

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

**Sudan Academy of Sciences (SAS)  
Atomic Energy Council**

**Investigation of Natural Radioactivity in Building  
Materials commonly used in Sudan**

**By**

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Master of Radiation and Environmental Protection*

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# *Dedication*

To

My mother and father

My husband, brother and Sisters

All my family

# ACKNOWLEDGEMENT

*It is a great pleasure to thank everyone who helped me write my thesis . I am sincerely and heartily grateful to my advisor, Dr. Usam Salih the guide advice with attention and care, he showed me throughout my thesis writing. Besides I would like to thank to my father for the support and provided me great information resources. I am truly indebted and thankful to my mother ,family ,and my husband for help and support . I would like to thank Hatem Ftayeb and Walid Hamza, those helped me in practical (laboratory of protection of the environment).*

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*Finally the biggest thanks for my mother and father , I am sure it would have not been possible without their help.*

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## ABSTRACT

Investigation of radioactivity content of commonly used building materials in Khartoum state is carried out during the year 2010. A total of 25 samples of natural and manufactured materials from different types of building materials have been collected and measured using gamma spectrometry system. The activity concentrations have been determined for radium ( $^{226}\text{Ra}$ ), thorium ( $^{232}\text{Th}$ ) and potassium ( $^{40}\text{K}$ ) in each sample. The concentrations of radium (represents activity of uranium and its decay series) have been found to range from 2.8 Bq/kg in (gravel) to 108.2 Bq/kg (porcelain), thorium between 48 and 302 Bq/kg and the potassium concentration varies between 82.3 Bq/kg in (gravel) to 1413.3 Bq/kg in (marble). The activity index has also been calculated and found that it is less than 1 (mean value of 0.77 range between 0.33 and 1.97), and less than 6 for surface materials.

The results have been compared with European previous studies. It is concluded that the measured radioactivity of building materials are within acceptable levels and does not poses any risk from radiation protection point of view.

## الخلاصة

هذه دراسة أجريت في العام 2010 للتحقق وقياس المحتوى الإشعاعي في مواد البناء المستخدمة في ولاية الخرطوم. تم جمع 25 عينة من مختلف مواد البناء الطبيعية والمصنعة وتم قياسها بواسطة المطياف الجامي . في أي عينة تم حساب التركيز الإشعاعي للراديووم-226 والبوتاسيوم-40. وقد وجد أن تركيز الراديووم (يمثل نشاط اليورانيوم وسلسلة الاضمحلال) يتراوح ما بين 2.8 بيكريل/كجم في الحصى و 108.18 بيكريل/كجم في البورسلين، تركيز الثوريوم بين 48 و 302 بيكريل/كجم، وكذلك وجد ان تركيز البوتاسيوم يتراوح من 82.3 بيكريل/كجم في الحصى الى 1413.3 بيكريل/كجم في الرخام. كما تم حساب مؤشر النشاط ووجد انه اقل من 1. و اقل من 6 في المواد السطحية .

وتمت مقارنة النتائج مع دراسات اوربية سابقة ومنها توصلنا الى ان النشاط الاشعاعي الذي تم قياسه في المدى المسموح به ولا يمثل خطراً وفقاً لمعايير الوقاية من الاشعاع.

# CHAPTER ONE

## INTRODUCTION

During the past few years, growing attention has been devoted to the effect of natural radioactivity. The exposure of the public to natural sources of radiation has been estimated by the United Nations Scientific Committee on the Effect of Atomic Radiation (UNSCEAR, 1988)[1]. Measurement of natural radioactivity in soil is very important to determine the amount of change of the natural background activity with time as a result of any radioactive release. Monitoring of any release of radioactivity to the environment is important for environmental protection. Studies of natural radioactivity are necessary not only because of their radiological impact, but also because they act as excellent biochemical and geochemical tracers in the environment. Also studies of U-series radionuclides present in nature have been of particular interest due to their relatively high biological mobility. Although natural radioactivity found in rocks and soils throughout the earth, the accession in specific areas varies relatively within narrow limits. The inhalation of radon and the short-lived daughter products that it decays to is a major contributor to the total radiation dose to exposed subjects. In the uranium mining environment, lung dose due to radon progenies may be sufficiently high to cause an increase in occurrence of lung cancer (UNSCEAR, 1993) [2]. Building materials represent source of radon in the houses.

In this work measurement of radioactivity in building materials using gamma spectroscopy were carried out. This study covered the whole Khartoum state.

The material collected for this study were: (1) basic building material like cement, ceramic, porcelain and thermal bricks are made in different part of Sudan such as Atbara and Barber. (2) Material made of local earth such as clay bricks, gravel, and sand.

## 1.2 Objectives:

### - General objective:

To assess the natural radioactivity in building materials in sudan.

### - Specific objective:

To measure the amount of natural radioactivity ( $^{226}\text{R}$ ,  $^{40}\text{K}$ ,  $^{232}\text{Th}$ ) in building materials From Khartoum state.

## CHAPTER TWO

### LITREURE REVIEW

Man is continuously exposed to ionizing radiation from naturally occurring radioactive materials (NORM). The origin of these materials is the Earth's crust, but they find their way into building materials, air, water, food and the human body itself. In many parts of the world, building materials containing radioactive material have been used for generations. As individuals spend more than 80% of their time indoors, the internal and external radiation exposure from building materials creates prolonged exposure situations [3].

Most building materials of terrestrial origin contain small amounts of NORM, mainly radionuclides from the  $^{238}\text{U}$  and  $^{232}\text{Th}$  decay chains and the radioactive isotope of potassium,  $^{40}\text{K}$ . The external radiation exposure is caused by the gamma emitting radionuclides, which in the uranium series mainly belong to the decay chain segment starting with  $^{226}\text{Ra}$ . The internal (inhalation) radiation exposure is due to  $^{222}\text{Rn}$ , and marginally to  $^{220}\text{Rn}$ , and their short lived decay products, exhaled from building materials into the room air.

