RADIOACTIVITY AND ELMENTAL ASSESSMENT OF SOME VEGETABLES GROWN ON MINE TAILINGS AROUNDJOS PLATEAU STATE,NIGERIA

PhD THESIS

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DECLARATION

I declared that the work in this thesis entitled, "RADIOACTIVITY AND ELEMENTAL ASSESSMENT OF SOME VEGETABLES GROWN ON MINE TAILINGS AROUND JOS PLATEAU STATE, NIGERIA" has been carried out by me in the department of Physics. The information derived from the literature has been fully acknowledged in the text and a list of references provided. No part of the dissertation was previously presented for another degree or diploma at this or any other institution

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DEDICATION

This research work is dedicated to my parent Hajiya Khadija Suleiman and Alhaji Umar Shu'aibu, and also my immediate family.

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CERTIFICATION

This thesis entitled, "RADIOACTIVITY AND ELEMENTAL ASSESSMENT OF SOME VEGETABLES GROWN ON MINE TAILINGS AROUND JOS PLTAEU STATE,NIGERIA" by MUHAMMAD UMARU SAIDU meets the regulations governing the award of Doctor of Philosophy (PhD) in Physics of Ahmadu Bello University, Zaria and is approved for its contribution to scientific knowledge and literary presentation.

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ABSTRCT

The soils of degraded tin minefield farm land in three LGA; Bokkos, Jos south, and Barikin-Ladi of extensive mining of tin on the JosPlateau state were analyzed for radioactivity and elemental concentrations. Cabbage (*Andira enemus*) (*Brassica olarecea*), potatoes (*Solamums spp*) and carrot (*Daucas carota)* grown on the degraded minefield at dry season and grown away from the degraded minefield at rainy season farming were also analyzed. Gamma-spectrometry using NaI(Tl) detector for activity concentration analysis and Neutron activation analysis (NAA) for elemental concentration analysis were carried out. AComparism of the activity concentration found in the soil with world values (UNSCEAR, 2000) was made and the mean activity concentration of K-40 ranged from 86.00±6.58 to 121.31±6.40Bqkg^{-1} (Average 108Bqkg^{-1}) which is far less than the world wide values 420Bqkg^{-1}. Ra-226 mean activity concentration ranged from 39.82±4.01 to 75.43±4.83 (Averaged 59Bqkg^{-1}) which is greater than 33Bqkg^{-1} the worldwide value. Th-232 activity concentration ranged from 44.46±2.39 to 62.06±2.87Bqkg^{-1} (Average 57Bqkg^{-1}) which is slightly greater than 45Bq/kg. The determined mean soil absorbed dose rate, effective dose rate, radium equivalent and external and internal indices ranged from 51.40 to 78.24 nGyh^{-1} (Average 67nGyh^{-1}), 63.06 to 96.03 μSvy^{-1} (Average 82μSvy^{-1}), 113.46 to 173.14 Bqkg^{-1} (Average 149Bqkg^{-1}) and 0.33 to 0.62 (Average 0.5) and 0.72 to 0.93 (Average 0.8) respectively. Apparently there is very minimal health risk with the soil samples since H_{ex} and H_{in} do not exceed the worldwide recommended value unity. The dry season vegetables revealed that the mean activity concentration of cabbage forK-40, Ra-226 and Th-232 were; 449.77±6.63, 27.56±3.20 and 23.91±0.8 in (Bq/kg) respectively, whereas the average annual effective dose and cancer risk were; 0.24±0.01mSv/y and 0.00058. The mean activity of carrot were;278.28±5.8, 31.52±3.01and 30.56±0.42 in (Bq/kg), whereas the average annual effective dose and cancer risk were; 0.25±0.01 and 0.00064 respectively. The mean activity of Potatoes were;357.02±5.75.56±6.95 and 14.52±1.10(Bq/kg), whereas the average annual effective dose and cancer risk were; 0.17±0.01 and 0.00042 respectively.The rainy season vegetables revealed that the mean activity concentration of cabbage for K-40, Ra-226 and Th-232 were; 140.07±.91, 30.08±2.82 and 43.98±3.04 respectively in (Bq/kg) whereas the average annual effective dose and cancer risk were; 0.31±0.02mSv/y and 0.00077. The mean activity of carrot were;77.97±4.30, 55.50±4.05 and 61.15±3.15 in (Bq/kg), whereas the average annual effective dose and cancer risk were; 0.42±0.02 and 0.00105 respectively. The mean activity of Potatoes were; 88.70±3.52, 32.48±2.84 and 62.03±1.82 in (Bq/kg), whereas the average annual effective dose and cancer risk were; 0.41±0.02 and 0.00102 respectively.Radium element and lead were not detected in the soil and the vegetables. Thorium elemental contents ranged from BDL-35.52 ppmin the soil and BDL-0.66±0.2 and BD – 0.04±0.02ppm from the dry and rainy season vegetables respectively.While Uranium ranged from BDL to 13.9±0.2 ppm in soil and BDL to 0.009±0.002 ppm in the vegetables. Thorium was detected at the rainy season vegetablesranging from BDL-0.32±0.02 ppm and Uranium was BDL in the rainy season vegetables. Potassium content is high ranging from 2608±110 to 23670±118ppm from the soil, 2856±20 to 49210±1132 ppm from the dry season vegetablesand 4870±229 to 43350±260ppm from the Rainy season vegetables. Arsenic was at below detection level at the dry season vegetables whereas their toxics element like Zinc, chromium and Vanadium have higher content in the soil and relatively higher in dry season vegetablesthan rainy season ones. The average seasonal elemental concentration of the vegetables in ppm, have higher values of

the order Cl (62200.00) > Zn (43160.00) > Al (27883.33) >Mg (7362.50) > K(6551.00) > Ca (3947.20) and the least value was Br (0.56) The determined Daily Intake of Metals (DIM) was in the order Cl (18660.00) >Zn (12948.00) >Al (8365.00) >Mg (2208.75) >K (1965.30) >Se (275.20) with the least value at Br (0.17) ppmThe Health Risk Index(H_Q) was found to be of the order Cl(207.33)> Zn (143.87)> Al (92.94) >Mg (24.54) Ca (13.16) > Se (3.06) > Na (2.26) > K (2.18)which are above the safe value " unity" (Charya et al 2008) The transfer factor (T_f) determined were; Co (57.83, 12.15 and 9.38 for cabbage, potatoes and carrot respectively), Yb (24.85, 25.69 and 38.23 for cabbage, potatoes and carrot respectively), Th (17.50, 19.64 and 23.57 for cabbage, potatoes and carrot respectively), Sb (15.00, 8.33 and 30.59 for cabbage, potatoes and carrot respectively) and Sm (10.32, 9.26 and10.47 for cabbage, potatoes and carrot respectively) These values were above the recommended value of 1.00. The study revealed that dangerous element cadmium and lead were not detected (or below detection limit) The implication of these findings to consumers is that;There was no potential risk due to exposure to radiation from the degraded soil. The high concentration K-40 from the dry season vegetables, indicated that they can be recommended for consumption by persons with shortage potassium content in their bodies. The dry season vegetables have no potential cancer risk (10% less than ICRP recommended value of 0.006) Although there is no safe dose, no potential cancer risk since cancer risk rainy season vegetables did not exceed the recommended values

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Appendix II:A reclaimed minefield farmland close to a mining pond in Jos-Plateau 223

ABBREVIATIONSAND SYMBOLS

amu	~	atomic mass unit
BLD	~	Barikin Ladi
BDL	~	Below Detection Limit
BKK	~	Bokkos
CAB	~	Cabbage
CAR	~	Carrot
CV	~	Certified Values
CF	~	Calibration factor
DIM	~	Daily Intake of Metals
DL	~	Detection Limit
DNA	~	Dioxo Nucleic Acid
FEP	~	Full Energy Peak
IAEA	~	International Atomic Energy Agency
ICRP	~	International Commission on Radiological Protection
INAA	~	Instrumental Neutron Activation Analysis
JJS	~	Jos South
L.G.As	~	Local Government Area
LOD	~	Limit of detection
NCRP	~	National Council on Radiation Protection
NORMs	~	Naturally Occurring Radioactive Materials

RDI	~	Recommended Daily Intake of Metals
TENORMs	~	Technologically Enhanced Naturally Occurring Radioactive Materials
NAA	~	Neutron Activation Analysis
PMT	~	Photomultiplier tube
MCA	~	Multi-Channel Analyzers
NMS	~	Miniature Neutron Source
POT	~	Irish potatoes
WHO	~	World Health Organization
SON	~	Standard Organization in Nigeria
NIS	~	Nigeria Industrial Standard
NAFDAC	~	National agency for Food and Drug Administration and Control
UNSCEAR	~	United Nation Scientific Committee on Atomic Energy Radiation

GLOSSARY

Background Radiation

Widespread radiation from space and from natural and human-made radionuclides originating in space and on the Earth

Cosmogenic

Radionuclides produced when space radiation interacts with molecules in the atmosphere.

Dose (or Effective Dose)

Amount of radiation energy absorbed by the body, which is calculated to account for the different types of radiation (such as alpha and beta) and how sensitive different organs are to radiation (for example, bone compared to lungs)

Gray (Gy)

An International System of Units (SI) unit for absorbed radiation dose that can be converted to traditional U.S. units of rad (1/100 of a Gy)

Rad

Former unit of radiation energy absorbed dose by a body which accounts for different types of radiation (1Gy=1J/Kg=100rad)

Primordial

Radionuclides present in the Earth when it formed.

Radionuclide

A radioactive element, man-made or from natural sources, with a specific atomic weight

Sievert (Sv)

An International System of Units (SI) unit for equivalent or effective radiation dose that can

be converted to traditional U.S. units of rem (1/100 of a Sv) or millirem (mrem; 1/100 of a milliSievert [mSv]

Space Radiation

Radiation originating outside the Earth's atmosphere, including solar radiation

Terrestrial Radiation

Radiation emitted by radionuclides in soil and rocks.

Cancer

Group of diseases involving abnormal cell growth with potential to invade or spread to other part of the body

Exposure

Amount of radiation caused by x- or γ-ray in air measure in Roentgen (R)

Dose rate

Amount of radiation energy per unit mass accumulated over period of time (Sv/h, Gy/h)

Dose

Radiation energy absorbed by a material peer unit mass

Equivalent Dose

Biological health effect of ionizing radiation that depend on dose and the type of radiation

Stochastic (probabilistic)

Biological damage by radiation energy to cell at all levels the radiation usually (cancer) hereditary

Non-stochastic (Deterministic)

Biological damage by radiation whose severity has threshold dose and increases with increasing dose

Scintillators

Crystals that emit visible radiation e.g Phosphors

Gamma spectroscopy

Method of detecting and quantifying radionuclides the size and energy of the characteristics gamma-ray emitted.

Daily intake of metals (DIM)

This is the product of daily vegetable consumption and mean vegetable of metal concentrations (mg/day, fresh weight)

Health risk of metals (H_Q)

The potential hazard of metal to human health through consumption of vegetables

Transfer factor (T_F)

The ratio of the toxic metal concentration in extracts of plants to soils on dry weight basis

CHAPTER ONE

1.0 INTRODUCTION

1.1 General Introduction

The world we live in is radioactive and has been since creation. In fact radioactivity is a fact of life because the radionuclides are found in rocks, water, air, plants and they are also found in us since we are products of our environment. Apart from stable chemical element, very low concentrations of radioactive element occur naturally in the environment (Michael and Leo, 2007). Natural radionuclides are classified into Primordial, secondary and cosmogenic radionuclides. The artificial radionuclides consist of those radionuclides produced by nuclear reactors, particles accelerators and generators. These radionuclides undergo radioactivity which is the spontaneous nuclear transformation of the nucleolus accompanied by the emission of particles (α, β^-, β^+etc.) and the emission of γ-radiation (Michael and Leo 2007).

Radioactivity can occur naturally by naturally occurring radioactive materials (NORMs) and through human intervention by technologically enhanced naturally occurring radioactive materials (TE NORMs). The emitted particles such as α and β are classified as ionizing particles since they carry charges and they cause the atom of materials to be ionized(separate into ions) γ-rays do not carry charge and they are said to be indirectly ionizing radiation.

Radiation interacting with matter can either be scattered or absorbed and the mechanism of the absorption of radiation are of greater interest to the field of radiation biology. Absorption of radiation in the body (tissue) may result in biological injury and is the

principle upon which radiation detection is based. Excessive exposure by man to radionuclides in the environment can cause sudden chromosomal change (mutation) in the cells which could lead to production of cancerous cells. The uptake of radionuclides by man is usually through food taken for survival. Vegetables (plants) are often taken as food and as well as medicine (Alan and Samuel, 1986). Most food stuffs contain some measurable amount of radionuclides continuously emitting radiation energy per unit mass (dose). It is reported that carrot contain about 3,400pci/kg of K-40 (ISU, 2012) the source of radionuclides and other element in plants/vegetables is either through contaminations (discharge of radionuclides from the environment) or through up take from the soil via the roots (INFOSAN, 2011) Andreas and Hans (2012) looked into active and non-active potassium and found that biochemistry of human, animal and plants metabolism cannot distinguish ^{39}K from either^{40}K or ^{41}K as well as other radionuclides. Organisms deal with all stable isotopes the same way as the radioactive and have no mechanism to separate active nuclides in normal metabolic pathway.

Mining of mineral resources are the most exploited natural resources which involve extraction, grinding (processing) ore concentrations and dispersal of tailings (Raman, (1988), Ferreira da Silver etal2004) Miming of cassetterites (SnO_2) an important ore of tin found in Nigeria has been in Jos- Plateau for several decades Onugha, (1992) Nowadays farming of crops such as Irish Potatoes (*Solamums spp)*, tomatoes (*lycopasicum spp)*, Cabbages (*Andira enemis)*, carrot (*Daucas carota)* and cucumber (*Cucumis sativus*) are carried out in Jos Plateau at the dry season (plate I). Most vegetables produced in Jos-Plateau during the dry season are grown on and around abandoned mine tailings with the ponds used as their main source of water for irrigation

(plate II). In the rainy season crops like dauro (*Soghum bicolor)*, acha (*Diosperos ebenum)*, sweet potatoes *(Pomoea batatus)*, maize (*Zee mays*) and millets (*Eleosine corocana*) are also cultivated. Generally, mining generate large concentration of highly soluble inorganic matter, some of which are considered toxic (Mousa 1997). Mining of minerals such as tin and gold have been found to be one of the major routes of exposure to heavy elements by man and animals (Kim, 2005). Ingestion of non-essential elements such as gold, mercury, and lead leads to the development of autoimmunity which results in to the diseases of the circulatory or central nervous system (Glover, 1995)

The aim of the research is to assess the radioactivity and the elemental content of the vegetables grown on the study area. This is very important because there is a global concern about the health risk of TENORMS resulting from mining and mineral processing activities.

The soils of degraded tin minefield farm land in three LGA;Bokkos, Jos south, and Barikin-Ladi of extensive mining of tin on the Jos Plateau were analyzed for radioactivity and elemental concentrations. Cabbage (*Andira enemus*) (*Brassica olarecea*), potatoes (*Solamums spp*) and carrot (*Daucas carota)* grown on the degraded minefield at dry season and grown away from the degraded minefield at rainy season farming were also analyzed.activity concentration analysis was achievedof with Gamma-ray spectrometry using NaI(Tl) detector and elemental concentration analysis was carried out applying Neutron activation analysis (NAA)using (NIRR-1). A Comparism of the activity concentration found in the soil with world values (UNSCEAR, 2000) wasmade. Absorbed dose rate, effective does rate and radium equivalent for the soil were

determined and this allow logical conclusions about the health risk of the populace. Radiological parameters such as internal and external hazard indices of the soil and cancer risk of the vegetables due to ingestion of NORMs were determined in the research in order to ascertain the health hazard of the populace. On the other hand daily intake of metals, transfer factor and health risk index were also determined.

1.2 Statement of the Research Problem

The deep mining which is the excavation of the underlying sand has created mining pits, man-made lakes, pools and ponds which have great effect on the people, animals and the environment of the Jos-plateau. Both mechanical and chemical processes are used in the Jos-Plateau tin mining in order to extract the desired product from the mined ore result in the production of waste known as tailings (Mangset and Sheyin, 2009). These tailings and other minerals like zircon and monazite are radioactive and are major source of external radiation hazard (Rabiu and Umar, 1995). IAEA (2003) reported 29,000 Bq/kg Th-232 for zircon in Nigeria. Excessive exposure by man to radionuclides in the environment can cause biological injury.

Radionuclides in foods (plants–vegetables) have continued to be a source of radiological problem for a long time. One of the main health concerns to consumers in the long term due to high radiation exposure is the development of cancer. Cancer type and target organ depends on the radionuclide.

The mining activities reduced the farm lands and irrigation farming is now carried out on the tailings near the created ponds which are also used as the sources of water. These tin mined ponds as they become filled up with water in rainy season become one of the

sources of soil erosion where mined minerals and radionuclides could be deposited on the rest of the farm lands (Patterson, 1986) Opened air vegetables can be contaminated by the release of radionuclides in the atmosphere and through absorption from the soil via the roots. This has become a natural problem since plants absorb mineral indiscriminately of radioactive nuclides and this has also become one of the major sources of contamination of food.

More so these vegetable which are grown on the tailings do not undergo any special preventive procedures before consumption by man or animals. The types and concentrations of the radionuclides transferred to the vegetables have always been of concern to health. The type of health effect that could result from the radiation exposure is also of concern and it depends on the type and quantity of radionuclide ingested.

Schonwald, (2004) and Makonvchik, (2003) reported that ingestion of large amount of radioactive potassium could lead to health hazard such as hyperkalemia, which strongly influence the cardiovascular system of man. On the other hand acute short of potassium could lead to hypokalemia of similar health disorder. Radioactive gas Ra-222 is hazardous to people and the gas is the product of radioactive decay of U-232 released from rocks and soils.

1.3 Aim and Objectives of the Research

The aim of the research is to assess the radioactivity and elemental content ofsome vegetables grown on mine tailings around Plateau State, Nigeria.

The objectives of this work are;

i. To determine the radioactivity concentrations in some vegetables and the soil/tailings on which the vegetables are grown.
ii. To compare the values of radioactivity assessed with international recommended limits.
iii. To assess the elemental content of the sampled vegetables and the sampled soil on which the vegetables are grown.
iv. To compare the determined elemental concentration in the sampled vegetables with international recommended limits.
v. To determine the cancer risk due to ingestion of NORMs from the vegetables
vi. To determine the health risk index due to intake of some non-essential element

1.4 Justification

Over the years activity concentrations of Ra-226, Th-232 and K-40 (Usikaluet al, 2011) and radioactive minerals like zircon and monazites (Rabiu and Umar, 1995) have been determined on the Jos, Plateau state tin mine areas and the results revealed a high background radiation level. Radiation monitoring and evaluation are routine and necessary undertakings. Therefore, consistence and comprehensive researches will allow radiological conclusion on the increase or decline of the radioactivity on the area of study.

The radioactivity levels in food depend on several factors. These factors include type of food, geographical region or location geology of the area on which the food are produced (INFOSAN, 2011) The Jos -plateau consist of granite rock (Adiuku et al, 2001). It is

therefore essential to assess the radioactivity and elemental concentration of the vegetables grown on the region because Jos-Plateau consists of granite.

Plants absorb nutrients for growth from the ground and they do not discriminate radioactive isotopes from non-radioisotopes as such there is tendency of accumulating high radiation level if present in the area.

The research will serve as a means of creating public awareness to the danger if any that could be associated with the consumption of the selected vegetables cultivated in the study area.

This research is important because there is a global concern about the health risk of NORMs resulting from mining and mineral processing activities and as a result national authorities are expected to establish guide lines and criteria for radiation

Manighandan (2009) presented that irrespective of biological necessary, plants absorbed primordial radionuclides present in the soil around their root region. This is facilitated by their chemical similarities with other element that plants normally need for growth. Plants/soil elemental transfer factor (T_f) assessment will help to draw significant conclusion on amount of NORMs and other toxic element that are absorbed by the vegetables under study.

The estimation of daily intake of metal (DIM) will serve as a tool for making decision on the health issues about diet habit of the people in the environment. Another yet important tool is the health risk indexes (HQ) which will be utilize to assess the health risk due to elemental concentration of non-essential or toxin elements.

The outcome of the research will create an economic benefit if the result is favorable or has no health risk where the vegetables and other crops in that area will meet high demand from other parts of Nigerian. However when the result has health risk, the reverse is the case.

The result to be obtained from the study area on assessment of radiation and elemental concentration of the selected vegetables will contribute to literature and will be utilized by radiation protection officers in Nigeria along with other agencies like NIS, NAFDAC etc.

The research is purely explorative and will serve as a tool for comparing radioactivity of NORMs in element concentration vegetables in Nigeria and other part of the world.

1.5 Scope and Limitations

The research covered three local government areas of the Jos-plateau and these are;Bokkos, Jos south, and Barikin-Ladi areas where the selected vegetables are massively grown around abandoned mined tailings. Three vegetables which are massively grown and consumed in the area were considered; and these are Irish potatoes, carrot sand cabbages. The research was first carried out at dry season (irrigation scheme using water from the abandoned ponds) and then during rainy season farming. The collection of samples were limited to the environment where the selected vegetables are grown on and around the tin mine tailings The analytical equipment/techniques utilized include Sodium Iodide thallium activated NaI(Tl) radiation detecting and counting system for the radioactivity and neutron activation analysis (NAA) using Miniature Neutron Source Reactor (MNSR); Nigeria Research Reactor (NIRR-I) for the elemental

characterization allobtained at Centre For Energy Research and Training (C.E.R.T.) Ahmadu Bello University, Zaria.

The scope of the work therefore is to measure the radioactivity concentration of NORMs in soil of the degraded mine failing, selected vegetables grown on the area of dry season and the selected vegetables grown away (rainy season). Radiological indices will be determined from the result so that logical conclusions are derived. The elemental concentrations of the same sets of samples will be measure, daily intake of metals (DIM), transfer factor(T_f) and health risk indices (H_Q) will be determined.

The research is limited to the above mention vegetables and soil, where other vegetables like tomatoes, cucumber, green beans, garden egg etc. are not considered. Background count using Geiger-Muller (G.M.) radiation detector would have been used to measure the background count of survey area but was not possible because of the ethnic/social conflict between Fulani and the inhabitant at that time of the research. The energy windows for the determinations of radioactivity concentrations with NaI(Tl) were limited to K-40, Ra-226 and Th-232 only. Windows for Co-59, Cs-137 were not considered the research will have covered more than three LGA but it was not possible due to economic dispensation and the ethnic conflicts.

