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# Measurements of Natural Radioactivity from Building Materials in the Rabigh Markets Area, Kingdom of Saudi Arabia

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## Abstract

Investigation of natural radioactivity levels of natural and manufactured samples of building materials used in the Rabigh Area, Saudi Arabia, is carried out during the year 2023-2024. A total of 15 samples of natural and manufactured materials from different types of building materials have been collected and measured using gamma spectrometry equipment. Most of the samples from each group had naturally occurring $^{40}K$ and radionuclides from the $^{238}U$ and $^{232}Th$ decay series. This means that most of the activity levels, including $^{40}K$, are safe for construction. The activity concentrations have been determined for $^{232}Th$, radium $^{226}Ra$, $^{212}Pb$, and $^{214}Pb$, as well as $^{214}Bi$, $^{228}Ac$, and $^{208}Tl$, and $^{40}K$ in each sample. However, samples with higher $^{226}Ra$ levels, such as the Cement Arab Cement Company sample, approach the exemption threshold of 1000 Bq/kg, meaning they need further study for long-term exposure risks. The Interlock Sand sample from Tipah Al-Khair Cement Products Factory had a particularly high $^{212}Pb$ concentration (378 ± 4.70 BBQ/kg), which may be linked to the geochemical properties of its raw materials. The experimental setup proved to be reliable, showing good detection efficiency and resolution. Higher levels of $^{226}Ra$ in some samples were close to regulatory limits, highlighting the need to choose materials carefully to reduce radiation risks. These results help improve our understanding of radiation safety in construction materials, these results help improve our understanding of radiation safety in construction materials. By addressing these issues, this study supports Saudi Vision 2030 by promoting innovation, safety, and public health in construction.

## Keywords

Building Materials, Gamma-Ray Spectrometry, Natural Radioactivity

## 1. Introduction

An essential consideration in determining possible health hazards to residents and guaranteeing adherence to global radiation safety regulations is the existence of natural radioactivity in building materials. Commonly found in natural building materials including rocks, sand, and cement are naturally occurring radioactive elements, mostly radionuclides like uranium-238 ($^{238}U$), thorium-232 ($^{232}Th$), and potassium-40 ($^{40}K$) [1]. These radionuclides raise the risk of lung cancer and other radiation-related illnesses by contributing to radon gas emissions and external gamma radiation exposure. Thus, in order to guarantee both public safety and regulatory compliance, it is essential to monitor and assess the natural radioactivity levels in building materials. A number of international organizations have set limits on the amount of natural radioactivity that can be present in building materials, such as the International Atomic Energy Agency and the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). Radiation dangers and possible exposure risks are often assessed using parameters like the gamma index, absorbed dose rate, exterior and internal hazard indices, and radium equivalent activity. To ascertain if building materials are suitable for construction, thorough radiometric examinations might yield important information [2] [3].

Natural radiation is a normal part of the environment that emanates from two main sources: cosmic radiation, which originates in outer space and passes through the atmosphere, and the decay of radionuclides [1]. Investigate a possible hazard originating from natural radionuclides in building materials in a selected historical building being reconstructed for housing. Both outdoor and indoor risks were evaluated through the radiological indices and estimated doses, based on measured activities of natural radionuclides in stone and brick materials of the building. The average measured activity concentrations of radionuclides were 7.32 Bq/kg for $^{226}Ra$, 40.05 Bq/kg for $^{232}Th$, and 546.64 Bq/kg for $^{40}K$ radionuclides. The average total activity concentration in building materials (594.0 Bq/kg) exceeded the world average value [4]. Cosmic radiation, which comes from space and travels through the atmosphere, and radionuclide decay in rock and soil are the two main sources of natural radiation, which is a normal component of the environment. Cosmic radiation, exterior radiation from radionuclides in the Earth's crust, and internal radiation from radionuclides inhaled or consumed and stored in the body are all examples of radiation originating from natural sources. Location along with certain human activities determines the severity of these natural exposures. Radiation from the earth is dependent on the local geology, while cosmic radiation dosage rate is influenced by elevation above sea level [5].

Driven by economic growth and infrastructure expansion, Rabigh, a fast rising industrial and residential neighbourhood in the Kingdom of Saudi Arabia (KSA), has seen a significant amount of construction activity in recent years. The region's geological makeup, which includes mineral-rich deposits and sedimentary layers, raises questions about the possibility of natural radioactivity in building materials that are sourced locally. Evaluating the radiation hazard indices of building materials is crucial to protecting public health and guiding regulatory regulations in the area due to the climate and long-term indoor occupancy patterns. Building materials cause direct radiation exposure because of their radium, thorium and potassium content [5].

Numerous investigations have been carried out in different parts of Saudi Arabia to determine the levels of man-made and natural radionuclides in environmental samples, such as soil, water, and construction materials. These investigations have ensured adherence to international safety regulations and have yielded important information about the radiological risks. A study conducted near the Ras Tanura refinery in Saudi Arabia utilized gamma-ray spectrometry to measure the activity concentrations of naturally occurring radionuclides, including $^{238}U$, $^{226}Ra$, $^{232}Th$, $^{40}K$, and anthropogenic $^{137}Cs$ in soil samples. The reported mean activity concentrations were 39.0 ± 4.8 Bq/kg for $^{238}U$, 23.2 ± 1.4 Bq/kg for $^{226}Ra$, 7.73 ± 1.2 Bq/kg for $^{232}Th$, 278 ± 9.8 Bq/kg for $^{40}K$, and 1.42 ± 0.5 Bq/kg for $^{137}Cs$ [6]. The study further assessed potential radiological risks to the public and the environment by calculating various radiation hazard indices. The findings indicated that the mean values of radium equivalent activity ($Ra_{eq}$), gamma absorbed dose rate (D) in air, annual effective dose equivalent (E), and external radiation hazard indices were all below the safety limits established by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). Consequently, the study concluded that the levels of gamma radioactivity in the soil do not pose a significant radiological health risk to residents in the vicinity of the refinery, as the measured hazard indices were within the permissible limits recommended by UNSCEAR and the International Commission on Radiological Protection (ICRP) [7]. A study conducted in Poland analyzed 60 cement samples obtained from the most popular manufacturers in the local market, ensuring that samples were taken from the same 25 kg bag of cement to maintain consistency 777. Similarly, in Ankara, Türkiye, a comprehensive study examined 183 samples representing 20 different structural and covering building materials commonly used in residential and commercial construction. These samples were collected from construction sites and suppliers to assess natural radioactivity levels using gamma-ray spectrometry with two detectors 888 [8]. In Saudi Arabia, a study in the Qassim region investigated 35 samples of natural and manufactured building materials sourced from local markets and construction sites [9].

In this study, samples of commonly used building materials (bricks, cement, gypsum, ceramics, marble, limestone and granite. External exposure is caused by gamma radiation resulting from the decay of the radionuclides present in material; the internal exposure is caused by inhalation of the decay products of radionuclides present in materials. Knowledge of the radioactivity levels of the materials used in buildings. The measures will also help in the development of standards and guidelines for the use and management of these materials. Several natural materials and those derived from industrial wastes and by-products have been shown to have high levels of radioactivity in many countries [1]. Therefore, this study presents the natural radioactivity of building materials in Arabia Saudi. All buildings materials contain different quantities of natural radionuclides. Thus, humans are constantly exposed to ionizing radiation from these materials. This material is from the earth's crust. Doses of gamma radiation and radon gas concentration within buildings are assessed by measuring direct exposure or by mathematical calculations [4] [10].

