DETERMINATION OF RADIONUCLIDES IN DUST AROUND SOME STONE QUARRY SITES IN ONDO AND EKITI STATES

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CERTIFICATION

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DEDICATION

I fully dedicate this project to almighty God for his divine protection, he is worthy of honor and praises. I also dedicate this project to my parents Mr and Mrs. David Akintade and my sisters Kate and Sharon for their support financially and their unending prayers towards me.

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LIST OF ACRONYMNS

AJNSA: - American Journal on Nuclear Science Agency

ISO: - International Organization for Standardization

IUPAC: - International Union of Pure and Applied Chemistry

WHO: - World Health Organization

NIOSH: - National Institute for Occupational Safety and Health

EPA: - Environmental Protection Agency

UNSCEAR: - United Nation Scientific Committee on the Effects of Atomic Radiation

IAEA: - International Atomic Energy Agency

ICRP: - International Commission on Radiological Protection

PCLRP: - Polish Central Laboratory for Radiological Protection

ABSTRACT

This study was undertaken to determine the natural radionuclides activities of ^{238}U, ^{232}Th, and ^{40}K as contaminants and their distribution from dust particles obtained from selected quarries in Ekiti and Ondo States. This work was performed in four quarries sites located in Ekiti and Ondo States and a control sample. The radioactivity concentrations of the natural radionuclides (^{238}U, ^{232}Th and ^{40}K) in the collected quarries dust samples were determined by gamma ray spectrometry. The radioactivity concentration values in the investigated dust samples ranged from (8.02 ± 2.0 to 25.00 ± 4.0) Bq $kg^{-}1$ for ^{238}U, (10.02 ± 1.0 to 32.06 ± 2.0) Bq $kg^{-}1$ for ^{232}Th, and (600.06 ± 2.0 to 1014.06 ± 1.0) Bq $kg^{-}1$ for ^{40}K. The total absorbed dose rate ranged from 34.944 $nGyh^{-1}$ to 73.051 $nGyh^{-1}$ with the control sample with the lowest absorbed dose rate and EKT 1 with the highest absorbed dose rate. The total absorbed dose rate values increase with the activity concentration, and consequently enhances the radiological impact on the people living in the surrounding communities of the quarries.

CHAPTER ONE

1.0 INTRODUCTION

1.1.0 Background to the study

Before the industrial era of the 19th century, dust in the environment had remained relatively low. However, due to industrialization, urbanization, technology advancement, dust in the environment have become much which in turn causes hazardous effect on the environment and the living organisms in the environment. Anthropogenic activities such as mining, crushing, grinding, milling, drilling, demolition, shoveling, conveying, screening, bagging and sweeping have become rampant. These have brought about sporadic rise in dust levels beyond the natural background levels in the environment.

Quarrying operations have hazards effect on workers and the surrounding communities. Assessing the consequential risks of the extraction of stone dust has been divided into individual work stages. The basic approach consists in assessing non-occupation exposure risks is by determining the concentrations in ambient air in the vicinity of the industries. During stone cutting in quarries, airborne dusts are generated. These airborne dusts (1 μm to 100 μm in diameter) are mainly in the form of particulates and may be transported to far distance from the factory sites. The small particles present greater hazard as they are resident for longer periods in the atmosphere from where they may gain access to respiratory and circulatory systems.

The characteristic properties of dust that are of great concern to the environment is that they are micro substances that has the ability to penetrate through anything that is larger than 1μm and they consists of contaminant that has harmful effect on the environment. Such contaminants include heavy metals, radionuclides, minerals, chemicals, microorganisms, etc. These properties pose serious threat to the survival of man and the ecosystem. Thus, dust have constituted an important group of environmental pollutants. Dust in homes, offices, and other human environments contains small amounts of plant pollen, human and animal hairs, textile fibers, paper fibers, minerals from outdoor soil, human skin cells, burnt meteorite particles, Heavy metals, Radionuclides and many other materials which may be found in the local environment.

Exposure to naturally occurring radionuclides contribute significantly to the exposure of human for radiation. Among these radionuclides are the radioactive isotope of potassium ^{40}K and the radionuclides originated from the decay of ^{238}U and ^{232}Th series, both widely spread in soil and rocks of the earth's crust. Naturally occurring radionuclides exposure may be internal or external. External exposure is caused prevalently by gamma radiation from radionuclides in the ^{238}U and ^{232}Th series and from ^{40}K. Higher radiation levels are associated with igneous rocks, such as granite, and lower radiation levels with sedimentary rocks. Internal exposure is linked to radionuclides intake but the main cause is the inhalation of ^{222}Rn and its short-lived decay products. Radon ^{222}Rn is part of the radioactive decay of the ^{238}U series, which is present in building materials. There are number of circumstances in which materials containing natural radionuclides are recovered, processed or brought into position that results in exposure to radiation, i.e. human intervention causes enhanced exposures. In August 2000, the Italian authorities implemented the European Basic Safety Standards Directive (EU BSS) laying down safety standards for the protection of the health of workers and the general public against the dangers from ionizing radiation into national legislative regulation. This study was undertaken to evaluate natural radionuclides activities of ^{238}U, ^{232}Th, and ^{40}K as contaminants to assess the background radiation and distribution of these radionuclides in the airborne dust generated from quarries to the surrounding, to establish a baseline data on the radiation profile of this area and to assess the radiological impact of these nuclides on the health of the people living in the surrounding communities as well as assessing the environment quality of the study area. (UNSCEAR, 2000).

1.2 JUSTIFICATION

Nigeria has different sites of ornamental stone quarries for extraction. Ondo and Ekiti states are examples of states where stone mining activities are carried out. Granite rocks which are abundant in these area is believed to contain radionuclide elements like uranium, thorium and potassium. The surrounding communities of these quarry industries are mostly less educated and unaware of the health effects of exposure to different levels of radionuclides in the dusts from the quarry sites. There is therefore the need to assess the exposure level of the inhabitant of these communities to radioactive pollution.

1.3.0 Aims and Objectives of the study

The objectives of this study include among others:

i. to establish a background data on the radiation profile of this area

ii. to assess the radiological impact of these nuclides on the health of the people living in the surrounding communities

1.4.0 Expected Contribution

This study is expected to:

i. Provide the distribution pattern of natural radionuclides activities of ^{238}U, ^{232}Th, and ^{40}K in the airborne dust generated from quarries to the surroundings.

ii. Results obtain would serve as a baseline data on the radiation profiles in case there is no human activities enhancing the radiation profile of this area

iii. Provide adequate information for environmental policy makers on the levels of radionuclides in the environment.

CHAPTER TWO

2.0. LITERATURE REVIEW

2.1.0 Definition of Dust

Dust is any small solid particles, conventionally taken as those particles below 75μm in diameter, which settle out under their own weight but which may remain suspended for some time (ISO 1995). Similarly, according to IUPAC (1990) dust is any small, dry, solid particles projected into the air by natural forces, such as wind, volcanic eruption, and by mechanical or man-made processes such as crushing, grinding, milling, drilling, demolition, shoveling, conveying, screening, bagging, and sweeping. Dust particles are usually in the size range from about 1 to 100 μm in diameter, and they settle slowly under the influence of gravity.

2.2.0 TYPES OF DUST

According to WHO (1997), the dust found in the work environment include:

1. Mineral dusts: - These are dust obtained through the mining of mineral resources from the ground. For example in the mining of coal, dusts are released during the mining process to the environment, such dusts can be called mineral dust. Dusts such as those containing free crystalline silica (e.g., as quartz), coal and cement dusts;
2. Metallic dusts: - These are dust gotten from metals, and also the dusts gotten from the mining of the metal ores and the extraction and purification of these ores to produce metals. These dusts contains large amount of heavy metals which can be detrimental to human health. Example of this type of dust includes such as lead, cadmium, nickel, and beryllium dusts;

3. Chemical dusts: - These are dusts obtained after some chemical analysis especially bulk chemicals and pesticides and also after some chemical experiment in the laboratory. Chemical dusts can be harmful to the environment and the living organisms around the area. Examples of this kind of dust includes pesticide and bulk chemicals dusts.
4. Organic and vegetable dusts: - These are dusts gotten from vegetables or plants. They can also be called organic dusts. These types of dusts are gotten from organic substances such as flour, wood, cotton and tea dusts, pollens.
5. Biohazards dusts: - These are dusts gotten from biological sources. Biohazard dusts can be harmful to the environment and the living organisms in the environment. Sources of biohazard dust are biological substances such as micro-organisms, viable particles, moulds and spores.
6. Naturally occurring dust: - These dusts are gotten from natural sources. They can be sourced from the occurrence of natural disasters and also any natural occurrence. Naturally occurring dusts include dusts gotten from natural sources such as volcanic ashes, and sandstorms.
7. Fibrous dust: - These dusts are sourced from fibers and other fibrous materials. Examples of fibers include asbestos (comprising two groups of minerals: the serpentines, e.g., chrysotile, and the amphiboles, e.g., crocidolite - "blue asbestos"). Other examples include synthetic fibrous materials such as Rockwool (or stone wool) and glass wool, as well as ceramic, aramid, nylon, and carbon and silicon carbide fibers. Particles with diameter $< 3\ \mu$ m, length $> 5\ \mu$ m, and aspect ratio (length to width) greater than or equal to 3 to 1, are classified as "fibers" (WHO, 1997).

2.3.0 SOURCES OF DUST

According to WHO (1997) sources of dusts in the environment include:

1. Natural sources
2. Anthropogenic sources

1. Natural Sources: these are due to the natural occurrences such as dust from sand storms, flaked off human skin, volcanic eruptions, insect wastes, from the atmosphere, the soil and burnt meteorites.
2. Anthropogenic Sources: these are due to human activities in the environment.

These include:

i. Industrial activities such as mining, refining, production of clothes and cottons, construction and demolition sites, storage piles, production of cements, ore/ stone crushing sites, blasting and drilling.

ii. Domestic activities such as sweeping, refuse burning, grinding, milling, shoveling, conveying, screening and bagging.

iii. Road dusts: these are dust picked up by vehicles traveling on roads, tire and brake wear dust from paved roads and potholes, dust from road construction sites.

iv. Agricultural activities such as harvesting of crops, hoeing of the soil, dust gotten from pollen grains, application of pesticides and fertilizers, vegetable dusts.

v. Dust gotten from organic and vegetable substances such as flour, wood, cotton, tea dust, pollens, viable particles, moulds and spores. (W.H.O 1997)

2.4.0 HEALTH EFFECT OF DUST

Dust particles vary in size from visible to invisible. The smaller the particle, the longer it stays in the air and the further it can travel. Large dust particles fall out of the air relatively close to where they are created. Large dust particle tend to be trapped in the nose and mouth when breathing in and can be readily breathed out or swallowed harmlessly. Smaller or fine dust are invisible and are more likely to penetrate deeply into the lungs while ultrafine particles can be absorbed directly into the blood stream. The type and size of a dust particle determines the toxicity of the dust. Particles small enough to stay airborne may be inhaled through the nose (nasal route) or the mouth (oral route). The probability of inhalation depends on particle aerodynamic diameter, air movement round the body, and breathing rate.