The precision of the measurement depends on the precision of the equipment used in C.E.R.T. They may or may not be subject to standardization

1.6 The Study Area

Plateau State is located between geographical coordinates; 9° 55' 0" North, 8° 54' 0" East in northern Nigeria in Africa. Half of the Nigeria's land is underlain by crystalline or

basement rocks which consist of granites, gneiss and migmatites while the other half by sedimentary rocks consists of schist, phyllites quartzite and marbles (Rahman 1988). Most rock type of the Jos-Plateau is granite and according to Strahler and Strahler (1973). Adegboye (2012) reported that tin mining industry which is the largest producer of columbite started in Jos-Plateau since 1903. Plateau state consists of 17 local government areas. Three local government areas; Jos south, Bokkos and Barikin -Ladi of extensive mining were selected for this work. The map of Nigeria and Plateau state is presented in figure 1.1.The selected sampled sites and the local government areas of Jos-Plateau state are shown in figure 1.2. The description of the sample Sites are;

1.) Barikin -Ladi local Government Area; A.PL. Old mines farmlands

2.) Jos -South Local Government Area; Kuru-Jantar Village, New mines of Gada-biyu near Faron junction

3.) Bokkos Local Government Area; Kai forestry/ nursery, Along Barikin- Ladi to Kabba Road

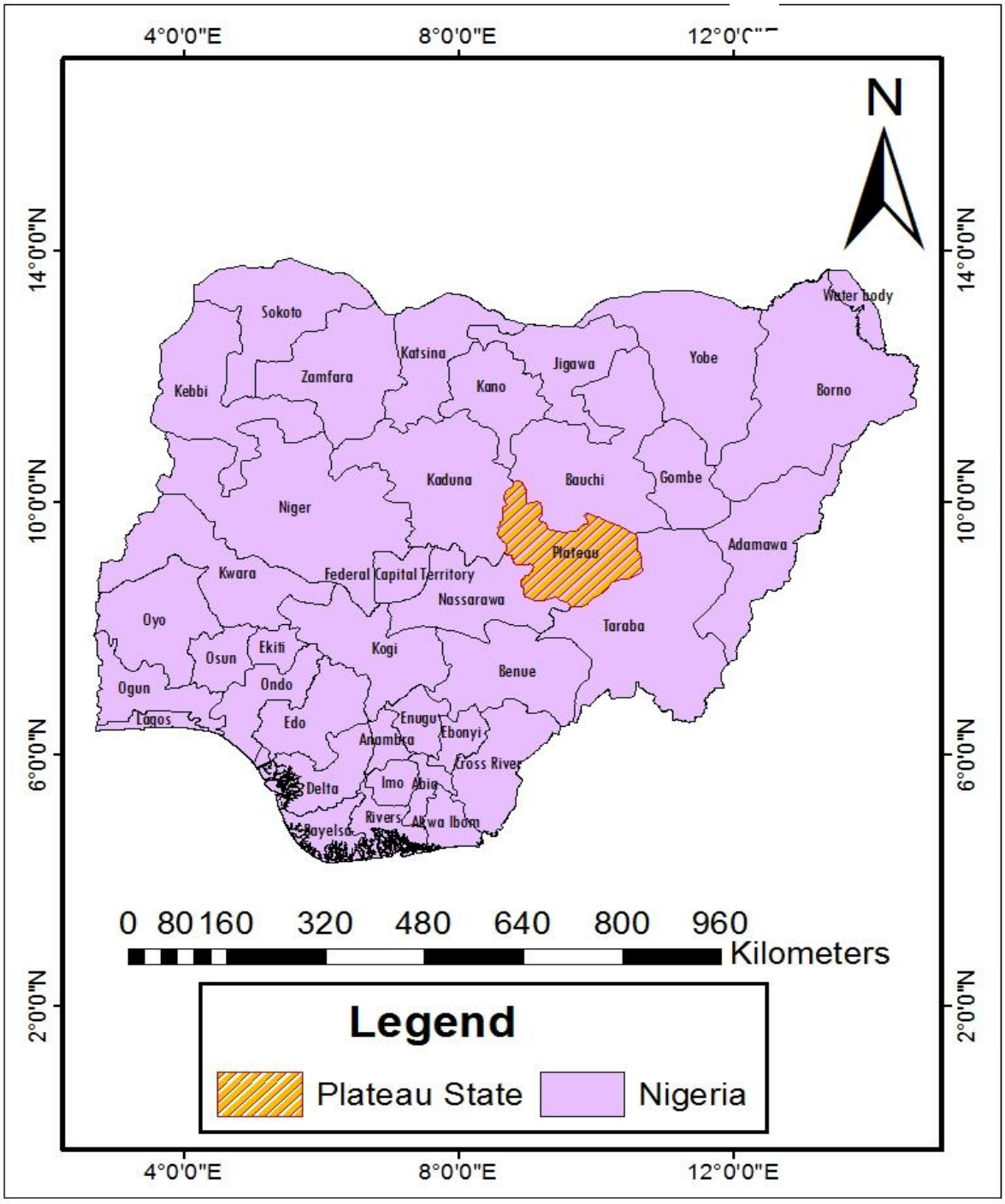


Figure 1. 1:Map of Nigeria Showing Plateau State
Source: Modified From Administrative Map of Nigeria.

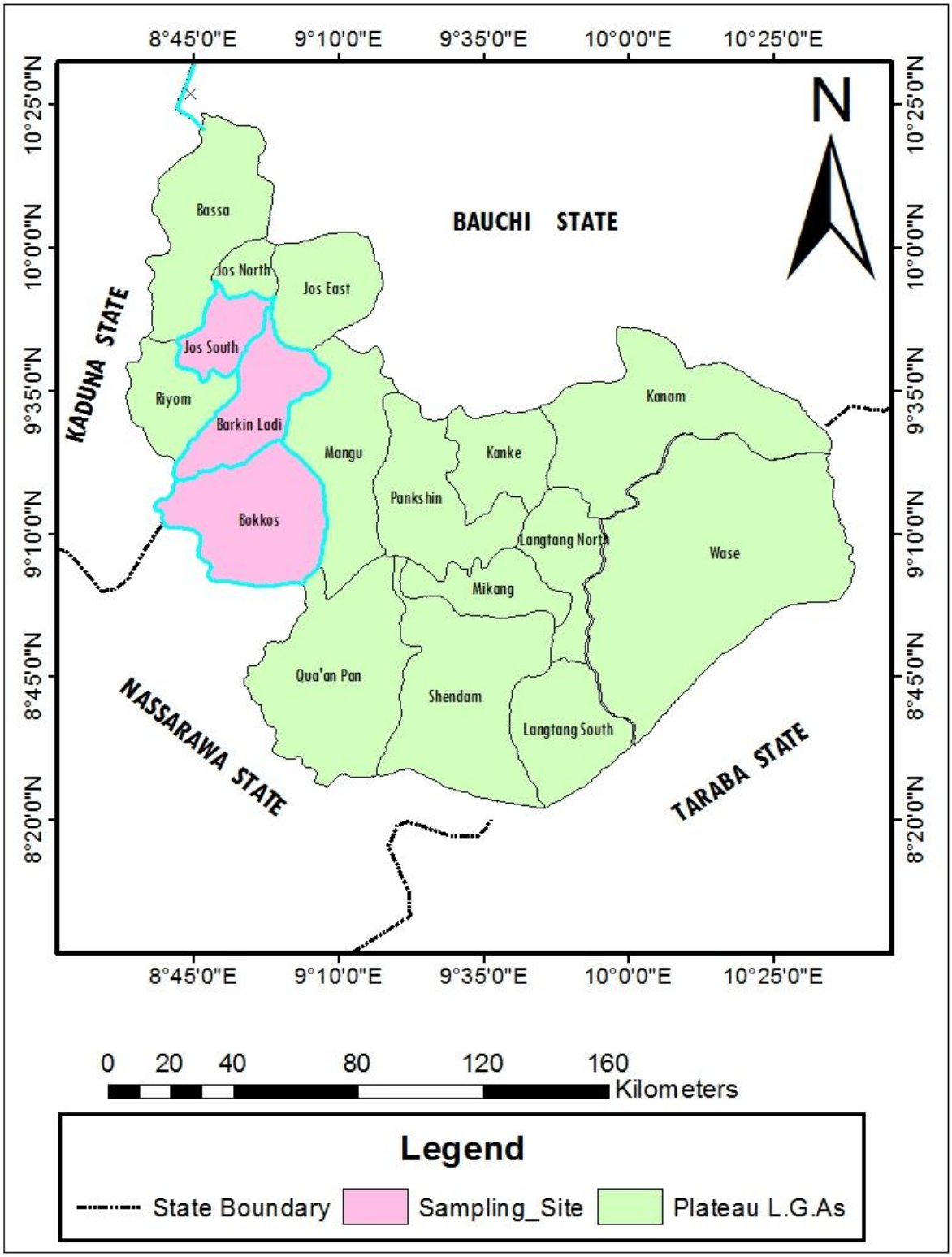


Figure 1. 2: Map of Plateau State Showing Sampling Sites
Source: Modified From Administrative Map of Plateau State.

1.6.1 Climate of the Plateau State

Though situated in the tropical zone, a higher altitude means that Plateau State has a near temperate climate with an average temperature of between 18 and 22°C. Harmattan winds which cause the coldest weather between December and February. The warmest temperatures usually occur in the dry season months of March and April. The mean annual rainfall varies from 131.75cm in the southern part to 146cm on the Plateau. The highest rainfall is recorded during the wet season months of July and August. The average lower temperature of Plateau State has led to a reduced incidence of some tropical diseases such as malaria. The Jos, Plateau is a source of many rivers in northern Nigeria and these include the Kaduna, Gongola, Hadejia and Yobe rivers (Plateau State, Wikipedia)

1.6.2 Geology of the Plateau State

The Jos Plateau is thought to be an area of younger granite which was intruded through an area of older granite rock, making up the surrounding states. These "younger" granites are thought to be about 160 million years old. This creates the unusual scenery of the Jos Plateau. There are numerous hillocks with gentle slopes emerging from the ground like mushrooms scattered with huge boulders. Also volcanic activity 50 million years ago created numerous volcanoes and vast basaltic plateaus created from lava flows. This also produces regions of mainly narrow and deep valleys and pediments (surfaces made smooth by erosion) from the middle of rounded hills with sheer rock The phases of volcanic activities involved in the formation of Plateau State have made it one of the mineral rich states in the country. Tin is still mined and processed on the plateau (Plateau State, Wikipedia)

1.6.3 Soil of the Plateau State

Alexander, (1986) explains the dependence of soil in various physical parameters such as rain fall, temperature, organic matter, relief /topographic 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 plateau soil into three major types which are the soil on granite, soils on lower basalt and soil on unconsolidated deposit and basement complex discuss below;

(*i*) Soil on Granite

These are usually coarse and well drained shallow soils. They have very weak differentiation of genetic horizon containing coarse element having solid rocks within 30cm depth. The crust is mainly ancient and formed under geographical and climatic condition. However they are ne formation as well. These types of formation may suggest high radioactivity environment (Alexander, 1986)

(*ii*)Soils on lower basalt

These new basalts accommodate variety of soils particularly along the steeper slopes and foot slopes or volcanic cones. On shallow slopes a soil varies 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. Research of weathered material is large. The soils are well structured, permeable and relatively formed (Alexander, 1986)

(iii) Soil on unconsolidated deposit and basement complex

These are associated with out crops or late rites. They grade down slopes with deeper to imperfectly drained slopes strongly mottled soil often with surface layer of yellow Aeolian loam. They are usually between A and B horizons. Along the slope from rock or late rites, out crops layers with gravels or iron stone are observed. Observation in the surface horizon often leaches with an alluvial B horizon or iron oxides (Alexander, 1986)

CHAPTER TWO

2.0 LITERATURE REVIEW

A review of the related literature concerning the research is presented in this section. Previous works done related to the thesis are also captured and highlighted in this section with a brief discussion about certain observations which were made at the end of each previous work done.

2.1 Radioactivity

Radioactivity is considered to be a phenomenon of spontaneous nuclear transformation of radionuclide (so-called radioactive decay), which is accompanied by the emission of particles (α, β–, β+ etc.), electron capture, proton emission, or the emission of fragments (i.e., the most common decay modes), and the emission of γ radiation(Michael and Leo 2007). Radioactivity is also indicated as radioactive transmutation. Radioactivity can occur both naturally (by naturally occurring radioactive materials NORMS) and through human intervention such as mining (by technologically enhance naturally occurring radioactive materials TENORMS).

The exact mode of radioactive transformation depends on two factors

(i) The type of instability i.e. neutron to proton ration is too high or too low

(ii) The mass energy relationship between the parent nucleus, daughter nucleus and the emitted particles.

2.2 Radioactive Decay Law

An unstable nucleus transforms into another nucleus spontaneously according to the law of radioactive decay. Radioactive decay is a random process on which the probability that an atom will decay during the time *dt*is given by:

$$-dN_t = \lambda N_o dt \qquad (2.1)$$

where:

λ is the constant of proportionality known as the decay constant

N_o is the number of radioactive element initially

$-dN_t$ is number of the radioactive element after time *dt* elapsed

The number of atoms decaying in time *t* is given by

$$N_t = N_o e^{-\lambda t} \qquad (2.2)$$

N_t is number of atoms present after the elapsed time *t*(Cember, 1986)

2.2.1 Radioactive Decay Fluctuation

The number of decay undergone by a radioactive source is in a period of time Δt which is short compared to the half- life of these source. The activity of the sources may be considered as constant. If repeated measurement of the number of decay *n* in time interval Δt are now taken fluctuation may be observed from measurement to measurement. This is due to statistical nature of the decay process and that the exact

number of decay at any time can never be predicted, but only the probability for such an even (Michael and Leo 2007).

Using the radioactivity decay law, the probability of observing n counts in a period is obtained using the Poisson's distribution as;

$$p(n, \Delta t) = \frac{m^n}{p} e^{-m} \quad (2.3)$$

where;

m=average number of counts in period Δt

n = number of the distributions of the statistical data

The standard deviation of distribution for the average number of counts is given by;

$$\rho = \sqrt{\mathrm{m}} \quad (2.4)$$

ρ= the standard deviation of distribution (Michael and Leo 2007)

2.3 Half-Life

A clearer quantity used to characterize the radionuclide instead of the decay constant λ is half-life. The half-life $T_{½}$ is the time it takes for the number of atoms to decrease to half the initial value (i.e., ½ = $e^{-\lambda t}$). Thus the half-life is related to the decay constant through the equation;

$T_{½}$= ln2/λ, that is, $T_{½}$= 0.693/λ (2.5)

2.4 Activity of Radionuclide

Activity (or emitter activity) is the quantity that characterizes the speed of radioactive decay. The activity A is the number of decays per unit time interval or the loss in the number of as yet undecayed nuclei per unit time interval. The activity expression is give mathematically as;

$$A_t = A_o e^{-\lambda t} \quad (2.6)$$

Where;

A_o =Initial activity of the material

A_t =Activity at any time t

The unit of activity is the Becquerel (Bq) which is disintegration per second. The older unit of activity was the Curie (1 Ci = 3.7×10^{10} Bq) (Michael and Leo 2007),

2.4.1 Specific activity

Specific activity (A_{SP}) is usually applied to quantify the activity of a radionuclide in a given mass of any radioactive material. It relates the activity and mass of the radioactive material. It is the activity A_{ct}per unit mass of the radioactive material (Cember, 1996) expressed as;

$$A_{sp} = \frac{A_{ct}}{A} = \frac{\lambda N_A}{A} \quad (2.7)$$

N_A Avogadro's number and A is the atomic mass of the radionuclide.

2.5 Interaction of Radiations with Matter

Michael and Leo, (2007) outlined the most important interaction of radiation α or β particles and γ-photons with electrons of an atom. α and β particles are classified as ionizing particles. This is because they carry electric charges that cause the atoms to separate into ions. Each separation creates an ion pair. γ-rays are said to be indirectly ionizing. Radiation interacting with matter can be either scattered or absorbed. The mechanisms of the absorption of radiation are of interest because:

(i) Absorption in the body tissue may result in biological injury.

(ii) Absorption is the principle upon which detection of radiation is based.

The transfer of energy from emitted radiations to matter occurs in two major ways: ionization and Excitation.

(i) Ionization: The process resulting in the removal of an electron from a atom, leaving the atom with a net positive charge.

(ii) Excitation: Addition of energy to an atomic system, transferring it from the ground state to an excited state.

Radiation can be classified into two groups:

(i) Ionizing, consisting of Particulate radiation (charged particles) such as alpha beta particles or Electromagnetic radiation such as X or gamma rays.

(ii) Non Ionizing, such as Neutrons

2.5.1 Interaction of Charged Particles

All atoms are normally electrically neutral. When a charged particle strikes an orbital electron, it ejects it from the atom resulting in the formation of an ion pair. Since the removal of the electron from the atom decreases the total number of negative charges by one, it leaves the atom with a net positive charge. The ion pair consists of:

(i) The positively charged atom.

(ii) The negatively charged electron.

Such particles capable of creating ion pair in this manner are called ionizing radiation.

The term used to compare and relate the ionizing powers of different types of charged particles is called the "specific ionization" Specific ionization is defined as the number of ion pairs per unit path length formed by ionizing radiation in a medium:

$$Specification = \frac{Number\ \ of\ ion\ pairs\ formed}{Path\ leng\,ht\ in\ cm} \tag{2.8}$$

2.5.2 Interactions of α Particle

An alpha particle is a helium nucleus striped of its orbital electrons. It is emitted from a radioactive atom with a velocity of about1/20 that of the speed of light and with energies ranging from 4 to 9 MeV. Alpha particles with their charge of +2 and their mass of 4amu create intense horizon. In dry air α particles generate 50,000 ion pairs per centimeter of its paths giving up about 34MeV per pair produced. A 4MeV α particle dissipates its

energy in about 2.5cm of travel. It slows stops and become a normal helium atom by adopting two electrons from its surroundings near the ends of its path it transfers some energy to neighboring atoms by atomic excitation. The added energy is then given off by the atom as fluorescent radiation or low energy X-Rays when the electrons drop back down to the inner orbital vacancies.

Because of its relatively large mass (2 neutrons and 2 protons), high electrical charge (+2) and low velocity, the specific ionization of an alpha particle is very high. That is, it creates many ion pairs in a very short distance. The range in air is only several centimeters even for the most energetic alpha particles.

Since the alpha particle has a very limited range in matter, it presents no external radiation hazard to man. Many alpha particles cannot penetrate the protective layer of skin. However, once inside the body, surrounded by living tissue, damage will be to the local area in which the alpha emitter is deposited. Thus, alpha emitters are an internal hazard and intake to the body must be prevented.

2.5.3 Interactions of β Particles

Beta particles with their charge of -1(or +1) , a mass of 0.000548amu, and very fast travel cause less intense ionization than α particles, typically 100 to 300 ion pairs per cm of path in dry air. Because of their small mass β particles are deflected easily and do not travel in a straight line. In dry air their total path length is 20m or less, β particles are more penetrating than α particle. Beta particles are emitted from the nucleus of a radioactive atom with a wide range of energies up to some maximum value. When a beta

is emitted that is below the maximum value, the neutrino carries away the rest of the energy.

Beta particles, like alpha particles, lose their energy by ionization and excitation, but because of their small mass (1/7300 of an alpha) and lower charge (1/2 of that of an alpha) the interactions take place at less frequent intervals. Generally 1mm or so of dense material is sufficient to stop beta particles. The rapid slowing or quick changes in direction causes β particles to emit x-rays (so-called bremsstrahlung). Therefore, the beta particles do not produce as many ion pairs per centimeter as alpha particles, and thus, have a greater range in matter. The beta particle's range in matter depends on the energy and the composition of the material.

Beta particles can interact with a nucleus of an element and give rise to X-rays by a method called Bremsstrahlung (German word for "Breaking Radiation") occurs when high speed beta particles approaches the nucleus of an atom. The electrical interaction between the negative beta particle and the positively charged nucleus causes the beta particle to be deflected from its original path or stopped all together. Their stoppage or deflection results in a change in velocity of the beta particle with the emission of X-rays of various energies. The likelihood of Bremstrahlung production increases with increasing atomic number of the absorber. For this reason, beta shields are made from low atomic numbered material, like aluminum or plastics.

Beta particles require energy of greater than 70 keV to penetrate the protective layer of the skin, and thus, are somewhat of an external hazard. The beta can also constitute an internal hazard. A beta particle has a greater range in tissue compared to an alpha particle

due to its low specific ionization. The beta particle gives up less energy per unit volume of tissue and, therefore, is not as effective in causing damage as an alpha particle.

2.5.4 Interaction of x-rays and gamma-rays

Gamma rays do not interact with matter in the same way as α and β particles because they have no charge and no mass and do not lose energy steadily in small, scattered amount. Instead they give away in large chunks in direct interactions.

From a practical radiation protection point of view, X-rays and gamma rays are identical, differing only in their place of origin. Gamma rays are emitted from excited nuclei with a discrete energy. X-rays are emitted when the extra-nuclear atomic structure undergoes a transition; i.e., an outer shell electron replaces a missing lower shell electron and an X-ray is produced. The energy of the X-ray is approximately equal to the difference in the electron energy level.

Since X- and γ - rays are charged less, they do not interact by electrostatic forces as in the case of charged particles, which cause ionization of matter directly along their path of travel. However, X- and gamma rays do have sufficient energy to release high energy secondary charged particles (electrons) from matter through one of the three basic interactions:

(i) The Photoelectric Effect

(ii) The Common Effect

(iii)Pair Production

The high speed electrons resulting from these interactions then cause ionization of the medium. Depending on the energy of the incident photon

2.5.5 The photoelectric effect

The Photoelectric Effect is the interaction of X-or γ-ray photons as well as other photons (such as light), whereby all of the energy of the photon is transferred to an inner shell electron (usually the k - shell), ejecting it from the atom and leaving the atom with an inner shell vacant. This shell vacant creates an excitation energy which corresponds to the Binding Energy (BE) of the ejected photoelectron.

The Kinetic Energy (KE) of the photoelectron is equal to the energy of the X or γ -ray photo minus the BE of the electron ejected.

If the X or γ -ray photon does not have sufficient energy to knock the inner shell electron loose, the reaction will not occur.

The resultant atom is now in an excited state and will decay to the ground state by emission of X-rays and fluorescent radiation with the total energy equal to the BE of the photoelectron. The energies of the secondary radiations are usually much lower than the primary X or γ -ray.

