ELEMENTAL AND RADIOLOGICAL HAZARD ASSESSMENT OF SEDIMENTS USED IN BUILDING BLOCKS ALONG THE BARIKIN LADI STREAM IN PLATEAU STATE, NIGERIA.

By:

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DEPARTMENT OF PHYSICS,

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DECLARATION

I hereby declare that the work in this thesis entitled "Elemental and Radiological Hazard Assessment of Sediments used in building Blocks along the Barikin Ladi stream in Plateau State Nigeria" has been carried out by me in the Department of Physics under the supervision of Dr.Y. I. Zakari and Dr. D. Adeyemo. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this thesis was previously presented for another degree or diploma at this or other institution.

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Name of Student	Signature	Date

CERTIFICATION

This titled " ELEMENTAL AND RADIOLOGICAL HAZARD ASSESSMENT OF SEDIMENTS USED IN BUILDING BLOCKS ALONG THE BARIKIN LADI STREAM IN PLATEAU STATE NIGERIA" by AmehAgada George (M.Sc./SCIEN/0884/2010-2011) meets the regulations governing the award of the degree of Masters of Science (Physics) of Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

I dedicate this work to my parents, Mr. and Mrs. Ameh G. E. You two have encouraged me throughout my life and the days and nights that have given birth to this work. May God bless you richly.

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I give God Almighty, my creator, my sincere appreciation for life and the success of this work. My profound gratitude goes to my supervisors: Dr. Y. I. Zakari and Dr. D. Adeyemo for their very professional coaching throughout this work. The head of Physics department, Dr. U. Sadiq must not be forgotten too. Thanks for your encouragements and the relieving 'gists' we had. I wish to acknowledge the staff of Centre for Energy Research and Training, Ahmadu Bello University, especially Professor M. O. A. Oladipo, Dr. Rose Onoja, Dr. Y. I. Viva, Mallam Baffa of gamma spectrometry section and Mallam Shehu of NAA section. Thank you all for every assistance and encouragement at one point or the other during this work.

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ABSTRACT

This study assessed the elemental and radiological hazards of sediments derived from Barikin Ladi stream and used in building blocks of residential homes. Sediment samples were collected from various locations along the stream and analysed using two methods: the NaI(Ti) gamma ray spectrometry technique was used to obtain activity concentration of ^{40}K, ^{226}Ra and ^{232}Th and the neutron Activation Analysis (NAA) technique for the elemental composition of same samples. The gamma ray spectrometry results obtained showed that the mean average activity concentrations for ^{40}K with the range of 102.18±3.27 - 424.73±2.63 Bq/kg is 301.26±7.06 Bq/kg; ^{226}Ra with the range of 13.44±0.12 - 368.53±11.61 Bq/kg is 109.84±5.83 Bq/kg and ^{232}Th with the range of 4.57±1.28 – 707.54±11.40 Bq/kg is 262±1.49 Bq/kg. The mean absorbed gamma dose rate and mean effective dose rate were found to be 234.50 nGy/h and 0.298 mSv/y respectively. NAA results showed that the mean values for Aluminium with the range of 11760 ±281- 76340 ± 611 mg/kg is 46102.5±367 mg/kg; Iron with the range of 2520±118 – 36510±365 mg/kg is 18096±270.38 mg/kg, Titanium with the range of 830±129 – 24220±630 mg/kg is 6036±291.5 mg/kg and Potassium with the range of 737±132 – 14640±410 mg/kg is 6014.63 ±200 mg/kg. Generally, the mean annual effective dose rate obtained is lower than the 1 msv/yr limit set by ICRP for public radiation exposure control.

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LIST OF ABBREVIATIONS IN ORDER OF APPLICATION

NAA - Neutron Activation Analysis

NORM - Naturally Occurring Radioactive Materials

UNSCEAR- United Nations Scientific Committee on the Effects of Atomic Radiation

LRDC - Land Resources Development Centre

ICRP - International Commission on Radiological Protection

EU - European Union

IAEA - International Atomic Energy Agency

CRM - Continuous Radon Monitor

EC - European Commission

MCA - Multi-Channel Analyzer

ALARA- As Low As Reasonably Achievable

PPM - Pats Per Million

BDL - Below Detection Limit

cps - counts per second

LIST OF SYMBOLS IN ORDER OF APPLICATION

NaI(Tl)	-	Thallium doped Sodium Iodide
^{40}K	-	potassium – 40
^{226}Ra	-	Radium – 226
^{232}Th	-	Thorium – 232
U – 238	–	Uranium - 238
Rn – 222	–	Radon 222
P_o – 218		Polonium 218
Bi – 214		Bismuth – 214
SiO_2	-	Silicon dioxide
H	-	Planck's Constant
λ	-	Wavelength
c	-	Speed of Light
m_o	-	Rest mass
Eγ	-	Energy of Gamma Ray
υ	-	Frequency
E_f	-	Final Kinetic Energy
E_B	-	Binding Energy

${}_a\sigma R$	-	Atomic Cross-Section of Raleigh Scattering
Φ	-	Fluence
ψ	-	Energy Fluence
ΣQ	-	Sum of Energy Changes
ε	-	Radon Emanation Power
C_{Ra}	-	Activity Concentration of Radium
C_{Th}	-	Activity Concentration of Thorium
C_K	-	Activity Concentration of Potassium
I	-	Activity Concentration Index
D	-	Gamma Dose Rate
ϕ	-	Neutron-Flux
$I\gamma$	-	Intensity of Gamma ray/Hazard Index
H_E	-	Annual Effective Dose
R_{aeq}	-	Radium Equivalent Activity Concentration
H_{EX}	-	External Hazard Index
nGy/h	-	nano-Gray per hour
m Sv/y	-	milli - Sievert per Year
Bq/Kg	-	Becquerel per Kilogram

Mg/Kg	-	milli – gram per Kilogram
Al	-	Aluminium
Ti	-	Titanium
Na	-	Sodium
Fe	-	Iron

CHAPTER ONE

1.0. Introduction

Exposure to natural sources of radiation is often influenced or can be influenced by human activities. Building materials, for instance, cause excess external gamma exposure due solely to their influenced exposure geometry when compared with that of the undisturbed earth's crust. Such excess in exposure is commonly excluded from any system of radiological protection. Construction materials can, however, cause substantial radiation exposure if they contain elevated levels of naturally occurring radionuclides.

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. The worldwide average indoor effective dose due to gamma rays from building materials is estimated to be about 0.4 mSv per year (UNSCEAR 2000).

Natural radioactivity is mainly connected with the presence of potassium K-40, radioisotopes of U-238 series and thorium Th-232 series. Dose rates from gamma radiation depend mainly on the concentrations of the above-mentioned radioisotopes in the soil and building materials. Radon Rn-222, a gaseous product of decay of radium-226, is extremely important in indoor exposure. Radon which is an inert gas moves freely through porous media such as building materials although usually only a fraction of that produced in the material reaches the surface and enters the air.

Building materials derived from rock and soil contains various amounts of natural radioactive nuclides. These materials contain mainly natural radionuclides of the Uranium (U-238) and Thorium (Th-232) series, and the radioactive isotope of Potassium (K-40). This is because the source of a material determines its composition. In the uranium series, the decay chain segment starting from radium (Ra-226) is radiologically the most important and therefore, reference is

often made to radium instead of uranium. The world-wide average concentrations of radium, thorium and potassium in the earth's crust are about 40 Bq kg^{-1} and 400 Bq kg^{-1}, respectively (EU, 1999).

Radiation exposure due to building materials can be divided into external and internal exposure. The external exposure is caused by direct gamma radiation. An inhabitant living in an apartment block made of concrete with average activity concentrations (40 Bq kg^{-1}, 30 Bq kg^{-1} and 400 Bq kg^{-1} for radium, thorium and potassium, respectively) receives an annual effective dose of about 0.25 mSv (which is in excess of the dose received outdoors). Enhanced or elevated levels of natural radionuclides in building materials may cause doses in the order of several mSv (EU, 1999).

The internal exposure is caused by the inhalation of radon (Rn-222), thoron (Rn-220) and their short lived decay products.

Radon is a noble gas, whose α-radioactive derivatives (Po-218, Pb-214, Bi-214, Po-214) permeate through various levels of the breathing system in a non-bound with aerosols form. Radon easily diffuses from the ground and building materials to indoor air and is the source of exposing bronchus and lungs (UNSCEAR 1988; Stidley C, Samet J 1993; Lubin J.H., Boice J. D, 1989).

Building materials are the most important source of indoor thoron. However, thoron concentrations are usually rather low. Indoor thoron can be an important source of exposure only under some rare conditions where the building materials contain high concentrations of thorium.

On the Jos Plateau of Nigeria, most especially in the rural areas, the people build houses for human habitation with dung natural earth and locally molded into brick blocks. The contribution of this building material to indoor exposure in these areas is of interest. It is one of those restricted areas of tropical Africa, where the systematic exploitation of its resources by

modern methods has created an 'economic island', surrounded by vast areas with a poorly developed exchange economy. It is also a geological island of volcanic formation, and both its varied landforms and its tin-based economy are closely associated with the various phases of volcanic transformation in the area, (Udo, 1970).

The Jos Plateau is probably the most striking morphological feature in Nigeria. It covers an area of about 1875 meters at a general level of about 718.8 meters above the sea level and is surrounded by high plains with altitude ranging from 625 to 935.5 meters (Udo, 1970).

The climate of Jos Plateau is much more pleasant than that of the surrounding plains. The most significant factor observed in this respect is the comparatively low relative humidity which is less than 25% between the months of November and March. The weather during the period is windy and dry. The open nature of the Plateau usually reinforces the wind speed, while the dry and bare ground provides considerable dust particles which intensify the hazy character of the harmattan. The mean annual rainfall is in the range of $1.0 - 1.4 \times 10^3$ mm, Ibeanu (1999).

The present day vegetation of the Plateau is mostly a product of centuries of destructive exploitation of the original woodland, which is now replaced by open grasslands.

Considerable destruction of woodland occurred in the early times when there was great demand for charcoal by local iron industry, which was based on the smelting of lateritic iron ore. However, in the early part of last century the clearance of woodland was intensified so as to meet the demand of the tin industry as reported by Udo (1970). The major occupations of the peasants are orchard farming, cultivation of potatoes, cassava, green vegetables, lettuce and tin ore mining.

These activities, especially the mining which generally involves excavation of land leave radionuclide-rich soil tailings on surfaces. Such soils are picked to make building materials, thereby constituting possible hazards to occupants and the public.

1.1. Geology of the Jos Area

The geology of Nigeria can simply be grouped into the crystalline basement rocks and sedimentary formations, each constituting nearly of equal proportion. Granite rocks dominate the crystalline basement and two distinct groups which differ considerably in age, structure and colour are the older and younger granite.

The Jos Plateau is the center of the younger granite and dated 164±4 Ma (Alexander, 1986). The rocks are predominantly SiO_2–saturated consisting of granites and rhyolites accompanied by quartz-bearing syenites, gabbros and dolerites.

1.2. The Soil of the Plateau

Alexander (1986) explained the dependence of soil in various physical parameters such as rainfall, temperature, organic matter, relief/topography, parent material and time. The nature of soil at any particular time is a function of these parameters. This suggests that soil structure varies from one particular climatic region to another. Certain soil type in the temperate region for example will be structurally different from a similar soil in a tropical zone. Hill (1978) classified the Jos Plateau soil into three major types, which include: soils of granite, lower basalts and unconsolidated deposits and basalts and basalt basement complex

1.2.1. Soils on Granite

These are usually coarse textured, well-drained shallow soils. They have very weak differentiation of genetic horizons, containing coarse elements having solid rocks within 30 cm depth. The crust is mainly ancient and formed under topographical and climatic conditions. However, they are new formations as well. These types of formation may suggest high radioactive environment (Hill 1978).

1.2.2 Soils on Lower Basalts:

These new basalts accommodate variety of soils particularly along the steeper slopes and foot slopes or volcanic cones. On shallow slopes, soils vary in depth and one strongly mottled. Horizon is often rich in organic matter, rich in plant nutrients, formed as crystalline basic rocks and alluvial deposits. Reserve of weathered materials is large. The soils are well structured, permeable and relatively young. (Hill 1978)

1.2.3 Soil on unconsolidated deposits and basement complex

These are associated with outcrops or laterites. They grade down slope with deeper to imperfectly drained strongly mottled soils often with a surface layer of yellow Aeolian loam. They are usually between A and B horizons. Along the slope from rock or late rite, outcrop layers of gravel or iron stone are observed in the surface horizon, often leach with an alluvial B horizon of iron oxides. (Hill 1978)

1.3 Statement of Research Problem

Tin mining and smelting in Barikin Ladi, the study area started many centuries ago. But major exploration of the tin fields started after the discovery of rich alluvial deposits of this area in the beginning of the twenty-first century (Hill, 1978). About three decades ago the area was reported to be high in radioactivity. Babalola (1984) and Oresegun (1986), revealed the adverse effect of Tin mining/milling activities on the mill workers in Jos, around Barikin Ladi. They reported a high activity concentration levels in Uranium and Thorium in the tailings. Mechanized tin mining activities carried out on the Jos Plateau usually involves heavy excavating of soil and removal of massive overburden which resulted in exhumation of primordial radionuclides such as Uranium, Thorium and ^{40}K.

Ibeanu et al., (2013) also reported on the validity of Tin mine stream sediments on construction of residential homes around Jos.

Mining operations constituted radiological problems of land devastation, landscape deterioration and rapid land deforestation. The report of Land Resources Development Centre (LRDC), (1996) indicated that some form of the mining activities had damaged some 316 sq km (3.70%) of the 8600 sq km of the Plateau (Babalola, 1984).

Tin mining involves extraction of minerals like Ilmenite, Columbite, Zircon, Xerotime and Monazite (Ibeanu et al., 2013). These minerals have been observed to contain high concentration of ^{40}K, ^{226}Ra and ^{232}Th (Ismail et al., 2000). Both radiological and chemical toxic elements have been associated with tin mining activities (Ibeanu, 2003).

Mining activities are mostly carried out around river banks or constructed ponds. This is because miners employ these bodies of water for washing off wanted and unwanted stream sediments from tin ores. In one way or the other, these stream sediments get to the banks and are easily accessible to residents especially for building and other uses.

1.4 Aim and Objectives of the Study

The aim of this study is to determine the radioactivity levels of Thorium, Potassium and Uranium in soil and rock samples and the elemental concentration of same samples obtained from the banks of river Barikin Ladi where tin mining sites are situated. To achieve more comprehensive results from the survey, the objectives are divided as:

1. To determine the elemental concentration in soil and rock samples obtained from Barikin Ladi river.
2. To determine the radioactivity levels of the same samples obtained from the same site.

3. To calculate the hazard indexes of the natural radionuclide's; Thorium, Potassium and Radium.
4. To compare calculated hazard indexes with standard values for samples.

The survey area is an old Tin ore mining site located at 9° 55' 0" North, 8° 54' 0" East in Barikin Ladi, in Plateau state.

1.5 Justification of the Research

Natural background radiation comes from cosmic rays from solar system and radioactive elements normally present in the soil. The cosmic rays and the natural terrestrial radionuclides sources in air, food and drinking water are the major contributors to worldwide radiation exposure (Tsoulfanidis,1995).

In addition to the natural background radiation, man-made sources of ionizing radiation due to technological advancement, such as nuclear weapon testing, nuclear power reactors, medical radiation in the form of diagnostic x-rays, radiation therapy, and tin mining and processing operations (Tsoulfanidis, 1995).

Mining activities involve mainly digging and turning out soil from the lower parts of the earth in search of minerals (Hill, 1978). The mined materials are then washed in rivers to remove sand and other unwanted materials. This is the method also employed in tin ore mining at the location of this research. Consequently, natural radionuclides buried in the soil are excavated and left to mix with top soil. The same top soil is later used directly as mud or sand prepared with cement to construct buildings or indirectly in making other building materials like tiles or roofing materials. Rivers also carry materials deposited to other regions and deposited at the banks. Other materials used in this region are gravel, clay, rock stones and mud. All these should be considered in this research.