Generally, natural building materials reflect the geology of their site of origin. The average activity concentrations of  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  in the Earth's crust are 35, 30 and 400 Bq/kg respectively [4]. However, elevated levels of natural radionuclides causing annual doses of several mSv were identified in some regions around the world, e.g. in Brazil, France, India, Nigeria, Iran. Recycled industrial by-products containing technologically enhanced natural occurring radioactive materials (TENORM) are extensively used in the construction industry. Coal ash, produced as waste in the combustion of coal, is used as an additive to cement, in concrete and in some countries bricks are made from fly ash. Coal slag is used in floor structures as insulating filling material.

Phosphogypsum, a by-product in the production of phosphorous fertilizers is used as building material, and red mud, a waste from primary aluminum production, is used in bricks, ceramics and tiles [5,6].

## **2.1 Radioactivity in Nature**

Our world is radioactive and has been since it was created. Over 60 radionuclides (radioactive elements) can be found in nature, and they can be placed in three general categories:

1. Primordial - from before the creation of the Earth
2. Cosmogenic - formed as a result of cosmic ray interactions
3. Human produced - enhanced or formed due to human actions (minor amounts compared to natural)

Radionuclides are found naturally in air, water and soil. They are even found in us, being that we are products of our environment. Every day, we ingest and inhale radionuclides in our air and food and the water. Natural radioactivity is common in the rocks and soil that make up our planet, in water and oceans, and in our building materials and homes, nowhere on Earth is free from natural radioactivity [7].

Naturally occurring raw building materials and processed products have radionuclides of the three most commonly known radioactive series such as: Uranium-radium series, thorium series and K-40 isotopes [8]. High concentrations of natural radionuclides in building materials can result in high-dose rates indoors. Gamma-irradiation from naturally occurring radioactive material (NORM) contributes to the whole body dose and in some cases  $\beta$ -irradiation contributes to the skin dose. As  $\beta$  particles have higher specific ionization than  $\gamma$ -particles, they lose their energy while they are still in the skin and cannot penetrate further into the body. Apart from  $\beta$  and  $\gamma$  radiations, there are other harmful effects of NORM.

One is the toxicity of uranium and radium and the other is the hazardous effects of Radon ( $^{222}\text{Rn}$ ) on lungs [9]. Especially the concentration of fly-ash (one of the constituents of cement together with sand and gravel) has the most critical role in the radon release process [10].

The radiation which people are exposed to may increase if they live in houses or buildings constructed by using materials whose radiation doses are above normal background level in the area. This may be due to fly-ash used in making cement. During the combustion process, the produced ashes are enriched in the above radionuclides [8]. This is due to the fact that during combustion, organic material is oxidized and the inorganic material (containing radionuclides) left behind has a smaller volume, so the activity per unit mass is increased. Therefore, determination of the activity of radionuclides belonging to uranium (represented by radium,  $^{226}\text{Ra}$ ) and thorium series and of  $^{40}\text{K}$  radioisotope is important to: evaluate the possible radiological risk and biological damage also to make standardizations about building materials.

## **2.2. Radium ( $^{226}\text{Ra}$ )**

Radium (chemical symbol Ra) is a naturally-occurring radioactive metal. Its most common isotopes are radium-226, radium 224, and radium-228. Radium is a radionuclide formed by the decay of uranium and thorium in the environment. It occurs at low levels in virtually all rock, soil, water, plants, and animals.

### **2.2.1 Sources of radium**

Radium forms when isotopes of uranium or thorium decay in the environment. Most radium (radium-226) originates from the decay of the plentiful uranium-238.

In the natural environment, radium occurs at very low levels in virtually all rock, soil, water, plants, and animals. When uranium (or thorium) occurs in high levels in rock, radium is often also found in high levels.

### **2.2.2. Radium Properties**

Radium is a naturally radioactive, silvery-white metal when freshly cut. It blackens on exposure to air.

Purified radium and some radium compounds glow in the dark (luminesce). The radiation emitted by radium can also cause certain materials, called "phosphors" to emit light. Mixtures of radium salts and appropriate phosphors were widely used for clock dials and gauges before the risks of radium exposure were understood.

Metallic radium is highly chemically reactive. It forms compounds that are very similar to barium compounds, making separation of the two elements difficult.

The various isotopes of radium originate from the radioactive decay of uranium or thorium. Radium-226 is found in the uranium-238 decay series, and radium-228 and -224 are found in the thorium-232 decay series.

Radium-226, the most common isotope, is an alpha emitter, with accompanying gamma radiation, and has a half-life of about 1600 years. Radium-228, is principally a beta emitter and has a half-life of 5.76 years. Radium-224, an alpha emitter, has a half life of 3.66 days. Radium decays to form isotopes of the radioactive gas radon, which is not chemically reactive. Stable lead is the final product of this lengthy radioactive decay series.

### **2.2.3. Radium uses**

In the early 1900's, when it was newly discovered, no one understood the dangers of radium. People were fascinated with its mysterious properties, especially the luminescence produced when it is mixed with a phosphor. Industries sprang up to manufacture hundreds of consumer products containing radium. Advertisements proclaimed its special powers and unique effects in such products such as hair tonic, toothpaste, ointments, and elixirs. Glow in the dark watch and clock faces were immensely popular.

Most of its original uses have been halted for health and safety reasons, but its wide use in luminescent paints continued through World War II, because the soft glow of radium's luminescence made aircraft dials, gauges and other instruments visible to their operators at night. Radium was also an early radiation source for cancer treatment. Small seeds were implanted in tumors to kill cancerous cells. Safer, more effective radiation sources, such as cobalt-60 have mostly replaced it.

Radium is a radiation source in some industrial radiography devices, a technology similar to x-ray imaging used in industry to inspect for flaws in metal parts. When radium is mixed with beryllium it becomes a good source of neutrons, useful in well logging devices and research. Radium also has been added to the tips of lightning rods, improving their effectiveness by ionizing the air around it.