2.5.6 The Compton Effect

Photons with energies much greater than the BE of the electrons in an atom may interact through essentially elastic scattering interactions in which the total KE of the system is conserved. In this interaction, the electron appears to the photon as a free electron as in figure 2.1

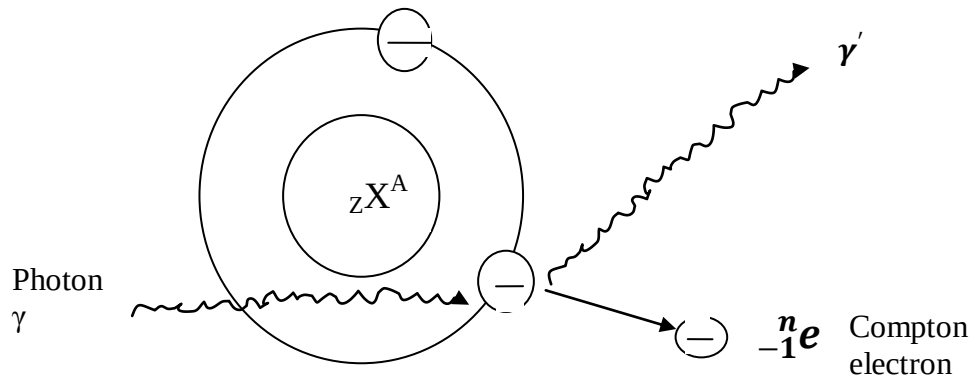


Figure 2. 1: Photon Interaction in Compton Effect

The primary γ-losses part of its energy to the Compton electron which gets scattered at an angle from the original direction of the incident γ, while the Compton scattered γ' is scattered at an angle. In this process, the scattered photon and Compton electron share the energy of the incident γ photon. The KE carried off by the Compton electron may be deposited locally (i.e., absorbed immediately by the surroundings). However, the energy carried off by the Compton scattered photon is not deposited locally. Therefore, this scattered photon can significantly contribute to the doses outside a shielding apparatus.

2.5.7 Pair production

High energy gamma photons transfer their energy primarily by pair production. A high energy X or γ-ray passing close to a nucleus suddenly disappears and an electron and a positron appear in its place. This interaction must take place in the neighborhood of a nucleus to conserve momentum.

Since both particles are created from energy supplied by the incident photon, the process is generically possible only when the photon energy is equivalent to the mass of the two electrons i.e.$2mc^2$ =1.02 MeV.

When the positron slows down (i.e., loses its KE), it will annihilate itself by combining with an electron. This produces two photons with energy of 0.51 MeV each. This "annihilation radiation" represents the energy equivalent of the rest mass of two electrons which is converted to pure energy according to the principles of Einstein's theories, in particular, given by equation 2.9

$$E = mc^2 \qquad (2.9)$$

where;

E = energy of two 0.51 MeV photons,

m = the rest mass of two electrons (1/1840 amu)

c = the velocity of high (3×10^8 m/sec).

Ionization process leaves the atom with net positive charge ion and an electron. Hence, ionizing radiation has the ability to affect the chemical state of a material and so cause changes which are biologically important, like in the case of incident radiation directly attacking the DNA of the water molecule in which ionizes water molecules and electrons are released. The ionized water molecule can react further forming highly reactive molecules such as hydrogen peroxide, or radicals such as hydroperoxy1. Depending on the received doses, this mechanism may cause damage to living tissue. If the dose is sufficient, the effect may be seen immediately, in the form of radiation poisoning.

However, lower dose may cause cancer in long in long term or it can lower the ability of the body to respond to infections by reducing or interfering with the immune system (Alan and Samuel, 1986) Therefore ionization is the process by which a particle of energy interacts and knockout electrons from molecules like water, DNA and proteins leaving it with net positive ions.

2.6 Radiation Units and Quantities

(a) Exposure: This is the quantity expressing the amount of ionization caused in air by x- or γ- radiation. The unit is Roentgen (R), this corresponds to the production of ions (of onesign)

1R= $1.6x10^{15}$ ion pairs/kg. The average energy required to produce an ion pair in the air is $5.4x10^{-18}$ Joule (J). This implies that 1R=$1.61x10^{15}x5.4x10^{-18}$J/kg equivalent to 0.0086J/kg of air.

(b) Radiation Dose: A dose is the quantity of energy deposited in any medium by any type of ionizing radiation. The former unit is "rad" (radiation absorbed dose). The SI unit is "Gray". The absorbed dose in grey is the energy in Joule (J) absorbed by a material of 1kg and it is a measure of the type of radiation source. 1Gy=1j/kg.

(c) Dose Equivalent: In health physics the biological health effect of radiation is of interest and the doses equivalent (equivalent dose) is a measure of the biological health effect of radiation. The biological health effect of ionizing radiation depends on its absorbed dose and the type of radiation. Its S.I. unit is Sievert "Sv". It was formally measured in "rem" (Roentgen equivalent to man). For example 0.01Gy (1Rad) of fast

neutron can do as much damage as 0.1(10Rad) of gamma radiation therefore the difference in the radiological effectiveness (quality factor Q must be taken into account).

Equivalent dose (Sv) = absorbed dose (Gy) x Q x N (2.10)

where Q = quality factor which a measure of a particular type of radiation to cause biological damage. Q = 1 for β, X and γ–rays, 5 for thermal neutrons and 20 for fast neutrons and alpha particles (Alan and Samuel, 1986)

N = further modifying factor which might take account of such factors as absorbed dose rate as fractionation. N=1 (assigned by ICRP).

(d) Dose rate: In controlling radiation hazard it is usually necessary to establish the time duration at which radiation is being received or accumulated the Grey and Sievert are units expressing amount of radiation which may have been received over period of time. The absorbed dose or equivalent dose received in 1 hour by a body is given by the rates Sv/h and Gy/h respectively.

The amount of radiation per annum which course biological damage on man is referred to annual effective dose. Radiation health protection officers have worked out recommendations on equivalent dose limit for radiation workers per annum in order to prevent stochastic and non -stochastic effects on radiation and are measured in Sv/y or Gy/year.

(e) Effective Dose (H): Fornon-uniform irradiation and reflecting the harm attributable to radiation of each organ weighting factors have been assigned to the various individual

organs as 1. The sum of the weighted organ doses is also known as effective dose equivalent, given by;

$$H = \sum_T W_T H_T \quad (2.11)$$

H_T = dose equivalent in tissue T

W_T = weighting factor for tissue T (Alan and Samuel, 1986)

2.7 Biological Effect of Radiation

Nuclear radiations have sufficient energy to cause ionization when they interact with cells. Cells are largely composed of water and the ionization of radiation in the later can lead to molecular changes and also to the formation of chemical species of a type which damaging to chromosomal material(DNA) the damage takes the forms of changes in the construction and function of the cells. In human body these may manifest themselves as clinical symptoms such as radiation sickness, cataracts, or in the larger term cancer (Alan and Samuel, 1986).

The process leading to radiation damage classified as initial physical stage, physiochemical stage, chemical stage and biological stage.

a) Initial physical Stage; When energy is deposited in the cells at this stage it lasts in a minute fraction of seconds (~10^{-16} of seconds) and cause ionization. In water the process is written as

$$H_20 \longrightarrow H_20^+ + e^- \quad (2.12)$$

Where H_20^+ is the positive ion and e^- is the negative ion.

b) Physiochemical stage; When energy is deposited in the cells, it may last for about 10^{-6} seconds and the interaction of ions formed with other water molecules results in a number of new products for instance the Positive dissociate immediately,

$$H_20^+ \rightarrow H^+ + 0H \quad (2.13)$$

Electron is picked up by a neutral H_20 molecule in the reaction

$$H_20^+ e^- \rightarrow H_20^- \quad (2.14)$$

$$H_20 \text{ Dissociates immediately} H_20^- \quad H + \rightarrow OH^- \quad (2.15)$$

The free radicals H and OH have an unpaired electron, chemically highly reactive and may combine with like radicals or react with other molecules in solution. The products of the reactions are H^+ and OH. Another products is hydrogen peroxide and is formed by the reaction,

$$OH + OH \rightarrow H_2O_2 \quad (2.16)$$

The hydrogen peroxide is a powerful oxidizing agent and can affect molecule or cells that did not suffer radiation damage directly. If the irradiated water contains dissolved oxygen, the free hydrogen radical may combine with oxygen to from the hydrogen peroxide radical

$$H+O_2 \longrightarrow HO_2 \quad \text{(non-reactive)} \quad (2.17)$$

(Cember, 1992, Alan and Samuel, 1992)

c) Chemical stage: This is the stage that last for few seconds in which the reaction products interacts with the important organic molecules of the cells. The free radicals and organic molecules may attacks the complex molecules which for the chromosomes.

Therefore, radiation is seen to produce biological effects by the production of free radical and hydrogen peroxide in the water of the body fluids. Hydroxide is strongly to biological molecules and is stable within the cell. It may be removed by a number of enzymes in the cell that are there to specifically protect against this material.

There is always a chance that a radioactive particle will score a direct hit on a DNA, but the odds of these are much smaller than the indirect damage due to hydrogen peroxide. Massive radiation damage to a cell usually results in the cell death. It is actually better than a situation in which the cell is damage to the point where the cell's deficiencies are over whelmed. Here it possible for the hydrogen peroxide or other fragments to actually damage the cellular mechanism, enzymes, and the like, or damage the DNA itself. If the genes on the DNA responsible for turning off cell division are damage, the cell continues to reproduce without control and this is cancer manifestation.

In comparing the damage of various types of radiation, we have to bear in mind which kind of radiation deposit the most energy or do most damage in a small volume of cells. In this regard, the most dangerous is the alpha radiation followed by beta and lastly gamma. The most common effect of radiation is mutation and cancer induction. Radiation can cause damage to DNA, and massive damage alters a gene or set of genes so that the resulting organism reveals the effects of the damage. Fertilized eggs, which have significant damage, simply do not develop.

They are sloughed off and aborted spontaneously. In fact, some estimates suggest that almost half of the fertilized cells are lost in this natural process (Cember, 1992) The action of radiation on the cell is classified as either Direct or Indirect as shown in figure2.2

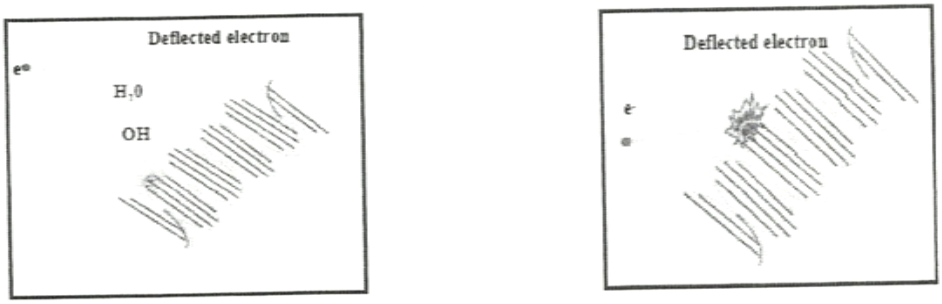


Figure 2. 2: Indirect attack and Direct attack

The effects of radiation on the body mostly depend on the amount of dose received, exposure time, type and the energy of the radiation, sensitivity of organs and the number of cells involved. Alpha and Beta are more ionizing although they cause less or no damage to the external body. But they cause most damage when emitted inside the human body. Gamma and X-rays are less ionizing and causes similar biological effects like burns and cancer by mutations.

In general during radiation interaction with body, cells are either excited and repair back with normal or reduced functions, or ionized to damage completely or change in functions.

d) Biological Stage: The time scale at this stage varies from tens of minute to tens of years depending on the particular symptoms. There are many ways in which the chemical stage can affect an individual and these effects can be conventionally divided into two classes; Somatic and Hereditary.

The somatic effects of radiation also consist of early radiation effect and letter effect. The early radiation effects are those that occur in a period of time from few hours up to few weeks after an acute exposure. (large dose is received over few hours or less) the effects are due to major depletion of cells' population in a number of body organ due to cells killings and the prevention or delay in cell division. Examples of the health effects are attributable to born marrow, gastrointestinal and neuromuscular. The late effects manifest itself over a long time as cancer.

2.7.1 Cancer Risks

Cancer is an over proliferation of cells in the body organ. It is considered to result from damage to the control system of a single cell causing it to divide more rapidly than a normal cell and transmitted to the daughter cell thereby causing abnormal cell increase as detriment to the normal cells.

The hereditary effect of radiation results from damage to reproductive cells. These damage takes the form of alteration known as genetic mutation in the hereditary materials of the cells (sperm) the damage may be passed on to the person's children and subsequently to the later generation.

Intake of radionuclide into the body will commit the target organ (or organs) or the whole body at risk from the radionuclide to a certain dose; the committed dose. The committed effective dose is the dose accumulated over 50 years representing the likely maximum lifespan of the individual following the intake (Aminu and Ahmed, 2013)

The ICRP cancer risk = $2.5x10^{-3}$ based on annual dose limit of 1mSv for general public giving annual death probability of 10^{-5} in 100,000 (Aminu and Ahmed, 2013)

2.8 Radiation Health Effect

Radiation induced damage to cells can produce two types of biological effects in humans ad these are; stochastic and non-stochastic or deterministic. Stochastic effects occur at all dose levels as a result of damage to the DNA. A modified cell that is still able to perform mitosis can give rise to a clone of cells that may eventually result in a deterministic cancer in the exposed person. Such effects develop in the long term, oftendecades after the exposure. A modified stem cell in the reproductive organs (gonads) that transmits genetic code to the descendants of the irradiated person may provide incorrect hereditary information and cause severe harm to some of those descendants.

The probability that effects will occur either in the exposed person (somatic effects) or in descendants (hereditary effects) increases in proportion to the equivalent dose. Deterministic effects occur at high doses when enough cells in an organ or tissue are killed or prevented from reproducing and functioning normally and there is a loss of organ function. A threshold dose exists above which the effects on an organ or biological system are clinically observable. The onset of the symptoms usually shortens (from weeks to hours) and their severity increases with increasing equivalent dose. The three principal sources of information on stochastic effects are epidemiological studies, involving statistical analyses, on the survivors of nuclear weapons attacks on Hiroshima and Nagasaki in Japan, on patients exposed to radiation for medical treatment or diagnosis, and on some groups of occupationally exposed employees. Some of these studies are ongoing.

Data on the deterministic effects come from studies of the side effects of radiotherapy, from effects on the early radiologists, from the Japanese survivors, and from the consequences of severe accidents that have occurred from industrial radiation sources.

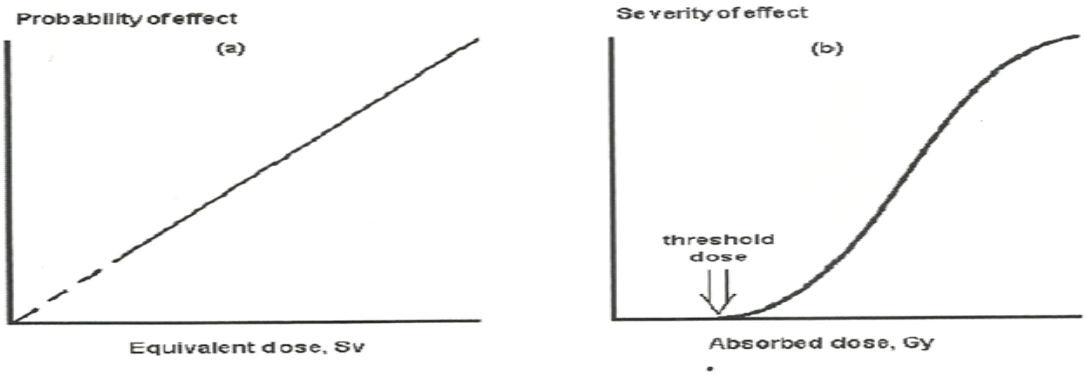


Figure 2. 3: Stochastic (probabilistic)and non-stochastic (Deterministic) effectscurves(Tela, 2013 adopted from IAEA, 2004)

Studies provide evidence of health effects at high doses and dose rates. It is assumed that the risk of inducing stochastic effects increases linearly as the dose is increased. There is a low risk associated with any low dose.

Deterministic effects are only likely to occur when the threshold dose for each effect is exceeded. The severity of the effect increases at higher doses.

Radiation effects are broadly divided into two categories:

(i) Deterministic effects, such as cataract formation, infertility, skin injury, and hair loss;

(ii) Stochastic effects (cancer and genetic effects).

The deterministic effects (primarily cataract and hair loss) have been documented by interventional radiologists and interventional cardiologists. There are no reports of such effects in gastroenterologists. The harm depends on the amount of radiation absorbed

inthe human body. Plates IIIa and IIIb present Biological effect of ionizing radiation as common examples of deterministic effect of radiation.



Plate IIIa (burn) **Plate IIIb (cataract)**

Plate I:Biological effect of ionizing radiation Tela,(2013)

2.9 Radiation Potential Effects

Potential biological effects depend on how much and how fast a radiation dose is received and radiation doses can be grouped into two categories, acute and chronic dose.

(a) Acute Dose

An acute radiation dose is defined as a large dose (10 rad or greater, to the whole body) delivered during a short period of time (on the order of a few days at the most). If large enough, it may result in effects which are observable within a period of hours to weeks.

Acute doses can cause a pattern of clearly identifiable symptoms (syndromes). These conditions are referred to in general as Acute Radiation Syndrome. As in most illnesses, the specific symptoms, the therapy and the prospects for recovery vary from one person to another and are generally dependent on the age and general health of the individual.

(b) Chronic Dose

When a small amount of radiation dose is received over a long period of time, the dose is said to be chronic. The body is better equipped to tolerate a chronic dose than an acute dose. The body has time to repair damage cost by this because a smaller percentage of the cells need repair at any given time

The body also has time to replace dead or non-functioning cells with new, healthy cells. This is the type of dose received as occupational exposures.

2.10 Possible Effects of Radiation on Cells

The possible health effects can be grouped as; cells are undamaged by the dose, cells are damaged, repaired the damage and operate normally, and cells die as a result of the damage.

(a) Cells are undamaged by the dose;

Ionization may form chemically active substances which in some cases alter the structure of the cells. These alterations may be the same as those changes that occur naturally in the cell and may have no negative effect.

(b) Cells are damaged, repaired the damage and operate normally;

Some ionizing events produce substances not normally found in the cell. These can lead to a breakdown of the cell structure and its components. Cells can repair the damage if it is limited. Even damage to the chromosomes is usually repaired. Many thousands of chromosome aberrations (changes) occur constantly in our bodies. We have effective mechanisms to repair these changes.

(c) Cells are damaged, repair the damage and operate abnormally;

If a damaged cell needs to perform a function before it has had time to repair itself, it will either be unable to perform the repair function or perform the function incorrectly or incompletely. The result may be cells that cannot perform their normal functions or that now are damaging to other cells. These altered cells may be unable to reproduce themselves or may reproduce at an uncontrolled rate. Such cells can be the underlying causes of cancers.

(d) Cells die as a result of the damage;

This occurs when a cell is extensively damaged by radiation, or is damaged in such a way that its reproduction is affected, the cell may die. Radiation damage to cells may depend on how sensitive the cells are to radiation.

All cells are not equally sensitive to radiation damage. In general, cells which divide rapidly and/or are relatively non-specialized tend to show effects at lower doses of radiation than those which are less rapidly dividing and more specialized. Examples of the more sensitive cells are those which produce blood called the hematopoietic stem cell and is the most sensitive biological indicator of radiation exposure.

2.11 Radiation Detection and measurement

Isotopes of a given element have nuclei with the same number of protons but different numbers of neutrons. Some isotopes are stable; however radioisotopes are unstable and disintegrate, with the emission of three main types of radiation.

Alpha emitters release a particle composed of 2 neutrons and 2 protons. The atomic number is therefore reduced by 2 and the atomic mass by 4. Alpha particles are so heavy that even with low velocity their momentum is high. They don't travel far, but when they collide with other molecules they do a lot of damage, therefore alpha emitters are considered to be quite hazardous.

When a beta particle emitter decays, one of its extra neutrons is converted to a proton, increasing its atomic number by 1 without changing its atomic mass. The breakdown is accompanied by the emission of a negatively charged particle of low mass, called the beta particle, and an uncharged particle of low mass, called a neutrino. For example, hydrogen consists of just one proton and one electron. Deuterium (2-H), a component of "heavy water," consists of a proton, an electron, and one neutron, and is a stable isotope. Tritium (3-H) is an unstable isotope of hydrogen, consisting of a proton, an electron, and two neutrons. When an atom of tritium decays, one of the neutrons is converted to a proton, one beta particle and one neutrino are released, and a helium isotope (3-He) remains. Tritium is called a "soft" beta emitter, because its beta particles have relatively low velocities. A hard beta emitter such as 32-P (phosphorous) is more dangerous because its beta particles carry more kinetic energy (however it is easier to detect - read on).

Gamma rays consist of electromagnetic radiation resembling X-rays. An example of a gamma emitter is 131-I (iodine). Gamma radiation may accompany either alpha or beta particle emission.

2.11.1 Methods of radiation detection

The method employed to detect radiation depends on the type of emitter and the intended purpose of detection. The most well-known method of detecting radiation is with an ionization chamber. A high energy particle can dislodge electrons from the atoms it strikes, producing pairs of ions. Particles are allowed to pass between parallel plates, one with a positive charge and one with a negative charge. As ionization takes place the ions each move to the plate with the opposite charge, producing a current. The current is read on a meter. The Geiger-Mueller counter is based on the ionization detection principle.

Photographic film can be exposed by all types of radiation, and is used to monitor exposure of personnel working with high energy emitters. A visible track in a cloud or bubble chamber can pick up radioactivity, as can a calorimeter if the energy emitted is quite high.

A problem with many methods of detection is that the energy of the emitter must be high enough to travel some distance through air. The particles emitted by many radionuclides, especially 14-C and 3-H labeled compounds, do not travel a significant distance in air, but pose a danger if internalized because of their proximity to molecules such as DNA. For example, a beta particle emitted by tritium cannot penetrate a sheet of paper, yet tritium in the body fluids can pose a significant hazard. A liquid scintillation detector can pick up radiation from "soft" beta emitters as well as from other radioisotopes. An ionizing particle is allowed to pass through a crystal or liquid phosphor, which absorbs its energy and re-emits the energy as flashes of light. Usually the emitter must be dissolved in liquid containing the luminescent compound, so that the distance traveled by the particle is very short.