This work seeks to investigate the radioactivity level in rock and soil used in building walls and floors around Barikin Ladi in plateau state, determine the hazard index and thereafter compare with standard hazard indexes. This may necessitate proposing methods for procuring safer materials for constructing walls and floors, should the values at the site be higher than standard values.

1.6 Scope of Study

Samples of building materials including sand, mud, clay, pebble sand, rock, gravel and gypsum all derived from areas around the mining site was collected. These samples were analyzed using the Neutron Activation Analysis (NAA) and gamma spectrometry for traces of Radium, Thorium, Potassium and Uranium. The activity levels of these radionuclides will be determined, and with the activity levels of the elements, the dose and hazard indexes of the samples for gamma radiation will be evaluated too.

CHAPTER TWO

2.0 LITERATURE REVIEW

Review of Previous Works:

One hundred and seventy seven samples of five types of building materials, i.e. cement, gypsum, cement blocks, gravel and brick, were gathered from different regions of Iran and analyzed by gamma spectroscopy to quantify radioactivity concentrations using a High Purity Germanium (HPGe) detector and a spectroscopy system(Simin Mehdizadeh et al., 2011) According to the results of this investigation, cement samples had maximum values of the mean Ra-226 and Th-232 concentrations, 39.6 and 28.9 Bq/kg, respectively, while the lowest value for mean concentration of these two radionuclide's were found in gypsum samples 8.1 and 2.2 Bq/kg, respectively. The highest (851.4 Bq/kg) and lowest (116.2 Bq/kg) value of K-40 mean concentration were found in brick and gypsum samples, respectively. The absorbed dose rate and the annual effective dose were also calculated from the radioactivity content of the radionuclides. The results showed that the maximum values of dose rate and annual effective dose equivalent were 53.72 nGy/h and 0.37 mSv/y in brick samples. The radium equivalent activities recalculated were below the permissible level of 370 Bq/kg for all building materials.

Natural radioactivity and Radon exhalation were assessed in Egypt by Gustavo Haquin, (2008). Haquin showed that building materials of natural origin reflect the geology of their site of origin. According to him, the average ^{226}Ra, ^{232}Th and ^{40}K activity concentration in the Earth's crust are 35, 30 and 400 Bq/kg.

M. Arogunjo in 2007 collected thirty soil samples within Lagos, Ibadan and Akure to determine effective doses of ^{40}K, ^{238}U, and ^{232}Th. The samples were analyzed using a Na(I) detector. Using the factor 0.7 $SvGy^{-1}$ recommended by UNSCEAR and the outdoor

occupancy factor of 0.2 recommended for the world average, the annual outdoor effective dose in Lagos, Ibadan and Akure ranged from 23.8 to 87.5μSv/yr with mean of 56.5±20.4, 34.3 to 186.4μSv/yr with mean of 93.3±45.5 and 39.6 to 126μSv/yr with mean of 82.2±33.9 respectively (A. M. Arogunjo, 2007).

S. O. Inyang et al in 2009 evaluated the effective dose in timber industries in Calabar, Nigeria to determine if the evaluated dose levels could lead to any radiological health effects in the workers (Articles from Journal of Medical Physics / Association of Medical Physicists of India).

Chijioke M. Amakom and Okechukwu P. Aghamelu (2003) investigated risks of Uranium and Radium doses that may be associated with pyroclastic rocks in Ebonyi state when used as construction materials. In their work, values of Uranium ranged from 0.02 – 0.05 Bq/g while that of Radium, 62.9 – 145.8 mBq/g (Global Journal of Science Frontier Research)

In 2011, the activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th in brick block and concrete block samples around Southwestern Nigeria were determined using gamma-ray spectrometry by K. P. Fasae. Results showed that the mean activity concentration values of 572.6±175.9 Bq/kg, 47.9±9.8 Bq/kg and 63.8±9.4 Bq/kg for ^{40}K, ^{226}Ra and ^{232}Th respectively in concrete blocks are higher compared with values of 351.1±3.1 Bq/kg, 6.2 Bq/kg and 39.8±3.5 Bq/kg obtained in brick blocks (Fasae, 2011).

Ademola Janet (2012), in Ekiti state also estimated Radon contribution from concrete block walls of typical Nigerian dwellings by gamma ray spectrometry measurements of Radium concentration using generic equation. Radon concentrations varied from 11.27 Bq/m^3 for a dwelling of dimensions 4.8 m x 4.8 m and 18.52 Bq/m^3 for a 3.6m x 3.6 m. The effective dose varied from 0.28 to 0.47 mSv (Ibeanu et al., 2013) recently estimated the validity of tin mine stream sediments in construction of residential homes around Kokop, Yelwa, Zawan and

Sabon Barki. The Kokop's mean recorded radium equivalent, mean annual effective dose and gamma activity concentration index were 2057.7±45.8 Bq/kg, 4.6 mSv/yr and 7.0, respectively. They advised that Kokop sediment samples were not safe for use in the construction of residential houses and hence pose a significant source of radiation hazards to occupants of such buildings.

2.1 Electromagnetic Radiation – Photons

Dual Nature: Wave and Particle

Radiation is the emission and propagation of energy through space or a material medium. It is a bundle of energy or photon given out by a radioactive element (radionuclide). It cannot be seen, heard, tasted or touched. This makes people think that our environment is radiation-free. Our world is radioactive. Every object, living and non-living is constantly bombarded with naturally occurring radiation and radiation by man (artificial radiation). Common types of radiation are sound, particles and electromagnetic waves(Tsoulfanidis,1995).

Particle radiation is energy propagated by moving particle that have a non-zero rest mass (and can therefore never reach the speed of light). Particles radiation includes; electrons, protons, neutrons, alpha particles and points, among others. Some natural sources of particle radiations are cosmic rays and the decay of radionuclide (Tsoulfanidis, 1995).

Electromagnetic radiations can be described as periodic, transverse vibrations of electric and magnetic fields, where the two field direction is perpendicular to each other. Electromagnetic energy is propagated at the speed of light = 3×10^{8}m/s in free space. Electromagnetic radiation includes x-rays, gamma rays, ultraviolet rays, visible light, infra-red, microwaves and radio waves (Tsoulfanidis, 1995).

In the latter part of 19th century, Heinrich Hertz carried out a series of experiments, demonstrating that an oscillating electric current sends out electromagnetic waves similar to light waves, but of different wavelength. Hertz proved, thereby, the earlier theory of James Clerk Maxwell that electric current oscillations would create alternating electric and magnetic fields, and radiated electromagnetic waves would have the same physical properties of light. A subsequent discovery by Pieter Zeeman in 1896 further discovered that a magnetic field would alter the frequency of light emitted by a glowing gas, known as the Zeeman Effect (Serway et al., 1997).

Max Planck, in 1990 also proposed a formula to explain that the vibrating particles in the heated walls of kiln could radiate light only at certain energies. These energies would be defined by the product of a constant having the units of energy x time and the radiation frequency. This became the universal Planck constant, h = 6.626 x 10^{-34}JsTsoulfanidis, (1995).

Einstein further demonstrated that the energy of the photoelectron depended on the energy of the photon that collided with the electron or, the product of the Planck's constant, h times the light frequency, υ, according to the formula:

$$E = h\upsilon = {}^{hc}/_{\lambda} \qquad (2.11)$$

Where λ is the light wavelength, c = speed of light. Equation (2.11) is called the Planck – Einstein relation (Woan, 2000).

Electromagnetic radiation may be classified according to its wavelength or origin. For example, gamma rays arise from the nucleus of an atom while x-rays come from extra nuclear electrons.

Since electromagnetic radiations or photons have properties of particles, they should also possess momentum. Momentum is the product of mass and velocity. For relativistic conditions, the mass of a particle is a function of its speed

$$M = \frac{m_o}{\sqrt{1-\frac{u^2}{c^2}}} \quad (2.12)$$

Where m and $m_0$are the particle relativistic and rest masses, u is the particle speed and c, the speed of light. Grateau and Savin (1999) transformed equation (2.12) by squaring both sides and then multiplying each side by $c^2[1-(u^2/c^2)]$ to yield the equation:

$$M^2 c^4 – m^2 u^2 c^2 = m_0^2 c^4 \quad (2.13)$$

Using $E = mc^2$ and $E_0 = m_0c^2$ to define the relativistic and rest energies and p = mu to define the particle momentum together with the fact the rest energy of the photon is always zero, i.e.

$m_0 = 0$, equation (2.13) becomes

$$E^2 – p^2c^2 = 0 \quad (2.14)$$

And

$$P = E/c \quad (2.15)$$

From equation (2.14) and (2.15), photon momentum can further be described by

$$P = E/c = hv/c = h/\lambda \quad (2.16)$$

The unit of momentum, p from relativistic calculations is MeV/c.

2.2 Gamma Radiation

Radionuclide decay processes often leave the product nuclide in an excited energy state. The product nuclide in such an excited state either falls directly to the ground state or descends in steps to lower energy states through the dissipation of energy as gamma radiation.

A nuclide in an excited energy state is referred to as a nuclear isomer, and the transition (or decay) from a higher to a lower energy state is referred to as isomeric transition. Gamma rays are emitted to discrete energies corresponding to the energy state transitions a nuclide may undergo when in an excited state. The energy, Eγ, of a gamma ray may be described as the difference in energy states of the nuclear isomers:

$$E\gamma = h\upsilon = E_1 - E_2 \qquad (2.17)$$

Where $h\upsilon$ is the energy of the electro-magnetic radiation described previously; E_1 and E_2 represent energy levels of the nuclear isomer.

2.2.1 Annihilation Radiation

The negatron or negative beta particle produced by beta decay or pair production will travel through matter until it has completely dissipated its kinetic energy through ionization, electron excitation or bremsstrahlung. The negatron then at rest acts as an atomic or free electron in matter (Glenn Knoll, 1989).

A positron or positive beta particle however, may be considered an "anti particle" of an electron and consequently, in the electron environment of atoms, has a definite instability (Glenn Knoll, 1989). A given positron emitted by pair production or by $\beta + decay$ will also dissipate its kinetic energy in matter through interactions similar to the negatron case. However, as the positron loses its kinetic energy and comes to a near stop, it comes into contact with an electron with nearly simultaneous annihilation of the positron and the electron

masses and their conversion into energy (Glenn Knoll, 1989). The energy released in this annihilation appears as two photons emitted in opposite directions. This transformation of mass into energy, considered as the reverse of pair production, is described as

$$e^{+} + e^{-} = 2h\upsilon = 2E\gamma \qquad (2.18)$$

Where a positron, e+, and electron, e-, combine to form two gamma-ray photons of energy.

2.2.2 Cherenkov Radiation

Charged particles, when they possess sufficient energy, may travel through matter at a speed greater than the speed of light in that material. This occurrence causes emission of photons of light. These photons extend over a spectrum of wavelengths from the ultraviolet into the visible portion of the electromagnetic radiation spectrum (Glenn Knoll, 1989).

The photon emission is a result of a coherent disturbance of adjacent molecules in matter caused by the traveling charged particles, which must possess certain threshold energy. This phenomenon has practical applications in the measurement and detection of radionuclides that emit relatively high- energy beta particles (L'Annunziata and Passo, 2002).

2.2.3 X-radiation

In electron capture decay process, an electron from one of the atomic shells (generally the innermost K shell) is absorbed by the nucleus, where it combines with a proton to form a neutron. No particle emission results from this decay process (L'Annunziata and Passo, 2002).

However, the vacancy left by the captured electron from the K-shell is filled by another electron from an outer shell. Transitions produced in electron shell energy levels result in the emission of energy as x-radiation. This radiation consists of photons of electromagnetic radiation similar to gamma radiation.

2.2.4 Bremsstrahlung

Bremsstrahlung is electromagnetic radiation similar to x-radiation. It is emitted by a charged particle as it decelerates in a series of collisions with atomic particles. A beta particle traveling through matter approaches a nucleus and is deflected by it. This deflection causes a deceleration of the beta particle and consequently a reduction in its kinetic energy with the emission of energy as a photon of bremsstrahlung or "braking radiation" (L'Annunziata and Passo, 2002).

The phenomenon is described by

$$h\upsilon = E_i - E_f \qquad (2.19)$$

Where hυ is the energy of the photon of bremsstrahlung, E_i is the initial kinetic energy of the beta particle prior to collision or deflection, producing a final kinetic energy, E_f, of the electron.

2.3 Radiation from Nature (Natural Radiation)

Radionuclides are found naturally in air, water, soil and in everything within the environment. Over 60 radionuclides can be found in nature. More are been discovered daily. This is the largest source of radiation. About 80% of natural radiation is the cosmic radiation (radiation from sun and stars). Other percentages come from the soil (primordial) and rocks. Cosmic radiation is less at the earth's surface due to the affected charged particles by the earth's magnetic field (Culot, 1976).

2.3.1 Primordial Radionuclides

Primordial radionuclides are left over from when the world and the universe were created. They are typically long-lived, with half-lives often on the order of hundreds of millions of

years. Radionuclides that exist for more than 30 half-lives are non-measurable. The progeny or decay products of the long-lived radionuclides are also in this heading. Here are a few of them:

Table 2.1: Half Life of Long-lived Radionuclides

Nuclide	**Symbol**	**Half**	**Life Natural Activity**
Uranium-235	^{235}U	7.04 x 10^8yr	0.72% of all natural Uranium
Uranium-238	^{238}U	7.04 x 10^9yr	99.2745% of all natural Uranium; 0.5 to 4.7ppmtotal in common rock types
Thorium-232	^{232}Th	1.41 x 10^{10}yr	1.6 to 20ppm in common; rocks with crustal average of 10.7ppm
Radium-226	^{226}Ra	1.60 x 103yr	0.42pCi/g(16Bq/kg) in limestone and 1.3pCi/g(48Bq/kg) in igneous rock
Radon-222	^{222}Rn	3.82 days	Noble gas; annual average air conc. Range btw 0.016pCi/L(0.6Bq/m^3) to0.75pCi/g(28Bq/m^3)
Potassium-40	^{40}K	1.28 x 10^9yr	Soil: 1-30pCi/g(0.037-1.1Bq/g)

(from Ademola, 2012)

Some nuclides like 232-Th have several members in their decay chains, example,

^{232}Th___>^{228}Ra___>^{228}Ac___>^{228Th}___>^{224}Ra___>

^{220}Rn___>^{21}6Po___>^{212}Pb___>Bi___>^{212}Po___>^{208}Pb(stable)

Some other primordial radionuclides are ^{50}V, ^{87}Rb, ^{113}Cd, ^{115}In, ^{123}Te and so on.

2.3.2 Cosmo Genic Radiation

Cosmic radiation permeates all of space, the source being primarily outside of our solar system. The radiation is in many forms, from high speed heavy particles to high energy photons and mourns. The upper atmosphere interacts with many of the cosmic radiations, and produces radioactive nuclides. They can have long half-lives, but the majority has shorter half-lives than the primordial nuclides (Ademola, 2012).

Here is a table with some common Cosmogonist Nuclides:

Table 2.2: Half-life of some Cosmo Genic Nuclides

Nuclide	**Symbol**	**Half-life**	**Source**	**Natural Activity**
Carbon-14	^{14}C	5730 yr	Cosmic ray interaction, 14N(n,p)14C	6pCig(0.22Bq/g)
Tritium-3	^{3}T	12.3 yr	Cosmic ray interactions with N and O; spallation from cosmic rays, 6Li (n,alpha)3H	0.032pCi/kg(1.2×10^{-3}Bq/kg)
Beryllium-7	^{7}Be	53.28 days	Cosmic-ray interactions with N and O	0.27pCi/kg(0.01Bq/kg)

(Ademola, 2012)

Some other Cosmo Genic Radionuclides are ^{10}Be, ^{26}Al,^{36}Cl, ^{80}Kr,^{32}Si and so on.