The objective of this study is to assess the natural radioactivity levels in both natural and manufactured building materials commonly used in the Rabigh Area, Saudi Arabia. Specifically, the study will determine the concentrations of naturally occurring radionuclides $^{226}$Ra, $^{232}$Th, and $^{40}$K in a total of 60 cement samples sourced from local markets. Gamma-ray spectrometry, utilizing an advanced electronic detector system, will be employed for precise measurements, data analysis, and graphical representation of the findings. This study represents an initial effort to systematically evaluate and discuss the collected data, providing a foundational understanding of the radiological characteristics of building materials in the region.

## 2. Material and Methods

### 2.1. Location of Study

The study area locations are markets in the Rabigh area city, Saudi Arabia. In Rabigh mapping, which is in western Saudi Arabia at 22.790670˚N 39.018962˚E, gamma-ray spectroscopy was used to find out how much Ra, Th, and K were in 15 common building materials that were valuable in Berber markets. The natural radionuclides associated with radiological risks were evaluated through radium equivalent activity.

### 2.2. Sample Collection and Preparation

#### 2.2.1. Collection of Samples

Samples of building materials were collected randomly from different Rabigh markets, where each sample was classified by its origin market. This study concentrated only on 15 samples of building materials that were stored in Rabigh **Local**, including a store in King Abdullah Economic City and a specialized store in the area for a specific type of cement. We also collected two additional samples: one from marble and another from tiles used by Almasseef Alawwal for paints and ceramics. A water sample used in the Maree Salman Al Khabout Factory for Cement Products and Taiba Al-Khair Cement Products Factory was also collected and tabulated in **Table 1**, **Figure 1**.

Table 1. Describe the collected sample.

| | Sample | Name of store |
|---|---|---|
| **S1** | Aggregate 3\16 | Taiba Al-Khair Cement Products Factory |
| **S2** | Aggregate 3\8 | Taiba Al-Khair Cement Products Factory |
| **S3** | Burkini | Maree Salman Al Khabout Factory for Cement Products |
| **S4** | Burkini | Taiba Al-Khair Cement Products Factory |
| **S5** | Cement | Arab Cement Company |

Continued

| | | |
|---|---|---|
| **S6** | **Interlock** | **Taiba Al-Khair Cement Products Factory** |
| **S7** | Marble | Almasseef Alawwal for Paints and ceramics |
| **S8** | Sand | Maree Salman Al Khabout Factory for Cement Products |
| **S9** | Sand | Taiba Al-Khair Cement Products Factory |
| **S10** | Tiles | Almasseef Alawwal for Paints and ceramics |
| **S11** | Water | Maree Salman Al Khabout Factory for Cement Products |
| **S12** | White sand | Taiba Al-Khair Cement Products Factory |
| **S13** | White sand | Maree Salman Al Khabout Factory for Cement Products |
| **S14** | Water | Taiba Al-Khair Cement Products Factory |
| **S15** | Red dye | Taiba Al-Khair Cement Products Factory |

#### 2.2.2. Building Material Sample for Taiba Al-Khair Cement Products Factory

**Figure 1** shows the building material "Interlock Taiba Al-Khair Cement Products Factory, Burkini Taiba Al-Khair Cement Products Factory, Aggregate 3\16 Taiba Al-Khair Cement Products Factory, and Aggregate 3\8 Taiba Al-Khair Cement Products Factory".

**Figure 1.** Taiba Al-Khair Cement Products Factory: Building material sample.

#### 2.2.3. The Sample Preparation Method

The samples were stored for four weeks to achieve a static equilibrium between the radioactive materials and the production of radon gas, these samples were air-dried and subsequently pulverized into fine grains using a laboratory-crushing machine and sieved through a 200 mesh, to ensure consistency, the samples will be homogenized and carefully placed into airtight plastic containers **Figure 2**. Then the samples were placed in 250 ml polyethylene containers with weighed 50 grams **Figure 3**. Gamma-Ray Spectroscopy technique is employed to analyze a

**Figure 2.** Crushing of samples.

**Figure 3.** 250 ml polyethylene contains building material samples.

variety of building material models. This will provide valuable insights into the radiation levels emitted by different materials.

### 2.3. Gamma-Ray Spectroscopy

Gamma-ray Spectroscopy, of different energies were used to characterize the gamma-ray spectroscopy system with HPGe detector at the Environmental Radioactivity and Measurement Laboratory of Al Qassim University. Therefore, radioactivity measurements were performed by gamma ray Spectroscopy, employing a scintillation detector 3" × 3". Its hermitically sealed assembly which includes a high-resolution NaI (Tl) crystal, photomultiplier tube (**Figure 1**), an internal magnetic light shield, and the measured activity concentrations for these natural radionuclides were compared with the reported data for other countries. The data obtained are essential for the development of standards and guidelines concerning the use and management of building materials [11]. The background radioactivity was determined using an empty container with the same geometry as that used for the prepared samples; this was sealed and stored for 4 weeks before determining the background measurement. After performing a correction for the background spectra, the specific activity concentration of natural radioactivity in the samples (Bq/kg) was calculated based on the count spectra of each sample using the gamma-ray photon peaks [12].

#### 2.3.1. Energy Calibration

An essential step in accurately quantifying the radioactive content of the samples involved calibrating the system with a certified mixed radionuclide standard, featuring well-characterized energies and activities. The calibration process used multiple certified sources, including Co-60, Cs-137, and Am-241 source. These sources were chosen to cover low, mid, and high gamma-ray energy ranges. They were obtained from Spectrum Techniques and are encapsulated to ensure safety and consistent geometry during calibration. Figure 4 illustrates the energy calibration line, showing a clear relationship between channel numbers and corresponding gamma-ray energies. The radionuclides and their corresponding detected energies are listed in Table 2.

Table 2. The radionuclides identified from the spectrum techniques calibration sources.

| Radionuclide | $T_1/_2$ (Half-Life) years | Energy (keV) | Channel Number |
|---|---|---|---|
| Am-241 | 432.2 | 59.54 | 5.1 |
| Cs-137 | 30.17 | 661.7 | 63.4 |
| Co-60 | 5.27 | 1173.2 | 107.5 |
| Co-60 | 5.27 | 1332.5 | 123 |

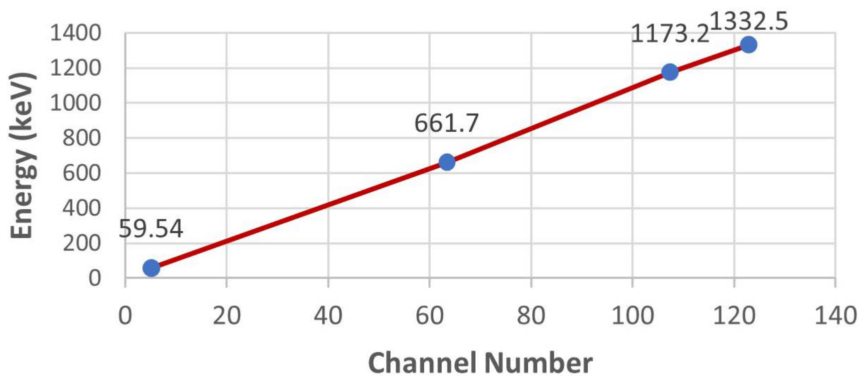



Figure 4. The energy calibration line for the NaI(Tl) detector, illustrating the linear relationship between channel numbers and corresponding gamma-ray energies.