2.11.2 Liquid scintillation counting

The mount of kinetic energy in a beta particle differs from one decay to the next. However, each radioisotope has a typical energy spectrum, that is, a predictable range of energies. Typical energy spectra for different radioisotopes can be radically different in shape and magnitude, as with the commonly used 14-C and 3-H. Figure 2.4 shows Energy spectra for two commonly used beta particles. Note that the horizontal scale is not linear(Michael and Leo 2007)

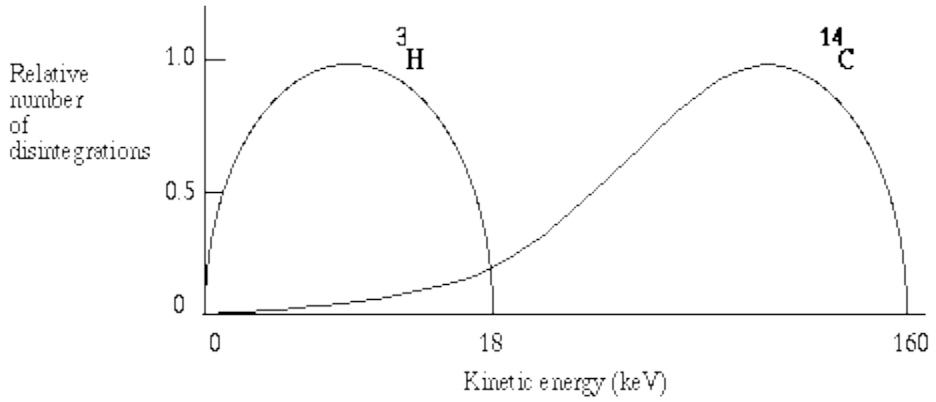


Figure 2. 4: Energy spectra for two commonly used beta particles(Michael and Leo 2007)

In liquid scintillation counting, the material containing radioisotopes is dissolved in an organic solvent containing an aromatic solute (the scintillant). When radioactive decay takes place, the energy of a beta particle is transferred by collision to an electron in the shell of the scintillant, exciting that electron. The electron then returns to its ground state, releasing a photon. The energy transfer can be from beta particle to solvent to scintillant, or directly to the scintillant and usually there are multiple collisions per β-particle. The number of photons emitted following each of the atomic disintegration is proportional to

the energy of the released beta particle. Top view of two simulated scintillation events showing path taken by photons: left pattern of a typical disintegration yielding a particle with energy of 1 keV: right pattern of a typical disintegration yielding a particle with energy of 10 keV shown in figure 2.5



Figure 2. 5: Working action of Detecting system(Michael and Leo 2007)

Now here is how the detection system works. The vial is lowered into a dark chamber with photoelectric detectors on each side. Each "flash" received by the detectors corresponds to one atomic number disintegration. The detectors are connected, via photomultiplier tubes, to a microprocessor unit that records not only each event, but also the number of photons detected during each event (brightness of the flash). At brief intervals, such as 1/100 second, the instrument calculates the number of flashes per unit time, displaying them as counts per minute (CPM) (Michael and Leo 2007).

2.11.3 Background and quenching

No detection system perfect, of course. In liquid scintillation counting, cosmic rays, beta particles from decaying potassium in the glass vial, spontaneous discharges from the very sensitive photon detectors, and chemicals dissolved in the scintillation fluid all can contribute to spontaneous flashes of light that are recorded as counts. The CPM

attributable to such sources are called background. Background counts are often so low relative to the activity being measured that they are ignored. However if the number of "real" counts is low, background counts can contribute to experimental error. It is a good practice to include a vial containing everything except added radioactivity as a control to determine the background level. Backgrounds CPM are then subtracted directly from the CPM for the experimental samples.

Unfortunately, there are two more little problems. No instrument is capable of recording all of the atomic disintegrations within a scintillation vial. Because of the geometry of the vial and photoelectric detectors some events go undetected. The maximum efficiency with which a low energy emitter such as tritium can be detected is about 70%. Worse yet, the energy of some photons is absorbed by chemicals in the solvent before the photon can reach the detector. The latter phenomenon is known as quenching. With the chemical quenching that is typical of most experiments, the usual counting efficiency for tritium is 30 to 40%, and sometimes much less. The amount of quenching can vary from sample to sample therefore it is often necessary to estimate the efficiency of counting for each individual sample.

Remember that the amount of light detected is proportional to the energy of the beta particle that was released by the disintegrating nucleus. When you prepare to count samples, you select appropriate "windows", that is, ranges of light intensity that the instrument will record as counts. The instrument records the amount of light detected following an event, and if that amount is within the energy range for a particular window, the event is recorded as one count. It is ignored if it falls outside the selected range. Each window is given a channel number, and the count for each window is given as CPM for

the corresponding channel. The frequency distribution of energy of beta particles emitted by decaying ^{14}C and apparent energy distribution to serve as is shown in figure 2.6

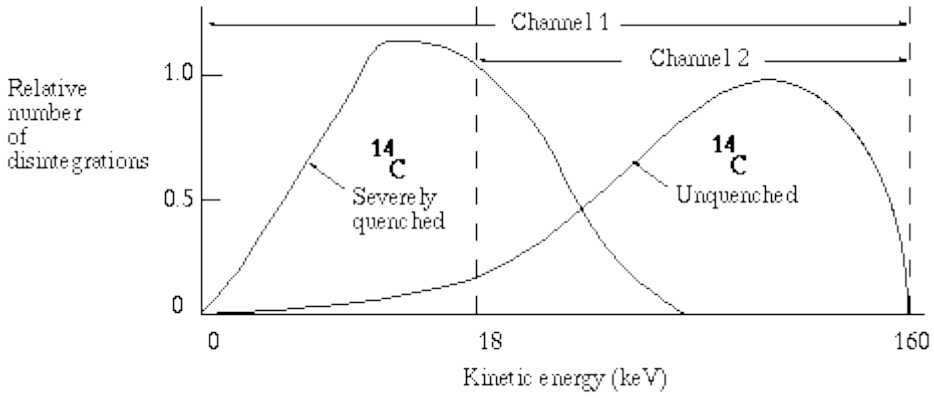


Figure 2. 6: Apparent energy distributions due to energy distribution in quenching of ^{14}C(Michael and Leo 2007)

As quenching takes place, the energy recorded for each event is less than it would be for an unquenched sample, since for each event the energy of some photons is absorbed before detection is possible. The energy spectrum is shifted to the left, and the greater the quenching the greater the shift. As the shift takes place, the ratio of counts in channel 2 to counts in channel 1 becomes smaller. That ratio is known as the sample channels ratio (SCR).

Counting efficiency is positively related to the SCR. To get a conversion factor between SCR and efficiency, equal known amounts of the isotope are added to a series of vials. Progressively greater amounts of a quenching agent, such as carbon tetrachloride, are added to each vial. The vials are counted and CPM is divided by known atomic (disintegration per minute) DPM to get the fractional efficiency of counting. For

example, if a vial with 20,000 DPM of tritium yields 5,000 CPM, the fractional efficiency of counting was 5,000/20,000 = 0.25, that is, 25% of the atomic disintegrations were detected. Fractional efficiency is plotted versus SCR to yield a quench curve. The instrument prints out CPM and SCR for each sample, therefore to get actual DPM in a sample the investigator must (1) subtract background CPM from the CPM for the sample, (2) determine fractional efficiency from the SCR for the sample, and (3) divide net CPM by the fractional efficiency.

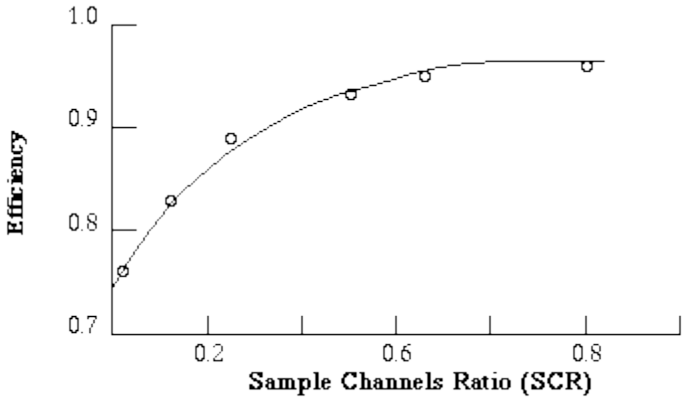


Figure 2. 7: The Quenching curve of sample channel ratio(Michael and Leo 2007)

From the quench curve, an SCR of 0.5 corresponds to an efficiency of 0.93. Then the estimated amount of radioactivity in the sample is (1323 - 23)/0.93 = 1398 DPM. (Michael and Leo 2007, Alan and Samuel, 1986)

There are other problems associated with the measurement of radioactivity that are not so easily solved. However, for single label experiments the quench correction is all you need. Review the special safety cautions for radioisotope work, and you are ready to go

2.11.4 Scintillation detectors

Historically scintillation detectors remain one of the available techniques used for detecting radiations. In the early years of nuclear physics, Rutherford and his team used to detect a particles using microscope to view scintillation from Zinc sulphate. The modem scintillation detectors followed from the production of materials that are transparent to their own fluorescent light (phosphor) and the development of photomultiplier tube (PMT) as an extremely sensitive detector of this light. The scintillation detectors rely on the fact that these materials (phosphor) will emit visible light when electrons change energy levels. As a result of interaction of radiation with matter, ionizing radiation can give electrons sufficient energy to move into a higher energy shell. Figure 2.8 shows the basic scintillation process.

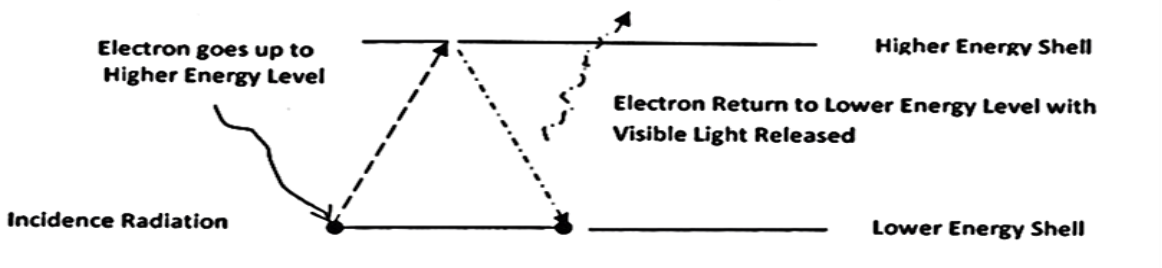


Figure 2. 8: Basic Scintillation process (Alan and Samuel, 1986)

In phosphors, these electrons do not remain in the higher energy level for very long instead, they fall back to their original level and, as they do so, they emit photons of visible light. These photons are directed at the photomultiplier tube's photocathode which emits electrons by the photoelectric effect. These electrons are electrically accelerated and focus to an electrical potential so that they strike the first dynode of the tube. The impact of a single electron on the dynode releases a number of secondary electrons which

are in turn accelerated to the second dynode. Each subsequent dynode impact releases further electrons and so there is a current amplifying effect at dynode stage. Each stage is at higher potential than the previous to provide the accelerating field. The resulting output signal in the form of a measurable pulse for each photon detected at the photocathode and is passed to the processing electronics. The pulse carries information about the energy of the original incident radiation on the scintillator. Thus both intensity and energy of the radiation can be measured.

Scintillators can be made of a variety of material depending on the intending applications. The most common scintillators used in gamma-ray detectors which are made of inorganic materials are usually an alkalide halide salts such as sodium Iodide (Nal) or cesium Iodide (CsI) and high purity germanium (HiPGe) Detectors. An impurity material called an activator is usually added to increase the characteristics of the detector by producing free carriers of electricity. The difference in the number of valence between the doping materials or dopant (either donors or acceptors of electrons) and host give rise to negative (n-type) or positive (p-type) carriers of electricity. Thallium is often used for this purpose NaI(TI) has excellent high yield alongside an almost linear response. It shows a small but measurable non-probability of its Scintillation response with deposited electron energy. It can be machined into variety of sizes and shapes (Ibeanu, 1999)

2.11.5 Gamma spectrometric and measurements

The use of Crystal scintillators is the most popular method for the detection of gamma-rays. Gamma-rays are not directly detected in its measurements; instead they produce charge particles in the scintillator crystal of interest and emit photons. These photons at the lower energy are subsequently collected by the photomultiplier tube (PMTs).

When gamma-ray passes through matter they can undergo these basics process which are; Compton scattering photoelectric and pair production. Each of these processes can create high energy electron or anti electrons (positrons) which interact with the scintillatoras charged particles. By adding up the energy collected in the surrounding of the photomultiplier tube (PMTs), we can determine the energy of the gamma ray detected. (IAEA, 1990)

2.11.6 Sodium Iodide Detector thallium NAI (Tl)

This a gamma-ray spectrometry used to measure low background level of radionuclides found in environment Sodium Iodide Detector, thallium is often used for this purpose Na (TI).

In gamma-ray spectrometry the characteristic photon energy is measured and used to quantify the different radionuclide in the sample. In order to quantify the activity of radionuclide of interest, the net count in distinct energy windows specific for gamma ray radiation energy of the particular radionuclide is recorded. The Schematic diagram of Measurement of Radiation, Sodium Iodide Detector is shown in figure 2.9

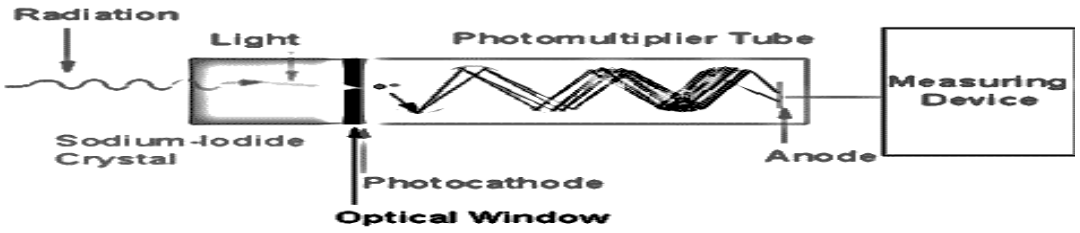


Figure 2. 9: Schematic diagram of Measurement of Radiation, Sodium Iodide Detector ISUHome, (2012)

A typical spectrum by NaI(Tl) scintillation spectrometer to measure low background radiation level is presented in figure2.10

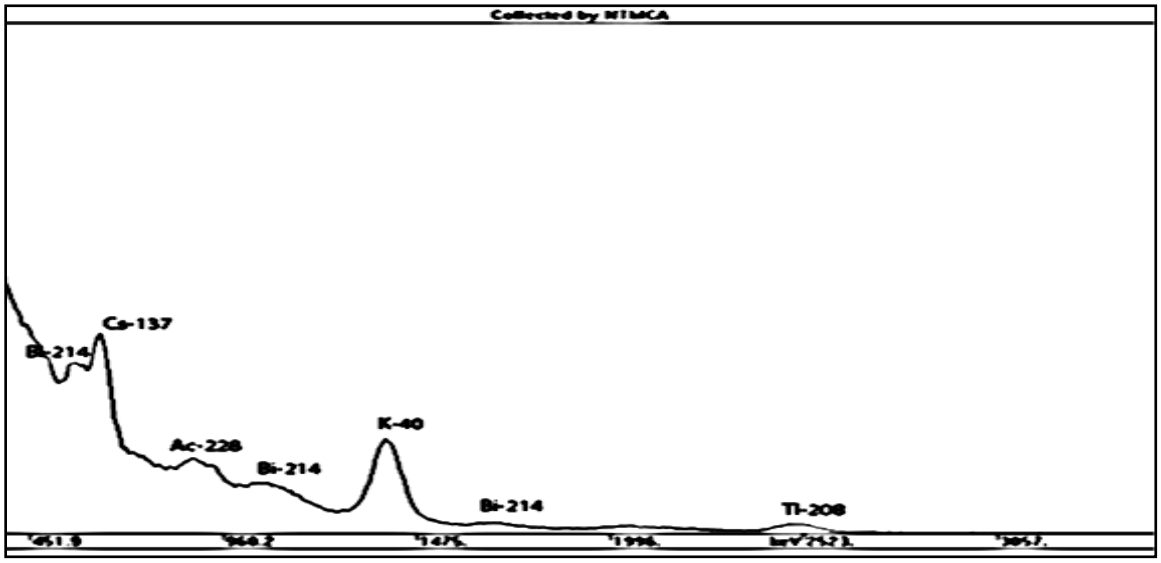


Figure 2. 10: A typical spectrum collected by NaI(Tl) scintillation spectrometer.
Source; Sadremomtaz,et al (2010)

Table 2. 1: Recommended window settings for a NaI(Tl) gamma-ray spectrometer

Energy widow	Detected radionuclide	Recommended window limit (keV)
K	^{40}K	13770-1570
U($_{226}$Ra)	^{208}Bi	1660-1860
Th	^{228}Tl	2400-2800

(Sadremomtaz et al, 2010)

The suggested window settings by the (IAEA, 1989) are shown in Table 2.1 and the. Full-energy peaks of the concern radionuclides are ;1.46 MeV for 40K, 1.76 MeV for 226Ra (214Bi), 2.62 MeV for 232Th (208Tl) and 662 keV(IAEA, 1989)

2.11.7 Comparism of Gamma-ray Spectrometry using NaI(Tl) and HPGe Detectors

Field gamma-ray spectrometry (NaI(Tl)) provides a convenient method for the determination of contamination levels following an accidental release of radionuclides to the environment. While field spectrometry can be performed with hyper pure germanium (HPGe) spectrometry systems, which provide the highest Peak-to Compton ratio and resolution, their use is complicated bythe need for cryogenic cooling of the detector. They must be kept constantly cooled at 77 K with liquid nitrogen or electromechanical coolers.

The size of the cryostat largely dictates the portability as well as the longevity of the system between re-fills, whereas power supply issues required by electromechanical systems remain a barrier for their convenient implementation (Sadremomtaz et al, 2010). NaI(Tl) scintillation detectors have the advantage of being more robust and thus relatively more portable, and can be manufactured in a range of sizes and consequently able to provide substantially higher relative detection efficiencies (Sadremomtaz et al, 2010). Furthermore, the cost of HPGe systems are more than 10 times higher than the NaI(Tl) spectrometry systems (Sadremomtaz et al, 2010). For environmental purposes, there are distinct advantages and value when the results from different techniques are comparable. In the process of NaI(Tl) spectrum analysis one should notice the possibility of peak interferences due to low resolution characteristics of the detector, for instance from ^{134}Te and ^{214}Bi peaks in the case of ^{137}Cs. There are, of course, specially developed procedures for quality spectral processing (Miller, 1997), By careful application of NaI(Tl) spectrometry system reasonable and satisfactory results can be achieved as far as

certain natural radionuclides (^{40}K,^{232}Th, $^{222}Ra$and ^{137}Cs) are concerned. NaI(Tl) provides a measure which is operationally easier to carry out than the HPGe systemand it is economical, efficient and less time-consuming with respect to soil and vegetation sampling. (Sadremomtaz et al, 2010)

2.12 Radioactive Equilibrium

Radioactive equilibrium for a decay chain occurs when each radionuclide decays at the same rate it is produced. At equilibrium, all radionuclides decay at the same rate. Understanding the equilibrium for a given decay series, helps scientists estimate the amount of radiation that will be present at various stages of the decay.

For example, as uranium-238 begins to decay to thorium-234, the amount of thorium and its activity increase. Eventually the rate of thorium decay equals its production its concentration then remains constant. As thorium decays to proactinium-234, the concentration of proactinium-234 and its activity rise until its production and decay rates are equal thereby reaching a radioactive equilibrium. the potential for radioactive equilibrium in three general cases are; secular, transient and no-equilibrium.

2.12.1 Secular Equilibrium

This is a phenomenon observed when a radioactive isotope decays via one or more daughter isotopes to a stable product as a result of the parent having longer (very much greater) half-life than any of its intermediate daughter. The activity from the daughter will increase until it is exactly equal to that of the parent (Michael and Leo 2007) when Uranium and Thorium are deposited, each daughter will attain equilibrium with its parent ^{238} U or ^{232}Th in a time dependent on its half-life. The nucleus with short half-life will

reach equilibrium first so that the time the longest lived daughter reaches equilibrium, whose series must have reached equilibrium as well.