Dust particles small enough to be inhaled can cause irritation of the eyes, coughing, sneezing, hay fever, asthma attack, chronic bronchitis, heart and lung disorder, byssinosis and coal worker pneumoconiosis. (WHO 1997)

2.4.1 Penetration and deposition of dust in the body

Particles small enough to stay airborne may be inhaled through the nose (nasal route) or the mouth (oral route). The probability of inhalation depends on particle aerodynamic diameter, air movement round the body, and breathing rate. The inhaled particles may then either be deposited or exhaled again, depending on a whole range of physiological and particle-related factors.

The five deposition mechanisms are

i. Sedimentation,

ii. Inertial impaction,

iii. Diffusion (significant only for very small particles < 0.5 μ m),

iv. Interception,

v. Electrostatic deposition.

Sedimentation and impaction are the most important mechanisms in relation to inhaled airborne dust, and these processes are governed by particle aerodynamic diameter. There are big differences between individuals in the amount deposited in different regions (Lippmann, 1977). The largest inhaled particles, with aerodynamic diameter greater than about 30 μ m, are deposited in the airways of the head, which is the air passages between the point of entry at the lips or nares and the larynx. During nasal breathing, particles are deposited in the nose by filtration by the nasal hairs and impaction where the airflow changes direction. Retention after deposition is helped by mucus, which lines the nose. In most cases, the nasal route is a more efficient particle filter than the oral, especially at low and moderate flow rates. Thus, people who normally breathe part or all of the time through the mouth may be expected to have more particles reaching the lung and depositing there than those who breathe entirely through the nose. During exertion, the flow resistance of the nasal passages causes a shift to mouth breathing in almost all people. Other factors influencing the deposition and retention of particles include cigarette smoking and lung disease. Of the particles which fail to deposit in the head, the larger ones will deposit in the tracheobronchial airway region and may later be eliminated by mucociliary clearance or - if soluble - may enter the body by dissolution. The smaller particles may penetrate to the alveolar region, the region where inhaled gases can be absorbed by the blood. In aerodynamic diameter terms, only about 1% of 10-μm particles gets as far as the alveolar region, so 10 μ m is usually considered the practical upper size limit for penetration to this region. Maximum deposition in the alveolar region occurs for particles of approximately 2-μ m aerodynamic diameter. Most particles larger than this have deposited further up the lung. For smaller particles, most deposition mechanisms become less efficient, so deposition is less for particles smaller than 2 μm until it is only about 10-15% at about 0.5 μm. Most of these particles are exhaled again without being deposited. For still smaller particles, diffusion becomes an effective mechanism and deposition probability is higher. Deposition is therefore a minimum at about 0.5 μm.

Wherever the particles are deposited, either in the head or in the lung, they have the potential to cause harm either locally or subsequently elsewhere in the body. Particles that remain for a long time have increased potential to cause disease. This is why inhaled particles are important in relation to environmental evaluation and control. (WHO, 1997)

2.5.0 RADIONUCLIDES

A nuclide is a general term applicable to all atomic forms of an element. Nuclides are characterized by the number of protons and neutrons in the nucleus, as well as by the amount of energy contained within the atom.

A radionuclide is an unstable form of a nuclide. They may occur naturally, but can also be artificially produced. A radionuclide or radioactive nuclide is a nuclide that is radioactive. Also referred to as a radioisotope or radioactive isotope, it is an isotope with an unstable nucleus, characterized by excess energy available to be imparted either to a newly created radiation particle within the nucleus or via internal conversion. During this process, the radionuclide is said to undergo radioactive decay, resulting in the emission of gamma ray(s) and/or subatomic particles such as alpha or beta particles. These emissions constitute ionizing radiation. Many radionuclides occur naturally, and others are produced artificially, for example in nuclear reactors and cyclotrons. (Ugwu *et al* 2008)

There are about 650 radionuclides with half-lives longer than 60 minutes. Of these, 34 are primordial radionuclides that existed before the creation of the solar system, and there are another 50 radionuclides detectable in nature as daughters of these, or produced naturally on Earth by cosmic radiation. There is a much larger number of radionuclides, more than 2400, with decay half-lives shorter than 60 minutes. Most of these are only produced artificially, and have very short half-lives. For comparison, there are about 254 stable nuclides.

All chemical elements have radionuclides. Even the lightest element, hydrogen, has a well-known radionuclide, tritium. Elements heavier than lead, and the elements technetium and promethium, exist only as radionuclides.

2.6.0 EFFECTS OF RADIONUCLIDES

Radionuclides that find their way into the environment may cause harmful effects as radioactive contamination. They can also cause damage if they are excessively used during treatment or in other ways exposed to living beings by radiation poisoning. Potential health damage from exposure to radionuclides depends on a number of factors, and "can damage the functions of healthy tissue/organs. Radiation exposure can produce effects ranging from skin redness and hair loss, to radiation burns and acute radiation syndrome. Prolonged exposure can lead to cells being damaged and in turn lead to cancer. Signs of cancerous cells might not show up until years, or even decades, after exposure. Exposure to excess level of background ionization radiation causes somatic and genetic effect that tend to damage critical and/or radiosensitive organs of the body, which ultimately can lead to death (Ajayi, 1999).

The effects of radionuclides can be divided into

I. Biological Effects

II. Psychological Effects

2.6.1 BIOLOGICAL EFFECTS

Radioactive contamination by definition emits ionizing radiation, which can irradiate the human body from an external or internal origin.

2.6.1.1 External Irradiation

This is due to radiation from contamination located outside the human body. The source can be in the vicinity of the body or can be on the skin surface. The level of health risk is dependent on duration and the type and strength of irradiation. Penetrating radiation such as gamma rays, X-rays, neutrons or beta particles pose the greatest risk from an external source. Low penetrating radiation such as alpha particles have a low external risk due to the shielding effect of the top layers of skin (WHO 1997).

2.6.1.2 Internal Irradiation

Radioactive contamination can be ingested into the human body if it is airborne like dust or is taken in as contamination of food or drink which will irradiate the body internally. The biological effects of ingested radionuclides depend greatly on the activity, the bio distribution, and the removal rates of the radionuclide, which in turn depends on its chemical form, the particle size, and route of entry. Effects may also depend on the chemical toxicity of the deposited material, independent of its radioactivity. Some radionuclides may be generally distributed throughout the body and rapidly removed, as is the case with tritiated water. Some organs concentrate certain elements and hence radionuclide variants of those elements. This action may lead to much lower removal rates. For instance, the thyroid gland takes up a large percentage of any iodine that enters the body. Large quantities of inhaled or ingested radioactive iodine may impair or destroy the thyroid, while other tissues are affected to a lesser extent. On the other hand, radioactive iodine is used in the diagnosis and treatment of many diseases of the thyroid precisely because of the thyroid's selective uptake of iodine. The radiation risk proposed by the International Commission on Radiological Protection (ICRP) predicts that an effective dose of one Sievert (100 rem) carries a 5.5% chance of developing cancer. Such a risk is the sum of both internal and external radiation dose. (WHO 1997).

2.6.2 PSYCHOLOGICAL EFFECT

The consequences of low-level radiation are often more psychological than radiological. Because damage from very-low-level radiation cannot be detected, people exposed to it are left in anguished uncertainty about what will happen to them. Many believe they have been fundamentally contaminated for life and may refuse to have children for fear of birth defects. They may be shunned by others in their community who fear a sort of mysterious contagion. Forced evacuation from a radiation or nuclear accident may lead to social isolation, anxiety, depression, psychosomatic medical problems, reckless behavior, even suicide. Such great psychological danger does not accompany other materials that put people at risk of cancer and other deadly illness. It is "only nuclear radiation that bears a huge psychological burden for it carries a unique historical legacy"(WHO 1997).

2.6.3 Sources of Environmental Radiation

The total radiation exposure of human of nearly 97.7% is from natural sources and only 2.3% is from manmade sources of radiation such as radioactive waste released from nuclear reactor operations and accident, fallout from weapon tests, exposure due to radioactive waste dispose. (Srinivasa *et al.,* 2015)

The sources of environmental radiation are often subdivided as natural and man-made radiation. The natural environmental radiation includes:

1 .Cosmic radiation which comes from the outer space.

2. Terrestrial gamma radiation which comes from the ground.

3. Naturally occurring radioactive isotopes, such as

    I. ^{238}U, ^{232}Th series in soils and building materials.

    II. ^{40}K which exists in everything containing K element.

    III. Radon and its decay products. (Ching, 2013)

The natural environmental radiation contributes the major radiation dose received by human. However, human have lived in this natural radiation environment for thousands of years. For the man-made environmental radiation which we are concerned about, it comes from:

I. The radio fallout due to nuclear explosion or nuclear accident such as Chernobyl accident.

II. The nuclear facilities such as the nuclear research reactor, the nuclear power plants, the radiological waste storage site, etc.

III. Industrial and medical usage. It has existed in many different fields of our living. (Ching, 2013).

All organisms including human beings on this earth irrespective of his place of stay and occupation is getting some dose of high energetic radiation, which exits all around us this is called natural background radiation. (Srinivasa *et al.*, 2015)

Today, these naturally occurring radioactive materials or sources deliver a large collective dose to the world population than do all man-made (artificial) sources combined. However, granite rocks contains high concentrations of radionuclides like uranium, thorium and potassium with uranium and thorium incorporated into the granite rocks in the crystallization of the last magma and residual solutions since their large ionic radii stop them from crystallizing out in the early silicates. (Shiva *et al.,* 2008)

Naturally occurring radionuclides contribute significantly to the exposure of human for radiation. Among these radionuclides are the radioactive isotope of potassium ^{40}K and the radionuclides originated from the decay of ^{238}U and ^{232}Th series, both widely spread in soil and rocks of the earth's crust. Naturally occurring radionuclides exposure may be internal or external. External exposure is caused prevalently by gamma radiation from radionuclides in the ^{238}U and ^{232}Th series and from ^{40}K. In August 2000, the Italian authorities implemented the European Basic Safety Standards Directive (EU BSS) laying down safety standards for the protection of the health of workers and the general public against the dangers from ionizing radiation into national legislative regulation. According to the title VII of EU BSS, the new legislative regulation introduces a special section regarding working activities carried out in quarries where the processing of extracted materials is a source of potential exposure because of natural radioactivity high levels arising from a large amount of primordial radionuclides in the ^{238}U and ^{232}Th series and ^{40}K. Italian regulations are fixed the action level of 1 mSv y-1 for workers in these activities. (Ibrahim *et al.*2013,).