### 2.3.2. Energy Resolution

One of the key parameters defining the performance of radiation detectors is energy resolution. This parameter reflects the detector's ability to precisely determine the energy deposited within it. Energy resolution is typically characterized and quantified by the Full Width at Half Maximum (FWHM) of a Gaussian spectral peak as a function of energy. In this work, the energy resolution of the detector was determined by measuring the FWHM of Gaussian-fitted photo peaks at $\gamma$-ray energies of 59.5 keV, 661.7 keV, 1173, and 1332 keV using Am-241, Cs-137, and Co-60 radioactive sources in Table 3 & Figure 5.

Table 3. Energy resolution of the NaI(Tl) detector.

| Radionuclide | Detected Energy (keV) | FWHM (keV) | Resolution (%) |
|---|---|---|---|
| **Am-241** | **59.5** | **6.8** | **11.51** |
| **CS-137** | **661.7** | **65.19** | **9.50** |
| **Co-60** | **1173.2** | **97.79** | **8.34** |
| **Co-60** | **1332.5** | **95.39** | **7.15** |

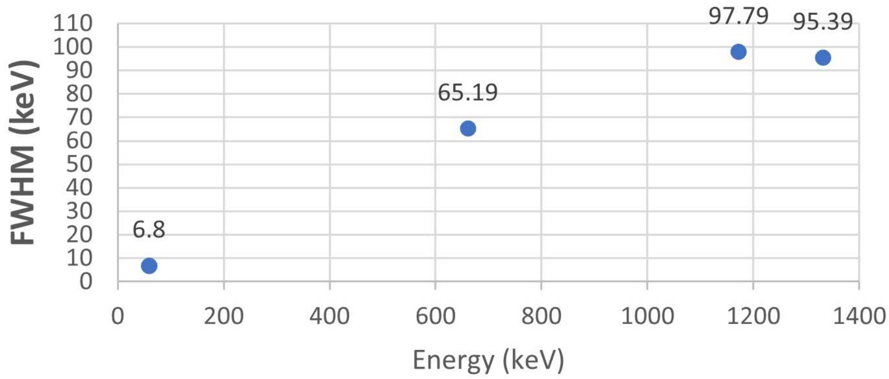



**Figure 5.** Energy resolution (FWHM) for the NaI(Tl) detector measured at $\gamma$-ray.

#### 2.3.3. Background Spectrum

Before collecting the spectrum of the sample, background spectrum must be recorded. This step is crucial to accurately measure the sample's activity by eliminating interference from background radiation. Several factors contribute to background radiation

- Natural environmental radioactivity from decay series and 40 K.
- Radioactive impurities present in the shielding material and detector.
- Cosmic radiation.
- Electronic noise and microphonic effects.

### 2.4. The Measurement of Activity Concentrations

#### 2.4.1 Radium Equivalent Activity $Ra_{eq}$

$$A_{eq} = A_{Ra} + \frac{10}{7} A_{Th} + \frac{10}{130} A_K \tag{1}$$

Where, $A_{Ra}$, $A_{Th}$, and $A_K$ stand for the activity concentrations (Bq/kg) of 226Ra, 232Th, and 40K, respectively. The maximum value of $Ra_{eq}$ must be less than the globally permissible limit 370 Bq/kg in order for the radiation danger from construction materials to be considered minor.

#### 2.4.2. Activity Concentrations Index I

Where the building material activity concentrations index $I$, I given by equation below

$$I = \frac{A1_{Th}}{200} + \frac{C_{Ra}}{300} + \frac{C_k}{3000} \tag{2}$$

#### 2.4.3. External Hazard Index (Hex)

External hazard index for samples under study is given by the following equation

$$Hex = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_k}{4810} \tag{3}$$

#### 2.4.4. Internal Hazard Index (Hin)

In addition to external hazard, Radon and its progenies are internally hazardous to the respiratory organs. The internal exposure to radon and its daughter products is quantified by "the internal hazard index", which is defined as:

$$Hin = \frac{A_{Ra}}{85} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \tag{4}$$

If the maximum concentration of $^{226}$Ra is half that of the normal acceptable limit, then $Hin$ will be less than unity for the safe use of a material in the construction of dwellings. The internal hazard is much more pertinent to the dwellers.

Gamma-radiation hazard index can be used to estimate the level of $\gamma$-radiation hazard associated with the natural radionuclides in specific materials which is defined as

**Gamma-radiation hazard index**

$$I_{\gamma r} = \frac{A_{Ra}}{150} + \frac{A_{Th}}{100} + \frac{A_k}{1500} \tag{5}$$

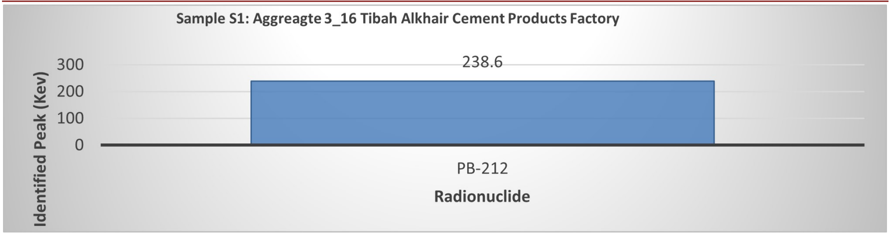
## 3. Results

The detail results are presented on the following tables from Sample $S_1$ to Sample $S_{15}$ for all samples detected the Identified Peak (Kev) corroding to Radionuclide with the Decay Chain.

Plotting between Identified Peak (Kev) vs Radionuclide below to show the Identified Peak (Kev) for all sample and the Radionuclide as shown from Sample $S_1$ to Sample $S_{15}$ below.

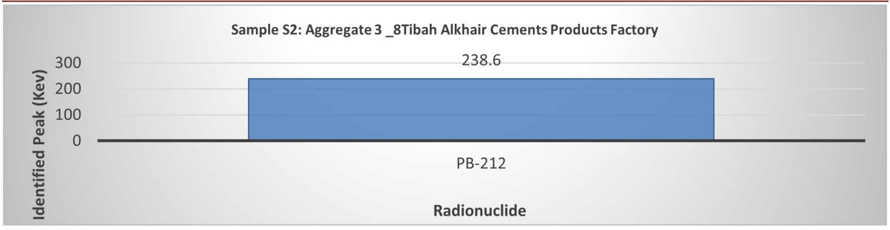
Sample $S_1$. Aggreagte 3_16 Tibah Al-Khair Cement Products Factory.

| Identified Peak (Kev) | Radionuclide | Decay Chain |
|---|---|---|
| 238.60 | Pb-212 | Thorium-232 Decay |



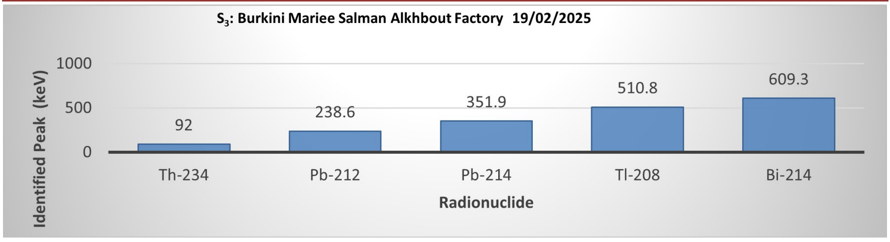

Sample $S_2$. Aggregate 3_8 Tibah Al-Khair Cements Products Factory.