2.3.3 Human Produced Nuclides

Humans have used radioactivity for one hundred years, and through its use, added to the natural inventories. The amounts are small compared to the naturally produced discussed earlier, and due to the shorter half-lives of many of the nuclides, there has also been a marked decrease since the halting of above ground testing of nuclear weapons. Some human-produced nuclides are listed in table 2.3.

Table 2.3; Half-Life of some Human-Produced Nuclides

Nuclide	Symbol	Half-Life	Source
Tritium	3H	12.3 yr	Produced from weapons testing and fission reactors, reprocessing facilities, nuclear weapons manufacturing
Iodine-131	$^{13}1I$	8.04 days	Fission product produced from weapons testing and fission reactors, used in medical treatment of thyroid problems
Iodine-129	^{129}I	1.57×10^{7}yr	Fission product produced from weapons testing and fission reactors
Cesium- 137	^{137}Cs	30.17 yr	Fission product produced from weapons testing and fission reactors
Strontium-90	90Sr	28.78 yr	Fission product produced from weapons testing and fission reactors
Technetium-99^{m}	^{99m}Tc	6.03 hr	Decay product of 99Mo, used in medical diagnosis
Plutonium-239	^{239}Pu	2.41×10^{4}yr	Produced by neutron bombardment of 238U

(Ademola, 2012)

Chief sources of primordial radiation are Uranium-238, Thorium-232 and Potassium-40. Cosmic radiation includes Hydrogen-3 (tritium) and Carbon-14. Radon is the gaseous component of the three decay series (Uranium-238, Uranium-235 and Thorium-232)

2.4 Ionizing and Non-ionizing Radiation

Ionizing radiations are those that have enough energy to remove electrons from atomic orbital. Directly ionizing radiation deposits energy in the medium through direct coulomb interactions between the directly ionizing charged particle and orbital electrons of the atoms in the medium (Markkanen, 2001).

Indirectly ionizing radiation deposit energy in the medium through a two-step process which are:

a. A charge particle is released in the medium (photons release electrons or positions: neutrons release protons or heavier ions).
b. The released charge particles deposit energy to the medium through direct coulombic interaction with orbital electrons of the medium.

   Non-lionizing radiations are those which do not have enough energy to remove electron from atomic shell.

2.5 Radiation in the Human Body

Humans are made up of chemicals; some of them are radionuclides, many of which are ingested daily in water and food. The estimated concentrations of radionuclides calculated for 70,000 gram adult based on ICRP 30 data is listed below:

Table 2.4: Radionuclide Concentrations for a 70,000 g Adult

Nuclide	**Total Mass of Nuclide found in the body**	**Total Activity of Nuclide found in the body**	**Daily Intake of Nuclides**
Uranium	90 g	30 pCi (1.1 Bq)	1.9 g
Thorium	30 g	3 pCi (0.11 Bq)	3 g
Potassium 40	17 mg	120 nCi (4.4kBq)	0.39 mg
Radium	31 pg	30 pCi (1.1 Bq)	2.3 pg
Carbon 14	95 g	0.4 Ci (15 kBq)	1.8 g
Tritium	0.06 pg	0.6 nCi (23 Bq)	0.003 pg
Polonium	0.2 pg	1 nCi (37 Bq)	~0.6 g

(Source: Ademola, 2012)

2.6 High Background Radiation Areas

Background radiation levels result from a combination of terrestrial (from the ^{40}K, ^{232}Th, ^{226}Ra, etc) and cosmic radiation (photons, muons, etc). The level is fairly constant over the world, being 8 – 15 rad/hr.

Around the world though, there are some areas with sizeable populations that have high background radiation levels. The highest levels are found primarily in Brazil, India and China. The higher radiation levels are due to high concentrations of radioactive minerals in soil. One of such mineral, Monazite, is a highly insoluble rare earth mineral that occurs in beach sand together with the mineral ilmenite, which gives the sands a characteristic black colour. The principal radionuclides in Monazite are from the ^{232}Th series, but there is also some Uranium and ^{226}Ra (L'Annunziata,2003).

2.7 Interaction of Radiation with Matter

The lack of charge or mass in electromagnetic gamma and x-radiations hinder their interaction with, and dissipation of their energy in matter. Consequently, gamma radiation and x-rays have greater penetration power and longer ranges in matter than the massive and charged alpha and beta particles of the same energy(L'Annunziata,2003).

The probability or cross section for each interaction depends on the photon energy and the atomic number of the attenuator (Podgosak, 2005). The photon interaction may be with a tightly bound electron, i.e. with an atom as a whole, with the field of the nucleus or with an essentially free orbital electron (L'Annunziata,2003).

In the context of photon interaction, a tightly bound electron is an orbital electron with a binding energy of the order of or slightly larger than, the photon energy, while a free electron is an electron with binding energy much smaller than the photon energy (Podgorsak, 2005).

During the interaction, the photon may completely disappear or may be scattered coherently or incoherently.

There are three (3) principal ways in which gamma and x- ray interact with matter, leading to transfer and absorption of energy in a medium. These include the following:

1. The photoelectric effects.

2. Compton scattering and

3. Pair productions.

2.7.1 The Photoelectric Effects

The energy of the photon may be completely absorbed by an atom. A photon of relatively low energy (less than 1 Mev) may transfer all its energy to tightly bound electron in an inner shell, causing the electron to be ejected from the absorber atom as shown:

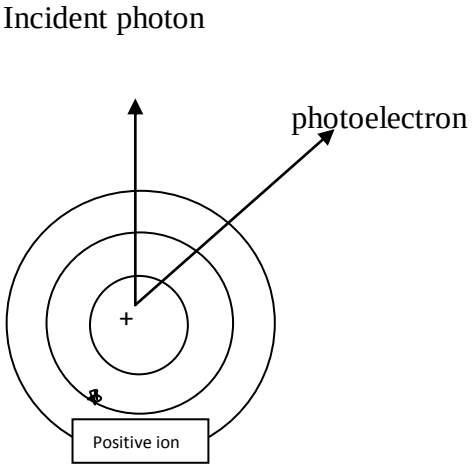


Figure 2.1: The photoelectric effects(L'Annunziata,2003).

The ejected electron, known as a photoelectron, will move through the absorber causing secondary ionization and excitation. For typical photon energies, the most probable origin of the photoelectron is the innermost electron orbit or K shell. The absorber atom is left in an

excited state with vacancy in one of its inner shells. This vacancy is quickly filled by the capture of free electrons from the absorber or by rearrangement of the electrons from other shells of the atom. In the latter case, electrons move from a higher energy shell to fill the vacancy, as they do so, energy is released in the form of characteristic X-rays. In a few cases, the x-ray produced by the above process will interact with an outer shell electron and cause it to be ejected from the atom; it has a low energy and is known as an auger electron.

Photoelectric effect is most likely to occur in materials with a high atomic number, so a materials such as lead (Z=82) makes a useful shielding materials for low energy photons. The photoelectric effects are relatively unimportant in low Z materials such as aluminum (Glenn Knoll, 1989).

The kinetic energy E_k of the photoelectron given by Einstein as;

$$E_K = h_\upsilon - E_B \qquad (2.20)$$

Where E_B = Binding energy of the photon and hυ= incident photon energy L'Annunziata,2003).

2.7.2 Coherent (Raleigh) Scattering

Here the photon interacts with a bound orbital electron (i.e. with the combined action of the whole atom). The event is elastic in the sense that the photon loses just a fraction of its energy and is scattered through a small angle. Since no energy transfer occurs from the photon to charged particles, coherent scattering (Compton effect) plays no role in the energy transfer coefficient. However, it contributes to the attenuation coefficient (Babalola, 1984).

$$_{a\sigma}R \; \alpha \; (Z/h_{\upsilon})^2 \text{ and } {}_{\sigma}R/P \; {}_{\alpha} \; Z/(h_{\upsilon})^2 \qquad (2.21)$$

where

$_{a\sigma}R$ = Atomic cross section of Raleigh scattering

$_{\sigma}R/P$ = Mass attenuation coefficient of Rayleigh scattering (Serway, 1997)

2.7.3 Compton Effect (Incoherent Scattering)

This represents a photon interaction with an essentially free and stationary orbital electron. The incident photon energy is much greater than the blinding energy of the orbital electron. The photon loses part of its energy to the recoil (Compton) electron and is scattered as photon through a scattering angle θ. The angle θ represent angle between the incident photon direction and the direction of the recoil electron (Glenn Knoll, 1989).

The angle at which the photon is scattered depends on its original energy and the transferred energy to the electron. Low energy photon transfer very little energy to the released electron and are scattered through large angles. However, high energy photon (10 to 1000 Mev) transfers most of their energy to the released electron and are not scattered very much.

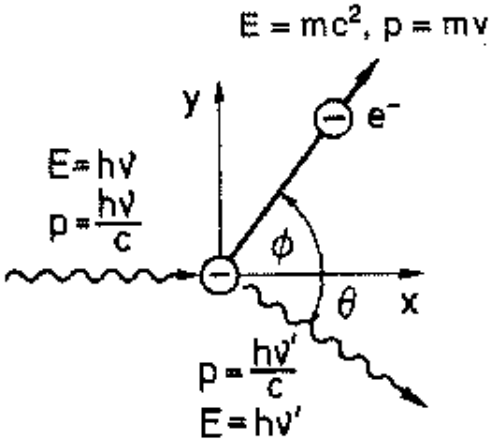


Figure 2.2: Compton Effect (Incoherent scattering) process (Koblinger, 1984)

The change in photon wavelength $\Delta\lambda$ is given by the well known Compton relationship

$$\Delta\lambda = \lambda c\,(1 - cos\theta) \qquad (2.22)$$

(Koblinger, 1984)

Where

$\lambda C =$ Compton wavelength of electron – h/MeC = 0.024A

The scattered angle θ and the recoil electron angle are related through the relationship:

$$\text{Cot } \theta = (1+\varepsilon) \tan (\theta/2) \qquad (2.23)$$

The scattered photon energy hv and kinetic energy of there Compton electron E_k are given as follows:

$$hv' = hv \frac{1}{1+\varepsilon(1+\cos\,\theta)} \qquad (2.24)$$

And

$$E_k = hv \frac{\varepsilon\,(1-cos\theta)}{1+\varepsilon(1-\cos\,\theta)} \qquad (2.25)$$

The energy of photon scattered at 90^0 and 180^0 is thus given as;

$$hv'\,(\theta = 90^0) = \frac{hv}{1+\varepsilon} \qquad (2.26)$$

And

$$hv'\,(\theta = 180^0) = \frac{hv}{1+2E} \qquad (2.27)$$

(Koblinger, 1984)

2.7.4 Pair Production

The interactions with matter considered earlier involve the transfer of gamma energy, in whole or in part, to atomic electrons of the irradiated material. Pair production, as another mechanism of gamma energy dissipation in matter, results in the creation of nuclear particles from the gamma energy (L'Annunziata, 2003).

This mechanism takes place when a photon with energy greater than 1.02 MeV interacts with the strong electric field close to a heavy nucleus of an absorber atom and produces two particles; an electron and a positron. The energy values of 1.02 Me V is the energy equivalent of the total mass of the positron-electron pair and any photon energy in excess of this value provide kinetic energy to the electron and positron then move off and lose kinetic energy through secondary ionization. A positron cannot exist without kinetic energy so when it has lost all its energy it will combine with an absorber atom electron, a process called annihilation of photons, each of 0.51 MeV. These photons are emitted in opposite directions from each other. For photons with energies above the threshold, the probability that pair production will take place increases with atomic number of the absorber. The effect also increases with photon energy slowly from 1.02 to 5 MeV and more rapidly above that pair production is most likely interaction for high energy photon in materials with a high atomic number (P. P. Dendy and B. Heaton, 1999).

When pair production occurs in field of an orbital electron the effect is referred to as triplet production and three particles (an electron, positron pair and the orbital electron) share the available energy. The threshold for this effects is $4MeC^2$ = 2.04 MeV.

2.8 Basic Dosimetric Quantities

2.8.1 Fluence and FluenceRate

The fluence Φ is the quotient dN by da, where, dN is the number of particles incident on a sphere of cross sectional area da, thus;

$$\Phi=\frac{dn}{da} \tag{2.28}$$

Fluence rate is the number of particles passing through unit area in unit time. It is usually measured in $m^{-2}s^{-1}$(Annunziata, 2003).

2.8.2 Energy Fluence:

The energy fluence, ψ is the quotient dRby da, where dR is the radiant energy incident on a sphere of cross sectional area da. Thus;

$$\varphi = \frac{dR}{da} \tag{2.29}$$

2.8.3 Kerma and Kerma Rate

The term kerma refers to kinetic energy released per unit mass of absorber. The kerma, K, is the quotient dE_{tr}bydm where dE_{tr} is the sum of the kinetic energies of all the charged particle liberated by unchanged particles in a mass dm of material thus;

$$K =\frac{dE\,\mathrm{tr}}{dm} \tag{2.30}$$

The special name for the unit of Kerma is gray (Gy) (L'Annunziata, 2003).

The Kermarate K is the quotient dk by dt where dk is the increment of Kerma in the time interval dt, thus:

$$k = \frac{\mathrm{dk}}{\mathrm{dt}} \tag{2.31}$$

If the special name gray is used, the unit of Kerma rate is gray per second (Gy/s)

2.8.4 Energy Imparted or Mean Energy Imparted

The mean energy imparted, ε, to the matter in a given volume equal the radiant energy, $R_{in}$of all those charge and unchanged lionizing particles which enter the volume minus the radiant energy, R_{out}, of all those charge and unchanged ionizing particles which leave the volume, plus the sum ∑Q, of changes of the energy of nuclei and elementary particles which occur in the volume, thus;

$$E = R_{in} - R_{out} + \sum Q \tag{2.32}$$

2.8.5 Absorbed Dose

The absorbed dose, D, is the quotient dm, where dε is the mean energy imparted to matter of mass dm,

$$D = \frac{\mathrm{d}\in}{\mathrm{dm}} \tag{2.33}$$

For a given material and radiation field, absorbed dose and kerma are then numerically equal when secondary electron and equilibrium is established. There will be important numerical differences between the two quantities wherever secondary electron equilibrium is not established (IAEA, 2005).

2.9 Radioactivity in Building Materials

All building materials contain various amounts of radioactive nuclides. Materials derived from rock and soil contain mainly natural radionuclides of the Uranium (^{238}U) and Thorium (^{232}Th) series, and the radioactive isotope of Potassium (^{40}K). In the Uranium series, the decay chain segment starting from Radium (^{226}Ra) is radiologically the most important and, therefore, reference is often made to Radium (EC, 1999). The knowledge of the natural radioactivity of building materials is important for the determination of population exposure to radiations, as most of the people spend ~80% of their time in-doors (UNSCEAR, 1993). High levels of radioactivity in construction materials can increase external and internal indoor exposure situations (ICRP, 1999). The internal and external radiation exposure from building materials creates prolonged exposure (Lee S. C. and C.K. Man, 2001). Currently, a worldwide effort is underway to measure the activity concentrations in building materials. Ceramic tiles are one of the commonly used decorative building materials: they are made of a mixture of earthly materials that have been pressed into shape and fired at a high temperature.

Generally, natural building materials reflect the geology of their site of origin. The average activity concentrations of ^{236}Ra, ^{232}Th and ^{40}K in the Earth's crust are 35, 30 and 400 Bq/kg respectively (UNSCEAR, 2000). However, elevated levels of natural radionuclides causing annual doses of several mSv were identified in more regions around the world, e.g. in Brazil, France, India, Nigeria, Iran.

2.9.1 TENORM and Building Materials

Man is continuously exposed to ionizing radiation from Technically Enhanced Naturally Occurring Radioactive Materials (TENORM). The origin of these materials is the earth's crust, but they find their way into building materials, air, water, food and human body itself.