2.9.0 THEORY OF ANALYTICAL PROCEDURE IN DUST ANALYSIS FOR RADIONUCLIDES

2.9.1 Drying

One of the most critical steps in the analytical process that can affect radionuclide content in dust samples is sample preparation. In most cases, treatment stage includes several operations such as drying, homogenization, grinding, sub-sampling, digestion and dissolution. Depending on the type of samples, analytical portions of dusts are usually dried before sampling. Removing water from dust samples gives a material that can be easily comminuted by suitable equipment. Each of these sampling stage may be a potential source of contamination thereby altering the original chemical constitution of the sample. (Zukowska and Biziuk, 2008).

The drying technique employed in this sampling is air drying.

Air Drying: - this involves the drying of the sample at room temperature. The sample is air dried to reduce the moisture content in the dust sample. All substances contains moisture to a certain level even if not noticed by the common eyes.

2.9.2 Sieving

This is a separation technique used in separating wanted elements from unwanted material or for characterizing the particle size distribution of a sample, typically using a woven screen such as a mesh or net. The mesh size used in the analysis of the dust sample is 0.02mm. (Wikipedia 2013).

2.9.3 Incubation

This is a technique used during the analysis for the determination of radionuclides in dust samples and also during the analysis of any sample using gamma spectroscopy as the analysis technique to ascertain equilibrium between the radionuclides in the sample. The sample were kept in a polyethylene counting vessels (Marinelli beakers) and were sealed gas-tight and stored for 4 weeks to allow radioactive equilibrium of the uranium and thorium series depending on the assumption of secular equilibrium, where the rate of decay of the daughters becomes equal to the rate of decay of the parent. (Ibrahim *et al*., 2013)

2.9.4 INSTRUMENTAL TECHNIQUES

Choice of Instrumental Techniques

Frequently, the radionuclides in dusts samples are not easily detected and they are present in trace quantities. Therefore, an analytical technique with sufficient sensitivity is required for the accurate determination of these radionuclides in dust samples (Zukowska and Biziuk, 2008).

The final choice of instrumental technique is influenced by the following factors:

I. Accuracy
II. Precision
III. Sensitivity
IV. Nature Of Interference
V. Simplicity of use
VI. Time required for the analysis
VII. Detection capability
VIII. Desired speed
IX. Cost of analysis, etc. (Zukowska and Biziuk, 2008).

2.9.5 TYPES OF INSTRUMENTAL ANALYSIS

The major techniques employed for radionuclides analysis are as follows:

1. Geiger Counter Analysis
2. Astronomical spectrometers
3. Planetary gamma-ray spectrometers
4. Total Absorption Spectroscopy
5. Pandemonium Effect Analysis
6. Alpha-particle spectroscopy
7. Liquid scintillation counting
8. Scintillation counter
9. Gamma Probe
10. Mass spectrometry
11. Gamma spectroscopy.

All these techniques have been shown to be excellent tools for the radionuclide analysis. For this analysis, gamma spectroscopy was used.

2.9.5.1 Gamma Ray Characteristics

Gamma rays are the highest-energy form of electromagnetic radiation, being physically the same as all other forms (e.g., x rays, visible light, infrared, radio) but having (in general) higher photon energy due to their shorter wavelength. Because of this, the energy of gamma-ray photons can be resolved individually, and a gamma-ray spectrometer can measure and display the energies of the gamma-ray photons detected. (Wikipedia, 2012)

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 electronic 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 (Wikipedia, 2015).

2.9.5.2 Principle and Instrumentation of Gamma Ray Spectroscopy

This is the science of identification and/or quantification of radionuclides by the analysis of the gamma-ray spectrum produced in a gamma-ray spectrometer (Amartek, 2010). It is also the quantitative study of the energy spectra of gamma-ray sources, in such as the nuclear industry, geochemical investigation, and astrophysics. It is a universal used technique, reliable, easy to use and easily automated. It is a widely used technique, well illustrated by the following list of examples:

1. Environment Radioactivity Monitoring
2. Health Physics Personnel Monitoring
3. Reactor Corrosion Monitoring
4. Nuclear Materials Safeguards and Homeland Security
5. Forensics and nuclear Forensics

6. Material testing
7. Geology and Minerology
8. Nuclear medicine and Radiopharmaceuticals
9. Industrial process Monitoring (Amartek, 2010).

The technique is based on the fact that most radioactive sources produce gamma rays, which are of various energies and intensities. When these emissions are detected and analyzed with a 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 a gamma source, and is a vital tool in radiometric assay. The gamma spectrum is characteristic of the gamma-emitting nuclides contained in the source. (Wikipedia, 2015)

2.9.5.3 Instrumentation of Gamma-ray Spectroscopy

The equipment used in gamma spectroscopy includes an energy-sensitive radiation detector, electronics to process detector signals produced by the detector, such as a pulse sorter (i.e., multichannel analyzer), and associated amplifiers and data readout devices to generate, display, and store the spectrum. Other components, such as rate meters and peak position stabilizers, may also be included. The most common detectors include sodium iodide (NaI) scintillation counters and high-purity germanium detectors. 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 counter) 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. (Wikipedia, 2015)

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. (Wikipedia, 2015)

2.9.5.4 TYPES OF DETECTORS

There are mainly three types of detectors which includes

1. Scintillation detectors

Scintillation detectors use crystals that emit light when gamma rays interact with the atoms in the crystals. The intensity of the light produced is proportional to the energy deposited in the crystal by the gamma ray. The mechanism is similar to that of a thermoluminescent dosimeter. The detectors are joined to photomultipliers that convert the light into electrons and then amplify the electrical signal provided by those electrons. Common scintillators include thallium-doped sodium iodide (NaI (Tl))—often simplified to sodium iodide (NaI) detectors—and bismuth germanate (BGO). Because photomultipliers are also sensitive to ambient light, scintillators are encased in light-tight coverings.

Scintillation detectors can also be used to detect alpha- and beta-radiation. (Wikipedia, 2015)

2. Sodium iodide-based detectors

Sodium iodide (NaI (Tl)) has two principal advantages:

1. It can be produced in large crystals, yielding good efficiency, and

2. It produces intense bursts of light compared to other spectroscopic scintillators.

NaI (Tl) is also convenient to use, making it popular for field applications such as the identification of unknown materials for law enforcement purposes. This type of detector works on the Compton scattering Principle. The distribution arises because of primary gamma rays undergoing Compton scattering within the crystal: Depending on the scattering angle, the Compton electrons have different energies and hence produce pulses in different energy channels.

If many gamma rays are present in a spectrum, Compton distributions can present analysis challenges. To reduce gamma rays, an anticoincidence shield can be used such as Compton suppressor. Gamma ray reduction techniques are especially useful for small lithium-doped germanium (Ge (Li)) detectors.

Sodium iodide systems, as with all scintillator systems, are sensitive to changes in temperature. Changes in the operating temperature caused by changes in environmental temperature will shift the spectrum on the horizontal axis. Peak shifts of tens of channels or more are commonly observed. Such shifts can be prevented by using spectrum stabilizers.

Because of the poor resolution of NaI-based detectors, they are not suitable for the identification of complicated mixtures of gamma ray-producing materials. Scenarios requiring such analyses require detectors with higher resolution. (Wikipedia, 2015)

3. Semiconductor-based detectors

Semiconductor detectors, also called solid-state detectors, are fundamentally different from scintillation detectors: They rely on detection of the charge carriers (electrons and holes) generated in semiconductors by energy deposited by gamma ray photons.

In semiconductor detectors, an electric field is applied to the detector volume. An electron in the semiconductor is fixed in its valence band in the crystal until a gamma ray interaction provides the electron enough energy to move to the conduction band. Electrons in the conduction band can respond to the electric field in the detector, and therefore move to the positive contact that is creating the electrical field. The gap created by the moving electron is called a "hole," and is filled by an adjacent electron. This shuffling of holes effectively moves a positive charge to the negative contact. The arrival of the electron at the positive contact and the hole at the negative contact produces the electrical signal that is sent to the preamplifier, the MCA, and on through the system for analysis. The movement of electrons and holes in a solid-state detector is very similar to the movement of ions within the sensitive volume of gas-filled detectors such as ionization chambers. Common semiconductor-based detectors include germanium, cadmium telluride, and cadmium zinc telluride.

Germanium detectors provide significantly improved energy resolution in comparison to sodium iodide detectors, as explained in the preceding discussion of resolution. Germanium detectors produce the highest resolution commonly available today. Cryogenic temperatures are vital to the operation of germanium detectors. (Wikipedia, 2015)

2.9.5.5 Detector Performance

Gamma spectroscopy systems are selected to take advantage of several performance characteristics. Two of the most important include

1. Detector resolution
2. Detector efficiency.

1. Detector Resolution

Gamma rays detected in a spectroscopic system produce peaks in the spectrum. These peaks can also be called lines by analogy to optical spectroscopy. The width of the peaks is determined by the resolution of the detector, a very important characteristic of gamma spectroscopic detectors, and high resolution enables the spectroscopist to separate two gamma lines that are close to each other. Gamma spectroscopy systems are designed and adjusted to produce symmetrical peaks of the best possible resolution. The peak shape is usually a Gaussian distribution. In most spectra the horizontal position of the peak is determined by the gamma ray's energy, and the area of the peak is determined by the intensity of the gamma ray and the efficiency of the detector. (Wikipedia, 2015)

2. Detector efficiency

Not all gamma rays emitted by the source that 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. Relative efficiency values are often used for germanium detectors, and compare the efficiency of the detector at 1332 keV to that of a 3 in × 3 in NaI detector (i.e., 1.2×10^{-3} cps/Bq at 25 cm). Relative efficiency values greater than one hundred percent can therefore be encountered when working with very large germanium detectors. 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 (Wikipedia, 2015).