When the half-life of the original radionuclide is much longer than the half-life of the decay product, the decay product generates radiation more quickly. Within about 7 half-lives of the decay product, their activities are equal, and the amount of radiation (activity) is doubled. Beyond this point, the decay product decays at the same rate it is produced a state called "secular equilibrium figure 2.11

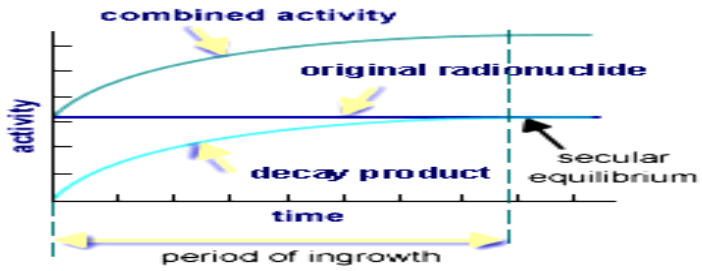


Figure 2. 11: Graphs illustrating the progress of ingrowths first case (Michael and Leo 2007)

2.12.2 Transient equilibrium

When the half-life of the parent is only few times greater than the half-life of the daughter the condition of transient equilibrium occurs. During that period, the parents undergo radioactive decay and the daughter activity builds up to establish a state of equilibriums with the parent activity. In transient equilibrium, the activity of the daughter is not equal to the activity of the parent and is given by the relationship;

$$A_d = A_p \frac{T_p}{T_p - T_d} \qquad (2.18)$$

A_d is the activity of the daughter

A_p is the activity of the parent

T_p is the half-life of the parent

T_d is the half-life of the daughter, (Perry, 2015)

The ratio of daughter to parent activity becomes greater as the half-lives become closer. The activity of the daughter changes with time because the parent activity is changing and at this condition the daughter appears to decay with the half-life of the parent, figure 2.12

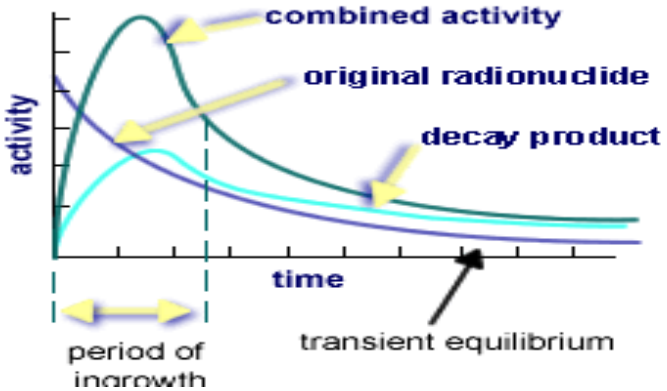


Figure 2. 12: Graphs illustrating the progress of ingrowths second case,(Perry, 2015)

2.12.3 No- equilibrium

If the half-life of the decay products is much longer than that of the original radionuclide, its activity builds up to a maximum and then declines. The original radionuclide eventually decays away and no equilibrium occurs figure 2.13 (Decay Product Has a Longer Half-Life)

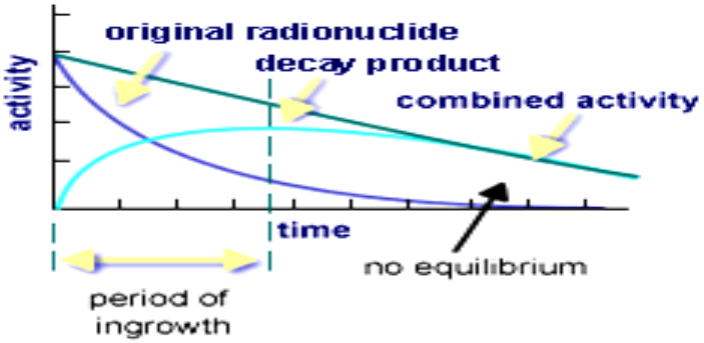


Figure 2. 13: Graphs illustrating the progress of ingrowthsthird case (Perry, 2015)

2.13 Sources of radiation dose

Radiation dose could arise from natural or man-made/artificial sources. Natural background radiation contributes about81% of the annual dose to the population and Man-Made backgroundradiation contributes the remaining19% (figure 2.14)

2.13.1 Natural radioactivity

Apart from stable chemical elements, very low concentrations of radioactive elements occur naturally in the environment. Natural radionuclide are classified into three categories; primordial, secondary and cosmogenic radionuclide

(i) Primordial radionuclide

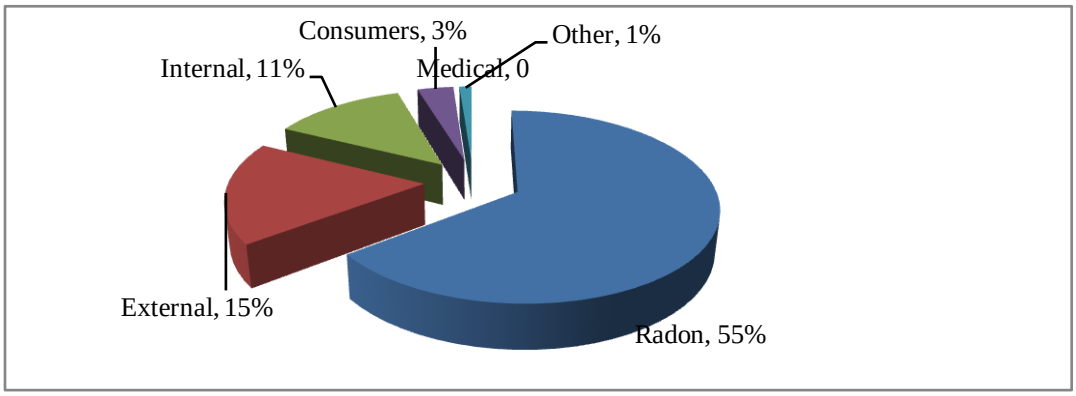


Figure 2. 14: The ubiquitous background radiation (Background Radiation; Natural versus Man-Made, 2002)

These radionuclide originated with other stable nuclide in the course of cosmic nucleogenesis thermal nuclear reactions in the core of a star, which then explored as a supernova and enrich the nucleus cloud from which the sun and the solar system originated. They become part of the Earth at the time when the solar system was formed about 4 to 5 billion years ago. Presently, only radionuclides with very long half-life (about 10^8 years) were preserved.

The most wide spread Primordial radionuclide is ^{40}K; average content in the earth crust is about 0.003%. ^{40}K with half-life of $T_{1/2}=1.277x10^9$ years disintegrate by β decay to ^{40}Ar(89%) and electron capture to ^{40}Ca (11%) both isotopes are stable(Michael and Leo 2007)

Another primary natural radionuclide is ^{232}Th found at very low levels in rock soil and water with half-life of $T_{1/2}=1.39x10^{10}$ years and gradually disintegrates by α decay into a number of radionuclide of Thorium decay chain (secondary radionuclides)

The most important natural radionuclide of primary origin in the earth crust is the ^{238}U with half-life of $T_{1/2}=4.468x10^9$ years and ^{235}U with half-life of $T_{1/2}=7.038x10^8$ years. Both of these isotopes of uranium gradually transformed y α decay into number of radionuclides of both uranium decay chains (Michael and Leo 2007)

(ii) Secondary radionuclide (NORMS)

The decay of primary natural radionuclide gives rise to a number of secondary radionuclide Natural radionuclide ^{238}U, ^{235}U and ^{232}U decay by α and letter by β into nuclei with are also radioactive much like their other decay product (radioactive decay

chains). In nature, there are three decay chains; ^{238}U, ^{235}U and ^{232}U and to certain extent they are similar consisting of isotopes mostly of α decay and a smaller part is also β decay. Radon ^{222}Rn is the most stable isotope in second half of the series; its decay products have a short half-life and disintegrate simultaneously by α and β decay Radon is a radioactive noble gas, one of the heaviest gasses and all the three natural decay chains result in stale isotopes of lead.

(iii) Cosmogenic Radionuclide

These are natural Radionuclides that currently originate by nuclear reaction (radiocarbon ^{14}C and tritium^{3}H) when high cosmic radiation passes through the earth's atmosphere

2.13.2 Artificial / manmade radioactivity

For the demand of present science and technology, industries and health services the few natural radionuclides are far from sufficient hence artificial radionuclides are produced at radiation control level. The artificial radiation sources comprise of various man-made radiation sources, or natural sources which are enhanced by technology. The largest man-made contributors to background radiation in the environment are the medical use of Radiation in diagnostic and therapeutic radiology. The world-wide estimated average Annual Man-Made Background Radiation is about 0.4 mSv/y (Cember, 1986). In developed industrialized nations, the average value is much closer to 1.0mSv/y. Other man-made radiations include the use of radioisotopes in researches or in bodies, radioactive waste disposal, occupational exposure and fallout from nuclear weapons used in wars or in listing (Alan and Samuel, 1986). The Average annual dose due to man-made radiation in the UK source for Diagnostic Radiology, Therapeutic Radiology and

use of Isotopes in Medicine are 220, 30 and 2 μSv/y respectively, (Alan and Samuel 1986). All radiation dose in whatever form when exposed to it over long time is capable of producing biological effect to man (IAEA, 1982). When radiation is used at controlled level, a large benefit is provided in life sciences. Artificial radionuclides can be produced by nuclear reactors, particles accelerators and radionuclides generators.

(i) Radionuclide produced by nuclear rectors

Radioactive nucleus is produced from stable nucleus by changing number of protons or neutron so as not to disturb the equilibrium configuration of the resulting nucleus it is achieved by bombardment of initial nucleus A with suitable particles-proton or neutrons (or α particles, deuterons, rarely also with heavy ions) which emits the nucleus and cause the respective changes- nuclear reaction. The resulting nucleus B is formed (mostly in excited state B′) which is frequently radioactive.

The simplest bombardment of nuclei is with neutron (n) because neutron has no charge and electrostatics repulsive forces do not function hence even a slow neutron can enter the nucleus. The use of neutrons results in the production of nuclei with abundance of neutrons and with β^- radioactivity. An intensive source of neutron is the nuclear reactor and so these β^- radionuclides are usually produced by bombardment of a suitable nuclear target in a special chamber of the reactor. Some reactions in the production of the radionuclide are;

$^{6}L(n,)^{3}H, ^{14}N(n,p)^{14}C, ^{32}S(n,p)\ ^{32}P$, and $^{98}MO(n,)\ ^{99}MO$.

Nuclear reactors are also used in the separation radionuclides from fission products of Uranium. In the nuclear reactor, the nuclei of ^{235}U (or ^{238}U) split into two nuclei after the

entrance of the neutrons. The necessary radionuclides (e.g., ^{99}Mo, ^{137}Cs and ^{90}Sr and other) are the isolated from these fission products by means of radiochemical separation methods. However, this is very difficult because the resulting nucleus requires satisfactory purity.

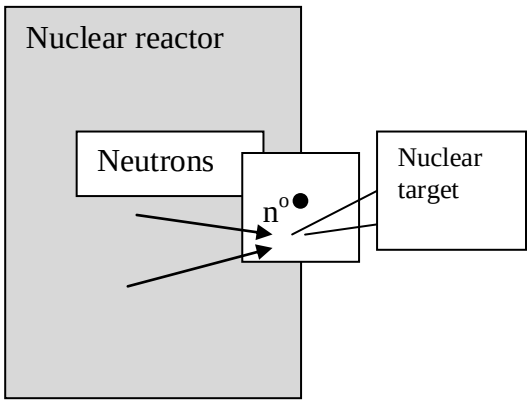


Figure 2. 15: Production of radioisotopes by bombardment of nuclear target in a reactor (Michael and Leo 2007)

(ii) Radionuclide Produced by particles accelerators

In order to produce positron (β^+) radionuclides it is necessary to add protons to the nucleus. For the proton p^+ to enter the nucleus it must be accelerated to a high energy state ranging from hundreds of keV to several MeV to overcome the electrostatics force (repulsive Coulomb force) of the positively charged nucleus. A cyclotron is a machine designed to accelerate clustered of charge particles by using a high frequency alternating voltage and a perpendicular magnetic field to spiral the beam out. The proton cluster is the brought out of the circular path by magnetic poles and fall into suitable target

With view to nuclear reaction and transmutation the nucleus can be bombarded with proton or other fast charged particles; deuterium or heavier nuclei of ions. Nuclei with an

abundance of proton are mostly radioactive or the decay γ electron capture; according to mode of production they are sometimes indicated as cyclotron radionuclides. Some reactions of radionuclide production are; $^{18}O(p,n)^{18}F$, $^{13}C(p,n)^{13}N$, $^{11}B(p,n)^{11}C$, $^{10}B(d,n)^{11}C$, and $^{56}Fe(d,n)^{57}C$ (figure 2.16)

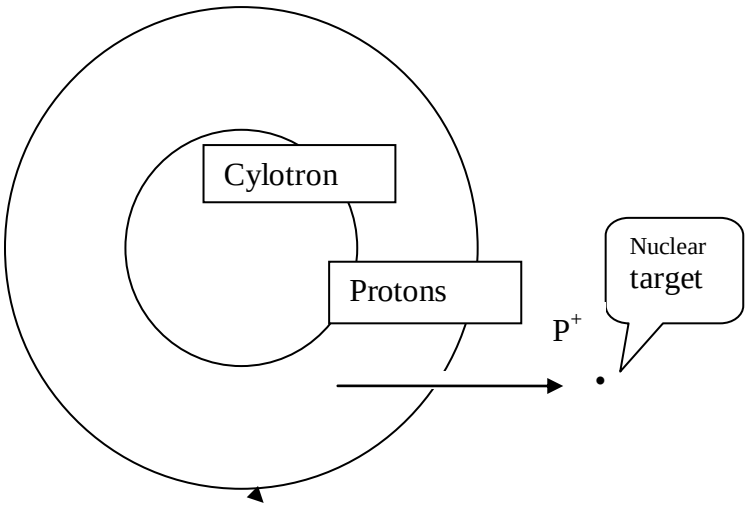


Figure 2. 16: Production of radioisotopes by bombardment of nuclear target in a Cyclotron (Michael and Leo 2007)

(iii) Radionuclide Produced by generators

Radionuclides generator are used to produce radionuclides with shorter half-lives from primary parent radionuclide with longer half-lives. Such a generator uses a moderately long-lived parent radionuclide that decays to produce short-lived daughter radionuclide. The parent radionuclide is usually absorbed on support material, such as ion exchange resin which is parked in a small, lead-shield column. The short lived radionuclide is then eluted with the support material with a solvent when needed. Among the most important is the molybdenum-technetium generator for the preparation ^{99m}Tc. Another example is

the ^{81}Rb generator for the preparation of the radioactive Krypton gas (^{81m}Kr)(Michael and Leo 2007)

For practical purposes the activity concentration can be define as the proportion of the activity compared to the total mass of the radioactive substance(i.e. the sum of the masses of all the radionuclides and stable nuclides contained in the substance).

2.14 Background radiation level

Background radiation dose consists of the radiation doses receive from natural and man-made background. The environment that surrounds us contains some amounts of radioactive (unstable) elements or radionuclides (radioisotopes) that are derived from primordial and secondary cosmogenic sources. In addition to naturally occurring radioactive materials (NORMs), technologically enhanced naturally occurring radioactive materials (TENORMs) and man-made (artificially produced) radionuclides have been introduced into ecosystems due to the proliferation of different nuclear applications in industry, medicine, mining and research. Radionuclides in the air, soil, water and rocks that make up Earth's geosphere and atmosphere can be transferred into the biosphere by many organisms and can also bioaccumulate in the food chain. This can result in an increase in population radiation doses and thus requires an understanding of the environmental behaviors of different radionuclides and estimation of their human risks.(Michael and Leo 2007)

2.14.1 High background Radiation areas

The background radiation level is fairly constant over the world being 8-15µRad/h. There are some exceptional areas however around the world having sizeable populations that

have high background radiation levels. The highest are found in Brazil, India and China (www. Background Radiation, Facts sheet, 2002). The higher natural background radiations are due to high radioactive minerals in soil. For instance the external radiation level in black monazites in Brazil found along beaches of range up to 5mRad/h (50 µGy/h) This value is about 400 times normal background in United State of America(U .S. A) Reports indicated that plants found near a hill in Brazil have absorbed so much radionuclidesthat can produce self-X-rays if placed on sheet of photographic papers (Esenbud and Gesell, 1997).

2.16 Terrestrial Radiation

Radiation that originates on Earth is called terrestrial radiation. *Primordial* radionuclides (radioactive chemicals that were present when the Earth formed about 4.5 billion years ago) are found around the globe in igneous and sedimentary rock. From rocks, these radionuclides migrate into soil, water, and even air. Human activities such as uranium mining have also redistributed these radionuclides. Primordial radionuclides include the series of radionuclides produced when uranium and thorium decay, as well as potassium-40 and rubidium-87.

In the past, one human activity that contributed to terrestrial radiation was production of nuclear weapons. Today, atmospheric weapons testing is not a significant contributor to background radiation because fallout has decayed since weapons testing was stopped in the United States, of America's testing which ended in 1963. The reactor accident at Chernobyl in 1986 is also not a significant source of background radiation in the United States (Ubiquitous Background, 2006)

2.17 Radionuclides in the Body

Terrestrial and cosmogenic radionuclides enter the body through the food we eat, water we drink, and air we breathe. As with all chemicals, radionuclides are used and eliminated by the body during normal metabolism. Some radionuclides decay away quickly but are replaced through fresh ingestion or inhalation. Other radionuclides decay more slowly and may concentrate in to the body.

2.18 Dose from Space Radiation

In the United States, most people receive an average dose from space radiation of about 0.3 mSv each year. In Honolulu (at sea level and near the equator) the average dose from space radiation is 0.2 mSv (200μSv), while in Colorado Springs (high altitude and latitude) the average space radiation dose is 0.7 mSv (700 μSv). The average space radiation dose makes up about 11 percent of the average total dose from background radiation (Grasty and LaMarre, 2004)

Traveling by airplane can expose people to slightly more space radiation because at high altitudes, there is fewer atmospheres to shield the incoming radiation. For example, one study found that on a flight from New York to Chicago, travelers would receive a dose of about 0.009 mSv. This dose can vary significantly, too, depending on flight path and the sun's 11-year cycle of solar flares. (Grasty and LaMarre, 2004)

2.19 Radionuclide Concentrations in Food and Environment

For practical purposes the activity concentration is define as the proportion of the activity compared to the total mass of the radioactive substance (i.e., the sum of the masses of all radionuclides and stable nuclides contained in the substance)

2.20 Vegetable/Soil Root Uptake of Radionuclide

In a field study on the transfer of primordial radio nuclides and fallout radio nuclides Manighandan (2009) presented that, irrespective of biological necessity, plants have been observed to take up many cat ions such as primordial radionuclide presents in their root regions. In the soil, each radionuclide follows complex dynamics in which part of it is transported into the soil solution while another part become strongly bound to the soil particles of the soil. The portion of these radio nuclides in the soil can be incorporated via the roots into the plants which are facilitated by their chemical similarity with other elements that the plants normally used for their growth

2.21 Elemental Concentration in Food

Over the years researchers in nutrition have contributed to man's understanding of health, environment and disease as required to the food taken for survival. Many of the minerals required by man are needed in small quantity than some vitamins. Elements could occur in food stuff in greater or lesser amount depending on various circumstances. The concentration of these elements may be either advantageous or detrimental to man. This can also be of interest to food processor and food nutritionist food toxicologist and also

other scientist of which this research is among. The activity and elemental content of food depend on its type, origin, environmental condition and its handling. In fact the present of some metals in the soils has been reported to affect the quality of foods, ground water, micro-organism activities and plants growth. Elemental concentration in food can be classified as non-essential elements and essential elements(Borgstrom, 1973)

2.21.1 Non-essential Elements

The activity that generates heavy metal and other elements in the soil such as mining could have delirious effects on environment and on the community living in such environments. The effects include environmental degradation and toxicological effect that may set in time. Ingestion of non-essential elements such as gold, lead and mercury lead to the development of autoimmunity which can lead to the diseases of the circulatory or central nervous system (Gover 1995) For instance exposure to heavy metals could cause various cancers, kidney damage and even death. Tin, Lead, Mercury, Cadmium, Ruthenium Nickel and Titanium have been classified as major food contaminants by Borgstrom, (1973).

2.21.2 Essential Elements

Nutrition as a scientific discipline evolved from physiology and chemistry. At early stage emphasis was made in identification of vitamins essential fats and amino-acids. Later mineral were seen to be required in our diet to prevent dietary deficiency diseases.

Tin, Iron, selenium, Zinc, Manganese, Copper, Molybdenum Cobalt Chromium Silicon and Nickel have been classified as micro- nutrients (Byrd and Andreas 1986).

2.21.3 Health effects of Heavy metals

Food is the major intake source of toxic metals by human beings where among food system, vegetables are the most exposed food to environmental pollution due to aerial burden. Vegetables take up heavy metals and accumulate them in their edible and non-edible parts at quantities high enough to cause clinical problems to both animals and human beings. Excessive content of metals beyond Maximum Permissible level (MPL) leads to number of nervous, cardiovascular, renal, neurological impairment as well as bone diseases and several other health disorders (Govver,1995)

Lead (Pb), cadmium (Cd), mercury (Hg), and arsenic (As) are widely dispersed in the environment. These elements have no beneficial effects in humans, and there is no known homeostasis mechanism for them (Kim, 2005) They are generally considered the most toxic to humans and animals; the adverse human health effects associated with exposure to them, even at low concentrations, are diverse and include, but are not limited to, neurotoxic and carcinogenic actions (Kim, 2005). Potential biomarkers include DNA and protein adducts, mutations, chromosomalaberrations, genes that have undergone induction and a host of other “early “cellular or sub- cellular events thought to link exposure and effect.

The Joint FAO/ World Health Organization Expert Committee on Food Additives (JECFA) established a provisional tolerable weekly intake (PTWI) for lead as 0.025 mg/kg body weight (BW) (JECFA, 2004). . 0.007 mg/kg BW for cadmium Mercury can be detected in most foods and beverages, at levels of < 1 to 50 μg/g Organo-arsenic

intakes of about 0.05 mg/kg body weight/day seemed not to be associated to hazardous effects.

2.22 Food safety

Food safety is one the most urgent issues that confront both African countries and international communities as a whole. The concern has been articulated to the establishment of higher quality and safety standard required on farmland where crops are grown, factories where food are processed and even the markets where the foods are retailed. Food producers are under great pressure to meet standards so as to build confidence using FAO/WHO standards. Effort to bring national standards up to international level will significantly enhanced the competitiveness of Nigeria /Africa agricultural produce in the world market

In this section, previous works that are relevant to the research will be reviewed and some of the limitations of these previous works will be highlighted.

2.23 Techniques for radioactivity and elemental analysis

There are various techniques for radioactivity and elemental assessment in biological and geological samples. Sodium Iodide thallium (NaI(Tl) has become one the most recently used tool for determination of the radioactivity.Mangset and Sheyin (2009) used NaI detector to determine the concentration of ^{40}K,^{226}Ra and ^{232}Th in soil. Neutron Activation Analysis (NAA) techniques for improving sensitivity in biological and geological matrix in elemental analysis were early studied by Rossbtch et al (1990), Petra et al (1990), Landsberger, (1992) and by Ahmed et al (2010) Data are now available for describing the health implication and clear way of promoting wide range of investigation

on the analytical capabilities of nuclear studies of heavy metal and nutrients (Jonah et al 2006, Adeyemo, 2002)

2.23.1 Neutron Activation Analysis (NAA)

Neutron activation analysis (NAA) is a highly sensitive method for accurate determination of elemental concentration in materials. The detection and measurement of the elements is achieved by measuring the characteristics gamma ray emitted from the radioactive isotopes produced. Standards are used as reference material depending on the type of sample to be measured that is biological, geological or archeological. The neutron sources that produce the characteristic gamma ray could be from reactors, accelerators and radioisotopes neutron emitters.

NAA in its instrumental form (INAA) especially with reactor has a multi-element capability, rapidity, and reproducibility of result, complementarily to other methods, freedom from analytical blank and independent to chemical state of elements. INAA is thus unique and reliable (Jonah et al 2006).

Instrumental neutron activation analysis (INAA) is used to determine the concentration of trace and major elements in a variety of matrices. A sample is subjected to a neutron flux and radioactive nuclides are produced. As these radioactive nuclides decay, they emit gamma rays whose energies are characteristic for each nuclide. Comparison of the intensity of these gamma rays with those emitted by a standard permit a quantitative measure of the concentrations of the various nuclides.