### **2.2.4. Radium in the environment**

Radium occurs naturally in the environment. As a decay product of uranium and thorium, it is common in virtually all rock, soil, and water. Usually concentrations are very low. However, geologic processes can form concentrations of naturally radioactive elements, especially uranium and radium. Radium and its salts are soluble in water. As a result, groundwater in areas where concentrations

of radium are high in surrounding bedrock typically has relatively high radium content.

All isotopes of radium are radioactive. As they decay, they emit radiation and form new radioactive elements, until they reach stable the lead. Isotopes of radium decay to form different isotopes of radon. For example, radium-226 decays to radon-222, and radium-228 goes through several decays to radium-224 before forming radon-220, see figure 2.1

### **2.2.5 Health Effects of Radium**

Radium emits several different kinds of radiation, in particular, alpha particles and gamma rays. Alpha particles are generally only harmful if emitted inside the body. However, both internal and external exposure to gamma radiation is harmful. Gamma rays can penetrate the body, so gamma emitters like radium can result in exposures even when the source is a distance away.

Long-term exposure to radium increases the risk of developing several diseases. Inhaled or ingested radium increases the risk of developing such diseases as lymphoma, bone cancer, and diseases that affect the formation of blood, such as leukemia and aplastic anemia. These effects usually take years to develop. External exposure to radium's gamma radiation increases the risk of cancer to varying degrees in all tissues and organs.

However, the greatest health risk from radium is from exposure to its radioactive decay product radon. It is common in many soils and can collect in homes and other buildings.[11]

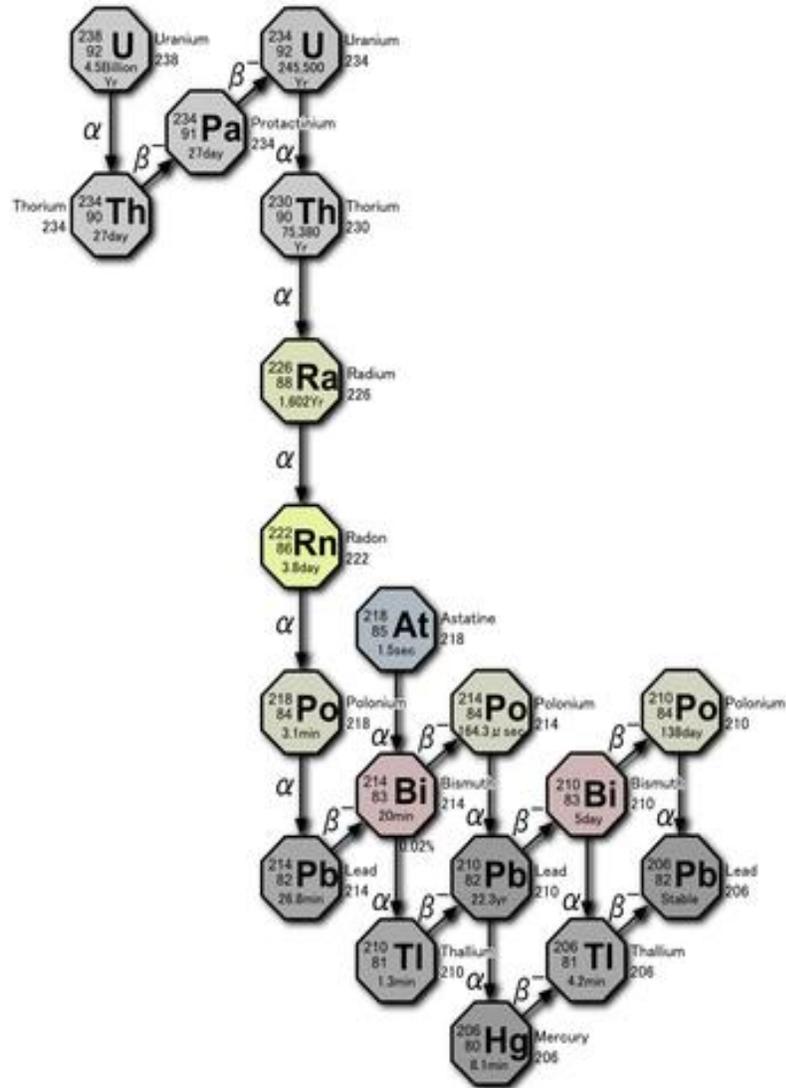


Figure 2.1 Uranium decay series (from  $^{238}\text{U}$  to  $^{206}\text{Pb}$ ).

### 2.3. Potassium ( $^{40}\text{K}$ )

The chemical element with the symbol **K** atomic number 19, and atomic mass 39.0983. Elemental potassium is a soft silvery-white metallic alkali metal that oxidizes rapidly in air and is very reactive with water, generating sufficient heat to ignite the hydrogen emitted in the reaction

Potassium ion is necessary for the function of all living cells, and is thus present in all plant and animal tissues. It is found in especially high concentrations

within plant cells, and in a mixed diet, it is most highly concentrated in fruits. The high concentration of potassium in plants, associated with comparatively very low amounts of sodium there, historically resulted in potassium first being isolated from the ashes of plants (potash), which in turn gave the element its modern name. Heavy crop production rapidly depletes soils of potassium, and agricultural fertilizers consume 93% of the potassium chemical production of the modern world economy.

The functions of potassium and sodium in living organisms are quite different. Animals, in particular, employ sodium and potassium differentially to generate electrical potentials in animal cells, especially in nervous tissue. Potassium depletion in animals, including humans, results in various neurological dysfunctions.

### **2.3.1. Potassium Isotopes**

There are 24 known isotopes of potassium. Three isotopes occur naturally:  $^{39}\text{K}$  (93.3%),  $^{40}\text{K}$  (0.0117%) and  $^{41}\text{K}$  (6.7%). Naturally occurring  $^{40}\text{K}$  decays to stable  $^{40}\text{Ar}$  (11.2% of decays) by electron capture or positron emission, or decays to stable  $^{40}\text{Ca}$  (88.8% of decays) by beta decay;  $^{40}\text{K}$  has a half-life of  $1.250 \times 10^9$  years. The decay of  $^{40}\text{K}$  to  $^{40}\text{Ar}$  enables a commonly used method for dating rocks. The conventional K-Ar dating method depends on the assumption that the rocks contained no argon at the time of formation and that all the subsequent radiogenic argon (i.e.,  $^{40}\text{Ar}$ ) was quantitatively retained. Minerals are dated by measurement of the concentration of potassium and the amount of radiogenic  $^{40}\text{Ar}$  that has accumulated. The minerals that are best suited for dating include biotite, muscovite, plutonic/high grade metamorphic hornblende, and volcanic feldspar; whole rock samples from volcanic flows and shallow intrusives can also be dated if they are unaltered.