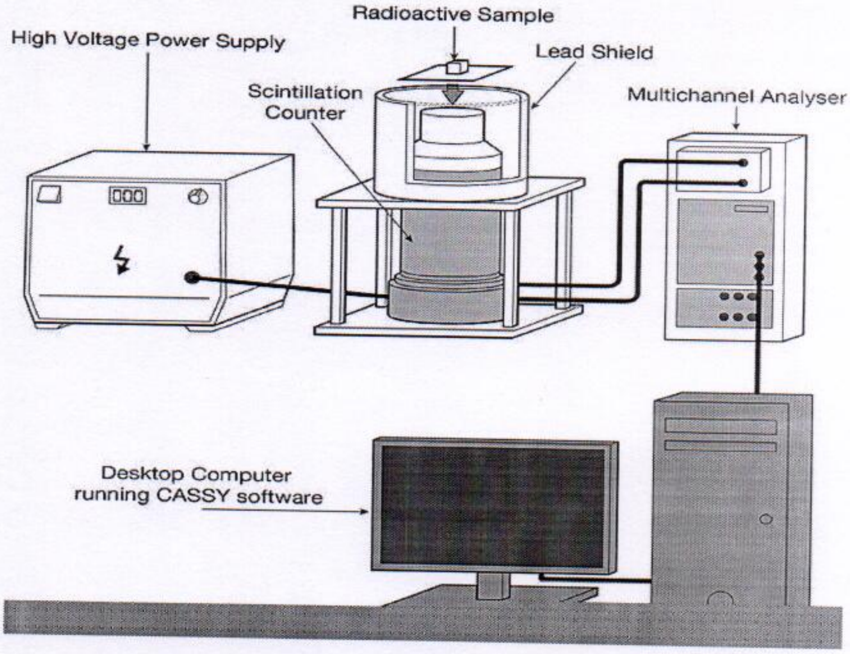

Figure 1: - A diagram showing a typical gamma spectrometer (Wikipedia, 2015)

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1.0 STUDY AREA

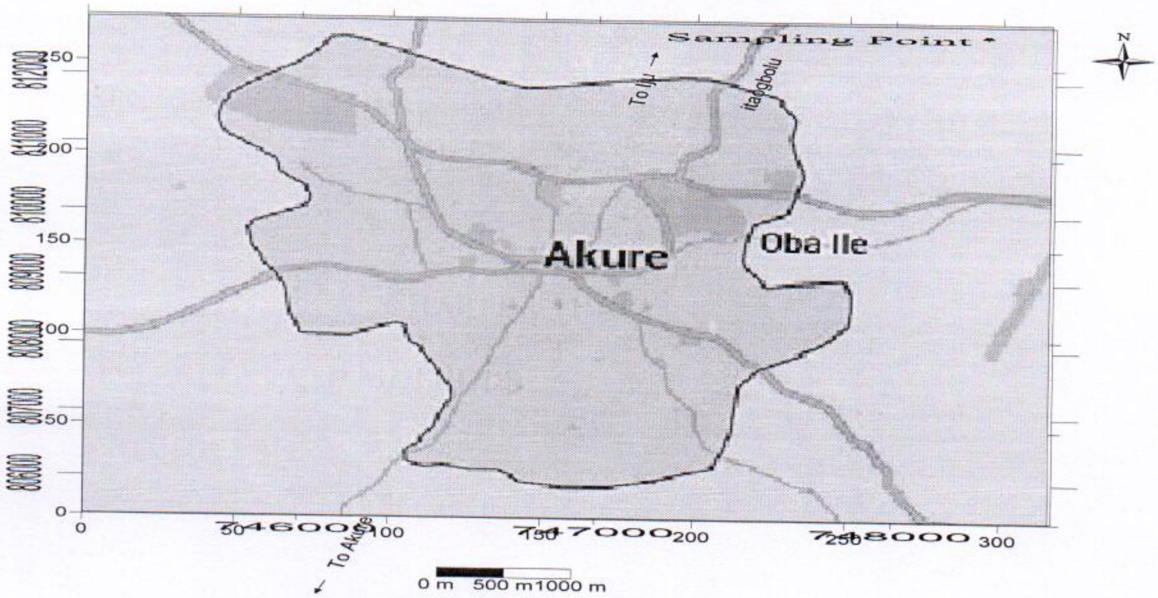

Fig 2: A geographical map of the study area in Akure, Ondo state.

Five representative dust samples used for this study were collected in Ekiti and Ondo States. The dust sample locations include the following villages: Itaogbolu, Shasha, Oye and Ikere. Samples were collected from each site and a control site. Four samples were collected from four quarry sites from the locations mentioned above and a control sample gotten from a non-quarry site.

The surrounding areas from each quarry sites consists of

i. Markets

ii. Vegetation

iii. Communities of people, houses and animals.

The quarry sites that the samples were collected are

i. Sam Chase Quarry and Asphalt Plant located at Itaogbolu, Ondo State. (AKT 1)
ii. Mac Engineering Constructions Limited located at Ikere town, Ekiti State. (EKT 1)
iii. Stone Works Quarry and Asphalt Plant located at Shasha, Ondo State. (AKT 2)
iv. Olaebimi Quarry and Asphalt Plant located at Oye-Ekiti, Ekiti State. (EKT 2)

The control sample was collected at Federal university Oye- Ekiti, Ekiti State. (CTL SA)

3.2.0 SAMPLE COLLECTION AND HANDLING

3.2.1 Sampling Method

In order to obtain fairly representative portion, four sampling locations around each quarry site were used for each dust sample. At each location, the samples were collected and pooled as one. All samples were subsequently labelled according to their locations.

3.2.2 Sampling Collection/Preservation

The samples were collected with polythene bags kept in different locations around the quarry sites in order to collect part of the dusts escaping from the quarry sites during the quarrying activities to the surrounding communities. After collection, 20g of the sample were weighed and air-dried at room temperature for a week to reduce the moisture content in the dust sample and to make the dust look dry. The dust was then sieved through 0.2mm sieves. The dust samples were sieved in order to remove the impurities that accompany themselves with the dust. Impurities such as small stones and other small substances. After sieving, the samples were weighed and 9 kg of the dust samples remained.

3.3.0 METHODS OF INSTRUMENTAL ANALYSIS

The activities of the investigated radionuclides in the dust samples were determined by direct gamma spectrometry, using a high purity germanium (HPGe) detector, with an efficiency of 30% relative to a 3″x 3″ NaI (Tl) scintillator and an energy resolution (FWHM) of 1.8 keV for the 1.33 MeV reference transition of ^{60}Co, was utilized for the measurements. The detection of gamma radiation is used to determine the concentration of the ^{40}K, ^{238}U and ^{232}Th.

The polyethylene counting vessels (Marinelli beakers) were sealed gas-tight and stored for 4 weeks to allow radioactive equilibrium of the uranium and thorium series depending on the assumption of secular equilibrium, where the rate of decay of the daughters becomes equal to the rate of decay of the parent. The prepared Marinelli beakers were placed on the detector endcap.

Both the sample and the detector were surrounded by a cylindrical graded-Z shield of 5 cm thickness of lead, 1cm thickness of Iron and 1cm thickness of aluminum to suppress the background radiation.

A spectroscopic amplifier, with an efficient pile-up rejecter, and an 8k ADC (Analog-to-Digital Converter) processed the signal. The MAESTRO-32 multi-channel analyzer emulation software was utilized for data acquisition, storage, display and online analysis of the spectra. Measurements with an empty Marinelli beaker, under identical conditions, were also carried out to determine the ambient background in the laboratory site. The latter was subtracted from the measured spectra to obtain the net radionuclide activities.

The gamma lines; 351.9 keV of ^{214}Pb, 609.3 keV of ^{214}Bi, 1120.3 keV of ^{214}Bi and 1674.5 keV of ^{214}Bi were used for determining ^{238}U. The gamma lines 338.34 keV of ^{228}Ac, 583.0 keV of ^{208}Tl, and 911.1 keV of ^{208}Ac were used for determining ^{232}Th series, while ^{40}K was measured by its gamma line 1460.7 keV. The uncertainty in the calculated efficiency was estimated to be 5 %.

3.4.0 QUALITY ASSURANCE

3.4.1 Precautions/Safety Measures

A set of procedures was followed in the course of the research work in order to ensure reliable and consistent results. These include the following:

I. Sample details such as name, location, code, etc. were carefully written on sample label at the point of collection to avoid mixing of samples.

II. Blank determinations were carried out and result subtracted from those of samples to correct for instrumental error.

III. A clean 0.2mm sieve and polyethylene plastic containers were used for sieving and storing the stone dust samples respectively in order to avoid sample contamination.

IV. The stone dust were incubated for four weeks to ascertain equilibrium between the parent and daughter radionuclide depending on the assumption of secular equilibrium.

V. All the apparatus used were thoroughly washed before they were used.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1.0 RESULTS

4.1.1 ACTIVTY CONCENTRATION OF RADIONUCLIDES IN THE DUST SAMPLES

The results of gamma-ray measurements of ^{238}U, ^{232}Th and ^{40}K activity concentrations of all quarry dust samples is given in Table 1. The sample activity concentrations are in order $^{238}\mathrm{U} < {}^{232}\mathrm{Th} < {}^{40}\mathrm{K}$. The radioactivity concentration values in the investigated dust samples ranges from (8.02 ± 2.0 to 25.00 ± 4.0 Bq $kg^{-}1$ for ^{238}U, (10.02 ± 1.0 to 32.06 ± 2.0) Bq $kg^{-}1$ for ^{232}Th, and (600.06 ± 2.0 to 1014.06 ± 1.0) Bq $kg^{-}1$ for ^{40}K. It is clearly evident that ^{40}K contributed most to the specific activity compared with ^{238}U and ^{232}Th.