Recycled industrial by-products containing Technologically Enhanced Natural Occurring Radioactive Materials (TERNOM) 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 (Auxier., 1997)

Doses from the gamma radiation and the radon indoor concentration are assessed by means of direct exposure measurements by mathematical calculations. The increased tendency in the building material industry to use industrial wastes as substitutes for natural products, having relatively high concentrations of NORM, and the increased exposure caused by them are the driving force for the development of standards and guidelines.

2.9.2 NORM in Building Materials

During the last three decades, there has been an increasing interest in the study of the radioactivity of different building materials. Several national surveys were conducted to establish the radioactivity concentrations in raw materials and industrial by-products (Sorantinand Steger,1983, Bruzzi and Tsaji,2000). The production process and the origin of the raw materials are the most important factors that determine the radionuclide activity concentration in the construction materials.

In order to compare the specific activities of materials containing different amounts of ^{226}Ra, ^{232}Th and ^{40}K, an index, called the radium equivalent concentration Ra_{eq} was defined based on the fact that 370 Bq/kg of ^{226}Ra, 259 Bq/kg of ^{232}Th and 4180 Bq/kg of ^{40}K produce the same dose rate (Beretka et al, 1985). Therefore, the Ra_{eq} of building material can be written as:

$$Ra_{eq} = C_{Ra} + 1.43C_{Th} + 0.077C_K \quad (2.34)$$

Gustavo, (2006)

Where C_{Ra}, C_{Th} and C_K are activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K, respectively in Bq/kg.

The raw materials commonly used in the construction industry may contain NORM at different activity concentrations according to their place of origin. Tables 2.5 and 2.6 present typical ranges of activity concentration of the natural radionuclides in natural raw materials and industrial by-products used in the construction industry.

Table 2.5: Activity Concentration Range of Commonly used Natural Raw Materials.

Material	**^{226}Ra (Bq/kg)**	**^{232}TH (Bq/kg)**	**^{40}K (Bq/kg)**
Sand quartz	3 – 39	3 – 56	12 – 1008
Basalt	10 – 22	10 – 21	231 – 420
Gravel	10 – 33	ND – 33	14 – 9333
Limestone	ND – 24	ND – 11	ND – 205
Clay	32 – 53	41 – 75	518 – 843
Wood	ND – 10	ND – 4	4 – 166

Gustavo, (2006)

Table 2.6: Activity Concentration Range of commonly used industrial by-products containing TERNOM.

Raw Material	**^{226}Ra (Bq/kg)**	**^{232}Th (Bq/kg)**	**^{40}K (Bq/kg)**
Fly ash	67 – 760	48 – 232	221 – 735
Zircon	3300 – 3900	680 – 750	45 – 56
Red mud	122 – 568	219 – 496	5 – 101
Phosphogypsum	600 – 1500	ND – 160	ND – 300

Gustavo, (2006)

2.9.3 Activity Concentrations in Building Materials

The activity concentrations of NORM in building materials vary according to the type and origin of the building material. The typical activity concentration (Bq/kg) in the most common building materials in Europe, for example concrete and sand-lime bricks is 40, 30 and 400 and 10, 10, 330 for ^{226}Ra, ^{232}Th and ^{40}K respectively (EUROPEAN COMMISSION, 1999). Tables 2.7 and 2.8 present typical values of NORM in masonry used, both as structural materials and covering layers.

Table 2.7; Activity concentration range (Bq/kg) of common building materials.

Building Material	**^{226}Ra (Bq/kg)**	**^{232}Th (Bq/kg)**	**^{40}K (Bq/kg)**
Concrete	18 – 67	3 – 43	16 – 1100
Light weight concrete	10 – 60	6 – 66	51 – 870
Bricks	7 – 140	8 – 127	227 – 1140
Gypsum	1 – 67	0.5 – 190	22 – 804
Cement	13 – 107	7 – 62	48 – 564

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Table 2.8; Activity Concentration Range (Bq/kg) of Selected Covering Building Materials.

Building Material	**^{226}Ra (Bq/kg)**	**^{232}Th (Bq/kg)**	**^{40}K (Bq/kg)**
Ceramics	25 – 193	29 – 66	320 – 1049
Granite	ND – 160	ND – 354	24 – 2355
Tiles	33 – 61	45 – 66	476 – 788
Marble	1 – 63	0.4 – 142	9 - 986

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2.9.4 Radon Exhalation from Building Materials

The radon emanation power or emanation, denoted by ε, is defined as the fraction of ^{222}Rn produced by the disintegration of ^{226}Ra in the grains of the material that can escape from it. The emanation power is dimensionless and ranges from 0 (no radon escapes from the material) to 1 (all radon escapes). The rate of radon exhalation is proportional to the gradient of the radon concentration in the internal pores (Culot, 1976).

$$E = - D[dC/dx]x = l \quad (2.35)$$

Where D is the effective diffusion coefficient and dC/dx is the change in the radon concentration.

The principal factors affecting the radon exhalation rate (from a building material) per unit activity concentration of ^{226}Ra are the porosity and the density of the material, the diffusion coefficient, the water content, the age and the composition of the material as seen in equation (2.35).

For the following boundary conditions: C(1) = C(-1)=0 and $[dC/dx]x = 0$. The radon exhalation rate E becomes:

$$E = \varepsilon.C_{ra.\ P.}\sqrt{\lambda D/P}.\ t_{anh}(\sqrt{\lambda p/D}.l) \quad (2.36)$$

Where ρ is the density, l is the half thickness of the material, p is the porosity of the material, λ is the decay constant of ^{222}Rn and $\varepsilon.C_{Ra}$ is the effective radium concentration (the fraction of the total radium which contributes to radon exhalation).

Radon exhalation from building materials has been studied since the early 1970's as one of the contributors to the indoor radon concentration (Nazaroff et al, 1988: Auxier et al, 1974). In

Hong Kong and the Netherlands it was found to be the major contributor to the population radon dose (Stoop and Uzza, 1998)

Radon exhalation from building materials has been studied since the early 70's as one of the contributors to the indoor radon concentration (Kovler, 2002). In Hong Kong and the Netherlands was found to be the major contributor to the population radon dose (Krstic et al., 2007)

The radon exhalation rate from concrete varies according to the age of the concrete, the water content and the addition of fly ash**.** The exhalation increases almost linearly with the moisture content up to 50-60%, peaks at 70-80% and decreases steeply for higher moisture levels (Stranden, 1983).The addition of fly ash to concrete generally increases the ^{336}Ra activity, while the radon exhalation rate slightly increases or even decreases (Kovler, 2002).

Several methods for exhalation measurements have been developed, as opposed to the well established gamma spectrometry procedures for the measurements of ^{236}Ra**,** ^{232}Th and ^{40}K. Measurements of radon from the exhaling area, into a closed chamber, purge and trap of the radon, radon flux measurements from the material surface and *in-situ* measurements have been reported**.**

2.10 Methods of Radon Activity Measurements in Building Materials

2.10.1 Closed Chamber Method

The closed chamber method is based on the measurement of the radon activity exhaled from the building material into an airtight closed chamber.

The radon concentration *N* in a closed chamber will grow with time according to the equation;

$$\frac{dN}{dt} = \frac{c}{V} - \frac{(\lambda+\lambda v)}{(\lambda+\lambda v)} \qquad (2.37)$$

Where V is the container volume, c *the* total exhalation rate of the sample, $\boldsymbol{\lambda}$ is the radioactive decay rate and λ_v is the leakage or ventilation rate

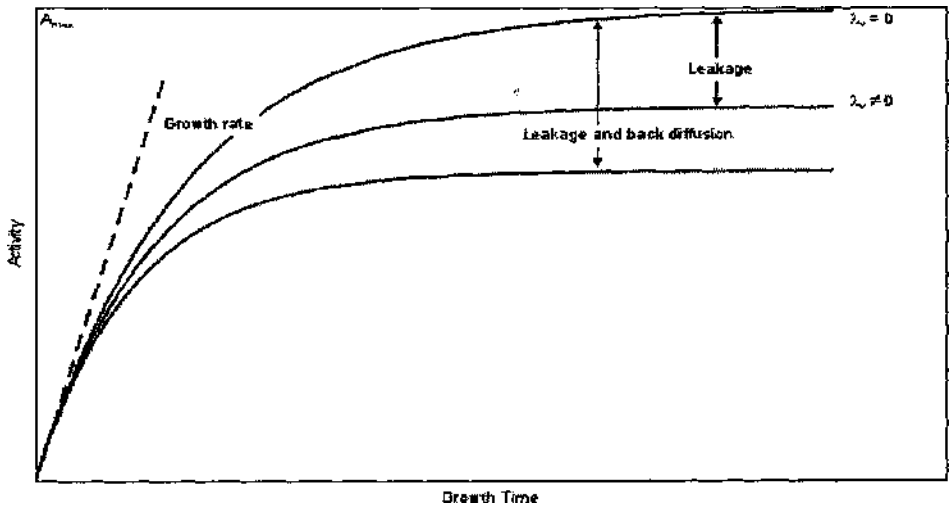


Figure 2.1**:** Radon activity ingrowths in a closed chamber as a function of time.

From Gustavo, (2006)

If the exhalation is depressed due to back diffusion the equilibrium value will be lower than the maximum expected. The total exhalation rate is then calculated by the first part of the in-growth curve (which can be approximated by a linear fit) (Somlai, 2008). It follows, however, from the theory, and it has also been documented experimentally that will decrease as Win creases**.** 'Because of so-called back diffusion**.** The decrease in *c depends* upon the properties of the material and upon the ratio of the sample volume to the free space volume (Somlai, 2008).

The radon is then measured by different means; collecting on activated charcoal (Man, 1989),use of an electrets ion chamber detector, solid state detectors or a continuous radon monitor (CRM). Only the last method, CRM, enables accounting for effects of leakage and back diffusion.

Radon exhalation from the cross sectional surfaces of the material must be prevented in order to simulate, as much as possible, exhalation from the watt. This is done by tightly covering the cross sectional surfaces with rubber and steel plates or other sealing materials so that only the two opposite surfaces of the material remain free to release radon (Somlai, 2008).

2.10. 2. Purge and Trap Method:

The purge-and-trap method (required, by the Dutch standard. NEN 2001b) consists of enclosing the sample in a container from which the exhaled radon is continuously purged with nitrogen gas at a relative humidity of 50% and 20°C (Haquin, 2006). The exchange rate of the sample container has to fulfill the following relationship:

$$\frac{Vs}{V} x \frac{\lambda}{\lambda+\lambda} < 0.1 \qquad (2.38)$$

Where V_S is the volume of the test sample in the container. This requirement guarantees that the radon concentration around the sample is sufficiently low to avoid back diffusion and thus ensure that the free radon exhalation is determined. The nitrogen stream from the sample container is directed through a device to trap the radon gas. The trapping device is based on cooled activated charcoal, cooled silica-gel or room temperature activated charcoal.

2.10.3. Radon Exhalation from Surfaces

The measurement of radon exhaled from the surface of building materials is performed after radon enters into a closed volume as an inverted cup or a semi hemispherical container. The method uses either the linear increase in the concentration of the radon and radon decay products or the integral radon concentration in the closed volume to determine theexhaledradon rate (Haquin et al., 2006). Another approach consisting of measuring the radon directly from the surface using an activated charcoal canister was used in as study to evaluate the reduction of the exhalation rate from concrete by covering materials (Simin Mehdizadeh et al., 2011)

2.10.4. In-situ Radon Exhalation Measurements

In-situ measurements performed directly from the wall or in a sealed room give the closest values to the true exhalation rate of radon into the room. These measurements are rather difficult to perform and few building materials, such as concrete, gypsum slabs or covering materials were investigated. The exhalation rate was determined from the radon concentration growth curve. Measurement of the exhalation directly from the wall demands the container to be clamped against the material surface with a special rack, or against the opposite wall, ceiling or floor with a long rod. The difficulty with these measurements is the fact that because radon is collected from only one side of the slab, back diffusion of radon exists from the container to the slab, especially if the measured material has a high porosity (Lee and Man, 2001).

Measurements of the exhalation rate in a sealed room are possible when the ventilation rate in the room is very low (Less than 1air exchanges every few hundred hours). Measurements were conducted in shielded spaces, which are rooms made of massive concrete equipped with an airtight steel door and window (Lee and Man, 2001)**.**

It is agreed that among commonly used building materials, ordinary concrete has the higher radon emanation coefficient with a mean value around 0.15 (range: 0. 1-0.4), while brick and gypsum have lower mean values, around0.05 and 0.08 respectively (Papastefanou et al., 2005).

The effects of wall covering on radon emanation have been studied for several materials and were found to vary according to the permeability of the covering layer (Lee and Man, 2001). Some plaster and paint will decrease the radon exhalation from painted walls, while at the same time the radon concentration will increase in the wall causing an excess in exhalation from unpainted parts of the wall**.**

The correlation between the exhalation rate measured under laboratory conditions and the in-situ exhalation rate is not fully understood and may vary significantly from one type of building material to another (Lee and Man, 2001). Simulation of the in-situ exhalation conditions in laboratory measurements was held by tightly covering the cross sectional surfaces with suitable sailing materials, so that only the two opposite surfaces of the material (the surface facing the room, and its opposite) remain free to release radon.

2.11 Dose Assessments Inside Buildings

The external and internal exposures in a dwelling are estimated by using the radionuclide concentrations in the building materials and the radon exhalation rate from them, respectively (Woan, 2000)**.** Several methods have been developed to assess those exposures.

2.11.1 Gamma Ray Exposure

The gamma ray exposure in a room is due to radiation emitted by decay products of the ^{23fi}Ra and ^{130}Th series and ^{40}K. Koblinger (Koblinger, 1984) first described a Monte Carlocode, based on basic photon transport models, for the calculation of the exposure rate in a standard room (4mx 5m x 2.8m) from radio nuclides in the wall**.** This method calculates the un-collided part of the dose, while the collided part can be treated by different approaches: using modified attenuation coefficients during the evaluation, of the "optical distance" between, the source and the detection point, inserting of build-up factors specially devised for this purpose or describing photon scattering effects by Monte Carlo simulations (Serway et al., 1997).

The dose calculation based on attenuation and build-up of photons from proposed by Stranden (Stranden, 1983) and modified by Mustonen (Mustonen et al., 1997) is described by the following expression

$$X = \frac{kAp}{4\pi} \sum_i Ei\, N(Ei) \mu a(Ei) \mu a(Ei) \frac{\int B(Ei-s)}{l2} e- ddV \qquad (2.39)$$

Where X is the exposure rate, k is a coefficient of units conversion, *A is* the activity concentration of the radio nuclide, *p is* the material density, *Ei* is the photon, energy, $N(E_i)$ is the number of photons emitted per disintegration, μ_a *(Ei)* is the linear attenuation coefficient in air, $B(E_i s)$ is the build-up factor at energy *E* for distance *s. 1* is the distance from the source point and d_i is the distance the photon travels in the building material. The integration is performed on the volume of the walls.

Another approach developed in the Netherlands for the calculation of the dose rate in a dwelling takes into account the characteristics of every specific house (the construction parts, the building materials used, the internal partitioning, doors and windows, etc.) as independent factors affecting the dose rate (Koblinger, 1984).

2.12 Internal Exposure to Radon

The evaluation of the internal dose caused by building materials is more complicated. The general parameters, apart from the exhalation rate of the building material, affecting the indoor radon concentration are the dimensions of the house (surface to volume ratio) and the ventilation rate.