Outside of dating, potassium isotopes have been used extensively as tracers in studies of weathering. They have also been used for nutrient cycling studies because potassium is a macronutrient required for life.

$^{40}\text{K}$  occurs in natural potassium (and thus in some commercial salt substitutes) in sufficient quantity that large bags of those substitutes can be used as a radioactive source for classroom demonstrations. In healthy animals and people,  $^{40}\text{K}$  represents the largest source of radioactivity, greater even than  $^{14}\text{C}$ . In a human body of 70 kg mass, about 4,400 nuclei of  $^{40}\text{K}$  decay per second. The activity of natural potassium is 31 Bq/g.

### **2.3.1. Physical and chemical properties of potassium**

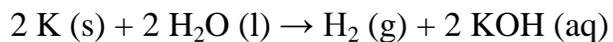
Potassium is the second least dense metal; only lithium is less dense. It is a soft, low-melting solid that can easily be cut with a knife. Freshly cut potassium is silvery in appearance, but in air it begins to tarnish toward grey immediately.

In a flame test, potassium and its compounds emit a lilac color, which may be masked by the strong yellow emission of sodium if it is also present. Cobalt glass can be used to filter out the yellow sodium color. Potassium concentration in solution is commonly determined by flame photometry, atomic absorption spectrophotometry, inductively coupled plasma, or ion selective electrodes

Potassium must be protected from air for storage to prevent disintegration of the metal from oxide and hydroxide corrosion. Often samples are maintained under a hydrocarbon medium which does not react with alkali metals, such as mineral oil or kerosene.

Like the other alkali metals, potassium reacts violently with water, producing hydrogen

The reaction is notably more violent than that of lithium or sodium with water, and is sufficiently exothermic that the evolved hydrogen gas ignites.



Because potassium reacts quickly with even traces of water, and its reaction products are nonvolatile, it is sometimes used alone, or as NaK (an alloy with sodium which is liquid at room temperature) to dry solvents prior to distillation. In this role, it serves as a potent desiccant.

Potassium hydroxide reacts strongly with carbon dioxide to produce potassium carbonate, and is used to remove traces of CO<sub>2</sub> from air. Potassium compounds generally have excellent water solubility, due to the high hydration energy of the K<sup>+</sup> ion. The potassium ion is colorless in water.[12,13]

## CHAPTER THREE

### MATERIAL AND METHODS

#### 3.1 Gamma-ray spectroscopy

The quantitative study of the energy spectra of gamma-ray sources, both nuclear laboratories (geochemical and astrophysical). Gamma rays are the highest-energy form of electromagnetic radiation; being physically exactly like all other forms (e.g., X rays, visible light, infrared, radio) except for higher photon energy and frequency, and shorter wavelength. (Because of their high energy, gamma-ray photons are generally counted individually, whereas the lowest energy forms of EM radiation (e.g., radio to sub-millimeter) are observed as electromagnetic waves consisting of many low-energy photons.) While a Geiger counter or Gamma Probe determine only the count rate (i.e. the number of gamma rays interacting in the detector in one second), a gamma-ray spectrometer also determines the energies of the gamma-rays photons emitted by the source. Radioactive nuclei (radionuclides) commonly emit gamma rays in the energy range from a few keV to ~10 MeV, corresponding to the typical energy levels in nuclei with reasonably long lifetimes. Such sources typically produce gamma-ray "line spectra" (i.e., many photons emitted at discrete energies), whereas much higher energies (upwards of 1 TeV) may occur in the continuum spectra observed in astrophysics and elementary particle physics. The boundary between gamma rays and X rays is somewhat blurred, as X rays typically refer to the high energy EM emission of atoms, which may extend to over 100 keV, whereas the lowest energy emissions of nuclei are typically termed gamma rays, even though their energies may be below 20 keV.

Most radioactive sources produce gamma rays of various energies and intensities. When these emissions are collected and analyzed with a gamma-ray spectroscopy system, a gamma-ray energy spectrum can be produced. A detailed analysis of this spectrum is typically used to determine the identity and quantity of

gamma emitters present in the source. The gamma spectrum is characteristic of the gamma-emitting nuclides contained in the source, just as in optical spectroscopy, the optical spectrum is characteristic of the atoms and molecules contained in the sample.

The equipment used in gamma spectroscopy includes an energy-sensitive radiation detector, a pulse sorter (i.e., multichannel analyzer), and associated amplifiers and data readout devices. The most common detectors include sodium iodide (NaI) scintillation counters and high-purity germanium detectors. [14]

### **3.2 System components**

A gamma spectroscopy system consists of a detector, electronics to collect and process the signals produced by the detector, and a computer with processing software to generate, display, and store the spectrum. Other components, such as rate meters and peak position stabilizers, may also be included.

Gamma spectroscopy detectors are passive materials that wait for a gamma interaction to occur in the detector volume. The most important interaction mechanisms are the photoelectric effect, the Compton effect, and pair production. The photoelectric effect is preferred, as it absorbs all of the energy of the incident gamma ray. Full energy absorption is also possible when a series of these interaction mechanisms take place within the detector volume. When a gamma ray undergoes a Compton interaction or pair production, and a portion of the energy escapes from the detector volume without being absorbed, the background rate in the spectrum is increased by one count. This count will appear in a channel below the channel that corresponds to the full energy of the gamma ray. Larger detector volumes reduce this effect.