| Identified Peak (Kev) | Radionuclide | Decay Chain |
|---|---|---|
| 238.60 | Pb-212 | Thorium-232 Decay |



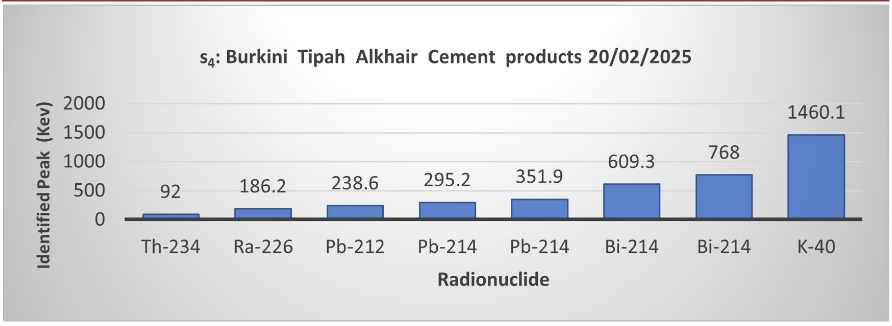
**Sample $S_3$.** Burkini Mariee Salman Alkhbout factory.

| Identified Peak (Kev) | Radionuclide | Decay Chain or Origin |
|---|---|---|
| 92.00 | Th-234 | Uranium-238 Decay |
| 238.60 | Pb-212 | Thorium-232 Decay |
| 351.90 | Pb-214 | Uranium-238 Decay |
| 510.80 | Tl-208 | Thorium-232 Decay |
| 609.30 | Bi-214 | Uranium-238 Decay |




**Sample $S_4$.** Burkini Tipah Al-Khair cement products.

| Identified Peak (Kev) | Radionuclide | Decay Chain |
|---|---|---|
| 92.00 | Th-234 | Uranium-238 Decay |
| 186.20 | Ra-226 | Uranium-238 Decay |
| 238.60 | Pb-212 | Thorium-232 Decay |
| 295.20 | Pb-214 | Uranium-238 Decay |
| 351.90 | Pb-214 | Uranium-238 Decay |
| 609.30 | Bi-214 | Uranium-238 Decay |
| 768.00 | Bi-214 | Uranium-238 Decay |
| 1460.10 | K-40 | Naturally Occurring |

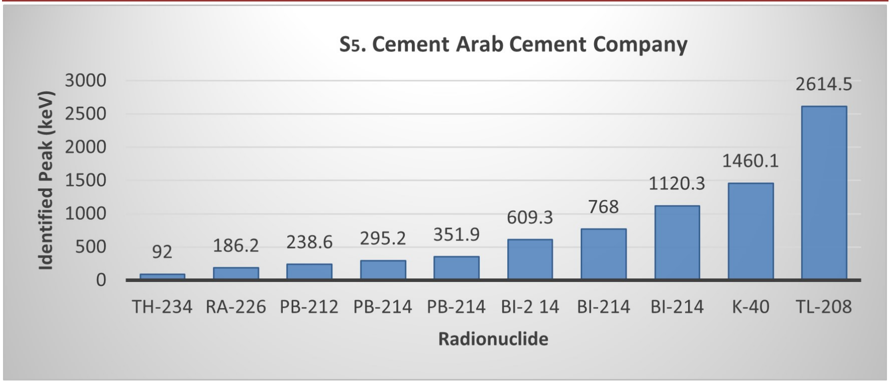



**Sample $S_5$.** Cement Arab Cement Company.

| Identified Peak (Kev) | Radionuclide | Decay Chain |
|---|---|---|
| 92.00 | Th-234 | Uranium-238 Decay |
| 186.20 | Ra-226 | Uranium-238 Decay |
| 238.60 | Pb-212 | Thorium-232 Decay |
| 295.20 | Pb-214 | Uranium-238 Decay |
| 351.90 | Pb-214 | Uranium-238 Decay |

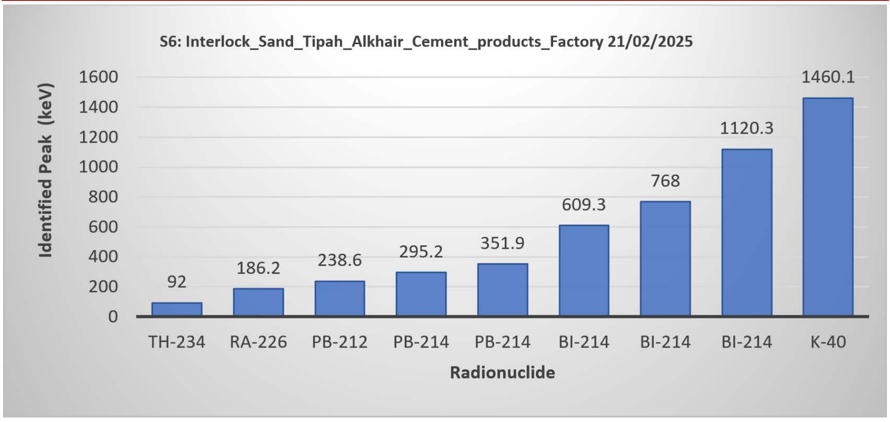
**Continued**

| | | |
|---|---|---|
| 609.30 | Bi-2 14 | Uranium-238 Decay |
| 768.00 | Bi-214 | Uranium-238 Decay |
| 1120.30 | Bi-214 | Uranium-238 Decay |
| 1460.10 | K-40 | Naturally Occurring |
| 2614.50 | Ti-208 | Thorium-232 Decay |




**Sample S6.** Interlock sand Tipah Al-Khair Cement Products Factory.

| Identified Peak (Kev) | Radionuclide | Decay Chain |
|---|---|---|
| 92.00 | Th-234 | Uranium-238 Decay |
| 186.20 | Ra-226 | Uranium-238 Decay |
| 238.60 | Pb-212 | Thorium-232 Decay |
| 295.20 | Pb-214 | Uranium-238 Decay |
| 351.90 | Pb-214 | Uranium-238 Decay |
| 609.30 | Bi-214 | Uranium-238 Decay |
| 768.00 | Bi-214 | Uranium-238 Decay |
| 1120.30 | Bi-214 | Uranium-238 Decay |
| 1460.10 | K-40 | Naturally Occurring |

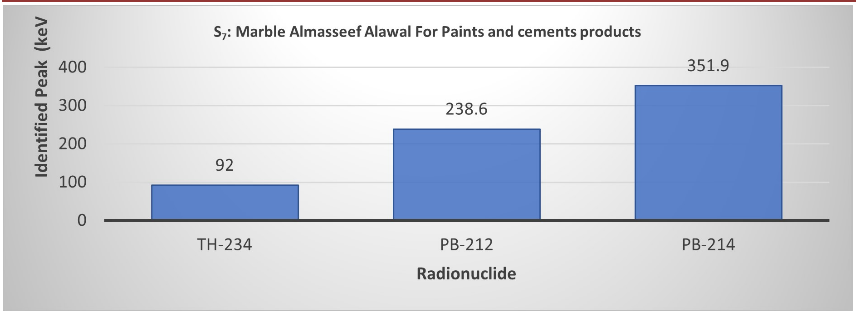



**Sample S7.** Marble Almasseef Alawal for paints and cements products.

| Identified Peak (Kev) | Radionuclide | Decay Chain or Origin |
|---|---|---|
| 92.00 | Th-234 | Uranium-238 Decay |