Expressions for the concentration of radon in indoor air from building materials were derived several authors. The diffusion pathway for ^{220}Rn is about 80 times smaller than for ^{222}Rn and its exhalation can occur only from the outer layer of the material (~1 mm).However, if there is a strong wind, it is quite possible that^{220}Rn atoms are forced out from deeper layers of the wall, causing the exhalation to increase (Koblinger, 1984). The indoor radon concentration in equilibrium is:

$$C=\frac{E.S}{V(\lambda+\lambda v)}+\frac{Co.\lambda v}{\lambda+\lambda v} \qquad (2.40)$$

(Koblinger, 1984)

Where E is the specific exhalation rate, S is the total wall, floor and ceiling area, V the room volume, A, is the radon decay constant C_o is the outdoor radon concentration and $\lambda_y$is the ventilation rate.

In general, ventilation is the key factor that affects the indoor radon, concentration and, on the average, an air-conditioned room has a higher radon concentration than a non-air-conditioned room in the same category of building, and the use of the building may slightly influence the radon concentration (Lee and Man, 2001)

2.13 Regulations on Radiations from Building Materials

The use of industrial by-products and residues containing elevated concentrations of radioactive material in building materials is increasing due to economic and environmental reasons. The national regulatory authorities often preach that "annual doses are restricted to a few mSv for the worst-case scenarios" (UNSCEAR, 2000).

A practical approach would be to treat exposure situations resulting from radioactive building materials as existing exposure situations rather than as planned exposure situations. In fact, most uses of building materials, even of those using NORM residues (e.g., coal ash**),** are de-facto existing exposure situations which can only be sensibly addressed by the use of reference levels or building codes, thus regarding them as a special case of NORM situations or by treating radioactive building materials as a general commodity**.**

Control on the radioactivity of building materials can be based on dose criteria for controls and on exemption levels. The dose criteria used for control should be defined as the excess exposure caused by building materials, i.e. the background dose from natural radio nuclides in the local typical environment need to be subtracted (Annunziata, 2003). For the external gamma radiation, the "local typical environment" can be defined either as the average dose received outdoors, or as the average dose received in a house built from materials with 'typical' activities (Bruzzi and Tsaji, 2000).

For the radon pathway, the evaluation of the excess dose caused by building materials is more complicated. Since most of the indoor radon at ground level is from the underlying soil, the contribution of building materials must be evaluated by using some theoretical model and general assumptions on the parameter values affecting the indoor radon concentration.

Another approach for considering the radon pathway is to limit the amount of ^{226}Ra in the building material so that the indoor radon concentration cannot rise above some pre-set level even under unfavorable conditions. The reference radon concentration for this purpose could be the lower limit of the action level for radon in dwellings (200Bq/m^3) recommended by the ICRP (ICRP, 1999) or some fraction of it. This will enable contributions from other sources, especially from the underlying soil, without exceeding the action level. In Hong Kong a high-rise building action level of 200 Bq/m^3 was proposed for existing buildings and 150Bq/m^3 for new buildings (European Commission, 1999).

The regulation standards commonly include an activity concentration index I as follows:

$$I = \frac{CRa}{ARa} + \frac{CTh}{ATh} + \frac{Ck}{Ak} \qquad (2.41)$$

Where C_x represents the activity concentration of radio nuclide in the building material and A_x is the activity concentration of radio nuclide *x*, which cause a predetermined dose,

2.13.1 The European Recommendation:

The European Commission (EC) set guidelines on the radiological protection principles concerning the natural radioactivity of building materials (RP-112 document) for the Member States (European Commission, 1999). Doses to members of the public should be kept as low as reasonably achievable. However, since small exposures from building materials are ubiquitous, control should be applied on exposure levels which are above typical levels of exposures and their normal variations.

Control should be based on a dose criterion which is established considering the overall national circumstances. Within the EU, doses exceeding 1 *mSv/y* should be taken into account from the

radiation protection point of view. Investigation levels can be derived for practical monitoring purposes, presented in the form of an activity concentration; index as in equation (2.39). The following activity concentration index (I) is derived for identifying whether a dose criterion is met;

$$I=\frac{C_{Ra}}{300\,Bq/kg}+\frac{C_{Th}}{200\,Bq/kg}+\frac{C_K}{3000\,Bq/kg} \qquad (2.42)$$

Gustavo,2006)

Where C_{Ra}. C_{Th}, C_K are the ^{226}Ra, ^{232}Th and ^{40}K activity concentrations (Bq/kg)in the building material. The activity concentration index shall not exceed the values presented in Table 2.9.

Table 2.9: Limits of the Activity Concentration Index.

Dose Criterion	**0.3 msv/y**	**1 mSv/y**
Materials used in bulk amount e.g. concrete	$I \leq 0.5$	$I \leq 1$
Superficial and other materials with restricted use, tiles, boards etc	$I \leq 2$	$I \leq 6$

(Gustavo, 2006)

Small and unavoidable exposures need to be exempted from any control. A uniform exemption level would allow free movement of most building materials within the EU.

Some traditionally used natural building materials, used for decades or centuries, contain natural radio nuclides at levels such that the annual dose of 1 mSv might be exceeded. In these cases, the detriments and costs of giving up the use of such materials should be analyzed, taking into account and should consider financial and social costs and benefits.

2.14 Historical Background of Radioactivity in Building Materials in Some Countries

The Czech Republic belongs to countries with highest indoor radon concentration in the world (mean radon value 140 Bq/m^3) the primary cause is the high radon concentration in the soil (Kumara et al., 2003). However, during the seventies and eighties there were found also three groups of houses with significantly elevated radium concentration in the building materials (Kumar et al., 2003):

i) houses in the small town Jachymov (Joachimstal) contaminated by residue from uranium paints factory and radium factory.

ii)houses from highly emanated autoclave aerated concrete produced from flying ash,

iii)Family houses from slag concrete. Some of the important details are summarized.

2.14.1 Houses in Jachymov:

Jachymov, the mining town known for mining but later uranium mining industry and radium producing factory. Due to silver and uranium exploration and factory producing uranium paints and radium before the World War II, the town was locally contaminated in the past. The residues from factories were also used as additive into plaster and mortar in a lot of the Jachymov's houses, with ^{226}Ra mass activity up to 1 MBq/kg in extreme cases and indoor gamma dose rates in the range of 10-

100 µGy/h. The contamination was not uniform. The case was revealed in the seventies, but that time there was no national legislation concerning indoor radon and indoor radioactivity (Kumar et al., 2003).

The remedy measures carried out in the seventies were drastic - the worst houses were demolished and material taken away and processed in uranium ore mills. Most remaining contaminated houses were mitigated later in the nineties. Remedial measures were based on detailed radon and gamma diagnostic and targeted removal of plasters and mortar, if there was only local contamination (Kumar et al., 2003).

2.14.2 Family Houses from Autoclaved Aerated Concrete

In the 1980 there were found groups of family houses built from autoclaved aerated concrete (^{226}Ra mass activity up 1 kBq/kg). The indoor radon concentration in extreme cases was up to 1000 Bq/m^{3}becauseof high emanation coefficient of this material (range 15-30 %). The indoor gamma dose rates were in the range of 0.1- 0.3 µGy/h.

Some twenty thousand houses from this material were built in the period 1963-1980. Fortunately, the aerated concrete was used in most of them only as the minor part of building material and hence indoor radon concentrations exceeded the intervention level only in about 1-2 % of these houses (Kumar et al., 2003).

2.14.3 Family Houses from Slag Concrete:

The last group was discovered in the 1987. There were found some 3000 factory-made family houses from slag concrete panels with ^{226}Ra mass activity in the range 1-10 kBq/kg. The source of the activity was slag from a small power plant burning high radioactive local coal from a mine near

Prague. The first Producer Company knew the radioactive danger of the slag from the fifties (Mavi and Akkurt, 2010)

After changes in the factory ownership the new management took no care of this danger and more than 2000 family houses were built in the period of 1972- 1983 distributed all over the country, most of them in Central Bohemia around Prague. All the peripheral and supporting walls were made from this material, while some partition walls were from bricks (Kumara et al., 2003). However because of small emanation coefficient of the material (only 1-5%) the indoor radon concentration was only in the range of 200-800 Bq/m^3. The indoor gamma dose rates in this group of houses were in the range of 0.5-2 $\mu Gy/h$; the spatial variation in rooms was characterized by a factor of 2, with highest values in the comer of peripheral walls (Mavi and Akkurt, 2010).

The owners of these houses were aware of the cause of their trouble and applied for remedial measures or the possibility to buy up these houses by the government. The government has agreed after great struggle in 1991. Most of the owners have accepted remedial measures; andonly4 % of the owners sold their houses. After some experiments, it was clear that radon removal by forced ventilation was the only effective and reasonable mitigation measure. The ventilation system with heat recovery, controlled by a central computer, was found to be most effective counter measure and was used in practice. Radon level was reduced to 30% of the former values on average. Other remedial measures (gamma shielding, removal of building material, wall covering by special radon proof materials, etc.) were tested in some cases but were rejected as non effective. This case revealed the differences in risk perception. As it turned out:

- despite the effective doses were the same, the fear of gamma exposure was generally much higher than that of radon exposure (radon exposure was supposed to be easily mitigated),

-The human exposure in houses built from man-made "radioactive" building materials (caused by failure of governmental supervision), was perceived worse compare to exposure from natural soil radon,

-while at the beginning nearly all owner called for buy -up of their radioactive houses by the government, only about 4 % really decided to sell it.

2.15 Development of Regulation in the Czech Republic After 1987

It was the mentioned experiences from the, past that lead to strict regulation of natural radioactivity. The first regulation, was prepared in 1987 for indoor radon agama exposure in existing houses and at the same time for natural radioactivity in building materials (Sharaf and Petit,1999)

2.15.1 Interventional Levels for Existing Houses:

The first recommendation on limitation of both indoor exposures (gamma and radon) in the houses was prepared in 1987 (Report SURO, 2005).

Recommended value for remediation of indoor radon exposure in existing building was set to400 Bq/m^3. Recommended value for indoor gamma dose-rate was set to 2 (μGy/h.

Having in mind both radon and gamma exposures, the special intervention level that summed up both exposures was defined by index S:

$$S=\frac{D}{2\mu Gy\ /h}\ +\frac{CRn}{400\,Bq\ /m3} \qquad (2.43)$$

(Report SURO, 2005).

Where *D is* the gamma dose rate (μGy/h) and C_{Rn} is the long-term radon concentration (Bq/m^3). This sum up rule (used only if D > 0.5 μGy/h) and value *S = 1* were used for decision making on remedial measures with governmental support (Report SURO, 2005).

2.15.2. Regulation Concerning the Natural Radioactivity of Building Materials:

The limit value ^{226}Ra was set to 120 Bq/kg. This value was derived from model room calculation so that the building material will contribute to indoor radon limit value (200 Bq/m^3) in new houses not more than 30% (under conservative conditions), having in mind that the underlying soil is the most important source of indoor radon (Sharaf and Petit,1999). The other systems of regulation based on limitation of radon exhalation rate or emanation coefficient were discussed but rejected at the end because of sophisticated measurements of exhalation, long term changes and complicated system of limitation (YU 1997, Roelofs 1994, Petropoulos2001).

2.15.3The European Regulation on Radioactivity in Building Materials:

The radiological protection principles concerning the natural radioactivity of building materials were developed in the second half of the nineteen nineties in the Europe. The European Commission (EU Recommendation no.112, 1999, Mustonen 1997, Markkanen 2001}) formulated philosophy, which could be summarized as follows:

i. Building materials cause .exposure by direct gamma radiation and by radon (Rn) released from the materials into indoor air. Their relative importance varies considerably, but both pathways should be considered when establishing radiological criteria for building materials (Sharaf and Petit,1999).
ii. When limits are set for exposure to natural radiation from building materials it must be clearly defined as to what extent the exposure caused by 'normal" background is included. The

dose criteria used for controls should, therefore, be defined *as* the excess exposure caused by building materials, i.e. the background dose from natural radio nuclides in 'normal' Earth's crust need to be subtracted (Sharaf and Petit,1999).

iii. The doses to the members of the public should be kept a slow as reasonably achievable. However, since small exposures from building materials are ubiquitous, controls should be based on exposure levels which are above typical levels of exposures and their normal (Jurgen Keifer, 1986).

CHAPTER THREE

3.0 Materials and Methods

Eight different soil and rock samples that are used in the construction of walls derived from places around river Barikin Ladi tin mining site situated at 9.58^{o} N and 8.82^{o}Ewere analyzed in this work. This same site is one of the major sources of building materials by the natives in Barkin Ladi local government area of Plateau state. The samples comprise of gypsum, sharp sand, rock stones, smooth sand, gravel stones, pebble sand, mud and clay.

3.1 Sample Collection

Both soil and rock samples were collected and randomly between 5 cm from the surface to about 30 cm deep around the river banks. They were packed in thoroughly clean cylindrical plastic containers of uniform sizes and colour. The containers were filled up to three – quarters of volume with the samples and then carefully sealed to avoid the loss of gaseous daughters from ^{238}U series before measuring their activities with the counting system.

Plate 3.1: The Mining Site



Barikin Ladi; $9^{o}55'$ N, $8^{o}82'$ E

3.2 Sample Preparation

Gypsum, rock stones gravel stones and pebble sand were crushed and sieved separately to tiny bits of 38µm. All samples, especially very wet clay and mud samples were oven dried at about 100^{o}Cand then taken to Centre for Energy Research and Training Ahmadu Bello University Zaria for analysis.

3.3 Sample Analysis

Two techniques were employed for analysis, all at Centre for Research and Training Ahmadu Bello University Zaria. The gamma spectrometry analytical method, specifically, the Thallium activated Sodium Iodide (NaI (Tl)) detector was used for counting. Its high light output and high density gives a considerable stopping power for gamma photons and hence makes it a very efficient detector for this work. The activity concentrations of ^{226}Ra, ^{232}Th and ^{238}U were determined using the detector.

The concentration of elements of interest was a major priority too. Therefore samples were investigated using Neutron Activation Analysis (NAA). 0.150 g – 0.18g of the powdered samples were wrapped in polyethylene and then placed in $7cm^3$ rabbit capsules. The polyethylene and rabbit capsules containing the samples were cleaned by soaking in 1:1 HNO_3 (Nitric acid) and then washed with de-ionised water in order to eliminate every contamination prior to irradiation (El-Tahir et al., 2003). The NAA facility at Centre for Research and Training Ahmadu Bello University was used for this technique too. The full (short and long) irradiation was done.

3.3.1 Short Irradiation

Samples were sent for irradiation one after the other through the outer irradiation channels where the neutron flux is 5 x 10^{11} n/cm^2 and the irradiation time was 60 s. The outer irradiation channels were chosen in order to eliminate corrections that may arise from nuclear interferences caused by threshold reactions notable.

3.3.2 Long Irradiation

Samples were irradiated for 6 hours in the smaller inner irradiation channels that enable exposure to the maxima value of thermal neutrons flux of 5 x 10^{11} n/cm^3. The flux was kept constant by monitoring the neutron flux reading from a fission chamber connected to the microcomputer controlled room. After irradiation the samples were retrieved via the same pneumatic transfer to the control chamber where they were collected and kept in a glass chamber for six days.

3.4 Calculation of Radiological Effects on Humans

With the activity concentrations of the samples, three other radiological quantities have been computed: the annual effective dose, the radium-equivalent concentration and the external hazard index.

3.4.1 Annual Effective Dose

To estimate the annual effective dose, H_E (mSv/y), the conversion coefficient from absorbed dose rate in air to effective dose (0.7 Sv/Gy) and outdoor occupancy factor (0.2) proposed by UNSCEAR (2000) given as:

$$H_E = D\ (nGy/h) \times 8760\ h \times 0.2 \times 0.7\ (Sv/Gy) \times 10^{-6} \qquad (2.44)$$

D (nGy/h) is the absorbed gamma dose rate given also by UNSCEAR (2000) as the absorbed gamma dose rate in air at 1 m above the ground surface for uniform distribution of ^{40}K, ^{226}Ra and ^{232}Th:

$$D = 0.042C_K + 0.462C_{Ra} + 0.604C_{Th} \quad (2.45)$$

3.4.2 The Radium-Equivalent Activity Concentration:

In order to compare the specific activities of materials containing different amounts of ^{226}Ra, ^{232}Th and ^{40}K, an index, called the radium equivalent concentration $Ra_{eq}$was defined based on the fact that 370 Bq/kg of ^{226}Ra, 259 Bq/kg of ^{232}Th and 4810 Bq/kg of ^{40}K produce the same gamma dose rate(Gustavo Haquin, 2008).