Table 1: Table showing the concentration of the radionuclides in the dust samples in Bq/kg

S/N	Sample Code	^{40}KBq/kg	^{40}K Error	^{232}ThBq/kg	^{232}Th Error	^{238}UBq/kg	^{238}U Error
1	AKT 1	1011.08	3	29.04	2	26.02	2
2	AKT 2	1013.04	2	26.02	3	25.00	4
3	EKT 1	1008.05	3	32.06	2	24.04	2
4	EKT 2	1014.06	1	27.02	4	25.01	3
5	CTL SA	600.06	2	10.02	1	8.02	2

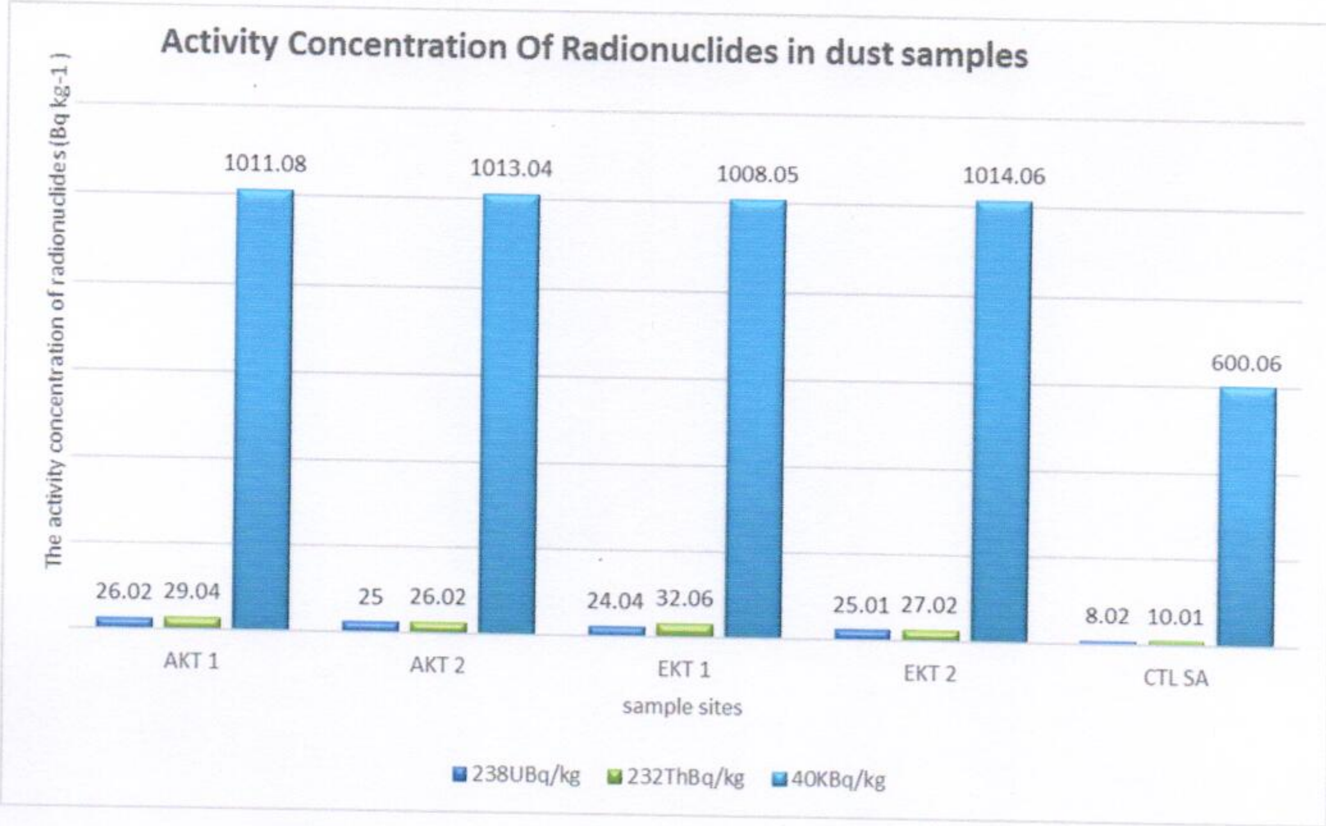

Figure 3: A graph showing the activity concentrations of radionuclides in the dust samples.

4.1.2 ELEMENTAL CONCENTRATIONS OF THE RADIONUCLIDES IN THE DUST SAMPLE

Table 3 presents the elemental concentrations of ^{238}U, ^{232}Th and ^{40}K. They were calculated after conversion of ^{238}U, ^{232}Th and ^{40}K in Bq/Kg to concentrations of ^{238}U and ^{232}Th in (ppm) as well as ^{40}K in % using the conversion factors given by Polish Central Laboratory For Radiological Protection:, 1Bq kg-1 of ^{238}U = 0.08045 ppm of ^{238}U, 1 Bq kg^{-}1 of ^{232}Th = 0.24331 ppm of ^{232}Th and 1 Bq kg^{-}1 of ^{40}K = 0.003296% ^{40}K. (PCLRP, 2000)

Table 2: A table showing the elemental concentrations of the radionuclides in the dust samples in ppm

S/N	Sample Code	^{40}K %	^{40} K Error	^{232}Th ppm	^{232}Th Error	^{238}U ppm	^{238}U Error
1	AKT 1	3.332	0.009	7.066	0.49	2.093	0.16
2	AKT 2	3.339	0.006	6.331	0.73	2.011	0.32
3	EKT 1	3.322	0.009	7.800	0.49	1.934	0.16
4	EKT 2	3.342	0.003	6.574	0.97	2.012	0.24
5	CTL SA	1.978	0.007	2.438	0.24	0.645	0.17

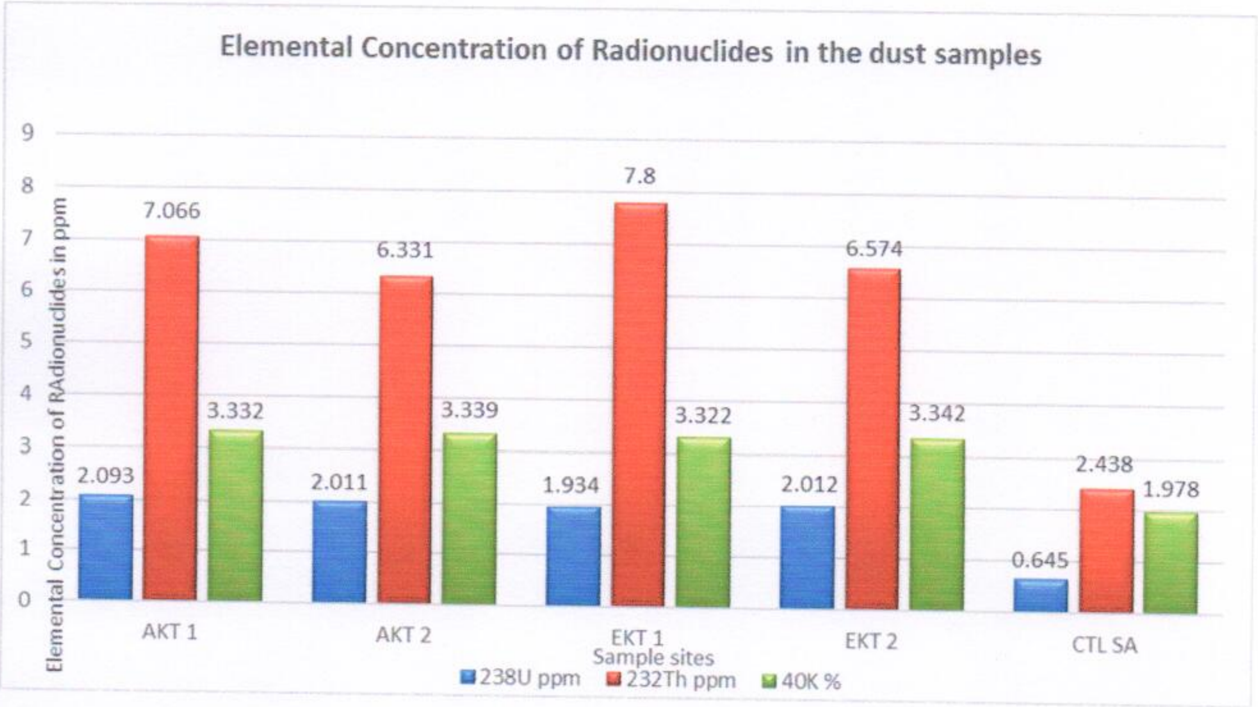

Figure 4: A chart showing the elemental concentration of radionuclides in the dust samples.

4.1.4 THE ABSORBED DOSE RATE

In order to assess the radiological impact of the investigated radionuclides in the dust samples, the γ- radiation doses can be estimated using equation (ii).

$$D = (0.462AU+0.621ATh+0.0417AK)\ nGyh^{-1} \ldots\ldots (ii)$$

Where: D is absorbed gamma dose rates,

AU represent the activity concentrations of ^{238}U in $Bqkg^{-1}$.

ATh represent the activity concentrations of ^{232}Th in $Bqkg^{-1}$.

AK represent the activity concentrations of ^{40}K in $Bqkg^{-1}$.

The absorbed gamma dose rates in air 1m above the ground surface for the uniform distribution of radionuclides (^{232}Th, ^{238}U, and ^{40}K) were computed on the basis of guidelines provided by European Commission Report on Radiological Protection Principles (1999). The conversion factors used to compute absorbed gamma dose rates (D) in air per unit activity concentration in ($1Bqkg^{-1}$) samples are 0.621 nGyh–1 for 232Th, 0.462 nGyh–1 for ^{238}U, and 0.0417 nGyh–1 for ^{40}K.

Table 3: A table showing the absorbed dose rates for the radionuclides in the dust samples in $nGyh^{-1}$

S/N	Sample Code	Dose Rate $nGyh^{-1}$
1	AKT 1	72.217
2	AKT2	69.925
3	EKT 1	73.051
4	EKT 2	70.620
5	CTL SA	34.944

4.1.5 THE ANNUAL EFFECTIVE DOSE EQUIVALENT (Deff)

The annual effective dose equivalent received by a member has been calculated from the absorbed dose rate by applying dose conversion factor of 0.7 SvGy-1 for the conversion coefficient from absorbed and the occupancy factor for outdoor as 0.2×10^{-6} (UNSCEAR, 1992) using the following equations:

Deff (Outdoor) ($mSvy^{-1}$) = (Absorbed dose) $nGyh^{-1} \times 8760h \times 0.7\ SvGy^{-1} \times 0.2 \times 10^{-6}$..... (iii)

The annual effective dose equivalent received values ranged from 0.043 mSv y-1 to 0.089 mSv y^{-1}.