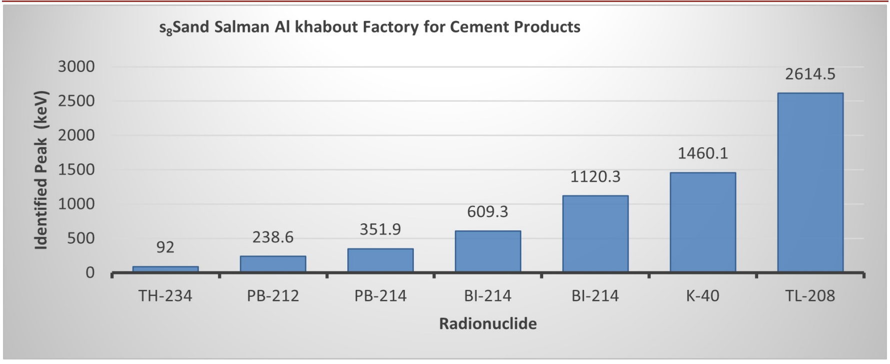
**Continued**

| | | |
|---|---|---|
| 238.60 | Pb-212 | Thorium-232 Decay |
| 351.90 | Pb-214 | Uranium-238 Decay |



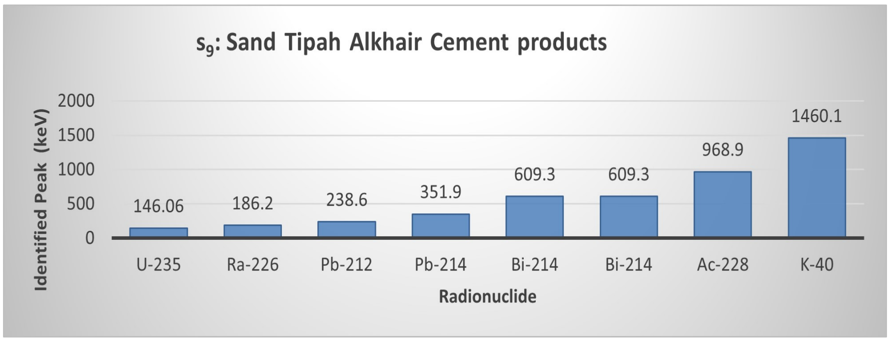

Sample $S_8$. Sand Salman Al Khabout Factory for cement products.

| Identified Peak (Kev) | Radionuclide | Decay Chain |
|---|---|---|
| 92.00 | Th-234 | Uranium-238 Decay |
| 238.60 | Pb-212 | Thorium-232 Decay |
| 351.90 | Pb-214 | Uranium-238 Decay |
| 609.30 | Bi-214 | Uranium-238 Decay |
| 1120.30 | Bi-214 | Uranium-238 Decay |
| 1460.10 | K-40 | Naturally Occurring |
| 2614.50 | Tl-208 | Thorium-232 Decay |



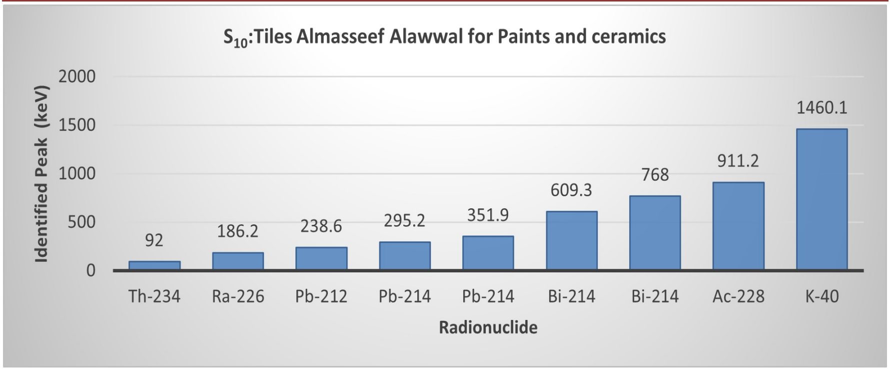

Sample $S_9$. Sand Tipah Al-Khair cement products.

| Identified Peak (Kev) | Radionuclide | Decay Chain or Origin |
|---|---|---|
| 146.06 | U-235 | Uranium-235 Decay |
| 186.20 | Ra-226 | Uranium-238 Decay |
| 238.60 | Pb-212 | Thorium-232 Decay |
| 295.20 | Pb-214 | Uranium-238 Decay |
| 351.90 | Pb-214 | Uranium-238 Decay |
| 609.30 | Bi-214 | Uranium-238 Decay |
| 968.90 | Ac-228 | Thorium-232 Decay |
| 1460.10 | K-40 | Naturally Occurring |



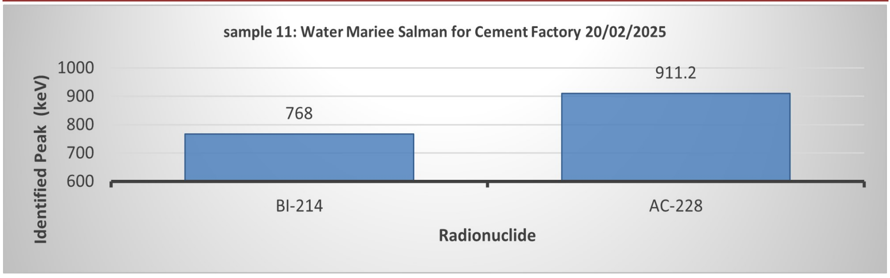

**Sample $S_{10}$.** Tiles Almasseef Alawwal for paints and ceramics.

| Identified Peak (Kev) | Radionuclide | Decay Chain |
|---|---|---|
| 92.00 | Th-234 | Uranium-238 Decay |
| 186.20 | Ra-226 | Uranium-238 Decay |
| 238.60 | Pb-212 | Thorium-232 Decay |
| 295.20 | Pb-214 | Uranium-238 Decay |
| 351.90 | Pb-214 | Uranium-238 Decay |
| 609.30 | Bi-214 | Uranium-238 Decay |
| 768.00 | Bi-214 | Uranium-238 Decay |
| 911.20 | Ac-228 | Thorium-232 Decay |
| 1460.10 | K-40 | Naturally Occurring |



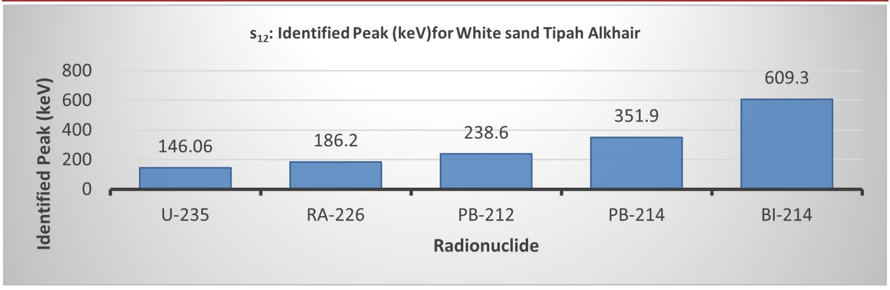

**Sample $S_{11}$.** Water Mariee Salman for Cement Factory.

| Identified Peak (Kev) | Radionuclide | Decay Chain |
|---|---|---|
| 768.00 | Bi-214 | Uranium-238 Decay |
| 911.20 | Ac-228 | Thorium-232 Decay |