Therefore, the $Ra_{eq}$of building material can be written as:

$$Ra_{eq} = 0.077C_K + C_{Ra} + 1.43C_{Th} \quad (2.46)$$

3.4.3 External Hazard Indices:

Two hazard indices are used in this work for assessment of excess gamma radiation from the building materials in order to be sure of the safety of building material usage. Beretka and Mathew (Beretka et al., 1985) introduced a hazard index for the external gamma radiation dose from building materials as given below:

$$H_{Ex} = \left[\frac{c_k}{4810} + \frac{c_{RA}}{370} + \frac{cTh}{259}\right] \leq 1 \quad (2.47)$$

The external hazard index as proposed by the European Commission (EC, 1999):

$$I_\gamma = \left[\frac{cRa}{300\,Bq/kg} + \frac{Cth}{200\,Bq/kg} + \frac{Ck}{3000\,Bq/kg}\right] \leq 1 \quad (2.48)$$

(Simin Mehdizadeh et al., 2011)

EC introduces two dose criteria for the gamma dose of building materials, an exemption criterion of 0.3mSv/y, and an upper limit of 1 mSv/y. Most of the countries apply their control on the upper limit (1 mSv/y). If the exemption level of 0.3 mSv/y is considered, the values of I_γ should be below 0.5 for materials used in bulk (i.e. brick and cement), but if the upper level of 1 mSv/y is considered, the values of I_γ should be below 1 for such materials. For superficial building materials with restricted use (i.e. tiles, boards), I_γ should be below 2 and 6, supposing the control value of 0.3 and 1 mSv/y, respectively (Simin Mehdizadeh et al., 2011).

3.5 Techniques for Radiation Detection and Analysis

3.5.1 Gamma Spectrometry:

Gamma spectrometry is a technique for determining the elements Uranium, Thorium and Potassium in bulk samples. The instrumentation is normally laboratory-based but can be adopted for in-situ field-based measurements (Culbert and Leighton, 1981)

Among the different techniques available for detection of natural and man-made radionuclide, gamma ray spectrometry is probably the most widely applied. A wide choice of detectors, with different characteristics together with advanced electronics and software is available for quantitative and qualitative analysis (Knoll, 1979). The two common options for gamma spectrometry are NaI (TI) and Ge (Li) detectors. HpGe (Hyper pure germanium detectors) and BGO (Bi4Ge3O12) detectors being used less frequently (Culbert and Leighton 1981).

Scintillation gamma spectrometry has been one of the basic methods used for the measurement of naturally occurring radionuclides in geological samples (Yener and Uysal, 1996). In gamma spectrometry, the gamma spectra from natural samples are measured in order to determine the bulk Uranium, Thorium and Potassium content of the samples (Yener and Uysal, 1996). Uranium and

Thorium are detected by the gamma rays emitted by their daughters, hence, the daughter's concentrations in rocks will only be the true representative of their actual concentration if they are in secular equilibrium with their daughter emitters (Dewu, 1986)

The properties of NaI (TI) scintillation detectors make them best suited for the detection of gamma rays. Its relatively high density and high atomic number makes it a gamma ray detector with high efficiency (Tsoulfanidis, 1983). NaI (TI) detectors are more efficient and cheaper than Ge (Li) or HpGe detectors and therefore they are preferably used in the environmental studies in which usually low activities are involved (Yener and Uysal, 1996). According to Cubert and Leighton, 1981, when the radionuclides which are present in a sample are qualitatively well known, not too numerous, and in small amounts as in the environmental analysis, the relatively cheap NaI crystals can give faster and statistically more precise results with smaller volume samples.

3.5.1.1 Determination of Radionuclides of Uranium and Thorium Series by Gamma Spectrometry

Since only a few radionuclides from the U-238 and Th-232 series emit gamma rays useful for gamma spectrometry, the assessment of the radionuclides content through the gamma spectrometry can only be obtained when the equilibrium conditions are achieved.

Fractioning of the chains due to geological or physical reasons may occur. Furthermore, for a correct quantitative evaluation of the radioactive elements, equilibrium with radon can be achieved only with containers with no leakage (and sufficient time should elapse to allow growth of radon-222 and gamma emitting daughters).

Typical gamma emitters and spectral lines adopted for the analysis of Uranium and Thorium contents in environmental samples are derived from specific literature (Smith and Wollernberg, 1978, Oslon, 1983) or from nuclear data tables (Lederer et al, 1978, ICRP, 1983).

The emission of Thorium-234 at 63.3keV can be conveniently used for evaluation of the Uranium-238 content not only because the equilibrium between these radionuclides is guaranteed by a relatively short half life of Thorium-234 but also because this energy is located in an undisturbed zone of the spectrum. Radium-226 may be measured by its direct emission at 185.99 keV, but account should be made for the presence at 185.55 keV of gamma emission from Uranium-235, normally present in geological samples.

Several gamma spectral lines with high yield of Lead-214 and Bismuth-214 are present. Emissions from Lead-214 at 295 and 352 keV and from Bismuth-214 at 609, 1120, 1764 keV

may be easily used. Polonium-210 may also be measured using its 46.5 keV gamma (Sgorbati, 1990).

Concentration of Uranium-235 may be evaluated by using the 185.55 keVpeak, if subtraction of the contribution of 185.99 keV gamma emission from Radium-226 is made. Spectral lines of lower intensities useful for evaluations of Uranium-235 are located at 114, 163 and 205 keV.

With regard to Thorium-232 series, the most useful spectral lines for examination of this chain are respectively 583 keV (Tallium-208) and 911, 969 keV(Actinum-228) (Sgorbati, 1990)

When selecting gamma photo peaks for analysis, account must be taken of the fact that it is desirable to analyse relatively large sample aliquots. If low-energy photo peaks are selected for analysis, a significant attention will occur within the sample, causing low count rate that may vary with sample density (Potts, 1987). The attenuation of the photons crossing a material medium becomes higher as their energy decreases (Martinez Lobo and Palomares 1991).

3.5.1.2 Secular Equilibrium

Secular equilibrium which is a phenomenon observed when a radioactive parent isotope decays via one or more daughter isotopes to a stable product, and is only observed if the parent has a longer (very much greater) half-life than any of its intermediate daughters. Under these conditions, a series of radioactive equilibra are set up so that the rate of decay of the parent isotope equals that of each of the daughters, which therefore equals the rate of formation of stable product. The decay chain is then said to be in a state of secular equilibrium (Potts, 1987). In other words if the half-life of the parent is at least ten times greater than that of the daughters and if there is essentially no change in the activity of the parent during the experimental observation, then the condition of secular equilibrium is attained (Ehmann and Vance, 1999). In this situation, the activity from the daughter of an initially pure parent will grow in or increase until it is exactly equal to that of the parent. Hence, when secular equilibrium has been achieved, the daughter will decay at exactly the same rate as the parent (Kathren, 1985).

After about five half-lives, the proportion of daughter isotope atoms effectively reaches a constant ratio with respect to the parent. In such a situation, the activity ratio between any two nuclides in the series is unity. That is the condition,

$N1\lambda1 = N2\lambda2 = \ldots\ldots = Nn\lambda n$

is satisfied. In this equation, N1, N2……,Nn are the number of atoms of the nuclide 1, 2,….,n and $\lambda1$, $\lambda2$,……,λn are their respective decay constants (Potts, 1987).

3.5.1.3 Uranium/Thorium Series Disequilibrium

However, the problem of the existence of radioactive disequilibrium in the U-238 series in natural substances was discovered (Cherdyntseo et al., 1955), also by Barnes (Barnes et al. in 1986). Authors since then have observed that U-234 and U-238 disequilibrium in various minerals, rocks and organisms (Bashir, 1989)

Uranium and Thorium series disequilibrium measurement are based on situations where secular equilibrium within the appropriate decay chain has been broken by some geochemical phenomenon. Samples are then analysed so that the parent content of a specified Uranium or Thorium decay series isotope can be compared with the concentration that would have been present had secular equilibrium not been broken.

The decay of Uranium-238 to Lead-206, and Thorium-232 to Lead-208, involves 19 and 11 daughters respectively. If none of these daughters is removed out of the series, sometimes after the formation of a Uranium or Thorium bearing crystal, a state of equilibrium is reached, whereby the loss of a daughter due to its decay is made up by the decay of the preceding parent. This occurs where the half-life of the parent is much larger than the half-life of the daughter. If one of the daughters is taken out of the system, however, disequilibrium is established and the nuclides above the one, which has been lost, become proportionally more enriched in the series, similarly, nuclides developed from the decay of the lost daughter are depleted in the series.

3.5.2 Neutron Activation Analysis Technique:

Neutron Activation Analysis (NAA) technique was discovered in 1936 when Hevesy and Levi (WinT. D., 2004) found that samples containing certain rare earth elements became highly radioactive after exposure to a source of neutrons. NAA is a very powerful analytical technique for

identifying many elements present in samples of unknown composition performing both qualitative and quantitative multi-element analysis of major, minor and trace elements in samples. Neutron Activation Analysis determines elemental content regardless of oxidation state, chemical composition or physical location.

An isotope of atomic mass A and atomic number Z when placed in a neutron flux will, in general, absorb a neutron to become the isotope (A+1, Z). Some resulting isotopes, being unstable, will decay, emitting one or more gamma-rays with energies and half life characteristic of the particular isotope. During irradiation the naturally occurring stable isotopes of most elements that constitute the alluvial samples are transformed into radioactive isotope by neutron capture. The number of radionuclide in activation of a natural isotope is given by the expression (Win D. T., 2004):

N = (Øσ_aAN_oA)/λ_((A+1)) [1-e^(-λ(A+1).^T)] e^(-λ(A+1) .^t)

And the activity is: 〖dN〗_((A+1))/dt

Where Ø is the neutron flux, σaAs the neutron absorption cross-section of the original isotope, NoA is the number of nuclei of element under consideration of isotope A, λ(A+1) is the constant of the created isotope, T is the irradiation time and t is the time between stop of irradiation and start of the counting of the activity.

The basic essentials required to carry out an analysis of soil samples by neutron activation analysis are a source of neutrons, HPGE gamma ray spectrometer coupled with a MCA and printer.

3.5.2.1 Neutron Flux:

Neutron flux is the amount of neutrons available for irradiation (Shiraki R. et al., 2005; Miller M. E. et al., 2004) and can be expressed as:

$$Ø = ((dN/dt))/(ε._GI._γKσσmN._A\ f(1-e.^(-λT))(1-e.^(-λt._m\ )))$$

Where tm is the real time measurement, T is the irradiation time, td is the transporting time, εG is geometry dependent efficiency of the detector, σ- thermal neutron capture cross section, λ- decay constant of product nuclei, A- the atomic weight of the element, m is mass of the bombarding element, dN/dt is the activity of the emitted gamma, NA- Avogadro number, f- the isotope abundance of target nuclei, Iγ is the intensity of the gamma ray line and K is the self-absorption of gamma rays in the sample. This same equation can be used for the determination of mass of unknown element present in the experimental sample.

CHAPTER FOUR

Results and Discussion

4.0 Discussion

4.1 Analysis by Gamma Spectrometry

This work investigated the risks of exposures from stream sediments derived from Barikin Ladi stream used in building blocks of houses. Tables 4.1 and 4.2 show activity concentrations of samples in counts per second (cps) and Bq/kg respectively. From table 4.2, the mean activity concentration of potassium-40 in all the assessed samples with a range of 102.18±3.27 – 424.73±2.63 Bq/kg is 301.26±7.06Bq/kg. That of Radium-226 with the range of 13.44±0.12 – 368.53±11.61 Bq/kg is 109.84±5.83 Bq/kg while for Thorium-232 with the range of 4.57±1.28 – 707.54±11.40 Bq/kg is 262±1.49 Bq/kg.

Only rock stones, gravel stones and pebble sand have permissible values of Radium-226, a daughter of Uranium, as far as international values are considered.

It can also be noted from table 4.3 that these same samples have met the < 370 Bq/kg of radium-equivalent activity concentration standard of European Union (Flores et al., 2005). Their values also explain the low hazard indices.

Gypsum, smooth sand, mud and clay have all failed the hazard index international standard of at most 1 msv/y if ALARA (As Low as Reasonably Allowed) must be adhered to.

4.2 NAA Analysis

The NAA analysis was carried out to further emphasize the results from the gamma spectrometry. Both long and short analyses were carried out. However, only elements with considerably high values per unit mass have been tabulated here.

As seen from table 4.4, high values were recorded in quite radioactive elements like potassium and titanium. For Aluminium with the range of 11760 ±281- 76340 611 mg/kg is 46102.5±367 mg/kg; Iron with the range of 2520±118 – 36510±365 mg/kg is 18096±270.38 mg/kg, Titanium with the range of 830±129 – 24220±630 mg/kg is 6036±291.5 mg/kg and Potassium with the range of 737±132 – 14640±410 mg/kg is 6014.63 ±200 mg/kg. This further justifies the active nature of the project site.

4.3 Table of Results

The activity concentration of samples from the gamma spectrometry laboratory are shown in tables 4.1 and4.2 in cps (count per second) and Bq/kg respectively.