The voltage pulse produced by the detector (or by the photomultiplier in a scintillation detector) is shaped by a multichannel analyzer (MCA). The

multichannel analyzer takes the very small voltage signal produced by the detector, reshapes it into a Gaussian or trapezoidal shape, and converts that signal into a digital signal. In some systems, the analog-to-digital conversion is performed before the peak is reshaped. The analog-to-digital converter (ADC) also sorts the pulses by their height. ADCs have specific numbers of "bins" into which the pulses can be sorted; these bins represent the *channels* in the spectrum. The number of channels can be changed in most modern gamma spectroscopy systems by modifying software or hardware settings. The number of channels is typically a power of two; common values include 512, 1024, 2048, 4096, 8192, or 16384 channels. The choice of number of channels depends on the resolution of the system and the energy range being studied.

The multichannel analyzer output is sent to a computer, which stores, displays, and analyzes the data. A variety of software packages are available from several manufacturers, and generally include spectrum analysis tools such as energy calibration, peak area and net area calculation, and resolution calculation.[15]

### **3.3 Calibration**

If a gamma spectrometer is used for identifying samples of unknown composition, its energy scale must be calibrated first. Calibration is performed by using the peaks of a known source, such as cesium-137 or cobalt-60. Because the channel number is proportional to energy, the channel scale can then be converted to an energy scale. If the size of the detector crystal is known, one can also perform an intensity calibration, so that not only the energies but also the intensities of an unknown source or the amount of a certain isotope in the source can be determined.

### **3.4 Detector efficiency**

Not all gamma rays emitted by the source and pass through the detector will produce a count in the system. The probability that an emitted gamma ray will interact with the detector and produce a count is the efficiency of the detector. High-efficiency detectors produce spectra in less time than low-efficiency detectors. In general, larger detectors have higher efficiency than smaller detectors, although the shielding properties of the detector material are also important factors. Detector efficiency is measured by comparing a spectrum from a source of known activity to the count rates in each peak to the count rates expected from the known intensities of each gamma ray.

Efficiency, like resolution, can be expressed in absolute or relative terms. The same units are used (i.e., percentages); therefore, the spectroscopist must take care to determine which kind of efficiency is being given for the detector. Absolute efficiency values represent the probability that a gamma ray of a specified energy passing through the detector will interact and be detected. The energy of the gamma rays being detected is an important factor in the efficiency of the detector. An efficiency curve can be obtained by plotting the efficiency at various energies. This curve can then be used to determine the efficiency of the detector at energies different from those used to obtain the curve. High-purity germanium (HPGe) detectors typically have higher sensitivity.[15]

### **3.5 Sample Collection**

Brick samples and other building materials have been collected from major local producers in Sudan which are mostly used in Sudanese dwelling especially in Khartoum. The raw materials of samples were taken from different locations representing the major sources of these materials. These include areas like Algrif garb, Algrif sharg, Alhajyosf and Alshegla . These areas represent the areas of the

clay brick. In addition to that, other building materials were obtained from local markets.

### 3.6. Sample preparation and counting

The materials are either in powder form (cement and sand) or as solid. The solid one (bricks, ceramic,... etc) were either crushed into small pieces or powdered. The samples were then closed and sealed in hermetically beakers (Samples weight were taken). The sealed samples were stored for 30 days before counting to allow  $^{226}\text{Ra}$  and its short-lived decay products to reach the secular equilibrium.

### 3.7 The Analysis

The container is put directly on the top of the detector and counted for at least three hours (10800 seconds) depending on counting statistics. the spectrum is stored in the computer, and the software used is “winTMCA32”.

The following equation used to obtain the efficiency curve of the detector.

$$\eta = \frac{N(\text{cps})}{I\gamma \cdot A[\text{Bq}]}$$

$\eta$  is the efficiency of the detector at specific energy .

N is the net area of the peak (count per second).

$I\gamma$  is gamma intensity .

A is activity of the standard.

The efficiency curve can be obtained at different energies (662,1173,1333) for Cs-137 and Co-60. This curve can be used to determine the efficiency of the detector at energies different from those. The result is done by computer and presented in tables and graphs. Figure 3.1

### 3.2 Building Materials Activity Index (*I*)

The activity index *I* for final building materials intended for use in building construction is

$$I = \frac{C_{Th}}{200} + \frac{C_{Ra}}{300} + \frac{C_K}{3000}$$

where  $C_{Th}$ ,  $C_{Ra}$  and  $C_K$  are the activity concentration values of  $^{232}\text{Th}$ ,  $^{226}\text{Ra}$  and  $^{40}\text{K}$  in the product expressed in Bq/kg. If the activity index *I* is 1 or less than 1, the material can be used as building material, so far as radioactivity is concerned, without restriction.

In case of surface materials and other materials with a minor use in building construction (such as thin tiles), no separate investigation is needed if the activity index *I* of the material is less than or equal to 6.[16]

\*factors 200,300,3000, Bq/kg were calculated for dose criterion limit of 1 msv  $\text{y}^{-1}$