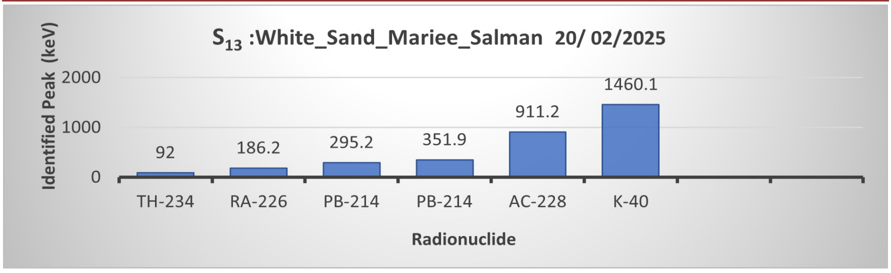
**Sample $S_{12}$.** White Sand Tipah Al-Khair.

| Identified Peak (Kev) | Radionuclide | Decay Chain |
|---|---|---|
| 146.06 | U-235 | Uranium-235 Decay |
| 186.20 | Ra-226 | Uranium-238 Decay |
| 238.60 | Pb-212 | Thorium-232 Decay |
| 351.90 | Pb-214 | Uranium-238 Decay |
| 609.30 | Bi-214 | Uranium-238 Decay |



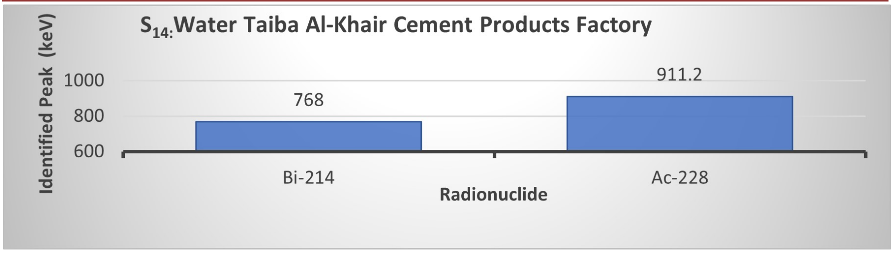

**Sample $S_{13}$.** White Sand Mariee Salman.

| Identified Peak (Kev) | Radionuclide | Decay Chain |
|---|---|---|
| 92.00 | Th-234 | Uranium-238 Decay |
| 186.20 | Ra-226 | Uranium-238 Decay |
| 295.20 | Pb-214 | Uranium-238 Decay |
| 351.90 | Pb-214 | Uranium-238 Decay |
| 911.20 | Ac-228 | Thorium-232 Decay |
| 1460.10 | K-40 | Naturally Occurring |




**Sample $S_{14}$.** Water Taiba Al-Khair Cement Products Factory.

| Identified Peak (Kev) | Radionuclide | Decay Chain |
|---|---|---|
| 768.00 | Bi-214 | Uranium-238 Decay |
| 911.20 | Ac-228 | Thorium-232 Decay |



**Sample $S_{15}$.** Red dye (Almost no peaks were detected).

| Identified Peak (Kev) | Radionuclide | Decay Chain |
|---|---|---|
| - | - | - |

## 4. Natural Radioactivity Levels in Building Material Samples

This section shows the results of material building samples collected from locations markets in Rabigh Area city, Saudi Arabia. The samples analyzed include aggregate, sand, marble, cement, tiles, and water. The activity concentrations of naturally occurring radionuclides like 40 K, 214 Bi, and 208 Tl, along with radionuclides from decay series such as 226 Ra and 232 Th, were measured. These radionuclides are commonly found in geological materials and are often used to assess radiation levels. The natural radionuclide concentrations in the samples likely reflect the geological composition and industrial processes related to these locations.

The measurements showed that the activity levels of radionuclides varied across the samples. The results, shown in **Table 4**, indicate that the activity concentrations of 40 K ranged from 5.08 ± 0.09 Bq/kg in the water sample to 485 ± 3.66 Bq/kg in the Aggregate 3 - 8 Tibah Al-Khair Cement Products Factory sample. Similarly, higher levels of 226 Ra (up to 366 ± 3.32 Bq/kg) were found in the Cement Arab Cement Company sample. These differences are due to the varying geochemical compositions of the raw materials and their geological origins.

According to previous studies, natural building materials often contain radionuclides like 40 K, 238 U (represented by 214 Bi), and 232 Th (represented by 208 Tl). The activity levels of these radionuclides are important to measure because they contribute to gamma radiation exposure from construction materials. Most of the measured values in this study fall within the natural background range defined by international safety standards, although a few samples require further investigation.

According to previous studies, natural building materials often contain radionuclides like 40 K, 238 U (represented by 214 Bi), and 232 Th (represented by 208 Tl). The activity levels of these radionuclides are important to measure because they contribute to gamma radiation exposure from construction materials. Most of the measured values in this study fall within the natural background range defined by international safety standards, although a few samples require further investigation. Therefore, samples are assumed to be in secular equilibrium; hence, a small number of radionuclides can reliably represent the activity of the entire decay series. For example, the $^{238}U$ Decay series is represented by $^{214}Bi$, and the $^{232}Th$ Decay Series is represented by $^{208}Ti$, ss shown in **Table 5** [8]. The chosen energies for 214 Bi and 208 Ti are relatively high and have a higher probability of gamma emission, making them suitable for accurate activity measurements. Lower-energy gamma rays, on the other hand, may experience self-attenuation within the sample, leading to underestimation of activity concentrations. This highlights the importance of selecting high-energy gamma rays for more reliable results.