The neutron flux parameters of the miniature neutron source (MNS) reactors are known to be very stables, thus permitting the use of semi-absolute NAA method (Akaho and Nyarko, 2002; Jonah et al, 2006) Nuclear reactors with high fluxes of neutron from uranium fission offer the highest availability for most elements. The neutron energy distribution and fluxes could be thermal flux/ epithermal flux and fast flux. (Figure 2.17)

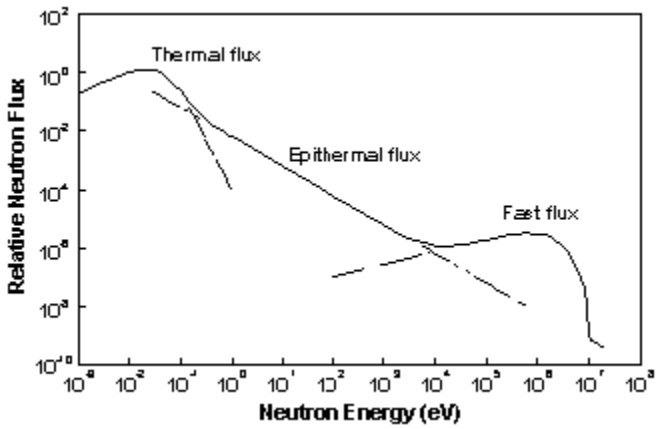


Figure 2. 17: A typical reactor neutron energy spectrums showing the various components used to describe the neutron energy regions. (Neutron activation analysis, Wikipedia)

The thermal neutron component consist of a low energy neutron moderated (energy below 0.5eV) while the epithermal component consist of energy (0.5eV to about 0.5MeV) partially moderated which induces (n, gamma) reaction on target nuclei. The fasts energy component or the original energy of the following fission (0.5MeV), very little to (n, gamma) reaction but instead induces further nuclear reactions (figure 2.18)

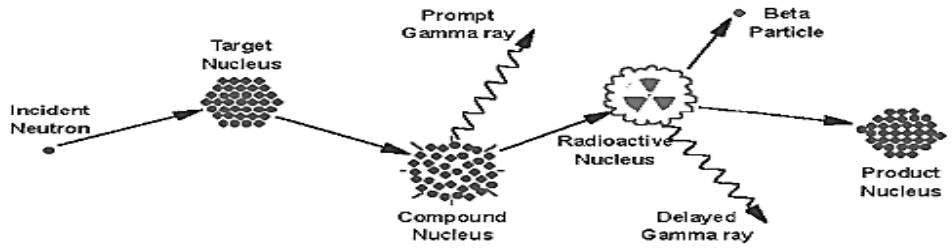


Figure 2. 18: Diagram illustrating the process of neutron capture by a target nucleus followed by the emission of gamma rays. (Neutron activation analysis, Wikipedia)

2.23.2 INAA Gamma-ray spectroscopy system (automated sample changer)

The detector is kept at liquid nitrogen temperatures (dewer under cave). The small box on top of the cabinet combines all the functions of the high voltage (HV) power supply, spectroscopy amplifier, and analog-to-digital converter. The resultant spectrum is shown on the computer screen a gamma-ray spectroscopy system consists of a detector (and high voltage power supply for the detector), pre-amplifier, spectroscopy amplifier, analog-to-digital converter, multi-channel analyzer, and an output device. A sample is presented to the detector (HiPGe in the case of gamma-ray analysis). In order to minimize thermal noise the detector is kept at cryogenic temperatures (liquid nitrogen, temperature = 77K). The initial signal is very small and the pre-amplifier, attached directly to the detector, amplifies this signal. The signal is shaped by the spectroscopy amplifier and then converted from an analog to a digital signal by the analog-to-digital converter. The results are stored in digital form (multi-channel analyzer). In modern gamma-ray spectroscopy systems the high-voltage power supply, spectroscopy amplifier, analog-to-digital converter, and multi-channel analyzer are combined into a single module (plate I)

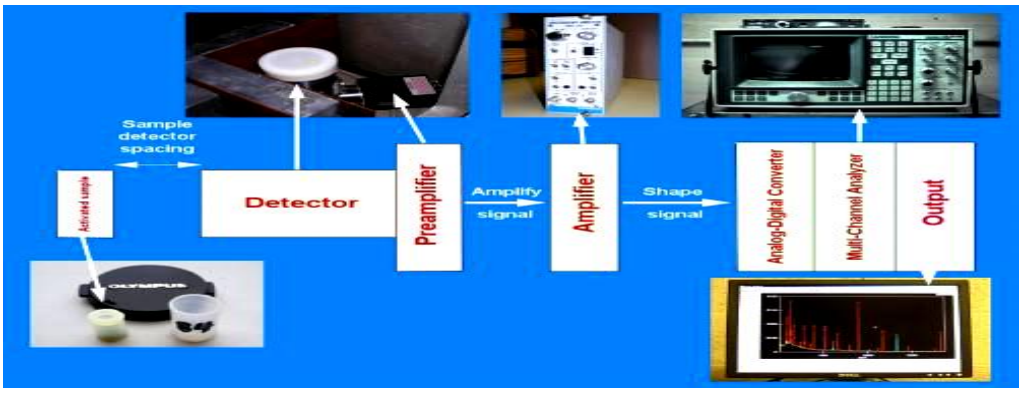


Plate II:Flow chart for Gamma-ray spectroscopy

A computer is used to visually show the resulting spectrum and to do calculations on the spectrum (plate II). Various algorithms are used to determine the shape and energy of each gamma-ray peak present in a spectrum and to determine the area encompassed by the peak (i.e., the gamma-ray intensity). Subsequent decay, interference (if required), fluency, fission product corrections, and comparison with a standard lead to a quantitative analysis.



Plate II: Gamma-ray spectroscopy system (automated sample changer).

2.24 Some Related Previous Wok Done

Supanti, et al (1989) used neutron activation analysis to determine the concentration of toxic elements such as Hg,Cr,Se,Pb,Cu and Zn in cereals (rice bean corn and wheat etc.) They discovered that concentration of this toxic elements were lower than their respective maximum permissible values.

In this work, there is no detail of the geology or soil activity, elements and concentration of the area where these cereals were obtained.

Jwanbot et al (2012) found that the activity Concentration of ^{40}K, ^{226}Ra and ^{228}Th in the food crops on the Jos Plateau using γ-ray spectrometry lied between 12.36 ±0.82 and 56.92 ± 8.84Bq/kg for ^{40}K,(1.46 ± 0.05 to 10.42 ± 0.04) Bq/kg for ^{226}Ra and from (1.53 ± 0.08 to 6.85± 0.42) Bq/kg for ^{228}Th. These relativity high values for the activity concentrations are said to be attributed to the series of tin mining activities that have taken place in these areas in the past decades. However, the values obtained suggested that the dose taken from intake of these radionuclides in the food crops is low and that harmful effects from these are not expected.

The researchers did not mention the seasons (dry or rainy season) in which these crops were obtained. Radiological indices assessments were not also indicated to explain more about the radiological health status.

Mangnset and Sheyin (2009) reported that the activity of the radionuclides Ra-226, Th-232 and K-40 ranged from 369.9 – 27930.0 Bq kg^{-1} in the mined tailings of Jos Plateau when sodium Iodide detector was used to measure the soil radioactivity. There was no detail about the efficiency calibration factor and the way samples were handled in this research.

Usikalu et al (2011) measured the concentration of Ra-226, Th-232and K-40 radionuclides in Jos Tin mine tailings and environment using hyper pure Germanium detector (HiPGe). The absorbed doses estimated from the activities were higher at the tailings and reduces away from the tailings. Values of 1,828.66, 252.08 and 171.07 $nGyh^{-1}$ where estimated at the mining site, 50m and 1km away respectively.

In this research other radiological parameters such as internal and external indices were not used.

Makon et al (2011) used a well-calibrated high-purity germanium detector to determine the specific activity concentration and derived Annual Effective Dose (AED) in three types of *vernonia* consumed within and outside Cameroon. The *Vernonia* samples were collected directly from the production farm, the measured specific activity of ^{238}U in the three types of *vernonia* ranged from 20 - 50 $Bqkg^{-1}$ with an average of 42 ± 15 $Bqkg^{-1}$, ^{232}Th from 9 - 22 $Bqkg^{-1}$ with an average of 17 ± 7 $Bqkg^{-1}$ while ^{40}K ranged from 115 - 460 $Bqkg^{-1}$ with an average of 302 ±36 Bq kg^{-1}. The average AED for ^{40}K, ^{238}U and ^{232}Th were 0.15, 0.92 and 0.92μSv y^{-1} respectively. ^{238}U and ^{232}Th showed the same trends both for the distribution of the radioactivity content and the AED. They reported that the discrepancies in the data can be attributed to many factors such as geological formation, foliar deposition, type and age of the plant, etc. Although the results obtained represent only some fractions of the standard limit, however they are within some range obtained in other countries.

The ranges of some of the other countries were not mentioned for comparing the data in this work. The health risks of the animals that consume these plants are not clearly stated in this research.

Din, et al (2010) used gamma ray spectrometer consisting of 3″ × 3″ NaI (TI) to investigate the distribution of Ra-226, Th-232 and K-40 in various parts of the Alfalfa plants from two different soils (farm using different quantities or species of fertilizer and valley) It was discovered that the activity concentration varies from soil to soil and

different parts of plants have different concentration of these radionuclides. It was found that the roots retained high values of Ra-226. Roots are known to retain heavy metals and radioactive elements when compared to any part of the plants (Lincoln et al 1989) and (Pulhani et al 2005).

In the review of this paper, the efficiency of the calibration factor was not stated.

Tela, (2013) Measured the Radioactivity in water and sediment of river Yobe North Eastern Nigeria using gamma-ray spectrometry technique. The mean dose rate, external and internal indices were also computed. Average absorbed dose rate of the samples ranged 40.12nGh^{-1}form to 60.10 nGh^{-1}It showed that there was no significant radiological health burden in the area studied. The specific measuring techniques and equilibration days were not mentioned in this research.

Bashir, et al (2013) used NaI(Tl) detector to determine and evaluate the radiological risk of ^{40}K, ^{226}Ra(^{238}U) and ^{228}Th in the flooded soil of Kudenda Kaduna state Nigeria. Values of R_{aeq} and H_{ex} for all soil samples were lower than the accepted safety limit values of 370 (Bq/kg) and below the limit of unity respectively.

In this paper the procedure of sample collection, handling and processing in order to avoid contamination were not specifically mentioned.

Girgisu et al (2013) presented a research in the assessment of radiological levels from Awwal artisanal gold mining exercise in Kebbi state. The result showed that the mean values of activities in of ^{40}K>^{226}Ra>^{232}Th. The radiological values obtained (annual effective dose rate 0.042mSv.y^{-1} was low and does not imply any significant health

concern to the local populate. In this paper, other radiological estimation such as effective dose rate and radiation hazard indices were not identified.

Yamusa, (2013) carried out a research on the standardization of analytical method for the determination of selenium in cereals. In his work, sample (wheat, maize and millet) were collected from Kaduna, Borno and Sokoto states in Nigeria. Standard addition method of INAA was used in the work with NIRR-I facility and twenty one elements were analyzed in all the samples. Highest selenium concentrations were from rice and maize samples. The type of rock or geology of the areas where the cereals are collected would play an important role in assessing the selenium concentrations.

Jonah, (2008) used the INAA to determine the concentration of As, Br, Cd, Cl, Mn, Na, and Zn in Ten samples of commonly used food in Nigeria. The samples where purchased from local retailed outlets in Zaria and environs with minimal sample preparation procedures, the samples were irradiated in a moveable BN capsule in one of the inner irradiation channels of the NIRR-1. There was no detailed information about the places and geology of the place where these elements are determined.

The principle of radiation protection outlined radiation safety recommendations of ICRP in its publications 26 of 1977 with the emerging differentiations between the two types of effects (stochastic and non-stochastic) which may be induced by ionizing radiations. The aim of radiation protection is to be able to prevent the detrimental non-stochastic effect of radiation and limit the probability of stochastic effects (Alan and Samuel,1986)

Intake of radionuclide into the body by consumption of the vegetables grown on the area of studies may pose danger (if exceeded the recommended values) as a result of internal

radiation hazards which will commit the target organ (or organs) or the whole body at risk from the radionuclide to a certain dose(the committed dose) The accumulation of non – essential element that may be present in the vegetables could also serve as a detriment to life. The ultimate goal of this work was to assess the health risk due to ingestion of NORMs and accumulation of non-essential element or toxics one if they may exist.

CHAPTER THREE

3.0 MATERIALS AND METHODOLOGY

In this section, the various methods and techniques that were used in order to achieve the objectives of the research are presented. Some important materials that were used in the research are also presented.

3.1 Choice of Sample Plants –Vegetables

A preliminary survey of the vegetables that are grown on the tin mined tailings in the selected local government areas was first carried out and the choice made was based on availability of the vegetables species in the sample locations. When large amount of radioisotopes are discharged into the environment, they can affect foods either falling onto the surface of food - vegetables or animal feed as deposits from air or through contaminated rain water/snow. Radioactivity in water can also accumulate in rivers and the see depositing on fish and sea food (INFOSAN, 2011). Barry, (2006) presented that in Africa; most vegetables are commonly grown from August- April on loamy soil where they require irrigation. Some of these vegetables grow up to about 600mm deep in temperatures around 15-18^{o} C. Chemical fertilizers were used in the production of the vegetables at certain proportion. The vegetables are eaten raw as Salad, juice or ordinary. The food value or medicinal content could be at the roots, stem, fruits or the combination of all. The vegetables considered for this research are: Carrots, potatoes (Irish) and Cabbage.

3.1.1 Samplings

The process of samplings is a very important step in meaningful analytical investigation. A great care was taken in order to ascertain that the samples analyzed truly represented the actual data in the field of study.

Table 3. 1: Samples collected in the study area

L. G. Area	Sample Code	Samples								
		Vegetables Rainy Season			Vegetables Dry Season			Soil		
		POT*	CAB*	CAR*	POT	CAB	CAR	SLS_1	SLS_2	SLS_3
Barikin/Ladi	(BLD)	3	3	3	3	3	3	3	3	3
Jos South	(JJS)	3	3	3	3	3	3	3	3	3
Bokkos	(BKK)	3	3	3	3	3	3	3	3	3
	Total Composite samples	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**

Collection of samples at irregular intervals of locations is referred to Radom samplings. This type of sampling gives a better representation of samples and data.

Random samplings were applied at each local government and for each farm land a representation of statistical data was obtained(Table 3.1) Three discrete samples were collected at three different positions randomly in a farmland and this was integrated to one sample for analysis.

s

3.1.2 Soil samples

Three soil samples from each of the three L.G.A were taken randomly in each of the farmland where the crops are cultivated around the abandoned tailings. The top soil of the farm land was first cleared before the soil was dug and collected from the depth of 0 to 6cm. the soil were mixed properly, collected in labeled polythene bags and exposed to sun to dry. Each soil sample was ground with cleaned dried agate Motor and pestle and then homogenized. The average required weights were taken for activity and elemental analysis

3.1.3 Potatoes samples

Each of the samples were peeled and sliced into very small bits and washed with running water after which they were sun dried on a clean polythene mat for several days. The partially dried sliced samples were then transferred into clean dried porcelain crucible and further dried in a thermostat oven at 105^{o}C. The hot dried samples were then placed in desiccators to cool after which they were grounded again and re-dried until it attained constant temperature (room temperature at 23.5^{o}C)

3.1.4 Carrots samples

The collected carrots samples were peeled and sliced into very small bits and rinsed with running water after which they were sun dried on a polythene mat for several days. The partial dried sliced samples were then transferred into cleaned dried porcelain crucible and dried again in a thermostat oven at 105^{o}C. The hot dried samples were then placed in

desiccators to cool after which they were ground again and re-dried until it attained constant temperature (room temperature at 23.5^{o}C)

3.1.5 Cabbage samples

The outer leaves of the harvested cabbage which contains large amount of impurities were peeled off. The bulb were then sliced into small pieces and washed with running tap water and then further rinsed with distilled water after which they were sun dried on a clean polythene mat for several days. The partial dried sliced were then transferred into cleaned dried porcelain crucible and dried again in a thermostat oven at 105^{o}Cuntil it attained constant temperature (room temperature at 23.5^{o}C)

The biological sample handling and treatment for the dry season (irrigation scheme) were irrigated from created ponds from the mining activities. The samples from the sampling areas that were not irrigated with the water from the mine ponds were also collected to serve as control. These biological samples were also homogenized and the required sizes were taken for activity concentrations analysis

3.2 Methodology

3.2.1NaI (Tl) Instrument used for Measurement of Radioactivity Concentration

The instruments used for gamma spectroscopy was Nal(Tl) which consists of a 7.62cm by7.62cm Na(Tl) detector housed in 6cm thick lead shield with Cadmium, and copper sheets optically coupled to a photomultiplier tube (PMT).The stated set-up is then incorporated with NIM Bin consisting of preamplifier, amplifier and MCA card system.

MAESTRO programmefrom ORTEC was used for data acquisition and analysis of the gamma spectra. In order to estimate the background counts an empty container was counted inside closed detector using the same container lid geometry and the readings were recorded. These were subtracted from the results obtained when the samples were used

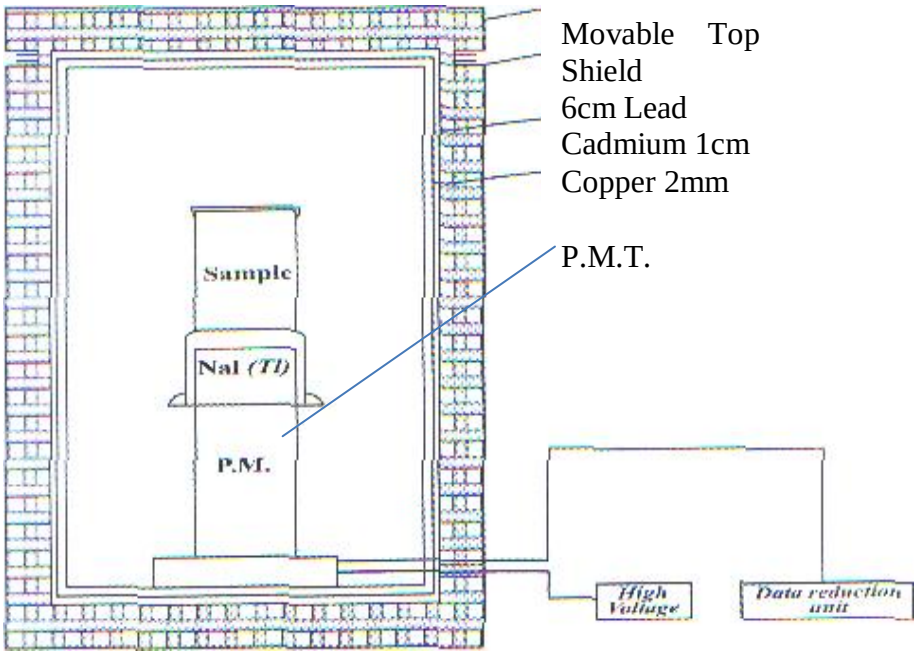


Figure 3. 1: An simplified Nal(Tl) detector Assembly of the Experimental set-up

There are two renowned ways of achieving spectra analysis for the energy discrimination needed for the qualitative and quantitative analysis of the radionuclide; the integral and the differential spectrometry. The integral spectrometry approach involves the recording of the whole spectrum from a predetermined low position that covers the energy peak of interest. The differential spectrometry involves acquisition of information on the energy peaks with an energy window set at about the peak (Ibeanu ,1999)

Table 3. 2: Spectral Energy windows used in analysis using Nal (Tl) gamma spectroscopy system

Elements analyzed	Isotope Used	γ-ray Energy(keV)	Energy windows(keV)
Th	Tl	2614.5	2460-2820
U	Bi	1764.0	1620-1820
K	K	1460.0	1380-1550

Source; Ibeanu,(1999)

In this particular work, differential spectrometry is employed in three channels. The ^{40}K channel was determined from the 1460keV energy peak, the ^{238}Uchannel of 1764 keV energy peak and the ^{232}Th channel having energy peak of 26l4 keV (table 2.3)

3.2.2 Calibration Factors (CF)

Calibration factors for each of the radionuclide implored for the analysis was obtained as follows:

$$\text{CF } {}^{40}\text{K} = \frac{CPS\ (K-40)}{(K-40)Bqkg^{-1}} \quad (3.3)$$

$$\text{CF } {}^{226}\text{Ra} = \frac{CPS\ (Ra-226)}{(Ra-226)Bqkg^{-1}} \quad (3.4)$$

$$\text{CF } {}^{232}\text{Th} = \frac{CPS\ (Th-232)}{(Th-232)Bqkg^{-1}} \quad (3.5)$$

Source; (Ibeanu, 1999).

Based on the above, the obtained calibration factors for this work were entered into table 3.2 and subsequently the activities at calibration were used to arrive at current activities of the radioisotopes.

Table 3. 3: Calibration, Conversion Factor and Detection Limit

Isotope	Calibration factor	Conversion Factor ($Bqkg^{-1}$)	Detection Limit(Bq/kg)
^{40}K	6.43	$\times 10^{-4}$	14.54
^{226}Ra	8.63	$\times 10^{-4}$	3.84
^{232}Th	8.77	$\times 10^{-4}$	9.08

Source: Ibeanu ,(1999)

For Energy calibration and Quantitative spectra analysis,the calibration factors (CF), conversion factor were obtained from the experimental works of Ibeanu (1999) table 3.3.