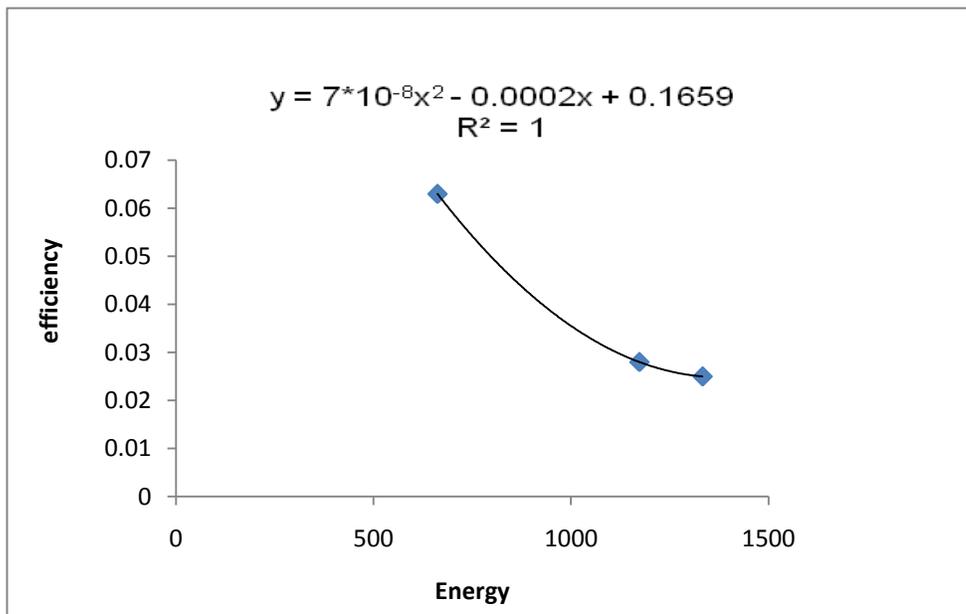


Figure 3.1: Efficiency Calibration Curve for NaI Detector

## CHAPTER FOUR

### RESULTS AND DISCUSSION

Natural radioactivity in the collected samples (from 25 types of building materials) was investigated in this study. This includes analyses of various radionuclides such as  $^{40}\text{K}$  and U-series nuclides. The main objectives of this analysis was to evaluate radioactivity content then derive radioactivity index for the purpose of radiation protection and safe used of the materials. The uranium (or radium) content of samples was evaluated via daughter isotopes that emit gamma rays. Radium content was evaluated mainly from gamma line of 609 keV of Bi-214 (assuming the secular equilibrium). It should be noted that under this assumption the radioactivity of radium represents activity of uranium and its decay series. Table 1 shows summary of the activity concentration of Ra-226 and K-40. These radionuclides are detected in all samples and found to give values in the range between 2.83 (gravel) and 108.18 Bq/kg (porcelain), the second higher activity concentration in the list is the marble which gives 66.56 Bq/kg for Ra-226. The range 82.29 Bq/kg (gravel) to 1413.33 Bq/kg (marble) for K-40. Table 2 shows the concentration of  $^{226}\text{Ra}$  and  $^{40}\text{K}$  in all samples. The results are presented in set of figures. Figure 4.1 shows distribution of radium content in the selected building materials and figure 4.2 shows the histogram of frequency of normal distribution of this radionuclide. Figure 4.3 shows the distribution of  $^{40}\text{K}$  in the samples and figure 4.4 shows the histogram of frequency of normal distribution of  $^{40}\text{K}$ .

The study investigates the most common building materials used in Khartoum state and most of the Sudanese houses. The result as shown in previous paragraphs indicates acceptable radioactivity content in these materials when compared with some global data. As an example the radioactivity contents of brick building materials used in Europe (see table 4.3) range 10-50 Bq/kg for  $^{226}\text{Ra}$  and 330-670 Bq/kg for  $^{40}\text{K}$ . While the present study the range between 8.4 to 47.2

Bq/kg and 116 to 560 Bq/kg respectively. Similar results were observed in other type of building materials. In general there was no big difference in concentration and most of data are within the range or less. The main causes of variation refer to the fact that: most building materials contain small amounts of NORM reflecting the geological variation of their site of origin.

The highest  $^{226}\text{Ra}$  content found in porcelain-ceramic types and the lower was in gravel. Similarly high  $^{40}\text{K}$  content was observed in marble-ceramic types but lower contents found in gravel also. The most interesting finding in the present study is the difference in concentration observed between tiles (mazzaiko) and porcelain which are derived from similar sources.

Table 4.1: Summary of radioactivity content in building material sample according to their origin.

Sample Type	Concentration [Ba/Kg] (The mean value)			Activity Index
	Th-232	Ra-226	K-40	
Brick	87.81	22.36	310.01	0.62
Clay-bricks	87.05	15.83	262.67	0.58
Cement	50.70	10.73	192.87	0.35
Surface materials	302.12	57.04	817.63	1.97
Others	48.05	10.36	155.83	0.33

Table 4.2: Concentration of  $^{226}\text{Ra}$  and  $^{40}\text{K}$  in all investigated samples

Code	Sample	$^{226}\text{Ra}$ concentration Bq/kg	$^{40}\text{K}$ concentration Bq/kg
R01	Thermal bricks	25.15	421.82
R02	white cement	13.51	87.27
R03	Cementic bricks (cedaba)	14.26	179.39
R04	Brick (cedaba)	18.58	560
R05	Red bricks	26.2	486.15
R06	lime stone	8.38	108.24
R07	Clay bricks (khartoum) (west Gerafe )	10.22	292
R08	Grinded(soft) powder (mazaiko)	10.13	196.36
R09	Building sand	10.04	134.05
R10	Cement (Atbra)	10.56	282.35
R11	Lime bricks	16.81	179.05
R12	Ceramic (sudan)	44.12	890
R13	Lime bricks (lime+sand)	47.15	227.69
R14	Porcelain	108.18	861.18
R15	Clay bricks (Omdrman)	16.61	149.09
R16	Cementic blocks	8.36	116
R17	Marble	66.56	1413.33
R18	Tiles (mazaiko)	9.29	106
R19	Lime	26.05	292.41
R20	Gravel	2.83	82.29
R21	Cement (Barbar)	8.11	209.66
R22	Clay brick (east Gerafe)	13.87	422.4
R23	Clay brick (Al-haj yousif)	20.12	213.33
R24	Clay brick (al-shegla)	18.31	236.52
R25	Gypsum	4.72	121.9