**Table 4.** Nutural radioactivity levels in different building material samples [11].

| | | Activity Concentration of Radionuclides in Different Sample | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Sample Name | Th-234 (92kev) | Pb-212 (238.6kev) | Pb214 (351.9 Kev) | Tl208 (510.8 Kev) | Bi214 (609.3 Kev) | Ra226 (186.2 Kev) | K-40 (1460.1 Kev) | Bi-214 (1120.3kev) | Ti-208 (2614.5kev) |
| S1 | Aggreagte_3_16_ Tibah_Al-Khair | - | 33.43 ± 0.32 | - | - | - | - | 290.22 ± 3.78 | - | 4.76 ± 0.22 |
| S2 | Aggregate3/8 Tibah Al-Khair | - | 32.25 ± 0.18 | - | 60.13 ± 0.18 | - | - | 485.04 ± 3.66 | - | 16.05 ± 0.41 |
| S3 | Burkini Mariee Salman Alkhbout | 380.70 ± 3.91 | 29.88 ± 0.29 | 33.12 ± 0.37 | 60.58 ± 0.74 | 30.87 ± 0.41 | - | 247.94 ± 3.37 | - | 9.19 ± 0.45 |
| S4 | Burkini Tipah Al-Khair Cement | 414.57 ± 5.49 | 34.04 ± 0.42 | - | 66.28 ± 1.04 | - | - | 46.74 ± 0.79 | - | 4.91 ± 0.30 |
| S5 | Cement Arab Cement Company | 423.65 ± 3.63 | 29.47 ± 0.26 | 40.13 ± 0.36 | 55.80 ± 0.63 | 32.91 ± 0.37 | 366.14 ± 3.32 | 120.00 ± 1.57 | 61.65 ± 1.12 | 4.05 ± 0.18 |
| S6 | Interlock Sand Tipah Al-Khair | 435.46 ± 5.54 | 378.11 ± 4.70 | 67.03 ± 0.93 | 64.51 ± 1.01 | 24.34 ± 0.42 | - | 53.93 ± 0.93 | - | 4.69 ± 0.29 |
| S7 | Marble Almasseef Alawal | - | 230.79 ± 2.17 | 38.70 ± 0.42 | - | - | - | - | - | - |
| S8 | Sand Salman Al_Khabout | - | 0.99 ± 0.33 | - | 3.05 ± .38 | - | - | 8.61 ± 0.34 | - | 37.18 ± 0.23 |
| S9 | Sand_Tipah_Al-Khair | 471.16 ± 6.09 | 36.67 ± 0.46 | - | 34.41 ± 0.53 | 59.63 ± 1.03 | - | 73.12 ± 1.14 | - | 4.35 ± 0.29 |
| S10 | Tiles Almasef | 515.26 ± 5.81 | 39.22 ± 0.43 | 72.60 ± 0.94 | 28.55 ± 0.44 | 55.94 ± 0.91 | - | 250.66 ± 4.32 | - | 4.53 ± 0.27 |
| S11 | Water_Mariee_ Salman | - | 16.95 ± 0.23 | - | 1.02 ± 0.07 | - | - | 5.08 ± 0.09 | - | 1.02 ± 0.07 |
| S12 | White_Sand_Tipah_Al-Khair | 394.12 ± 4.92 | 32.59 ± 0.38 | 58.27 ± 0.81 | 58.22 ± 0.81 | 46.38 ± .80 | - | 24.50 ± 0.45 | - | 4.09 ± 0.25 |
| S13 | White_Sand_Mariee_Salman | 373.67 ± 4.86 | 28.65 ± 0.36 | - | 59.65 ± .92 | - | - | 271.02 ± 4.42 | - | 3.70 ± 0.24 |
| S14 | Water Taiba Al-Khair Cement | - | 16.95 ± 0.23 | - | 1.02 ± 0.07 | - | - | 5.08 ± 0.09 | - | 1.02 ± 0.07 |
| S15 | Red_Dye Almost | - | - | - | - | - | - | - | - | - |

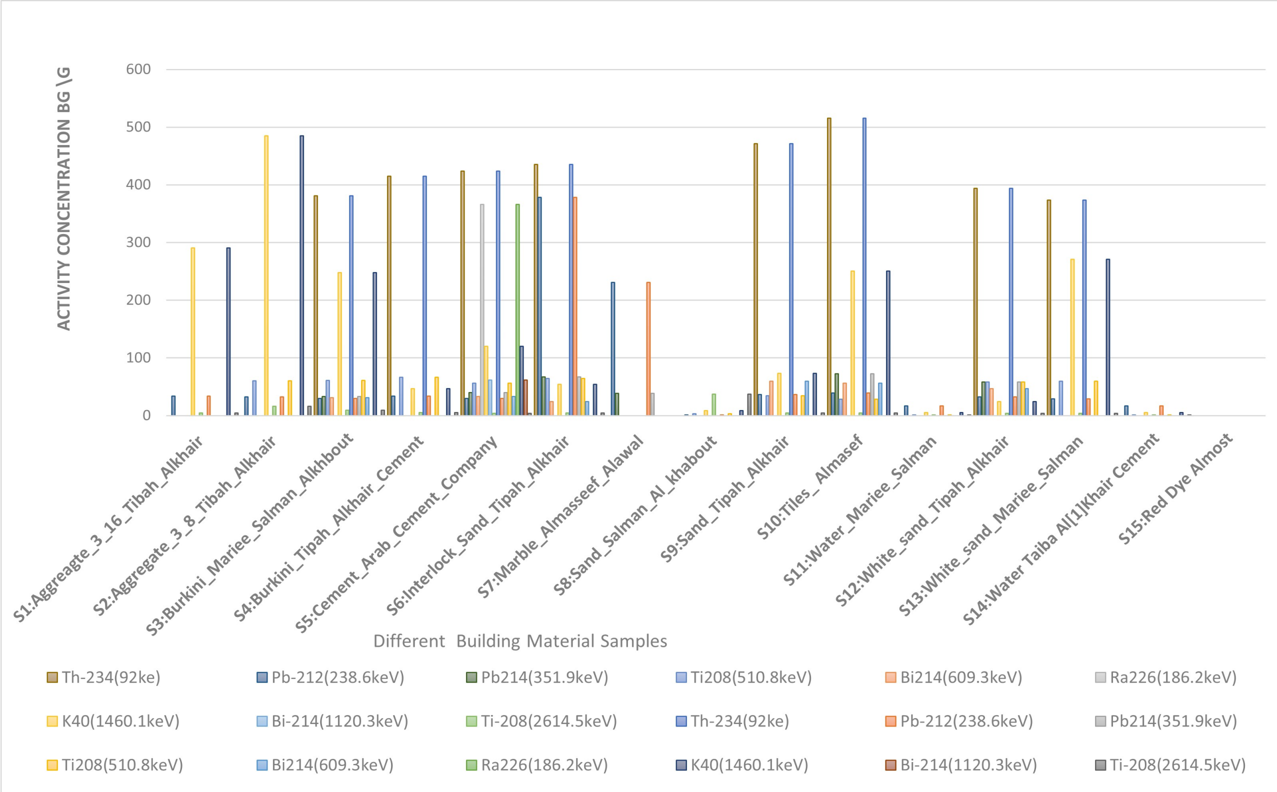



**Figure 6.** Activity concentration of radionucildes in different sample.

## 5. Radionuclides and Their Decay Chain

According to **Table 5** the Radionuclides and their Decay Chain were detected

**Table 5.** Radionuclides and their decay chain.

| Nuclide | Daughter | Energy (Kev) | Gamma Probability (%) |
|---|---|---|---|
| | 234Th | 92.0 | 2.81 |
| | 226Ra | 186.1 | 3.6 |
| | 214 Pb | 295.2 | 19.3 |
| | | 351.9 | 37.6 |
| $^{238}U$ | 214 Bi | 609.3 | 46.1 |
| | | 1120.3 | 15.1 |
| | | 1729.3 | 2.9 |
| | | 1764.5 | 15.4 |
| | 210Pb | 46.5 | 4.3 |
| | 228 Ac | 338.4 | 11.3 |
| $^{232}Th$ | | 911.2 | 25.8 |
| | | 964.8 | 5.0 |
| | | 969.1 | 15.8 |

Continued

| | | | |
|---|---|---|---|
| | **212Pb** | **238.6** | **43.3** |
| | 212Bi | 727.3 | 6.7 |
| | 208 Ti | 510.8 | 22.6 |
| | | 583.0 | 85.4 |
| | | 2614.5 | 99.7 |
| **Naturally Isotope$^{40}$K** | | 1460.8 | 10.7 |

Table 6. The radium equivalent activity of Th-234, Ra-226, and K-40 (Bq/Kg), as well as the level index and external and internal hazards index.