Table 4: A table showing the Annual Effective dose rates for the radionuclides in the dust samples in $mSvy^{-1}$

S/N	Sample Code	Annual Effective Dose Equivalent ($mSvy^{-1}$)
1	AKT 1	0.088
2	AKT2	0.086
3	EKT 1	0.089
4	EKT 2	0.087
5	CTL SA	0.043

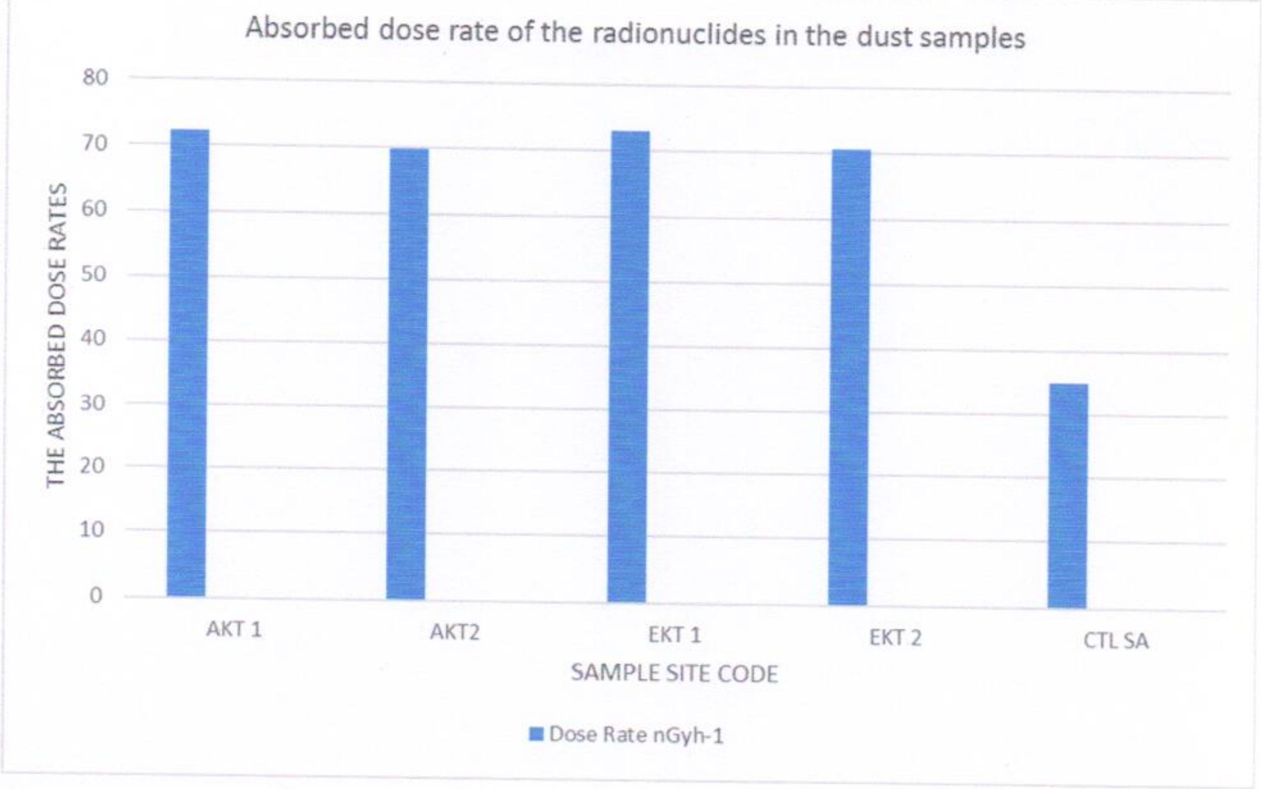

Figure 5: - A chart showing the absorbed dose rate of each sample site.

4.2.0 DISCUSSION

The activity concentration of radionuclides in the dust sample ranges from (8.02 ± 2.0 to 25.00 ± 4.0) Bq kg^{-}1 for ^{238}U, (10.02 ± 1.0 to 32.06 ± 2.0) Bq kg^{-}1 for ^{232}Th, and (600.06 ± 2.0 to 1014.06 ± 1.0) Bq kg^{-}1 for ^{40}K with sample AKT1 with the largest concentration for Uranium, EKT1 with the largest concentration for Thorium, EKT2 with the largest concentration for Potassium and the control sample with the lowest concentration for the three nuclides. Reported by (UNSEAR, 1997) the radionuclides activity concentration must not exceed 30 Bq kg^{-}1 for

^{232}Th, 35 Bq kg^{-}1 for ^{238}U and 400 Bq kg^{-}1 for ^{40}K. This means that the activity concentrations for this study exceeds the (UNSEAR, 1997) standard.

The elemental concentration of radionuclides in the dust samples ranges from (1.449 ± 0.17 to 2.253 ± 0.32) ppm for ^{238}U, (4.807 ± 0.24 to 7.800 ± 0.49) ppm for ^{232}Th and (3.293 ± 0.007 to 3.342 ± 0.003%) for ^{40}K.

The absorbed dose rate for this study ranged from 34.944 nGyh^{-1} to 73.051 nGyh^{-1}. The average gamma dose rate of this study is 64.15 nGyh^{-1}. The recommended acceptable total absorbed dose rate by the people living in the surrounding communities in areas containing γ -radiations from ^{238}U and ^{232}Th series and their respective decay progenies, as well as ^{40}K, must not exceed 55 nGyh^{-1}. According to (ICRP, 1994) and (UNSEAR, 2000), the absorbed gamma dose rate must not exceed 18.93 nGyh^{-1}. It is obvious that the calculated total absorbed dose rates in this study exceeds the range of the accepted dose levels with the control sample below the accepted dose levels. It is clear that the absorbed dose rates depend on the activities of γ -emitters (e.g. ^{238}U, ^{232}Th and ^{40}K). Therefore, the total absorbed dose rate values increase with the activity concentration, and consequently enhances the radiological impact on the surrounding communities. Literatures indicate an average outdoor terrestrial gamma dose rate in the world ranging from 10 nGyh^{-1} to 200 nGyh^{-1}. It is clear that the average gamma dose rates are in the range of the world average. The level of gamma radiation is directly associated with the activity concentrations of radionuclides in the sediment samples. (Obed et al, 2005) reported a dose rate of 24.6 nGyh^{-1} in the population dose distribution to soil radioactive concentration levels in 18 cities across Nigeria. This is an agreement with the mean value obtained in the present study from each of each of either quarries in this study site. But the value is smaller than the value obtained at the control site with gamma absorbed dose rate value of 34.944 nGyh^{-1}. None of the values from this study near the extraneous value of 10.6 $nGyh^{-1}$ obtained in in-situ measurements in the exposure to high background radiation level in the mining area of Jos Plateau. (Ademola, 2008). The highest value from this study which is gotten from EKT 1 is higher than the world average of 70 $nGyh^{-1}$. This high absorbed gamma dose rate is due to the increased quarrying activities in that site.

The annual effective dose equivalent for this study ranges from 0.043 from the control sample to 0.089 from EKT 1, which is below (ICRP, 1992) and (UNSEAR, 2000) standard of 1 $mSvy^{-1}$ and it is also below (ICRP, 1991) standard.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The study reveals the levels of radionuclides in the dusts from the quarry sites in some areas in Ekiti and Ondo states and their effects to the environment and the surrounding communities. The highest activity concentrations of ^{238}U was found in Sam Chase Quarry and Asphalt Plant located at Itaogbolu, Akure, Ondo State and ^{232}Th were found in Mac Engineering Constructions Limited located at Ikere town, Ekiti State while 40K was found in Olaebimi Quarry and Asphalt Plant located at Oye-Ekiti, Ekiti State. The lowest activity concentrations of ^{238}U, ^{232}Th and ^{40}K were recorded in the control site (Federal University Oye, Ekiti).

From environmental point of view, results indicated that the dust gotten from these quarries have human impacts because the radionuclide levels are above the standard absorption rate. There are some potential risk of such industry has an effect on the environment, which requires attention, mitigations, and management to protect the existing human health.

5.2 RECOMMENDATION

In view of the health risks associated with the radionuclides ^{238}U, ^{232}Th and ^{40}K, efforts should be made by concerned authorities to eradicate this pollutants in the environment and also educate surrounding communities on the danger of these quarry sites and ways in which they can protect themselves and quarry management strategy should be implemented to avoid the negative impacts of dust contamination.

REFERENCES

Ajayi, O.S. and Ajayi, I.R. (1999). A survey of Environmental Gamma Radiation levels of some areas of Ekiti and Ondo States, Southwest Nigeria, *Nigerian Journal of Physics* Vol 11, 17-21

Ademola, J.A (2008). Exposure to High Background Radiation Levels in Tin Mining area of Jos, Pleateau, *Nigeria. Journal of Radiological Protection* 28, 93 - 99

AMARTEC (2014) Advanced Measurement Technology Gamma Spectroscopy ORTEC Scientific Equipment. http://www.ametek.com/

Belle, B.K. and Ramani, R.V. (1997). Laboratory evaluation of a two-phase spray system for airborne dust suppression. *Applied Occupational and Environmental Hygiene* 12(12):872-881.

Brígido, F., Barreras, O.C, Montalván E.A, Queipo G.A., Sánchez, P. (1999). Environmental Gamma Radiation Measurements on province of Camagüey, Cuba. *International Symposium on Nuclear and Related Techniques in Agriculture, Industry and Environment* 959-7136-04

Chen, C.J., Lin Y.M. (1996) Assessment of building materials for compliance with regulations of ROC *Environment International*.

Cheng, L. (1973). Formation of airborne respirable dust at belt conveyor transfer points American *Industrial Hygiene Association Journal* 34(12):540-546.

Ching-Chung, H. (2013). Environmental Radiation Monitoring in Taiwan. *Radiation Monitoring Center, Atomic Energy Council.*

Environmental Protection Agency EPA, (2012) Basic Information about the Radionuclides Rule http://www.water.epa.gov/

European Commision Report on Radiological Protection Principles (1999). Conversion Factor to Compute Absorbed Dose Rate from Activity Concentration of radionuclides.

Fasasi, M.K., Tchokossa, .P. Ojo, J.O., and Balogun F.A. (1999). "Occurrence of Natural Radionuclide and Fallout Cesium–137 in Dry Season Agricultural Land of South Western Nigeria". *Journal of Radiation, Analytical and Nuclear Chemistry*. 240(3):949.

Ibrahim Jabbar Husain, Sadiq Hassen Lefta. (2013). "Radon Concentration of Ground Water in Babylon Governorate". *Journal of Academic Research International*. 4(3): 260-263.

International Atomic Energy Agency (IAEA) (2003) *Guidelines for Radioelement Mapping Using Gamma Ray Spectrometry Data, Vienna.*

International Atomic Energy Agency (IAEA). (1994). *Handbook of parameter values for predicting of radionuclide transfer in temperate environments*. Technical report series no. 364. Vienna: IAEA. 2.

International Commission on Radiological Protection (ICRP) (1991). Human respiratory tract model for radiological protection. Publication 66. Analysis of the ICRP 24(1-3). Elsevier Science Ltd., Oxford, UK.

International Commission on Radiological Protection (ICRP) (1992). Human respiratory tract model for radiological protection. Publication 66. Analysis of the ICRP 24(1-3). Elsevier Science Ltd., Oxford, UK.