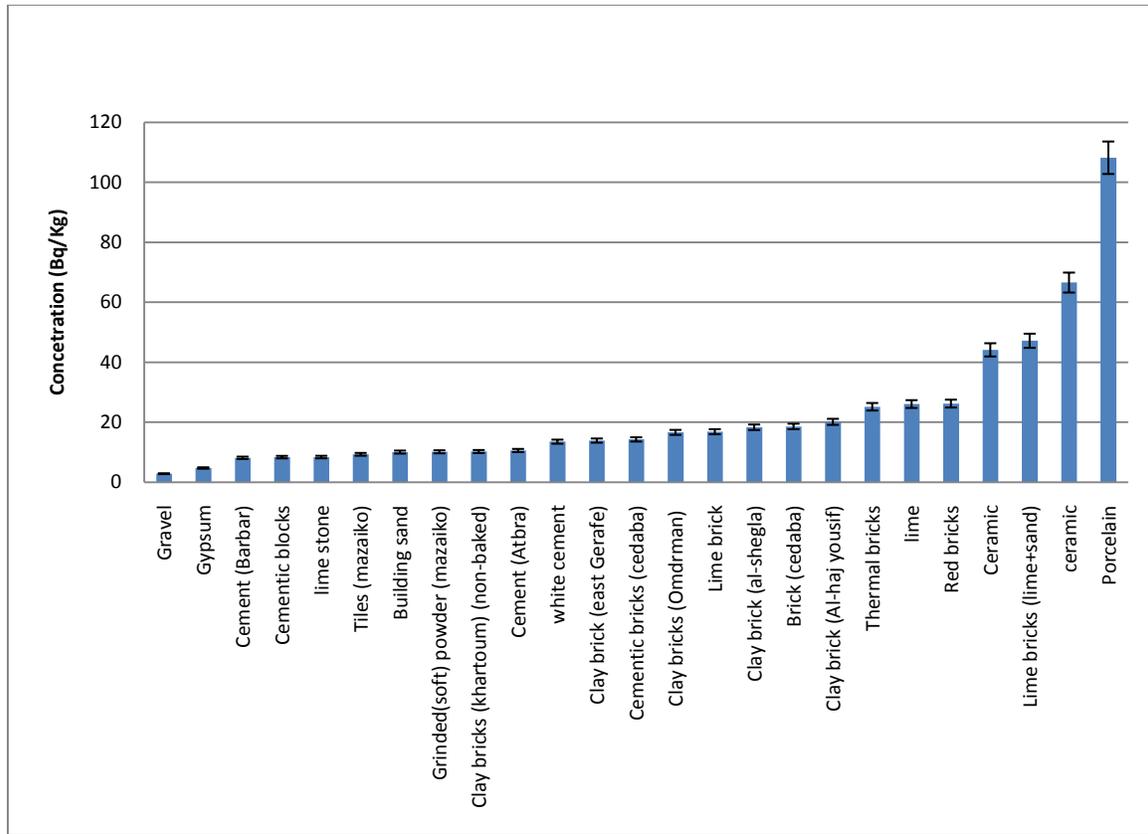


Figure 4.1: Distribution of Ra-226 in the samples expressed in Bq/Kg from low-to-high values