3.0 Energy calibration of NaI(Tl) detector

The calibration of MCA was carried out to relate the energy of the channel chambers. The amplified voltage was set to 900 Volts at constant coarse gain of 16V while the amplifier line gain was varying between 4 and 5 to ensure ^{137}Cs single channel number of 180. The photo peaks source ^{137}Cs with a single peak of energy 661.6 keV and ^{60}Co with double peaks of energies 1173.2 keV and 1332.5keV respectively which was obtained after counting period of 100 seconds. For calibration of the bulk samples, IAEA standard reference series RG Th-1, RGU-1 and RGK-1 were used for calibration and comparative analysis to determine the activity concentration (Bq/kg) the samples respectively. Table 3.1 showed the spectral energy window used in the sample analysis. 1764 keV gamma-line of 214Bi for ^{238}Uws used in the assessment of the activity concentration of ^{226}Ra of Tl was used for ^{232}Th. The single 1460.0 keV gamma line of ^{40}K was used in its content evaluation (Yuewmen, 1999)

3.3.1 Sample preparation and Analysis using Nal (Tl) detector

The collected soil and vegetable Samples were left open in the laboratory for a minimum of 24 hours to dry under ambient temperature. The dried samples were pulverized into a fine powder and passed through a standard mesh (500 µm) The samples were thoroughly homogenized and packed to fill 25g plastic containers which were then hermetically sealed with the aid of PVC tape to prevent escape of gas components such as ^{222}Rn and ^{220}Rn from the samples. All samples were weighed and stored for a minimum of 24days prior to measurement in order to attain radioactive secular equilibrium between ^{226}Ra and ^{228}Ac and their short-lived progeny (half-lived of ^{222}Rn) Comparative analysis was adopted where the sampleand the IAEA standard reference materials were mounted on

the detector surface [Nal (Tl)] and counted for 29,000sec.The count rate in counts per second (cps) was obtained for each radionuclide in every sample analyzed, Plate III



Plate III: Prepared Samples in labeled containers

The detector is coupled to multichannel analyzer (MCA) through a preamplifier base. The spectral and half-life times of the NORM were acquired using MAESTRO softwareandconversion factors which is different from each nuclide were applied to obtain activity concentration in Bq/kg. The final result is obtained after the subtraction of the background counts.

3.4 Evaluation of Results

In this section various techniques for evaluation or interpretation of the results and calculations involving radiological parameters are highlighted.

In order to assess any radiological hazard due to the exposure to radiation arising from radionuclides present in the soil and the vegetables concerned, many parameters can be used. Some important aspects of radiological indices necessary in this research and highlighted in this section include Radioactivity, health Hazards and radiological indices

3.4.1 Activity concentration

The results in count per second are automatically divided by the calibration factor and the result obtained is in Bq/kg and the activity concentrations of the samples were obtained using the equation 3.6 (Jibirin*et* al, 2007):

$$C(Bqkg^{-1}) = k\, C_n \qquad (3.6)$$

Where $k=\frac{1}{\varepsilon \rho_\gamma M_s}$, C_n is the activity concentration of the radionuclide in the sample given in Bq/kg

C_n is the count rate under the corresponding peak, ε.is the detector efficiency at the specific γ-ray energy, ρ_γ is the absolute transition probability of the specific γ-ray and M_s is the mass *(*kg*).* The detection limit (DL) of a measuring system describes its operating capability without the influence of the samples. The DL given in $Bqkg^{-1}$ which is required in estimate of the minimum detectable activity in samples was obtained using equation (3.7), (Jibiri *et aL,* 2007):

$$DL\ (Bqkg^{-1}) = 4.65\ \frac{\sqrt{C_b}}{t_b} k \qquad (3.7)$$

where $C_b$is the net background count in the corresponding peak, t_b is the background counting time (s) and k is the factor that converts counts per second (cps) to activity concentration ($Bqkg^{-1}$)

All the obtained raw data were converted to convectional units using conversion factors of $8.632x10^{-4}$, $8.768x10^{-4}$ and $6.431x10^{-4}$ for ^{40}K, ^{226}Ra and ^{232}Th respectively to determine their activity concentrations. With the counting time of 29,000 seconds for each sample, the environmental γ -ray background of the laboratory site was determined

using an empty container under identical measuring conditions, This then gave the below detection limit (DL) limits to be 310.99 Bqkg-^{1} for ^{40}K. 16.21 Bqkg-^{1} for ^{226}Ra and 123.16 Bqkg-^{1} for ^{232}Th respectively. This was subtracted from the measured γ-ray spectrum of each sample.

3.4.2 Absorbed Dose rate Air

In order to asses any radiological hazard the exposure to radiation arising from radionuclides present in both the soil and vegetables concerned can be determined in terms of many parameters. The mean activity concentration of ^{40}K,^{226}Ra(^{238}U) and ^{232}Th (Bq/kg) in the soil and vegetables are used to calculate the absorbed dose rate given by the following expression

$$D(nGyh^{-1}) = 0.462A_{Ra} + 0.621A_{Th} + 0.0417A_{K} \quad (3.8)$$

(Chang, et al 2008)

A_{Ra}, A_{Th} and A_{K} are the activity concentrations of Ra, Th and K respectively.

In this case it is assumed that the contributions of other naturally occurring radionuclides are insignificant. The absorbed dose D is due to gamma radiation in air at 1m above the ground surface for uniform distribution of naturally occurring radionuclides the coefficients are in nGyh^{-1} per Bq/kg (UNSCEAR, 2000)

3.4.3 Annual Effective Dose Equivalent (AEDE) (μSvy^{-1})

The absorbed dose rates in air at 1m above the ground surface does not directly provide the radiological risk to which an individual is exposed (Jibirin, et al 2007). The absolved dose can be considered in terms of annual effective dose equivalent from outdoors

terrestrial gamma radiation which is converted from the absorbed dose by taking into account two factors, namely the conversion coefficient from absorbed dose in air to effective and the outdoors occupancy factor. The annual effective dose equivalent can be estimated using the following formula;

$$E_{ff}D)\ (\mu Svy^{-1}) = \text{Dose rate}\ (nGyh^{-1}) \times 24h \times 365.25 \times 0.2 \times 0.7SvGy^{-1} \times 10^{-3} \quad (3.9)$$

Turhan and Gundiz (2008), the values of those parameters used in the UNCEAR (2000) report are $0.7SvGy^{-1}$for the conversion coefficient from absorbed does in air by adults and 0.2 for outdoor occupancy factor.

3.4.4 Effective dose rate($E_{ff}D$) (μSvy^{-1})

$$E_{ff}D)\ \mu Svy^{-1}) = \text{Dose rate}\ (nGyh^{-1}) \times 24h \times 365.25 \times 0.2 \quad (3.9)$$

(for In - situ values) UNSCEAR,2000)

3.4.5 Radium equivalent activity ($Ra_{eq.}$)

Due to a non-uniform distribution of natural radionuclide in the soil sample the actual activity level of ^{40}K, ^{226}Ra and ^{232}Th in the sample can be evaluated by means of a common radiological index called Radium equivalent activity. It is the most widely used index to assess the radiation hazard and can be calculated using equation 3.10 given by Berekta and Mathew (1995) This estimates that 4810 Bq/kg of ^{40}K,370 Bq/kg of ^{226}Ra and259 Bq/kg of ^{232}Th produce the same gamma-ray dose rate.

This is used to assess the hazard associated with materials that contain^{40}K, ^{226}Ra and ^{228}Th.

$$Ra_{eq}(Bq/kg) = A_{Ra} + 1.43A_{Th} + 0.077A_k \quad (3.10)$$

A_k,$A_{Ra}$and A_{Th} are the activity concentration of ^{40}K, ^{226}Ra and ^{232Th}. The result will give a single value representing the activity levels of the K,Ra and Th which takes account of their associated radiation hazard. The permissible maximum value of the radium equivalent activity = 370 Bq/kg. This corresponds to an effective dose of $1Svy^{-1}$ for the general public.

3.4.6 Estimation of Radiation Hazard Indices

Radiation exposure due to Ra-226, Th-232 and K-40 radiation sources could be classified as external and internal. The associated external hazard is defined in terms of external hazard index or outdoor radiation hazard index and is denoted as H_{ex} while The internal hazard index explain the internal exposure to carcinogenic radon and is denoted by H_{in}.

In order to limit the natural exposure attributed to natural radionuclides in the samples to the permissible dose equivalent of $1mSv.y^{-1}$, the external hazard index based on a criterion have been introduced using a model proposed by Krieger (1981) and applied by (UNSCEAR, 2000)

The external hazard index $H_{ex}$is defined in terms of external or outdoor radiation hazard and its value should be equal or less than unity equation 3.11. The internal hazard index $H_{in}$is defined in terms o the internal exposure due to casinogenic radon and is given in equation 3.12 which should also be unity or less.

i) External hazard indices

$$H_{ex} = \frac{ARa}{370} + \frac{ATh}{259} + \frac{Ak}{4810} \leq 1 \qquad (3.11)$$

ii) Internal hazard indices

$$H_{in} = \frac{ARa}{185} + \frac{ATh}{259} + \frac{Ak}{4810} \leq 1 \quad (3.12)$$

where

ARa, ATh and AK are the activities of radium, thorium and potassium respectivelyand for values of indices less than unity the radiation hazard will be negligible. Maximum values of $H_{ex}$and H_{in}equal to unity correspond to the upper limit of radium equivalent activity 370 Bq/kg (UNSCEAR, 2000).

3.4.7 Average annual committed effective dose, $E_{ave,}$ for ingestion of NORMS (K-40, Ra-226 and Th-232)

The aim of radiation protection is to be able to prevent the detrimental non-stochastic effect of radiation and limit the probability of stochastic effects (Alan and Samuel, 1986)

Having obtained the values for the specific activity concentrations of the individual naturally occurring radionuclides in the vegetable, the average annual committed effective dose, $E_{ave,}$ for ingestion of NORMS in the vegetables were calculated using the expression in equation (3.13).

$$E_{ave}=IpDCF_{ing}A_{sp} \quad (3.13)$$

Where DCF_{ing} is the dose conversion factor for ingestion, for each radionuclide (i.e., 2.8 × 10^{-5} mSv Bq^{-1}, 2.3 × 10^{-4} mSv Bq^{-1} and 6.2 × 10^{-6} mSv Bq^{-1} for ^{226}Ra, ^{232}Th and ^{40}K respectively for an adult (Aminu and Ahmed, 2013); (UNSCEAR 2000)), I_p is the consumption rate from intake of NORMS in the vegetable/ plants.

The food consumption patterns for different types of diet (raw unprocessed food per year per capita) for African; cereals,roots and tubers, Vegetables, fruit, meat, fish and milk were 130, 130, 26, 45, 17, 15, and 29 (kg) respectively (IAEA, 1999) (for cabbage,

carrots and potatoes, 26 kg was used) and A_{sp} is the activity concentration in the vegetable sample (Tettey-Larbi, 2013)

3.4.8 Estimation of cancer risk

The risk to cancer incurred by population is estimated by assuming a linear dose effect relationship with no threshold as per ICRP practice. For low doses ICRP fatal cancer risk factor is 0.05 Sv^{-1}. The risk factor states the probability of a person dying of cancer by 5% for total dose of 1Sv received during life time.

Cancer Risk = estimated annual committed dose (50yr life time of man) (Sv) x0.05 Sv^{-1} (3.14)

3.5 Determination of Elemental concentrations using Instrumental Neutron Analysis (INAA)

One of the most commonly used methods of investigation of elemental concentration is the use of Instrumental Neutron Analysis (INAA). This is achieved by activating the elements in the Geological or biological sample using a research nuclear reactor with moving neutron (neutron flux). The activated samples from the rector are then transferred into (HiPGe) detector for final elemental analysis.

3.5.1 Method of NAA elemental concentration analysis

Elemental Measurement using INAA are usually made using the comparator method which means that the unknown sample and a standard of known concentration are irradiated under identical experimental conditions.

The samples is exposed to neutrons (irradiated) for a predetermined length of time taking into consideration the half-life of the element of interest (t_1)

It is then transferred to the counting section and allowed to cool or decay for a definite length of time (t_d). The gamma ray spectrums acquired for counting time (t_c) represents the type of induced radionuclide o interest. The area under the full energy peak (FEP)of interest is calculated and represents the amount of induced radionuclide of interest.

For data processing the gamma-ray spectrum analysis software WINSPAN,2004 used by (Liyu, 2004) based on the practice of using the activity induced at time after irradiation for time t_1 and given by the equation;

$$A_o = \frac{\varepsilon \sigma_Q \rho W_Q \varphi}{M_Q} = N_A\left(1 - e^{-\lambda t_i}\right) ds^{-1} \quad (3.15)$$

Where;

A_o = activity of element Q at the end of radiation (d^{s-1})

σ_Q = neutron capture cross section of element (m^2)

ρ = fractional abundance of particular isotope of element Q

M_Q = atomic weight of element Q to be measured

N_A= Avogadro's number (mol^{-1})

λ= decay constant of induced radionuclide (s^{-1})

t_i = irradiation time (s)

φ= is the flux of neutron used in irradiation ($m^{-2}s^{-1}$)

W_Q = weight of element Q irradiated

Known as basic equation for activation analysis applied by (IAEA,1990) and Adeyemo (2002)

After irradiation the induced radioactivity decays according to

$$A_t = A_o e^{-\lambda t_d} \quad (3.16)$$

t_d = time after end of irradiation, i.e. decay time

$$\lambda = \frac{0.693}{T_{1/2}} \quad (2.17)$$

$T_{1/2}$= half life of induced radionuclide.

One gram or less of sample sealed in polyethylene for short irradiation, or high purity quartz capsules for long irradiation, is irradiated along with the elemental standard of interest. Short irradiation lasts about 1-5minutes while long irradiation is up to a week. After each irradiation the samples are counted on a HiGe(Li) detector connected to a multichannel analyzer for varying time periods, Taking the advantage of different half-lives and the activation cross section of the elements.(σ_Q, M_A, N_A,ε, ρ are the same)

In addition to INAA calculations WINSPAN,2004 performs peak analysis remote control of the MCA and other auxiliary functions such as efficiency calibration and other nuclear data generation with the use of standards for calibration (relative method) for the calculation of the concentration of each element in the sample with thermal neutron .the INAA equation reduces to the simplest form

$$\frac{\mathrm{Ws}}{\mathrm{W_{st}}} = \frac{\mathrm{N_s}}{\mathrm{N_{st}}} \frac{\mathrm{Ds}}{\mathrm{Dst}} = \frac{\mathrm{N_s\, e^{-\lambda\, tds}}}{\mathrm{N_s\, e^{-\lambda\, tdst}}} \quad (3.18)$$

Where;

Ns=net photo peak area of the radionuclide of interest in the sample

N_{st}=net photo peak area of the radionuclide of interest in the standard

Ws= weight of element of interest in the sample irradiated

Wst= weight of element of interest in the standard irradiated

$\mathrm{Ds} = \mathrm{e}^{-\lambda\, \mathrm{td}}$ =Decay factor for sample

D_{st} =$\mathrm{e}^{-\lambda\, \mathrm{tdst}}$ =Decay factor for standard

t_d=decay time for sample

t_{dst}=decay time for standard

λ = decay constant

The unknown concentration of element of interest in the sample $C_s$is given by

$$C_s=\frac{A_S}{A_r}=\frac{W_S}{W_r}\text{or}=\frac{W}{M} \quad (3.19)$$

Where;

A_S = activity of sample, W_s weight of sample

A_r = activity of standard W_r weight of standard

M = the known weight of the irradiated sample

W = the weight of element irradiated

3.5.2 Nigeria Research Reactor-1 (NIRR-1)

For the purpose of this work, Nigeria Research Reactor-1 (NIRR-1) was used for elemental concentration determination. The reactor is the first and only reactor in Nigeria which is based Centre for Energy Research and Training (CERT) Ahmadu Bello University Zaria. It is a low-power nuclear reactor, which is highly enriched with uranium fuel, with water as moderator and beryllium as reflector. The associated facility for radioactivity measurement is the gamma-ray data acquisition system which consists of a horizontal dip stick High-purity Germanium (HiPGe) detector with 100% relative efficiency at 1332.5 keVgamma ray line. A Multi-Purpose Gamma-Ray Spectrum Analysis (WINSPAN, 2004) software was used for data processing.

Nigeria Research Reactor-1 (NIRR-1) has Maximum Capacity of 31 kW power and 1.0 $x10^{12}$ $ncm^{-2}s^{-1}$ neutron flux with the computer system of control unit (Plate IV)

Reactor core is 23cm high and 23cm in diameter cylindrical and concentric cycles. It contains maximum of 350 fuel pins (Out of which 3 are domant and 347 were active.)



Plate IIII: Computer system of INAA control unit of NIRR-1

3.5.3 Validation of the INAA experimental procedure

In order to validate the experimental procedure of the 2 analytical techniques used this research work, certified referenced materials are used and results of these analyses agreed with all the elements (^{28}Al, ^{27}Mg, ^{18}Cl ^{49}Ca,^{66}Cu,^{51}Ti, ^{52}V, ^{116m}In,^{24}Na, ^{42}K, ^{165}Dy, ^{56}Mn, ^{152m}Eu,^{24}Na, ^{42}K, ^{76}As, ^{82}Br, ^{140}La,^{153}Sm,^{198}Au,^{239}Np(U), ^{72}Ga, ^{122}Sb,^{46}Sc, ^{141}Ce, ^{60}Co, ^{51}Cr, ^{134}Cs, ^{152}Eu, ^{177}Lu, ^{131}Ba, ^{86}Rb, ^{182}Ta, ^{160}Tb, ^{175}Yb, ^{322}Pa(Th), ^{65}Zn, ^{59}Fe, ^{181}Hf) with that of the provided values implying that results obtained for the analysis of these composite samples is valid.

3.5.4 The INAA experimental procedures

Four irradiation schemes were used to detect and measure short-lived and long-lived nuclides in the samples based on their half- lives.L1,L2 and S1,S2where L1 and L2are long and S1and S2 are short irradiation schemes were adopted for validation in this research.

The first schemes (S1) comprises of nuclides with short-lives which were measured after decay/cooling time of (t_c) 2-15 minutes. The nuclides determined were; ^{28}Al, ^{27}Mg, ^{18}Cl ^{49}Ca,^{66}Cu,^{51}Ti, ^{52}V, ^{116m}In

In the second scheme (L1) nuclides of longer half-lives were determined after decay/cooling time of 3-4h, using a counting time of t 10minuntes the nuclides measured were;, ^{24}Na, ^{42}K, ^{165}Dy, ^{56}Mn, ^{152m}Eu

In the third scheme (S2) long-lived nuclides were also determined using irradiation time of 6hr at the decay/cooling time of 4-5days, counting time of 30minnute and the nuclides determined were;^{24}Na, ^{42}K, ^{76}As, ^{82}Br, ^{140}La,^{153}Sm,^{198}Au,^{239}Np(U), ^{72}Ga, ^{122}Sb

The fourth irradiation scheme (L2) nuclides of longer half-lives were determined at a decay/cooling of 10-15days,and counting time of 60minnutes,where the determined nuclides included;^{46}Sc, ^{141}Ce, ^{60}Co, ^{51}Cr, ^{134}Cs, ^{152}Eu, ^{177}Lu, ^{131}Ba, ^{86}Rb, ^{182}Ta, ^{160}Tb, ^{175}Yb, ^{322}Pa(Th), ^{65}Zn, ^{59}Fe, ^{181}Hf. Table 3.4 shows the Routine Irradiation and Measuring Regimes Developed for NIRR-1facilities

Table 3. 4:TheRoutine Irradiation and Measuring Regimes Developed for NIRR-1facilities

Neutron Flux/irradiation channel	**Procedure**	**T_{irr}**	**T_d**	**T_m**	**Activation products**
$1x10^{11}$ n/cm^2/outer irradiation channel th(B4,A2)	S1	2min	2-5min	10min	^{28}Al, ^{27}Mg, ^{18}Cl ^{49}Ca,^{66}Cu,^{51}Ti, ^{52}V, ^{116m}In
	S2	2min	3-4h	10min	^{24}Na, ^{42}K, ^{165}Dy, ^{56}Mn, ^{152m}Eu
$5x10^{11}$ n/cm^2/outer irradiation channel (B1,B2,B3andA1)	L1	6h	4-5d	30min	^{24}Na, ^{42}K, ^{76}As, ^{82}Br, ^{140}La,^{153}Sm,^{198}Au,^{239}Np(U), ^{72}Ga, ^{122}Sb
	L2	6h	10-15d	60min	^{46}Sc, ^{141}Ce, ^{60}Co, ^{51}Cr, ^{134}Cs, ^{152}Eu, ^{177}Lu, ^{131}Ba, ^{86}Rb, ^{182}Ta, ^{160}Tb, ^{175}Yb, ^{322}Pa(Th), ^{65}Zn, ^{59}Fe, ^{181}Hf

Source; Jonah et al (2006)

T_{irr} is the time of irradiation of samples

T_d is the delay time

T_m time of measurement

3.5.5 Comprism of certified values with results of the analysis

Table 3. 5:Comparison of certified values with the standardized results in ppm or as indicated in % for certified reference materials IAEA-336(Lichen) and IAEA – 359(Cabbage)

	IAEA-336(Lichen)		IAEA-339(Cabbage)	
	For this research (TW)	(CV)	For this research (TW)	(CV)
Al	709±35	579-790	175±13	-
As	BDL	0.55-0.71	BDL	0.096-0.104
Ba	BDL	5.3-7.5	BDL	10.5-11.5
Br	11.0±1.3	11.2-14.6	8.0±3.0	-
Ca(%)	BDL	-	1.97±0.12	1.8-1.9
Ce	BDL	1.11-1.45	BDL	-
Co	BDL	0.24-0.34	BDL	-
Cr	BDL	0.89-1.23	BDL	1.24-1.26
Cs	BDL	0.097-0.123	BDL	-
Cu	BDL	144	BDL	78.6
Eu	BDL	0.019-0.027	BDL	-
Fe(%)	BDL	0.038-0.048	BDL	0.014-0.15
K(%)	BDL	0.16-0.21	3.3±0.4	-
La	0.66±0.04	0.56-0.76	0.27±0.05	-
Lu	BDL	0.004-0.009	BDL	-
Mg(%)	BDL	-	BDL	0.21-0.22
Mn	61±2	56-70	29.4±0.8	31.3-32.5
Na	317± 16	280-360	676±30,	567-601
Rb	BDL	0.063 -0.83	BDL	-
Sc	0.16±0.	0.15-0.17	BDL	-
Sm	BDL	0.092-0.12	BDL	-
Tb	BDL	0.012-0.016	BDL	-
Th	BDL	0.12-0.16	BDL	-
V	BDL	1.25-1.69	BDL	-

TW means certified values; BDL means below detection limit, adopted and used for this analysis with the same reactor

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Table 3.5 indicated the certified reference materials for the biological work utilized for this work were IAEA- 359 (Cabbage) and IAEA 336 (Lichen) for biological samples. Certified values for reference used for the determination of the soil elemental concentration wereIAEA – 405and IAEA-SL-3 for geological samples. A Multi-Purpose Gamma-Ray Spectrum Analysis (WINSPAN, 2004) software was [capable of analyzing twenty six (26) elements] used for data processing. This serves as quality control assesment for the four irradiation schemes

Table 3. 6:Comparison of certified values with the standardized results in ppm or as indicated in % for cerfied reference materials IAEA-SL-3 and IAEA – 405