| Material | Activity concentration, Bq/kg | | | $Ra_{eq}$ | Hin | Hex | $I_\gamma$ |
|---|---|---|---|---|---|---|---|
| | Th-234 (92keV) | Ra226 (186.2keV) | K40 (1460.1keV) | | | | |
| S1 | - | - | 290.22± 3.78 | 22.33 | 0.06 | 0.145 | 0.097 |
| S2 | - | - | 485.04± 3.66 | 37.31 | 0.101 | 0.101 | 0.162 |
| S3 | 380.70± 3.91 | - | 247.94± 3.37 | 564.92 | 1.52 | 1.52 | 1.99 |
| S4 | 414.57± 5.49 | - | 46.74± 0.79 | 595.84 | 1.61 | 1.61 | 2.3 |
| S5 | 423.65± 3.63 | 366.14± 3.32 | 120.00± 1.57 | 980.56 | 3.64 | 5.97 | 3.38 |
| S6 | 435.46± 5.54 | - | 53.93± 0.93 | 626.23 | 1.69 | 1.69 | 2.2 |
| S7 | - | - | - | - | - | - | - |
| S8 | - | - | 8.61± 0.34 | 0.66 | 0.002 | 0.002 | 0.003 |
| S9 | 471.16± 6.09 | - | 73.12± 1.14 | 678.71 | 1.83 | 1.83 | 2.38 |
| S10 | 515.26± 5.81 | - | 250.66± 4.32 | 755.37 | 2.04 | 2.04 | 2.66 |
| S11 | - | - | 5.08 ±0.09 | 0.39 | 0.001 | 0.001 | 0.003 |
| S12 | 394.12± 4.92 | - | 24.50± 0.45 | 564.91 | 1.53 | 1.53 | 1.98 |
| S13 | 373.67±4.86 | - | 271.02± 4.42 | 554.66 | 1.5 | 1.5 | 3.72 |
| S14 | - | - | 5.08 ±0.09 | 0.39 | 0.001 | 0.001 | 0.002 |
| S15 | - | - | - | - | - | - | - |

## 6. Activity Concentration of Radionucildes in all Different Samples

In all different sample Figure 6 clearly shows the concentration of radionuclides in all different sample where all the differences in radionuclide activity highlight the need for further studies. For example, potassium-rich materials caused higher 40K levels, while processing techniques and material mixtures affected the levels of other radionuclides. The water sample had the lowest activity levels because of its low solid content, showing how sample composition affects radionuclide levels. Table 5 assessment of radiation hazards to evaluate the radiation impact due to utilization of building materials originating from the region, the following radiation hazard indices were proposed. The activity concentrations of radionuclides in the all samples are calculated as in Table 6 where the diagram in Figure 7 for

Radium equivalent activity as $Ra_{eq}$, external hazard index Hex, and internal hazard index Hin and gamma-radiation hazard index I$\gamma$ for any building material, it well be classified as not safe material if it complied with the proposed values of the hazard indices, where the $Ra_{eq}$ index should be <370 and the other indices Hex and Hin should be <unity [13] and I$\gamma$ should be ≤3 [14].

When compared to the International Atomic Energy Agency (IAEA) safety standards, most of the activity levels, including 40K, are considered safe for construction. However, samples with higher 226Ra levels, such as the Sample $S_5$: Cement Arab Cement Company sample, approach the exemption threshold of 1000 Bq/kg, meaning that it well be classified as not safe material and this need further study for long-term exposure risks. The Interlock Sand sample from Tipah Al-Khair Cement Products Factory had a particularly high 212Pb concentration (378 ± 4.70 Bq/kg), which may be linked to the geochemical properties of its raw materials. To ensure these materials are safe, radiological hazard indices like the Radium Equivalent Activity ($Ra_{eq}$), External Hazard Index (Hex), and Gamma Index (I$\gamma$) calculated in the Table 4 and Table 5. Early results suggest that most samples are within safe limits for construction, but $S_5$: Cement Arab Cement Company with higher levels of 226Ra which has higher $Ra_{eq}$ = 980.56. Where Hex and Hin value $\gg$ than 1 which equal 2.65 and 5.97 this Building Materials sample need more attention and do not represent significant radiological health risk. Testing soluble samples, like water, for leaching is also important to assess their environmental impact. These results underline the importance of detailed radiological assessments to ensure materials meet safety standards and are safe for use in homes and industries.

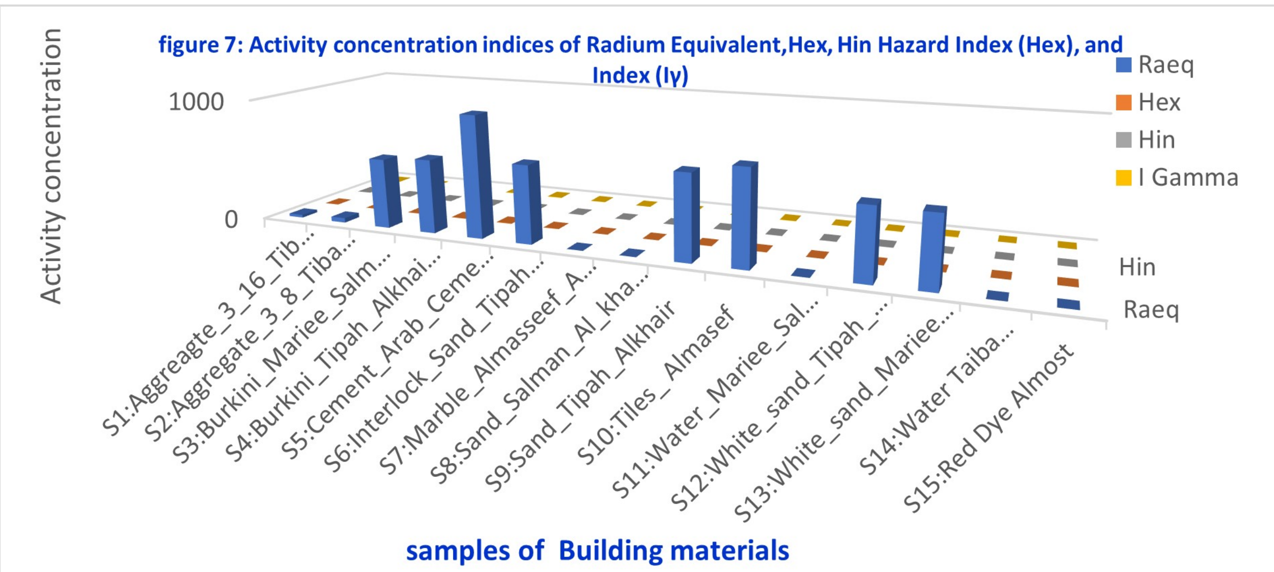



Figure 7. Activity concentration indices of Radium Equivalent, Hex, Hin Hazard Index (Hex), and Index (I$\gamma$).

## 7. Conclusion

This study successfully assessed the natural radioactivity in building materials using gamma-ray spectrometry, providing valuable data on radionuclide concentrations and their health implications. Radioactive nuclei, including naturally occurring K-40 and radionuclides from the Uranium-238 and Thorium-232 decay series, were detected in most samples. The findings demonstrate the reliability of the experimental setup, with optimal detection efficiency and resolution. The outcomes were contrasted with previous investigations carried out throughout Europe. From the standpoint of radiation safety, it is determined that all measured radioactivity of building materials is within permissible limitations and does not present any dangers. These results contribute significantly to understanding radiation safety and can inform future research and regulatory guidelines for building material use. This study aligns with Saudi Vision 2030 by promoting sustainability and public health through the assessment of natural radioactivity in building materials using advanced gamma-ray spectrometry.

## Suggestions

1. To more precisely and comprehensively ascertain the radiation background of building materials in the governorate and to understand the damages resulting from these operations.
2. It is recommended that a future study be conducted that encompasses all areas of Rabigh Governorate from a natural geological perspective.
3. It's recommended that samples of building materials be collected at various depths and that these be connected to the radioactivity concentration of building materials that are presently offered in the governorate's markets as well as the accuracy of the findings.

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## Conflict of Interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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