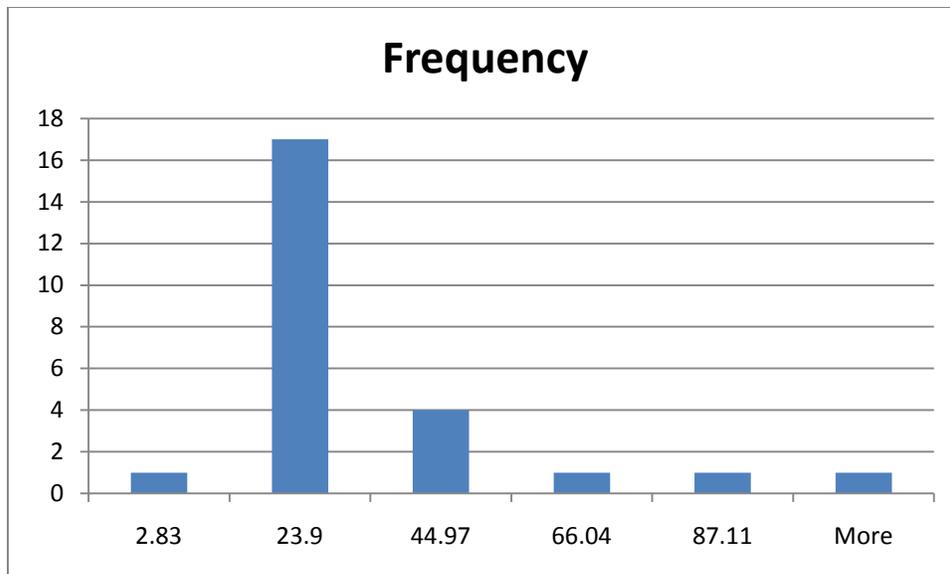


Figure 4.2: Frequency distribution of Ra-226 content in the sample

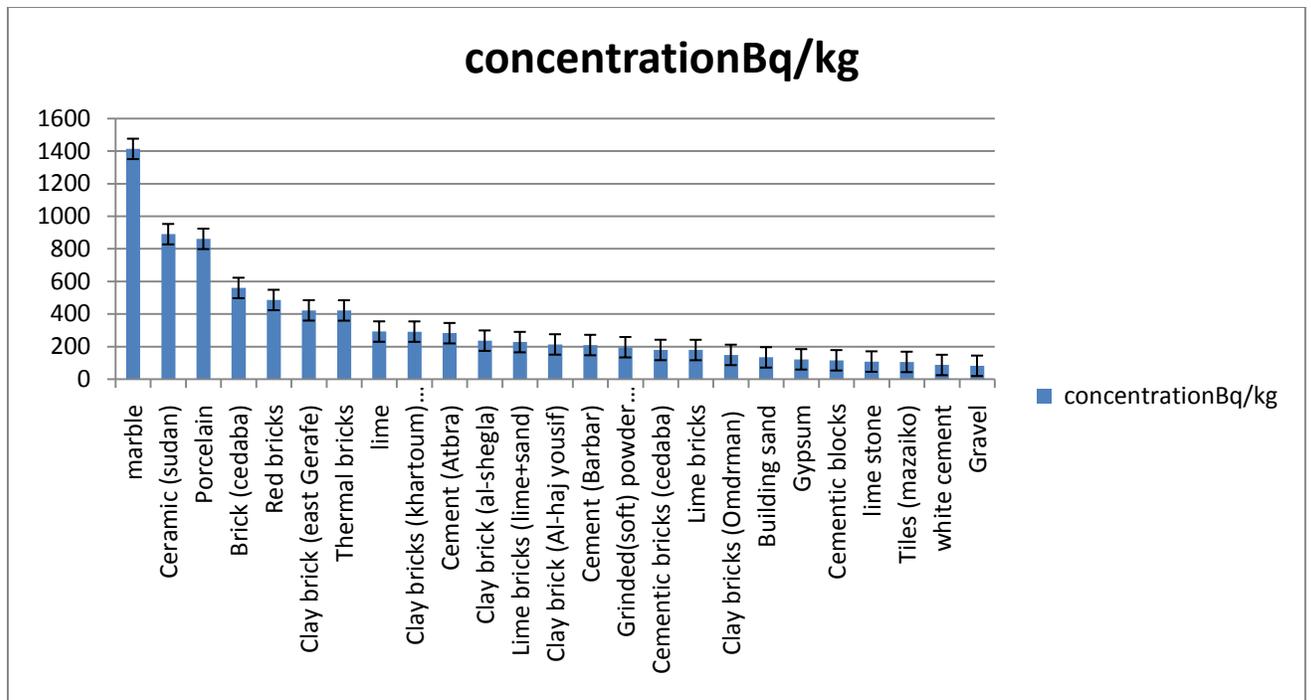


Figure 4.3: Distribution of K-40 in the samples expressed in Bq/Kg from high-to-low values.

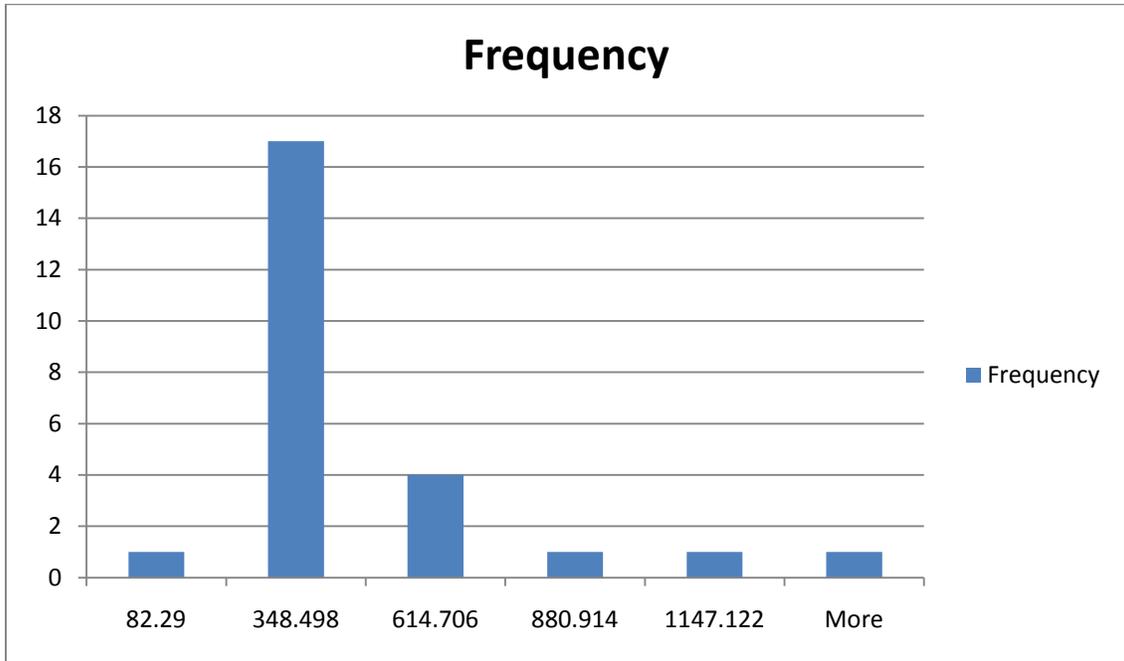


Figure 4.4: Frequency distribution of K-40 content in the sample.

Table 4. 3: typical activity concentration in common building materials used in Europe  
{RP \_112 1999}

Material	$^{226}\text{Ra}$	$^{40}\text{K}$
Clay (red) bricks	50	670
Sand_ lime bricks	10	330
Natural Gypsum	10	80

Table 4.4: Radioactivity in Surface Building Materials

Sample	$^{226}\text{Ra}$ Concentration (Bq/Kg)	$^{40}\text{K}$ Concentration (Bq/Kg)
Porcelain	108.18	861.18
marble	66.56	1413.33
Ceramic (sudan)	44.12	890
Tiles (mazaiko)	9.29	106

Table 4.5: Other Building Materials

Sample	$^{226}\text{Ra}$ Concentration (Bq/Kg)	$^{40}\text{K}$ Concentration (Bq/Kg)
lime	26.05	292.14
Grinded(soft) powder (mazaiko)	10.13	196.36
Building sand	10.04	134.05
lime stone	8.38	108.24
Gypsum	4.72	121.9
Gravel	2.83	82.29

## CONCLUSION

As observed from the present study, there is a noticeable variation in radioactivity content of building materials. The main causes of this variation refer to that: most building materials contain small amounts of NORM which reflect the geological setting of their site of origin.

From radiation protection point of view there exist some national and international regulations and guidelines. Radioactivity in building materials is treated as existing exposure situations rather than as planned exposure situations. Controls on the radioactivity concentration of building materials are based on dose criteria and on exemption levels. The dose criterion is established considering the overall national circumstances but it is thoroughly accepted that external doses exceeding 1 mSv/y should be taken into account. The present study add to baseline data valuable information that can be used in future studies like normal exposure to ionizing radiation or development of national exposure limits.

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## APPENDIX

### NCRP

Estimates of concentrations of uranium, and potassium in building materials (NCRP 94, 1987, except where noted)

Material	$^{226}\text{Ra}$ mBq/g	$^{40}\text{K}$ mBq/g
Cement	46	237
Natural gypsum	15	148
Clay Brick	111	666

(NCRP) National Council on Radiation Protection.