The calibration factors are:

K-40: 0.000643

Ra-226: 0.000863

Th-232: 0.000877

Table 4.1: Activity Concentration in Count Per Second (CPS)

SAMPLE ID	**K- (cps)**	**Ra-226(cps)**	**Th--232(cps)**
Gypsum	0.155±0.004	0.318±0.010	0.512±0.005
Sharp sand	0.172±0.006	0.104±0.004	0.064±0.002
Rock stones	0.066±0.002	0.012±0.000	0.004±0.001
Smooth sand	0.173±0.002	0.232±0.001	0.621±0.010
Gravel stones	0.215±0.012	0.042±0.004	0.080±0.003
Pebble sand	0.230±0.007	0.060±0.006	0.063±0.002
Mud	0.268±0.002	0.123±0.008	0.343±0.006
Clay	0.273±0.002	0.186±0.007	0.332±0.005

Table 4.2: Samples and their activity Concentrations in Bq/kg

S/N	SAMPLE ID	K-40 (Bq/kg)	Ra-226 (Bq/kg)	Th-232 (Bq/kg)
1.	Gypsum (0-20cm)	240.59±5.63	368.53±11.61	583.49±5.30
2.	Sharp sand (0-20cm)	267.50±8.86	120.16±4.06	73.09±2.28
3.	Rock stones (0-20cm)	102.18±3.27	13.44±0.12	4.57±1.28
4.	Smooth sand (0-20cm)	269.60±3.71	268.30±1.53	707.54±11.40
5.	Gravel stones (0-20cm)	333.64±18.66	48.32±5.68	90.65±3.53
6.	Pebble sand (0-20cm)	358.16±11.20	70.22±6.37	72.18±2.73
7.	Mud (0-20cm)	416.49±2.49	142.41±9.03	391.45±6.50
8.	Clay (0-20cm)	424.73±2.63	215.87±8.22	180.54±2.88
MEAN VALUES:		301.36±7.06	109.84±5.83	262.93875±4.49

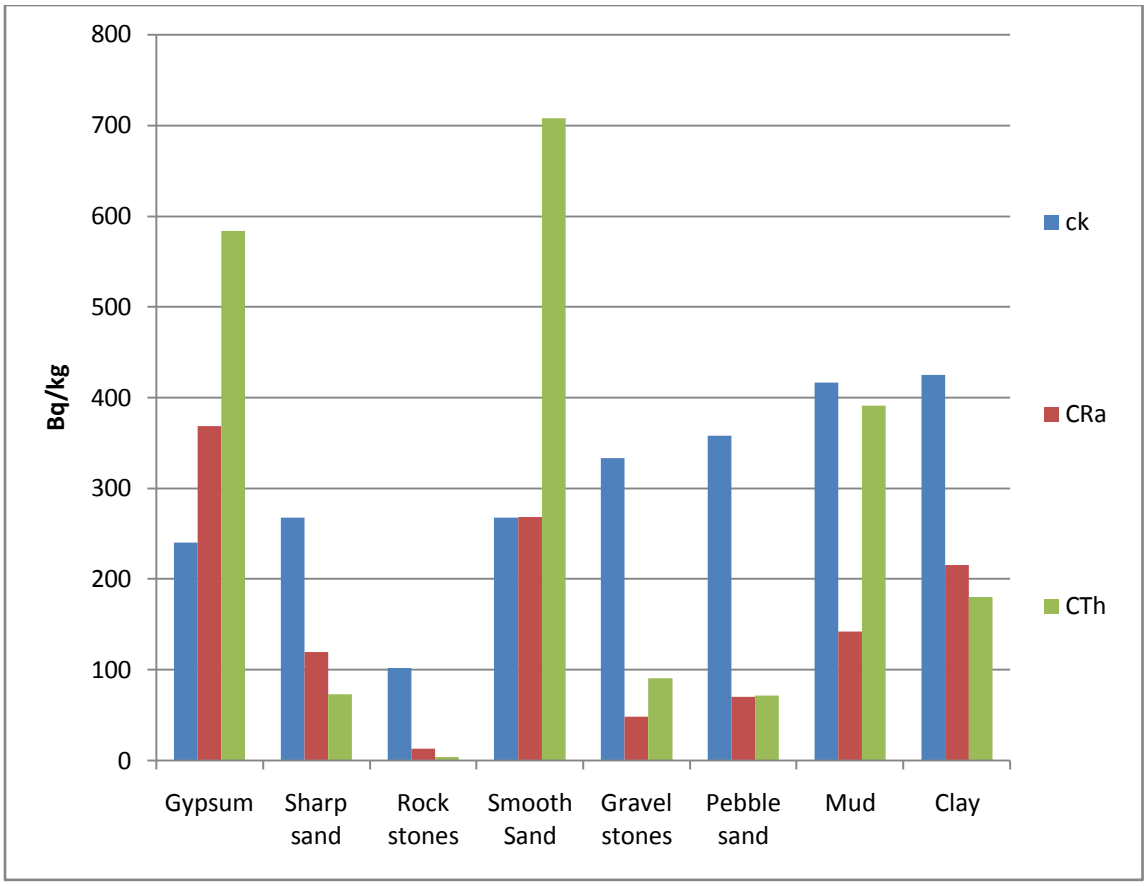


Fig. 4.1: Mean plot for Activity Concentrations, C_k, C_{Ra} and C_{Th} of Samples

C_k = Activity Concentration of Potassium

C_{Ra} = Activity Concentration of Radium

C_{Th} = Activity Concentration of Thorium

4.3: Table of computed results of absorbed gamma dose rate, D(nGy/h), annual effective dose, H_E(msv/y), Radium-equivalent activity concentration, Ra_{eq} (Bq/kg) external hazard indices, H_{ex} and I_γ respectively

Sample	**D (nGy/h)**	**H_E (mSv/y)**	**Ra_{eq} (Bq/kg)**	**H_{ex}**	**I_γ**
Gypsum	532.79±8.8	0.65±0.01	1221.44±19.62	3.31±0.53	4.23±0.07
Sharp sand	110.90±3.62	0.13±0.00	245.28±8.00	0.67±0.02	0.86±0.03
Rock stones	13.26±0.97	0.02±0.00	27.84±2.20	0.08±0.01	0.10±0.01
Smooth sand	562.55±7.75	0.69±0.01	1300.69±18.12	3.52±0.05	4.52±0.06
Gravel stones	91.09±5.54	0.11±0.01	203.64±12.16	0.56±0.03	0.73±0.04
Pebble sand	91.08±5.07	0.11±0.01	201.02±11.15	0.55±0.03	0.71±0.04
Mud	319.72±8.21	0.39±0.01	734.25±18.53	1.99±0.05	2.57±0.06
Clay	226.62±5.65	0.28±0.01	506.25±12.55	1.38±0.03	1.76±0.04
MEAN:	**243.50**	**0.30**	**555.11**	**1.51**	**1.94**

4.4:EUROPEAN UNION Standard Values of Hazard Index

Dose Criterion	0.3 mSv/yr	1mSv/yr
Materials used in bulk	$I \leq 0.5$	$I \leq 1$
Superficial/ Materials with restricted use	$I \leq 2$	$I \leq 6$

(Gustavo, 2006**)**

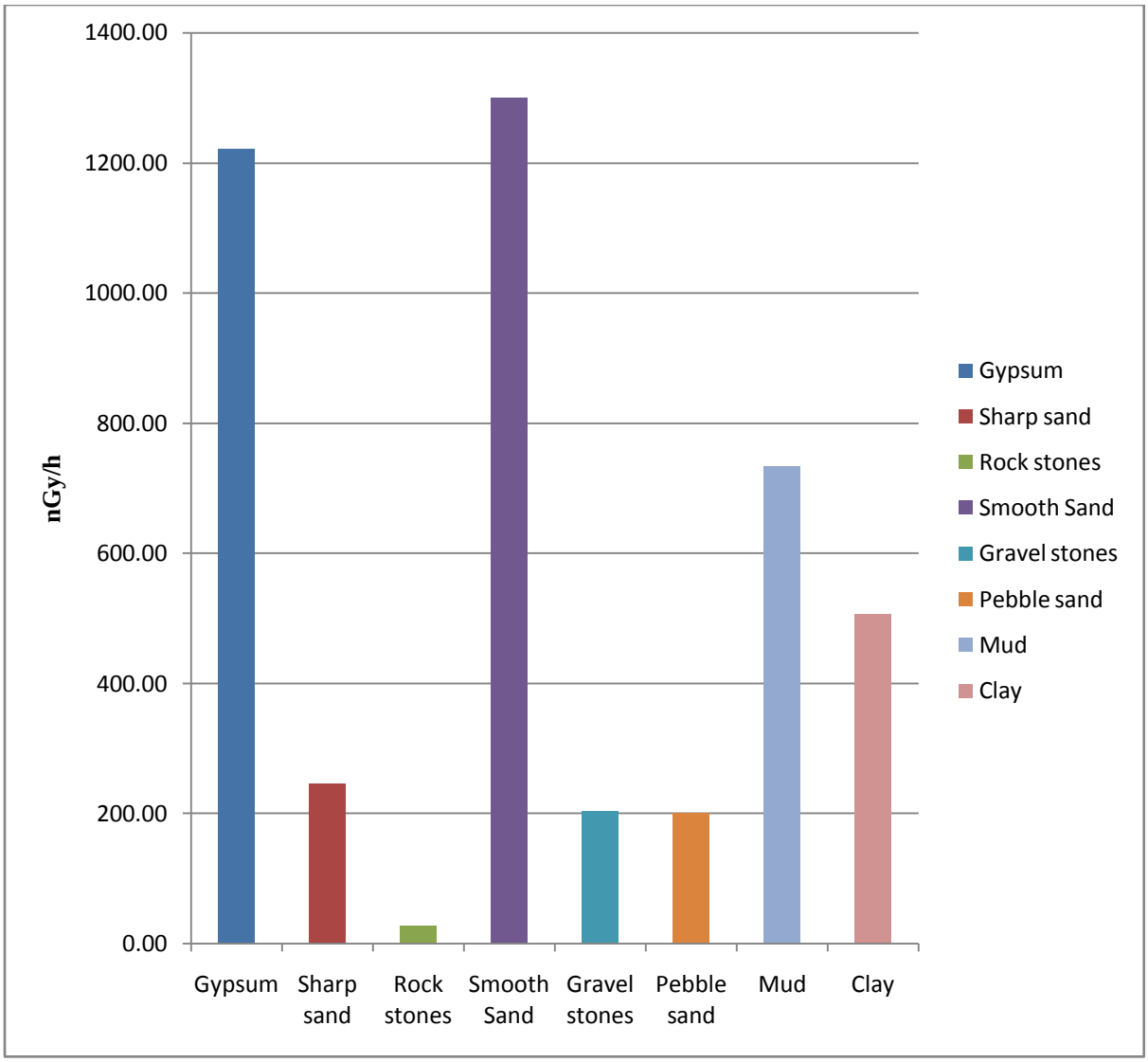


Fig.4.2: Mean Plot for Absorbed Gamma dose rate of Samples

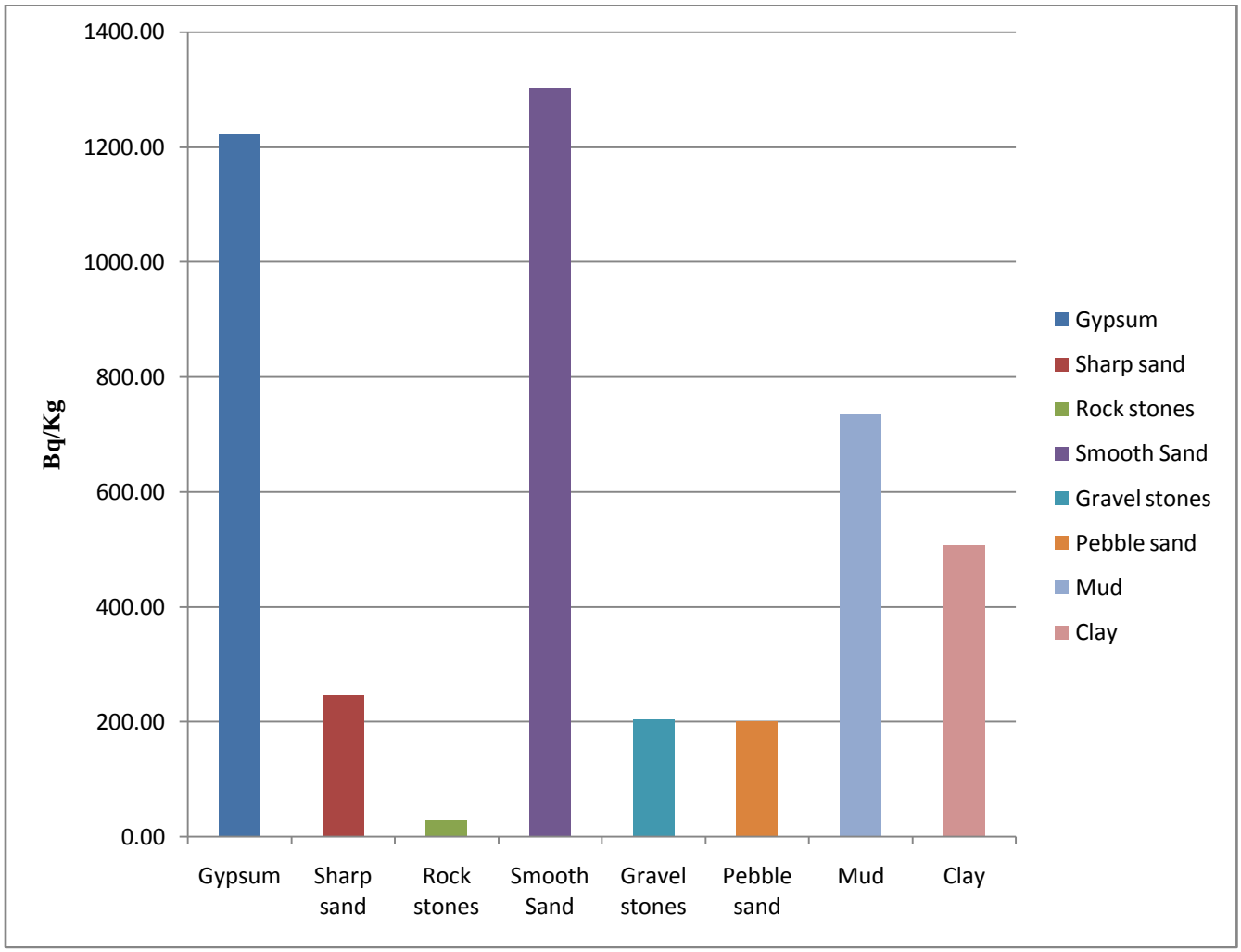


Fig 4.3: Mean Plot for Radium - Equivalent Activity Concentration of Samples

4.5: Comparison between the Activity Concentrations and Raeq in this work with those of other Countries.

Sample	C_{Ra}	C_{Th}	C_K	R_{aeq}	Reference
Clay:					
Egypt	30	21	289	82	Medhat, 2009
Algeria	65	51	675	190	Amrani&Tahtat,2001
Bangladesh	29	53	292	127	Mantazul et al., 1998
Iraq	59	12	934	146	Hussain et al., 2010
Barikin Ladi	**215**	**180**	**424**	**506**	**Present work**
Red mud:					
Malaysia	33	24	443	101	Yasir et al., 2007
Iraq	120	15	978	215	Hussain et al., 2010
Barikin Ladi	**142**	**391**	**416**	**734**	**Present work**
Gravel:					
Egypt	13	23	193	65	El-Taher, 2011
Pakistan	33	321	57	83	Iqbal et al., 2000
Bangladesh	25	55	228	21	Mantazul et al., 1998
Barikin Ladi	**48**	**90**	**333**	**203**	**Present work**
Sand:					
Malysia	27	22	581	90	Yasir et al.,2007
India	09	52	66	84	Kumar et al., 2003
Pakistan	20	29	383	91	Faheem et al., 2008
Egypt	33	27	385	101	Medhat, 2010
China	41	22	303	95	Xinwei, 2004
Barikin Ladi (Sharp sand)	**120**	**73**	**267**	**245**	**Present work**
Gypsum:					
Egypt	39	25	226	92	Medhat, 2009
India	08	-	27	10	Kumar et al., 2003
Barikin Ladi	**368**	**583**	**240**	**1221**	**Present work**
Soil:					
Malaysia	30	26	479	104	Yasir et al., 2007
Bangladesh	21	38	464	112	Mantazul et al., 1998
Egypt	16	07	102	28	El-Taher, 2011
Barikin Ladi(Smooth sand)	**268**	**707**	**269**	**1300**	**Present work**

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Table 4.6: Analytical results of instrumental Neutral Activation Analysis (NAA) of samples in mg/kg

Sample	**Al**	**Ca**	**Ti**	**Na**	**K**	**Fe**
Gypsum	63800±383	BDL	3182±299	307±2	6140±129	26750±294
Sharp sand	32570±326	BDL	2492±237	278±3	6071±267	25170±303
Rock stones	19790±99	8255±842	830±129	821±3	2376±93	4673±364
Smooth sand	11710±281	BDL	24220±630	18±2	BDL	2520±118
Gravel stones	75060±450	1960±512	4854±325	866±5	9364±393	35740±322
Pebble sand	13850±180	BDL	BDL	216±3	737±132	3798±148
Mud	75700±606	BDL	6310±360	449±3	8789±176	36510±365
Clay	76340±611	BDL	6400±352	565±5	14640±410	11880±249

Al: Aluminum, Ti: Titanium, Na: Sodium, K: Potassium, Fe: Iron

All results are in mg/kg (ppm)