International Commission on Radiological Protection (ICRP) (1994). Human respiratory tract model for radiological protection. Publication 66. Analysis of the ICRP 24(1-3). Elsevier Science Ltd., Oxford, UK.

International Organization for Standardization (ISO), Geneva (1995). Air Quality - Particle Size Fraction Definitions for Health-related Sampling. ISO Standard 7708.

International Union of Pure and Applied Chemistry (IUPAC) (1990). Glossary of atmospheric chemistry terms. Applied Chemistry Division, Commission on Atmospheric Chemistry. Pure and Applied Chemistry 62 (11):2167-2219.

James L.W., (2013) Health Hazards of Mining and Quarrying, safe work bookshelf, http://www.ilo.org/safework_bookshelf/english?content&nd=857170934.

Krmar M., Slivka J., Varga E., Bikit I., and Veskovic M., (2009) Journal of Geochemical Exploration, 100(1), 20-24.

Leung K.C., Lau S.Y., Poon C.B (1990). Gamma radiation dose from radionuclides in Hong Kong soil. *Journal of Environmental Radioactivity*, 11, 279-290.

Lemele A., de Araujo A.J., Lapae S.J.,. Respiratory Symptoms and Spirometric Tests of quarry workers in Rio de Janeiro. Rev Assoc Med Bras; 40:23-35 (1994).

Lippmann M (1977). Regional deposition of particles in the human respiratory tract. In Lee DHK, Murphy S (editors), Handbook of Physiology: Section IV, Environmental Physiology, 2nd edition. Williams and Wilkins, Philadelphia. Pp. 213-232.

Makobia, C.F., Tchokossa, P., Olomo, J.B., and Balogun, F.A. 2003. "Assessment of the Natural Radioactivity Content of Some Liquid Paints available in Nigeria. NJP. 15(1):14-19.

Mashaallah A, Mohammad RZ, Ali AF. (2013) Prevalence of Silicosis among workers in stone-cutter and Silica Powder Production Factories. Tanaffos 2006; 5:31-6.

Miller, K.M. 1992. "Measurement of External Radiation in United States Dwellings". Radiation Protection Dissymmetry. 45:535 – 539.

Morrow PE (1992). Dust overloading of the lungs: update and appraisal. Toxicology and Applied Pharmacology 113:1-12

Ningappa C., Sannappa J., Chandrashekara M.S., Paramesh L. (2009); Studies on radon/thoron and their decay products in granite quarries around Bangalore city, India, *Indian Journal of Physics*, 83, 8, P.1201,

National Institute for Occupational Safety and Health (NIOSH) (2005); Guidelines for the Safety and Health Protection of Workers in Ornamental Stone Quarrying ; DHHS (NIOSH) Publication No.2005 ; www.cdc.gov/niosh.

Nwibo A.N., Ugwuja E.I., Nwambeke N.O., Emelumadu O.F., Ogbonnaya LU (2012) Pulmonary problems among quarry workers of stone crushing industrial site at Umuoghara, Ebonyi State, Nigeria, *International Journal of Occupation and Environmental Medicine*, 3, (4);

Nwosu, B.C.E. and Sanai, A.O. (1974). "Report of the Radiation Hazards in Mines of Jos Area". *Bulletin of the Nigerian Institute of Physics.* 1:57

Obed, R .I, Farai I. P, Jibiri N. N, "Population dose distribution due to soil radioactivity concentration levels in 18 cities across Nigeria". *Journal of Radiological Protection.* 25(3). 27-40.

Osibote, O.A., Olome, J.B., Tchokossa, P., and Balogun, F.A. (1999). "Radioactivity in Milk Consumed in Nigeria Ten Years after Chernobyl Reactor Accident". Nuc Instl and Meth A. 472:778.

Olaomo, J.B., Tchokossa, P., and Aborisade A.C. (2003). "Study of Radiation Protection Guidelines in the use of Building Materials for Urban Dwelling in South-West Nigeria". NSP. 15(1):7-13.

Polish Central laboratory For Radiological Protection (2000). "Conversion Factors to Elemental Concentration of Radionuclides from Activity Concentration of Radionuclides.

Shiva, N.G., Prassad, N., Nagaiah, Th., Ashok, Karunakara, (2008). "Concentration of ^{226} Ra, ^{232}Th, and ^{40}K in the soils of Bangalore Region, India. *Journal of Health Physics* 94(3): 246-271.

Srinivasa, E., Rangaswamy D. R. and J. Sannappa (2015). Study on Natural Gamma Radiation Hazards in and around Hassan District, Karnataka State, India. *International Journal of Advanced Research in Science and Technology* 4(1), .237-240

Stranden, E., (1979). "Radioactivity of building materials and the gamma radiation in dwellings *Journal of Physics and Engineering in Medicine and Biology*, 24 (5)

Thorpe A, Ritchie AS, Gibson MJ, Brown RC (1999). Measurements of the effectiveness of dust control on cut-off saws used in the construction industry. Annals of Occupational Hygiene 43(7):443-456.

Tim D., Steenland, K., Nelson D.I., Leigh .J.; (2004) Occupational Airborne Particulates, Assessing the environmental burden of disease at national and local levels; Environmental Burden of Disease Series, No.7; World Health Organization Protection of the Human Environment; Geneva.

Trautmannsheimer M., Schramel P., Winkler R., Bunzl K. (1998): Chemical fractionation of some natural radionuclides in a soil contaminated by slags. *Environ Science Technology,* 32, 243- 2.

Ugwu, E.I., K.O. Agwu, and H.M. Ogbu. (2008). "Assessment of Radioactivity Content of Quarry Dust in Abakaliki, Nigeria". Pacific Journal of Science and Technology. 9(1):208-211.

United Nation Scientific Committee on the Effects Of Atomic Radiation (UNSCEAR), (1992) Sources and Effects of Ionizing Radiation. Report to General Assembly, with Scientific Annexes, United Nations, New York.

United Nation Scientific Committee on the Effects Of Atomic Radiation (UNSCEAR), (2000) Sources and Effects of Ionizing Radiation. Report to General Assembly, with Scientific Annexes, United Nations, New York.

United Nation Scientific Committee on the Effects Of Atomic Radiation (UNSCEAR), (1997). "Effect and Risks of Ionizing Radiation". Report to the UN General Assembly.

United Nation Scientific Committee on the Effects Of Atomic Radiation (UNSCEAR), (1988). "Effect and Risks of Ionizing Radiation". Report to the UN General Assembly.

World Health Organization (WHO), (2014) Hazard Prevention and Control in the Work Environment: Airborne Dust 99, 14.

World Health Organization, Geneva (WHO) (1997). Determination of Airborne Fiber Number Concentrations - A Recommended Method, by Phase Contrast Optical Microscopy (Membrane Filter Method).

Wikipedia (2012). Gamma ray https://en.wikipedia.org/wiki/Gamma ray

Wikipedia (2013). Sieving https://en.wikipedia.org/wiki/Sieving

Wikipedia (2015). Gamma ray spectrometer https://en.wikipedia.org/wiki/Gammaspectrometer

Wikipedia (2015). Gamma spectroscopy https://en.wikipedia.org/wiki/Gammaspectroscopy

Yu K.N., Guan Z.J., Stocks Z.J., Young E.C.M. (1992) Study of natural radioactivity and the state of radioactive disequilibrium in U-series for rock samples, North Eastern Desert, Egypt *Journal of Environmental Radioactivity*, 17: 31–48.

Zukowska. J and Biziuk, M., (2008). "Methodological Evaluation of Method for Dietary Heavy Metal Intake". *Journal of Food Science*, Vol 73(2): 21-29.

APPENDIX

CALCULATIONS:

