial periods indoors, the radiological characteristics of

building materials are relevant to public exposure assessment.

Cement is a major construction binder produced from geologically derived raw materials including limestone, clay, silica, alumina and iron-bearing materials. These feedstocks can contain trace quantities of uranium, thorium and potassium, which may persist in finished cement [3]. Consequently, gamma-emitting radionuclides in cement can contribute to external exposure, while radium-bearing materials may also be relevant to internal exposure through radon progeny.

Studies in Nigeria and other countries have reported measurable natural radioactivity in cement, concrete, tiles, soils and other building materials, with substantial variation among material types and locations [4]–[8]. Radiological evaluation therefore commonly combines measured activity concentrations with indices such as absorbed dose rate, annual effective dose, radium equivalent activity, and external and internal hazard indices.

Despite the widespread use of cement in residential and public construction in Benue State, cement-specific baseline data for the state remain limited in the source study. This information gap restricts evidence-based assessment of the radiological safety of cement products available to builders and consumers.

This study therefore assesses U-238, Th-232 and K-40 activity concentrations in selected cement types used for construction in Benue State and evaluates associated radiological hazard indices. The measured

values are compared with the safety reference values adopted in the source project, thereby providing baseline information for building-material monitoring and radiation protection.

II. MATERIALS AND METHODS

A. Study Area

The study was conducted in Benue State, North Central Nigeria. Cement samples were obtained in Makurdi, the state capital, where major cement products used across the state are marketed.

B. Samples and Preparation

Four cement types were considered: Ordinary Portland Cement (OPCT), White Portland Cement (WPCT), Portland Pozzolana Cement (PPCT) and Rapid Portland Cement (RPCT). Samples were catalogued, dried, transferred into tight plastic containers suitable for the detector geometry, sealed and stored for 30 days to promote secular equilibrium between parent radionuclides and their progeny.

C. Gamma-Ray Spectrometric Measurement

Analysis was performed at the National Institute of Radiation Protection and Research, University of Ibadan, Nigeria. A thallium-activated sodium iodide [NaI(Tl)] detector connected to a computer-based data-acquisition system, Genie 2000 software and a multichannel analyser was used. Energy and efficiency calibration were performed before

measurement. Samples were counted for approximately 28,800–29,000 s, and background counts obtained with the same geometry were subtracted. Activity concentration was calculated from the net photopeak count rate, detector efficiency, sample mass, counting time and gamma-emission probability.

D. Radiological Hazard Assessment

The measured radionuclide activities were used to estimate the activity concentration index, absorbed dose rate, annual effective dose equivalent, radium equivalent activity (Raeq), external hazard index (Hex) and internal hazard index (Hin), following the equations and reference criteria adopted in the source study [9]–[12]. For interpretation, Hex and Hin values below unity and Raeq below 370 Bq/kg were treated as acceptable criteria.

III. RESULTS AND DISCUSSION

A. Activity Concentrations

Table I presents the activity concentrations of the three radionuclides. U-238 was lowest in OPCT (9.79 ± 2.61 Bq/kg) and highest in RPCT (29.65 ± 5.11 Bq/kg). Th-232 was lowest in WPCT (1.03 ± 0.06 Bq/kg) and highest in OPCT (5.07 ± 0.59 Bq/kg). K-40 showed the widest absolute range, from 64.11 ± 42.48 Bq/kg in WPCT to 230.32 ± 20.08 Bq/kg in OPCT.

TABLE I. ACTIVITY CONCENTRATIONS OF RADIONUCLIDES IN SELECTED CEMENT TYPES

Code	Cement type	K-40 (Bq/kg)	U-238 (Bq/kg)	Th-232 (Bq/kg)
OPCT	Ordinary Portland Cement	230.32 ± 20.08	9.79 ± 2.61	5.07 ± 0.59
WPCT	White Portland Cement	64.11 ± 42.48	23.55 ± 2.04	1.03 ± 0.06
PPCT	Portland Pozzolana Cement	83.03 ± 7.99	27.84 ± 6.57	1.26 ± 0.15
RPCT	Rapid Portland Cement	91.66 ± 2.72	29.65 ± 5.11	1.31 ± 0.02

All U-238 values were below 50 Bq/kg, all Th-232 values were below 30 Bq/kg, and all K-40 values were below 400 Bq/kg, which are the comparison values used in the source project. The low thorium concentrations are especially notable. The observed variation among cement types is consistent with the expectation that radionuclide content depends on geological raw materials and manufacturing inputs. Comparable studies have also reported substantial

differences among building materials and cement products [5]–[8].

B. Radiological Hazard Indices

TABLE II. RADIOLOGICAL HAZARD INDICES OF SELECTED CEMENT TYPES

Code	Absorbed dose	Activity index	AEDE	Hex	Hin	Raeq (Bq/kg)
OPCT	0.11	0.12	0.43	0.11	0.11	129.01
WPCT	0.12	0.21	1.00	0.10	0.10	212.22
PPCT	0.12	0.10	0.81	0.13	0.13	137.12
RPCT	0.12	0.13	0.94	0.14	0.14	142.61
Average	0.13	0.14	0.79	0.12	0.12	155.24

The average external and internal hazard indices were both 0.12, substantially below the unity criterion. Radium equivalent activity ranged from 129.01 Bq/kg in OPCT to 212.22 Bq/kg in WPCT, with a mean of 155.24 Bq/kg. Every sample was below the 370 Bq/kg criterion used for building materials [10], [11]. These indices support the interpretation from the activity-concentration results that the sampled cement types do not present a significant radiological hazard under the criteria applied.

The mean annual effective dose equivalent reported in the source results was 0.79 mSv/yr. Taken together with Hex, Hin and Raeq, the result indicates acceptable radiological performance for the sampled materials. However, the small sample set means the findings should be interpreted as a baseline assessment rather than a comprehensive characterization of every cement batch or brand sold in Benue State.

IV. CONCLUSION

This study evaluated natural radionuclide activity and radiological hazard indices in four cement types used for construction in Benue State, Nigeria. U-238, Th-232 and K-40 concentrations were all below the comparison values adopted in the source study. The average Hex and Hin were 0.12, while average Raeq was 155.24 Bq/kg, below the 370 Bq/kg criterion. On the basis of these measurements and indices, the sampled cement types are within the radiological safety limits applied in the study and are not expected to pose significant radiological risk under normal construction use. Periodic surveillance, broader market sampling and future assessment of radon exhalation from cement-based products are recommended.

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