BDL: Below detection limit

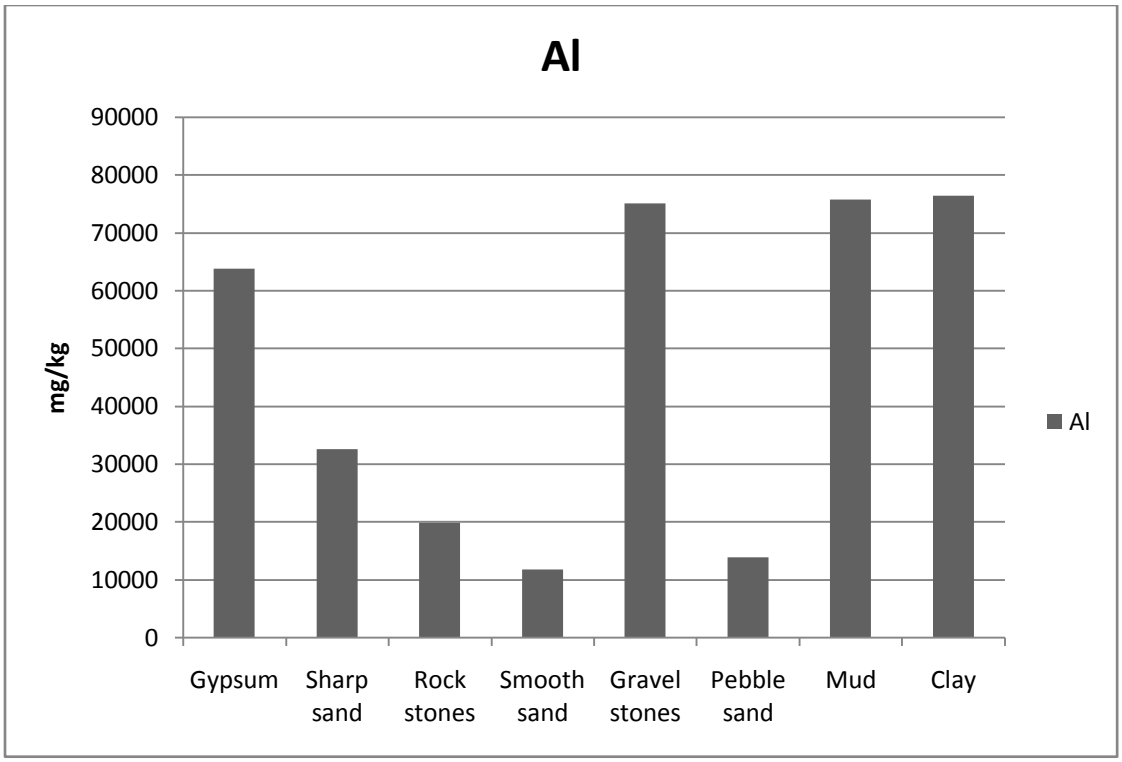


Fig. 4.4: Elemental Analysis Plot for Aluminium in Sample

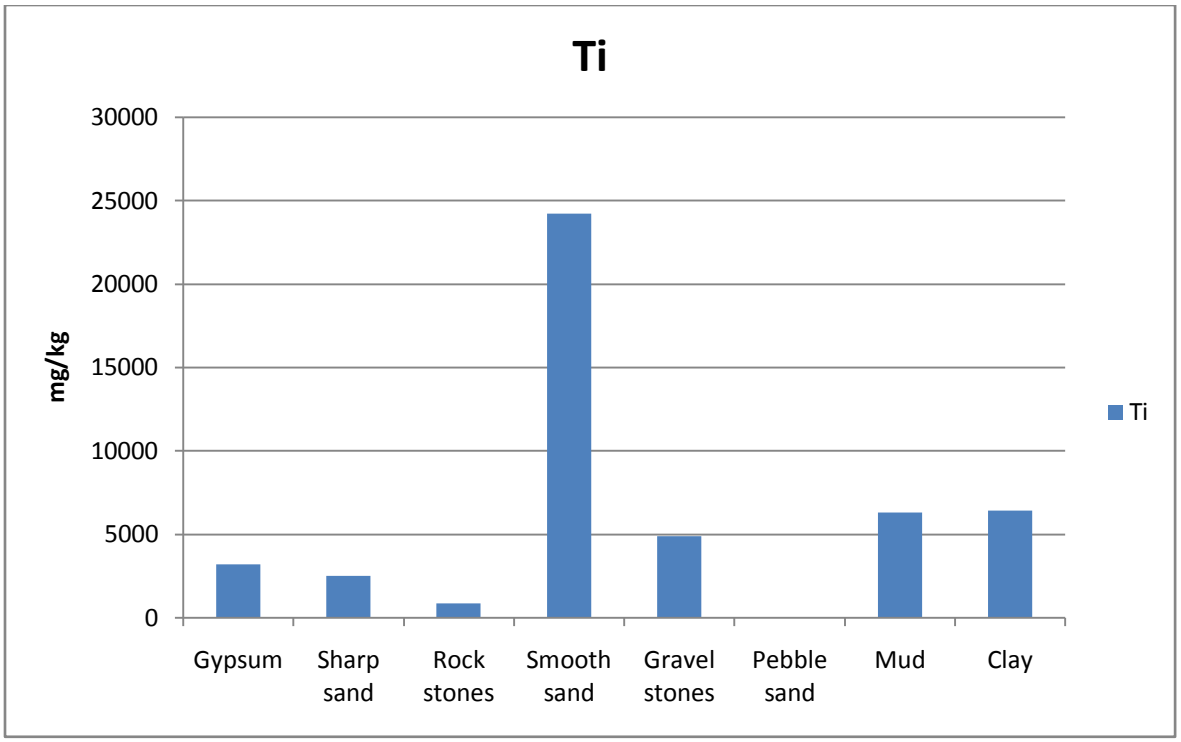


Fig. 4.5: Elemental Analysis plot for Titanium in samples

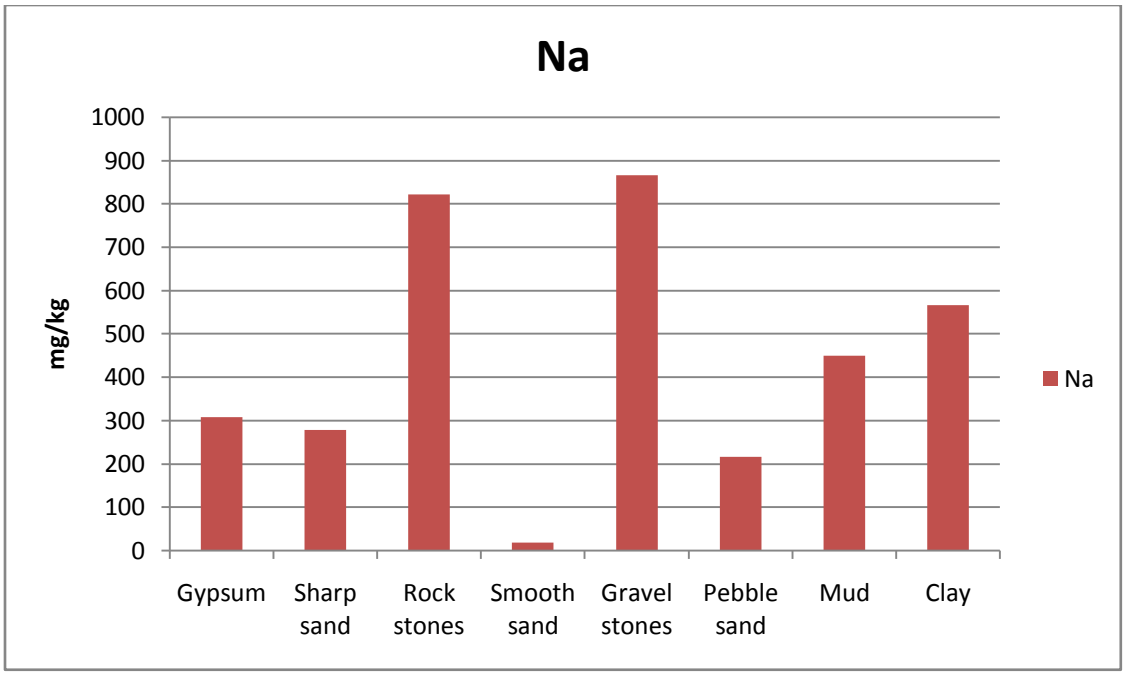


Fig 4.6:Elemental Analysis plot for Sodium in Samples

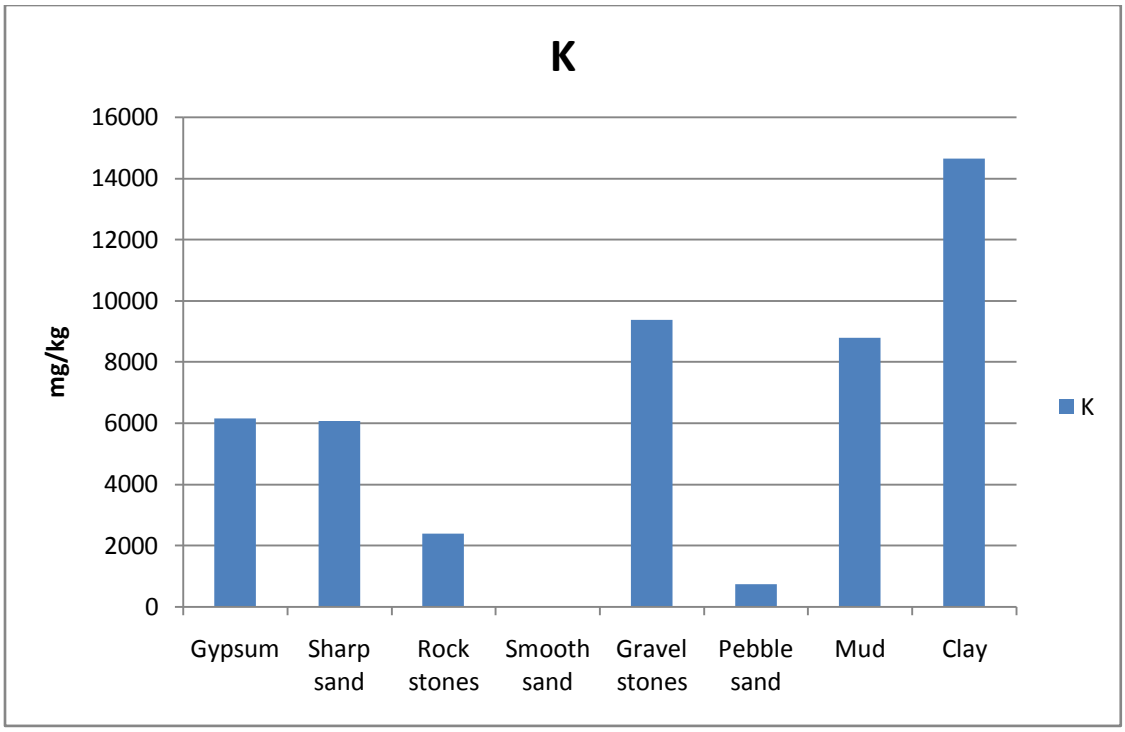


Fig. 4.7: Elemental Analysis Plot for Potassium in Samples

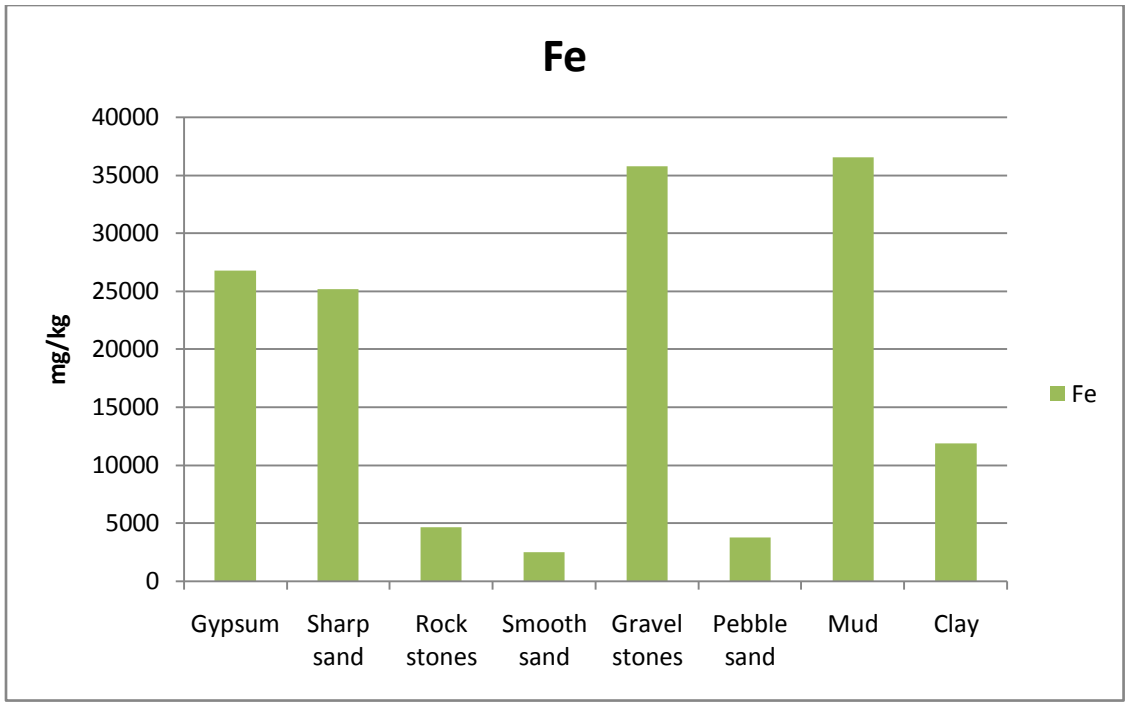


Fig.4.8: Elemental Analysis plot for Iron in Samples

Table 4.7: NAA Results of same Elements from Abuja Metropolis:

Element	**Karu**	**Aso Radio**	**Airport soil**	**Airport road**
Aluminum	3972±40	5860±70	5195± 60	BDL
Titanium	9821±756	5971±770	9160±714	8917±695
Sodium	2633±13	1628±0.001	4710±23	1652±9.9
Potassium	1937±40	6196±7600	2500±50	2110± 30
Iron	5280±30	6640±170	4210±140	13100±2000
Calcium	770±140	840±140	BDL	BDL

(from B. E. Kongo et al., 2009)

All results in Parts Per Million (PPM). BDL: Below Detection Level

CHAPTER FIVE

CONCLUSION, SUMMARY AND RECOMMENDATION

5.1 Conclusion

In this study, values of the activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th in stream sediments were determined. The radium-equivalent activity concentration and the annual effective doses were also computed. Focus was on sediment samples used directly as building materials in and around Barikin Ladi local government in Plateau state.

These physical quantities evaluated are crucial in determining the exposure potentials to members of the public and more to inhabitants of buildings constructed from these materials. In this work it can be concluded that the mean absorbed gamma dose rate and the mean effective dose rate were 243.50 nGy/h and 0.298 mSv/y respectively. The mean annual effective dose rate is lower than the 1 mSv/y dose rate limit recommended by ICRP for public radiation exposure control.

However, some of the samples recorded high values of radium-equivalent activity concentration. Such samples include gypsum, smooth sand, mud and clay. The use of these samples should be avoided immediately since high radium-226 implies high Uranium – the deadliest metal known to man.

5.2 Summary

Although no amount of radiation is permissible, sharp sand, rock and gravel stones collected from the banks of river Barikin Ladi in Plateau Nigeria situated between $9^{o}55'0''$north, and $8^{o}54'0''$may not be too harmful to be used in the construction of walls and floors of residential buildings.

However, Gypsum, smooth sand, mud and clay soils collected from same banks may be too radioactive to be used for the same purpose.

5.3 Recommendations

At the end of this work, the following recommendations are hereby proposed

* Internal exposure resulting from consumption of foods grown in and around the site of this work (like yam, cassava and cabbage etc.) should be determined.

* Another work should be done to investigate the activity concentration of ^{40}K, ^{226}Ra and ^{232}Th in drinking water in the same region.

* A hand-held dose rate meter should be used when carrying out a similar work in the region in order to compare computed values with measured values.

* Determination of gross alpha and beta concentration in drinking water, food and plants from the study area should be carried out.

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