AKT 1. To calculate the elemental concentration of ^{232}U, we use

If 1Bq kg-1 = 0.08045 ppm

Then 26.02 Bq kg-1 = $\frac{26.02 \times 0.08045}{1}$

= 2.093ppm

Error: - The error of 232U is ± 2.0. To calculate the error in ppm, we use

$26.02 + 2.0 = 28.02$

If 1Bq kg-1 = 0.08045

Then 28.02 Bq kg-1 = $\frac{28.02 \times 0.08045}{1}$

-

= 2.254ppm

Therefore, to calculate the error, we subtract 2.093 from 2.254

= (2.254- 2.093) ppm

= 0.1

Therefore, the elemental concentration of 232U is 2.093 ± 0.16ppm

2. To calculate the elemental concentration of ^{238}Th, we use

If 1Bq kg-1 = 0.24331ppm

Then 29.04 Bq kg-1 = $\frac{26.02 \times 0.24331}{1}$

= 7.066ppm

Error: - The error of ^{238}Th is ± 2.0. To calculate the error in ppm, we use

29.04 + 2.0 = 31.04

If 1Bq kg-1 = 0.243310

Then 31.04 Bq kg-1 = $\frac{31.04 \times 0.24331}{1}$

= 7.552ppm

Therefore, to calculate the error, we subtract 7.066 from 7.552

= (7.552- 7.066) ppm

= 0.49

Therefore, the elemental concentration of ^{238}Th is 7.066 ± 0.49ppm

3. To calculate the elemental concentration of ^{40}K, we use

If 1Bq kg-1 = 0.003296%

Then 1011.08 Bq kg-1 = $\frac{1011.08 \times 0.003296}{1}$

= 3.332%

Error: - The error of ^{40}K is ± 3.0. To calculate the error in ppm, we use

1011.08+ 3.0 = 1014.08

If 1Bq kg-1 = 0.003296

Then 31.04 Bq kg-1 = $\frac{1011.08 \times 0.003296}{1}$

= 3.342%

Therefore, to calculate the error, we subtract 3.332 from 3.342

= (3.342 – 3.332) %

= 0.009

Therefore, the elemental concentration of ^{40}K is 3.332± 0.009%

AKT 2. To calculate the elemental concentration of ^{232}U, we use

If 1Bq kg-1 = 0.08045 ppm

$$\text{Then } 25.00 \text{ Bq kg-1} = \frac{25.00 \times 0.08045}{1}$$

$$= 2.011\text{ppm}$$

Error: - The error of 232U is ± 2.0. To calculate the error in ppm, we use

25.00 + 4 = 29.00

If 1Bq kg-1 = 0.08045

$$\text{Then } 29.00 \text{ Bq kg-1} = \frac{29.00 \times 0.08045}{1}$$

-

$$= 2.333\text{ppm}$$

Therefore, to calculate the error, we subtract 2.011 from 2.333

= (2.333- 2.011) ppm

= 0.32

Therefore, the elemental concentration of 232U is 2.011 ± 0.32ppm

2. To calculate the elemental concentration of ^{238}Th, we use

If 1Bq kg-1 = 0.24331ppm

$$\text{Then } 26.02 \text{ Bq kg-1} = \frac{26.02 \times 0.24331}{1}$$

$$= 7.066\text{ppm}$$

Error: - The error of ^{238}Th is ± 3.0. To calculate the error in ppm, we use

$26.02 + 3.0 = 31.04$

If 1Bq kg-1 = 0.24331

Then 31.04 Bq kg-1 = $\frac{31.04 \times 0.24331}{1}$

= 7.552ppm

Therefore, to calculate the error, we subtract 7.066 from 7.552

= (7.552- 7.066) ppm

= 0.49

Therefore, the elemental concentration of ^{238}Th is 7.066 ± 0.49ppm

3. To calculate the elemental concentration of ^{40}K, we use

If 1Bq kg-1 = 0.003296%

Then 1013.04 Bq kg-1 = $\frac{1013.04 \times 0.003296}{1}$

= 3.339%

Error: - The error of ^{40}K is ± 2.0. To calculate the error in ppm, we use

$1013.04 + 3.0 = 1015.08$

If 1Bq kg-1 = 0.003296

Then 31.04 Bq kg-1 = $\frac{1015.04 \times 0.003296}{1}$

= 3.345%

Therefore, to calculate the error, we subtract 3.338 from 3.342

= (3.345 – 3.338) %

= 0.006

Therefore, the elemental concentration of^{40}K is 3.338± 0.006%

EKT 1. To calculate the elemental concentration of ^{232}U, we use

If 1Bq kg-1 = 0.08045 ppm

Then 24.04 Bq kg-1 = $\frac{24.04 \times 0.08045}{1}$

= 1.934ppm

Error: - The error of 232U is ± 2.0. To calculate the error in ppm, we use

24.04 + 2.0 = 26.04

If 1Bq kg-1 = 0.08045

Then 26.04 Bq kg-1 = $\frac{26.04 \times 0.08045}{1}$

= 2.094ppm

Therefore, to calculate the error, we subtract 1.934 from 2.094

= (2.094- 1.934) ppm

= 0.16

Therefore, the elemental concentration of 232U is 1.934 ± 0.16ppm

2. To calculate the elemental concentration of ^{238}Th, we use

If 1Bq kg-1 = 0.24331ppm

Then 32.06 Bq kg-1 = $\frac{32.06 \times 0.24331}{1}$

= 7.800ppm

Error: - The error of ^{238}Th is ± 2.0. To calculate the error in ppm, we use

$32.06 + 2.0 = 34.06$

If 1Bq kg-1 = 0.24331

Then 31.04 Bq kg-1 = $\frac{34.06 \times 0.24331}{1}$

= 8.287ppm

Therefore, to calculate the error, we subtract 7.800 from 8.287

= (8.287- 7.800) ppm

= 0.49

Therefore, the elemental concentration of ^{238}Th is 7.800 ± 0.49ppm

3. To calculate the elemental concentration of ^{40}K, we use

If 1Bq kg-1 = 0.003296%

Then 1008.05 Bq kg-1 = $\frac{1008.05 \times 0.003296}{1}$

= 3.322%

Error: - The error of ^{40}K is ± 3.0. To calculate the error in ppm, we use

$1008.05 + 3.0 = 1011.05$

If 1Bq kg-1 = 0.003296

Then 31.04 Bq kg-1 = $\frac{1011.05 \times 0.003296}{1}$

= 3.324%

Therefore, to calculate the error, we subtract 3.332 from 3.324

= (3.324 – 3.322) %

= 0.009

Therefore, the elemental concentration of^{40}K is 3.322± 0.009%

EKT 2 . To calculate the elemental concentration of ^{232}U, we use

If 1Bq kg-1 = 0.08045 ppm

Then 25.01 Bq kg-1 = $\frac{25.01 \text{ x } 0.08045}{1}$

= 2.012ppm

Error: - The error of 232U is ± 3.0. To calculate the error in ppm, we use

25.01 + 3.0 = 28.01

If 1Bq kg-1 = 0.08045

Then 28.01 Bq kg-1 = $\frac{28.01 \text{ x } 0.08045}{1}$

-

= 2.253ppm

Therefore, to calculate the error, we subtract 2.012 from 2.253

= (2.253- 2.012) ppm

= 0.24

Therefore, the elemental concentration of 232U is 2.012 ± 0.24ppm

2. To calculate the elemental concentration of ^{238}Th, we use

If 1Bq kg-1 = 0.24331ppm

Then 27.02 Bq kg-1 = $\frac{27.02 \text{ x } 0.24331}{1}$

= 6.574ppm

Error: - The error of ^{238}Th is ± 4.0. To calculate the error in ppm, we use

27.02 + 4.0 = 31.02

If 1Bq kg-1 = 0.24331

Then 31.02 Bq kg-1 = $\frac{31.02 \times 0.24331}{1}$

= 7.547ppm

Therefore, to calculate the error, we subtract 6.574 from 7.547

= (7.547- 6.574) ppm

= 0.49

Therefore, the elemental concentration of ^{238}Th is 6.574 ± 0.49ppm

3. To calculate the elemental concentration of ^{40}K, we use

If 1Bq kg-1 = 0.003296%

Then 1014.06 Bq kg-1 = $\frac{1014.06 \times 0.003296}{1}$

= 3.342%

Error: - The error of ^{40}K is ± 1.0. To calculate the error in ppm, we use

1014.06+ 1.0 = 1015.06

If 1Bq kg-1 = 0.003296

Then 31.04 Bq kg-1 = $\frac{1015.06 \times 0.003296}{1}$

= 3.345%

Therefore, to calculate the error, we subtract 3.342 from 3.345

= (3.345 – 3.342) %

= 0.003

Therefore, the elemental concentration of^{40}K is 3.342± 0.003%

CTL SA. To calculate the elemental concentration of ^{232}U, we use

If 1Bq kg-1 = 0.08045 ppm

$$\text{Then } 8.02 \text{ Bq kg-1} = \frac{8.02 \times 0.08045}{1}$$

= 0.645ppm

Error: - The error of 232U is ± 2.0. To calculate the error in ppm, we use

8.02 + 2.0 = 10.02

If 1Bq kg-1 = 0.08045

$$\text{Then } 10.02 \text{ Bq kg-1} = \frac{10.02 \times 0.08045}{1}$$

-

= 0.81ppm

Therefore, to calculate the error, we subtract 2.093 from 2.254

= (0.81- 0.645) ppm

= 0.17

Therefore, the elemental concentration of 232U is 0.645 ± 0.17ppm

2. To calculate the elemental concentration of ^{238}Th, we use

If 1Bq kg-1 = 0.24331ppm

Then 10.02 Bq kg-1 = <u>10.02 x 0.24331</u>

1

= 2.438ppm

Error: - The error of ^{238}Th is ± 1.0. To calculate the error in ppm, we use

10.02 + 2.0 = 12.02

If 1Bq kg-1 = 0.24331

Then 12.02 Bq kg-1 = 12.02 x 0.24331

1

= 2.67ppm

Therefore, to calculate the error, we subtract 2.67 from 2.438

= (2.67- 2.438) ppm

= 0.24

Therefore, the elemental concentration of ^{238}Th is 2.438 ± 0.24ppm

3. To calculate the elemental concentration of ^{40}K, we use

If 1Bq kg-1 = 0.003296%

Then 600.06 Bq kg-1 = 1011.08 x 0.003296

1

= 1.978%

Error: - The error of ^{40}K is ± 3.0. To calculate the error in ppm, we use

600.06+ 2.0 = 602.06

If 1Bq kg-1 = 0.003296

Then 602.06 Bq kg-1 = 602.06 x 0.003296

1

= 1.985%

Therefore, to calculate the error, we subtract 1.985 from 1.978

= (1.985 – 1.978) %

= 0.007

Therefore, the elemental concentration of ^{40}K is 1.978± 0.007%

ABSORBED DOSE RATE

D= (0.462AU+0.621ATh + 0.0417AK)

AKT 1 (0.462 X 26.02 + 0.621X 29.04 + 0.0417X 1011.08)

= 12.0214 + 18.03384 + 42.1620

= 72.217 nGyh^{-1}

AKT 2 (0.462 X 25.00 + 0.621X 26.02 + 0.0417X 1013.04)

= 11.55 + 16.1584 + 42.2437

= 69.952 nGyh^{-1}

EKT 1 (0.462 X 24.04 + 0.621X 32.06 + 0.0417X 1008.05)

= 11.10648 + 19.90926 + 42.0356

= 73.0514 nGyh^{-1}

EKT 2 (0.462 X 25.01 + 0.621X 27.02 + 0.0417X 1014.06)

= 11.5546 + 16.77924 + 42.2863

$= 70.6203 \text{ nGyh}^{-1}$

CTL SA $(0.462 \text{ X } 8.02 + 0.621\text{X } 10.02 + 0.0417\text{X } 600.06)$

$= 34.944 \text{ nGyh}^{-1}$

ANNUAL EFFECTIVE DOSE EQUIVALENT

Deff (Outdoor) (mSvy^{-1}) = (Absorbed dose) $\text{nGyh}^{-1} \text{ x } 8760\text{h x } 0.7 \text{ SvGy}^{-1} \text{ x } 0.2 \text{ x}10^{-6}$

AKT 1 $(72.217 \text{ x } 8760 \text{ x } 0.7 \text{ SvGy}^{-1} \text{ x } 0.2 \text{ x}10^{-6})$

$= 0.088 \text{ mSvy}^{-1}$

AKT 2 $(69.952 \text{ x } 8760 \text{ x } 0.7 \text{ SvGy}^{-1} \text{ x } 0.2 \text{ x}10^{-6})$

$= 0.086 \text{ mSvy}^{-1}$

EKT 1 $(73.051 \text{ x } 8760 \text{ x } 0.7 \text{ SvGy}^{-1} \text{ x } 0.2 \text{ x}10^{-6})$

$= 0.089 \text{ mSvy}^{-1}$

EKT 2 $(70.620 \text{ x } 8760 \text{ x } 0.7 \text{ SvGy}^{-1} \text{ x } 0.2 \text{ x}10^{-6})$

$= 0.087 \text{ mSvy}^{-1}$

CTL SA $(34.944 \text{ x } 8760 \text{ x } 0.7 \text{ SvGy}^{-1} \text{ x } 0.2 \text{ x}10^{-6})$

$= 0.043 \text{ mSvy}^{-1}$