Element	CRM IAEA-SL-3 (sediment) For this research (TW)	(CV)	CRM IAEA – 405 (Soil)For this research (TW)	(CV)
Al	2.4± 0.1	2.3-2.6	7.2±0.3	7.3-8.3
As	3.9± 0.4	3.0-3.4	21.2±0.5	22.9-24.3
Ba	160± 34	-	509±	-
Br	5.4±1.6	4.8-6.4	66±17	60-110
Ca(%)	11.2± 0.5	10.7-11.5	2.2±0.	-
Co	9.1± 0.7	-	14.4 ±0.9	13.0-14.4
Cr	63± 9	-	78 ±10	80-88
Cs	BDL	1.2-1.5	12.6 ±1.2	10.4-14.6
Eu	BDL	0.6-0.7	1.3±0.2	0.9- 1.6
Fe(%)	2.6±0.1	-	3.7 ±0.1	3.7-3.8
Ga	BDL	-	16.3±2.7	-
Hf	5.1±0.3	8.5-9.7	6.2±0.4	4.9-6.9
K(%)	0.91±0.04	0.79-0.96	2.48±0.09	1.77-3.21
La	22.7±0.6	21.5-23.5	33.6±0.9	33.1- 47.7
Lu	0.3±0.009	0.27-0.33	0.30±0.09	0.28-0.65
Mg (%)	2.50±0.14	2.4-2.9	1.1±0.1	1.1-1.3
Mn	391±10	-	98.9±6.8	90-100
Na (%)	0.67±0.	0.630-0.702	406±11	1.1-1.3
Sb	BDL	0.46-0.66	1.67±0.05	484 -506
Sc	4.44±0.3	3.6-4.2	13.1±0.9	11.5-15.5
Sm	5.2±0.3	3.5-4.1	7.4 ±0.5	6.5-7.2
Ta	BDL	0.65-0.75	BDL	-
Th	8.31±0.05.	6.5-7.5	15.0±1.2	12.2-16.4
Ti(%)	0.31±0.05	0.23-0.29	0.34±0.06	-
V	18.8± 1.8	-	98.9±6.8	90 -100
Yb	2.4±0.3	1.8-2.0	3.2±0.4	2.2 -3.9

S. A. Jonah et al (2006) found for the same MNSR , adopted and used for this analysis with the same reactor

TW means the work of Johna et al (2006)

CV means Certified values

BDL means below detection limit

Table 3. 7:Nuclear Data and Limits of Detection for Some Elements Using Adopted Experimental Condition

Target isotope	Product isotope by (n,γ)reaction	Half-life	Gamma enrgy (keV)	Counting scheme	Limits of detection
^{23}Na	^{24}Na	14.96h	1368.60	L1	40.0
^{26}Mg	^{27}Mg	9.46min	1014.4	S1	7250.0
^{27}Al	^{28}Al	2.24min	1778.89	S1	17.0
^{17}Cl	^{18}Cl	37.24min	1642.7	S2	2900.0
^{41}K	^{42}K	12.36h	1524.58	S1	2400.0
^{47}Sc	^{46}Sc	83.81d	889.28	L2	0.2
^{48}Ca	^{49}Ca	8.72min	3084.54	S1	6600.0
^{50}Ti	^{51}Ti	5.76 min	320.08	S1	2500.0
^{51}Cr	^{51}Cr	27.7d	320.98	L2	23.0
^{51}V	^{52}V	3.75min	1434.08	S1	15.0
^{55}Mn	^{56}Mn	2.58h	846.76	S2	0.9
^{58}Fe	^{59}Fe	444.5d	1099.25	L2	829.0
^{60}Co	^{61}Co	5.27yrs	1173.2	L2	3.0
^{55}Cu	^{56}Cu	5.10min	10.39.20	S1	172.0
^{64}Zn	^{65}Zn	243.9d	1115.55	L2	120.0
^{71}Ga	^{72}Ga	14.1h	834.10	L1	1.0
^{75}As	^{76}As	26.32hr	559.10	L1	1.2
^{82}Br	^{82}Br	35.3hr	776.5	L1	3.0
^{85}Rb	^{86}Rb	18.8d	1076.60	L2	30.0
^{115}In	^{116}In	54.8d	1097.30	S1	0.5
^{121}Sb	^{122}Sb	64.8hr	564.24	L1	0.5
^{133}Cs	^{134}Cs	2.06yr	795.85	L2	1.7
^{131}Ba	^{132}Ba	11.8d	496.30	L2	364.0
^{139}La	^{140}La	40.3hr	4596.31	L1	0.2
^{140}Ce	^{141}Ce	32.5d	145.44	L2	14.0
^{151}Eu	^{152}Eu	13.3yr	1408.50	L2	0.6
^{152}Sm	^{153}Sm	46.27hr	103.18	L1	0.1
^{159}Tb	^{160}Tb	72.3d	879.38	L2	1.1
^{164}Dy	^{167}Dy	2.33h	94.70	S2	0.7
^{174}Yb	^{175}Yb	4.19d	396.33	L1	0.9
^{176}Lu	^{177}Lu	6.71d	208.36	L2	0.1
^{180}Hf	^{181}Hf	42.4d	482.2	L2	1.1
^{181}Ta	^{182}Ta	115d	12214	L2	1.0
^{197}Au	^{198}Au	2.7d	411.8	L1	0.02
^{232}Th	^{233}Th	27.0d	312.01	L2	1.2
^{238}U	^{239}U	2.3d	227.20	L1	1.5

Source; Jonah et al (2006)

WhereL1 and L2are long and S1and S2 are short irradiation schemes adopted for validation for the respective elements in this research.

3.5.6 Nuclear Equations for the Targeted Nuclides and their Gamma Energies

The reaction for this activation analysis is known as neutron capture reaction because the incident neutron is completely absorbed a target nucleus with the emission of prompt γ-ray whose energy Eγ is characteristically used to identify the element. The general equation for this process is

$${}^{A}_{Z}X + {}^{1}_{0}n \rightarrow {}^{A+1}_{Z}Y + \gamma \ \ldots\ldots\ldots\ldots\ldots\ldots \text{E}\gamma \qquad (3.20)$$

where

X is the target nucleus

A is the atomic mass of the isotope

Z is the atomic number of the target element

γ is the gamma ray

Eγ is the energy emitted

A+1 is the atomic mass of the product isotope

Y is the product isotope

The reactions therefore are,

$^{26}\text{Mg} + {}^{1}\text{n} \rightarrow {}^{27}\text{Mg} + \gamma$ Eγ =.1014.40 keV

$^{27}\text{Al} + {}^{1}\text{n} \rightarrow {}^{28}\text{Al} + \gamma$ Eγ = 1778.88 keV

$^{37}\text{Cl} + {}^{1}\text{n} \rightarrow {}^{38}\text{Cl} + \gamma$ Eγ =1642.70 keV

$^{48}Ca + {}^{1}n \rightarrow {}^{49}Ca + \gamma$	$E\gamma = 3084.54$ keV
$^{51}V + {}^{1}n \rightarrow {}^{51}V + \gamma$	$E\gamma = 1434.06$ keV
$^{75}Se + {}^{1}n \rightarrow {}^{76}Se + \gamma$	$E\gamma = 161.93$ keV
$^{55}Mn + {}^{1}n \rightarrow {}^{56}M + \gamma$	$E\gamma = 856.76$keV
$^{23}Na + {}^{1}n \rightarrow {}^{24}Na + \gamma$	$E\gamma = 1368.60$keV
$^{41}K + {}^{1}n \rightarrow {}^{42}K + \gamma$	$E\gamma = 1524.58$ keV
$^{75}As + {}^{1}n \rightarrow {}^{76}As + \gamma$	$E\gamma = 559.10$ keV
$^{139}La + {}^{1}n \rightarrow {}^{140}La + \gamma$	$E\gamma = 1596.21$keV
$^{152}Sm + {}^{1}n \rightarrow {}^{153}Sm + \gamma$	$E\gamma = 103.18$ keV
$^{238}U + {}^{1}n \rightarrow {}^{239}U + \gamma$	$E\gamma = 227.60$ keV
$^{45}Sc + {}^{1}n \rightarrow {}^{46}Sc + \gamma$	$E\gamma = 889.24$ keV
$^{50}Cr + {}^{1}n \rightarrow {}^{51}Cr + \gamma$	$E\gamma = 320.98$keV
$^{58}Fe + {}^{1}n \rightarrow {}^{59}Fe + \gamma$	$E\gamma = 1099.25$keV
$^{59}Co + {}^{1}n \rightarrow {}^{60}Co + \gamma$	$E\gamma = 1173.20$ keV
$^{64}Zn + {}^{1}n \rightarrow {}^{65}Zn + \gamma$	$E\gamma = 1115.55$ keV
$^{81}Br + {}^{1}n \rightarrow {}^{82}Br + \gamma$	$E\gamma = 776.50$ keV
$^{85}Rb + {}^{1}n \rightarrow {}^{86}Rb + \gamma$	$E\gamma = 1076.60$keV

$^{121}Sb + {}^{1}n \rightarrow {}^{122}Sb + \gamma$ $E\gamma = 56424$ keV

$^{130}Ba + {}^{1}n \rightarrow {}^{132}Ba + \gamma$ $E\gamma = 496.30$keV

$^{151}Eu + {}^{1}n \rightarrow {}^{152}Eu + \gamma$ $E\gamma = 1408.50$ keV

$^{169}Tb + {}^{1}n \rightarrow {}^{160}Tb + \gamma$ $E\gamma = 879.38$ keV

$^{174}Yb + {}^{1}n \rightarrow {}^{175}Yb + \gamma$ $E\gamma = 396.33$keV

$^{232}Th + {}^{1}n \rightarrow {}^{233}Th + \gamma$ $E\gamma = 312.01$ keV

3.5.7 Sample preparation for INAA Using NIRR-1 Facilities

Polythene bags for sealing samples and sample vials were washed with distilled water three (3) times and placed in dilute acid (HCI) in the ratio 2:3 of acid: deionized distilled water for two (2) days, the materials (polythene bags and sample vials) were removed and rinsed with deionized distilled water three (3) times, and allowed to dry in an oven (Ketong 101) that is maintained at a temperature of 60^{0}C for two (2) hrs. 0.3-0.5g of each of the powdered samples was weighed out using a metler AE 240 analytical balance. Each of the weighed samples was sealed in a polythene bags and placed in the vials. The vials were then covered and cello taped to secure the covers and at this stage, the samples are ready for irradiation.

3.5.8 Sample irradiation for the INAA Using NIRR-1 Facilities

The NIRR-I is specially designed for neutron activation analysis and is capable of determining, major, minor and even trace elements in different sample matrices. It is a low power nuclear reactor which has highly enriched uranium as fuel, light water as

moderator and beryllium as a reflector. For the irradiation, four (4) schemes were adopted based on half-life of product radionuclide. For the element leading to short-lived activation products the samples are sent to the outer irradiation channel (B4) were the neuron spectrum is soft'. For elements leading to long-lived activation products, samples are irradiated for six (6) hours in any of the small irradiation channels (A1, B1, B2, and B3) to take advantage of the maximum value of thermal neutron flux in the inner channel (Okoh, 2010).

The biological samples were prepared for both long-lived and short-lived irradiations, the samples were sent to the outer irradiation channel (B4) through pneumatic rabbit system (PRS) and the samples were irradiated for five (5) minutes at half power with neuron flux of $1x10^{11}$ n/em^2s. For the long-lived irradiation, the samples were sent to the inner irradiation channel (B^2 and B^3) and irradiated for six hours at half power with neutron flux of $5x10^{11}$ n/cm^2s. (Okoh, 2010)

3.5.9 Radioactivity measurements of the induced radionuclides

Radioactivity measurement of induced radionuclides was performed by the P-C based gamma-ray spectrometry set up. (Liyu, 2004)

The associated facility for radiation measurement is a gamma-ray data acquisition system which consists of a horizontal dip-stick high-purity germanium (HPGe) detector (plate V) with a relative efficiency of 10% at 133.5 KeV gamma-ray line, the MAESTRO emulation software compatible with the ADCAM® multi-channel analyzer (MCA) card, associated electronic modules and a computer (Jonah et al., 2006).The below detection

limit (BDL) of the elements V, Br, Zn, Ba, Tb and Th were improved from 15.0, 3.0, 120.0, 264.0, 1.1 and 1.2 to 6.0, 0.5, 40.0, 70.0, 1.0 and 0.2 (ppm) respectively



Plate IV: High purity Germanium (HiPGe) detector used for elemental analysis

Following the short irradiation regime, the first round of counting was performed for ten (10) minutes (i.e. Si) after a waiting time of two (2) to fifteen (15) minutes. Samples were placed on a flexi-glass sample holder designated as 'H2' which corresponds to source detector geometry of 5cm. the second round of counting also carried out for ten (10) minutes, following the short irradiation regime (S2) after a waiting period of three (3) to four (4) hours. Samples were counted on a flexi-glass holder designated as "HI" corresponding to the source-detector geometry of 1cm (Liyu, 2004).

For the long irradiation regime, the first round of counting (radioactivity measurement) was carried out for thirty (30) minutes, following the long irradiation (i.e. L2) using the holder 'HI' after a waiting period of four (4) to five (5) days. The second round of

counting was performed for sixty (60) minutes (i.e. L2) after cooling time of ten (10) to fifteen (15) days, samples were counted using flexi-glass holder 'HI'. The choice of cooling time and sample detector geometry is such that detectors dead time is controlled to be less than 10% (Jonah et al., 2006)

3.5.10 Calculation of oral intake of metals from soil through vegetables

Calculation of oral intake of metals from soil through vegetables was calculated following Cui et al. (2004).

Daily intake of metals (DIM) = daily vegetable consumption ×mean vegetable metal concentrations (mg/day, fresh weight) (3.17)

The required amount of vegetables in our daily diet must be 300 to 350 g per person has been suggested by WHO guideline (WHO 1998).

3.5.11 Calculation of health risk index of metal contamination of vegetable

Risk to human health by the intake of metal-contaminated vegetables was characterized using a hazard Quotient (H_Q) (U.S. Environmental Protection Agency US EPA 1989). H_Q is the ratio between exposure and the reference oral dose (R_fD). If the ratio is lower than one (1), there will be no obvious risk. An estimate of the potential hazard of metal to human health (H_Q) through consumption of vegetables is determined by the following equation 3.21

$$HQ = (Div)x(Cmeta)/R_fDxBo \quad (3.21)$$

Where (Div) is the daily intake of vegetables (kg/day), (Cmetal) is the concentration of metal in the vegetable (mg/kg), R_{fD} is the oral reference dose for the metal (mg/kg of body weight/day) and Bo is the human body weight (kg). Although the H_Q-based risk assessment method does not provide a quantitative estimate for the probability of an

exposed population experiencing a reverse health effect, it indeed provides an indication of health risk level due to exposure to pollutants (Chary et al. 2008).

3.5.12 Transfer factor (T_f)

Metal concentration in the extracts of soils and plants were calculated on the basis of dry weight. The plant transfer factor (T_f) was calculated as follows:

$$T_f = Cplant/Csoil \quad (3.22)$$

Where Cplant and Csoil represents the toxic metal concentration in extracts of plants and soils on dry weight basis, respectively

3.6 Materials used in the study

The materials used in the research are;

Sodium Iodide (NaI) detector

Nigeria Research Reactor-1 (NIRR-1)

High purity Germanium (HiPGe) Detector

Multi-Purpose Gamma-Ray Spectrum Analysis (WINSPAN, 2004) software for data processing

IAEA Biological Standard Reference Materials

IAEA Geological Standard Reference Materials

Vegetables (Irish potatoes, Carrot and Cabbage)

Dryer and Mettler Balance

Agate Mortar and pestles

Shovel and Digger,

Poly ethane Bags

Plastic containers

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

Presently in many parts of the world, there has been an increasing interest on radioactivity measurements of our environments. The interest becomes necessary because of health implication of the populace (Belivermis, et al 2009) Mining activity has been one of the major sources of radioactivity in our environment and in turn affects man directly or the food he consumes. In this research, emphasis were made on radiological measurements in soil and some selected vegetables grown on abandoned mine fields of Jos –plateau, Nigeria. There are two broad classes of the samples: the geological consisting of soils on the abandoned tin mine areas on which farming activities were carried out and biological consisting of the three types of vegetables (potatoes, cabbage and carrot) The radioactivity and radiological hazard assessment for the soil samples were determined in this research. For the case of the vegetable samples, the activities (potassium 40, radium-226 and thorium-232) and hazard indices were determined for each vegetable obtained in the dry season and those obtained in rainy season.

The activity concentration measurement was achieved by the use of gamma-ray spectrometry detecting instruments with a view of predicting possible hazards from the soil and ingested foods. The other part of the research was the determination of elemental concentration in both the soil (geology) and the vegetables (biological) using Instrumental Neutron Activation Analysis technique.

4.1 Radioactivity concentrations in soils

The concentration of radionuclides in the collected samples indicated the nature of human activities in the area as well as geological formation of the area under studies. The results summarize the specific activity of K-40, Ra-226 and Th-232 in the soil (Bq/kg) Samples Collected at the Sites of the selected L.G.As

4.1.1. Results Showing the Activity concentrations of the Soil Samples Collected at the Sites in Barikin Ladi L.G.A

Table 4.1 presents the specific activity concentration of K-40, Ra-226 and Th-232 in the soilsamples collected at Barikn Ladi L.G.A sites.

Table 4. 1:The Activity of the Soil Samples at Barikin Ladi L.G.A.

S/No	Sample ID	K-40 (Bq/kg)	Ra-226 (Bq/kg)	Th-232 (Bq/kg)	TOTAL(Bq/kg)
1	BLDS1	176.5163±9.02	34.9942±2.46	41.7332±2.96	253.2437±14.44
2	BLDS2	98.2893±9.09	29.4322±4.87	43.1015±2.96	170.8230±7.92
3	BLDS3	89.1135±2.18	55.0406±5.91	50.0570±1.25	194.2111±17.16
Mean	-	121.3060±6.40	39.8200±4.01	44.4640±2.39	206.0926±9.84
Range	-	89.1135-176.5163	29.4322-55.0406	41.73318-50.0570	170.8230-253.2437

BLDS1 - 3 soil sample of Barikin-Ladi for 3 points

From table 4.1, the activity of K-40 obtained is higher than Ra-226 and Th-232 and ranged from 176.5160±9.02 to 89.1135± 2.18 Bq/kg with mean activity of 121.306±6.40Bq/kg. The activity concentration of Ra-226 ranged from 55.0406± 5.91 to 29. 4322± 4.87 Bq/kg with mean activity of 39.820 ± 01Bq/kg..The activity concentration of Th-232 ranges from 50.057 ±1.23 to 41.733±2.96 Bq/kg with mean activity of 44.964± 2.39 Bq/kg.

4.1.2 Results Showing the Activity concentrations of the Soil Samples Collected at the in Bokkos L.G.A Sites

Table 4.2 presents the specific activity concentration of K-40, Ra-226 and Th-232 in the soil samples collected at Bokkos L.G.A (Bq/kg).

Table 4. 2:The Activity of the Soil Sample collected from Bokkos L.G.A.

S/No	Sample ID	K-40 (Bq/kg)	Ra-226 (Bq/kg)	Th-232 (Bq/kg)	TOTAL(Bq/kg)
1	$BKKS_1$	109.1750±8.71	46.3500±1.18	52.566±2.39	208.0910±12.28
2	$BKKS_2$	42.4572±9.02	73.0010±4.40	51.3110±4.78	166.7690±18.20
3	$BKKS_3$	106.3760±2.02	63.9620±7.53	87.571±3.31	257.9090±12.86
Mean	-	86.0027±6.58	61.1043±4.37	63.8160±7.53	210.9230±14.45
Range	-	42.4572-109.1750	46.3500-73.0010	51.3110-87.5710	166.7690-257.9090

BKKS1-2 Soil samples of Bokkos for 3 points

From table 4.2 the activity of concentration of K-40 is distinctly higher than those of Ra-226 and Th-232 in $BKKS_1$ and $BKKS_2$ with activities 109.1750± 8.71 and 106.3760± 2.02 respectively. BKK_3 has the least value of concentration activity of K-40 as 42.4572±9.02Bq/kg. The activity concentration of K-40ranges from 109.1750± 8.71 to 45702±9.02Bq/kg with mean activity of 86.0027±6.58. The activity of Ra-226 ranges between 73.001± 4.40 to 46.3500±1.18 Bq/kg with mean activity of 61.104 ± 4.37 Bq/kg. The activity of Th-232 ranges from 87.571± 3.31 to 51.311 ± 4.78 Bq/kg with mean activity of 63.8160±7.53Bq/kg.

4.1.3 Results Showing the Activity concentrations of the Soil Samples Collected at the in Jos south L.G.A Sites

Table 4.3 presents the specific activity concentration of K-40, Ra-226 and Th-232 in the soil samples collected at Jos southL.G.A.(Bq/kg).

Table 4. 3:The Activity of Soil Sample collected from Jos -South LG.A.

S/No	Sample ID	K-40 (Bq/kg)	Ra-226 (Bq/kg)	Th-232 (Bq/kg)	TOTAL(Bq/kg)
1	JJSS1	116.7960±9.80	75.319±4.17	61.5730±2.39	253.6880±16.36
2	JJSS2	122.2390±8.40	97.6820±4.98	60.2050±1.94	280.1260±15.32
3	JJSS3	110.1090±6.69	53.3020±5.33	64.4080±1.93	227.8190±13.95
Mean	-	116.3813±8.30	75.4343±4.83	62.0620±2.87	253.8777±15.21
Range	-	110.1090-116.7960	53.3020-97.6820	60.2050-64.4080	227.8190-280.1260

JJS1-3 soil samples of Jos south for 3 points

From table 4.3 the radioactivity concentration ofK-40 is higher than the Ra-226 and Th-232 and it ranges from 122.2390± 8 40 to 110.1090± 6.69 Bq/kg with mean activity of 116.3813± 8.30Bq/kg. Ra-226 has activity ranging from 97.682 ± 4.98 to 53.3010± 5.33 Bq/kg with means value of 75.4343±4.83Bq/kg. The activity concentration of Th-232 ranges between 64.4080±1.93 to 60.2050±1.94Bq/kgwith mean activity of 62 0620± 2.87Bq/kg

4.1.4 Mean Specific Distribution of Radioactivity in soil samples from the three L.G.As

Fig. 4.1 presents the bar chart of the mean activity concentration of k-40, Ra-226 and Th-232 as determined by the Gamma-ray spectrometry analysis from the three LGAs of the collected soil samples

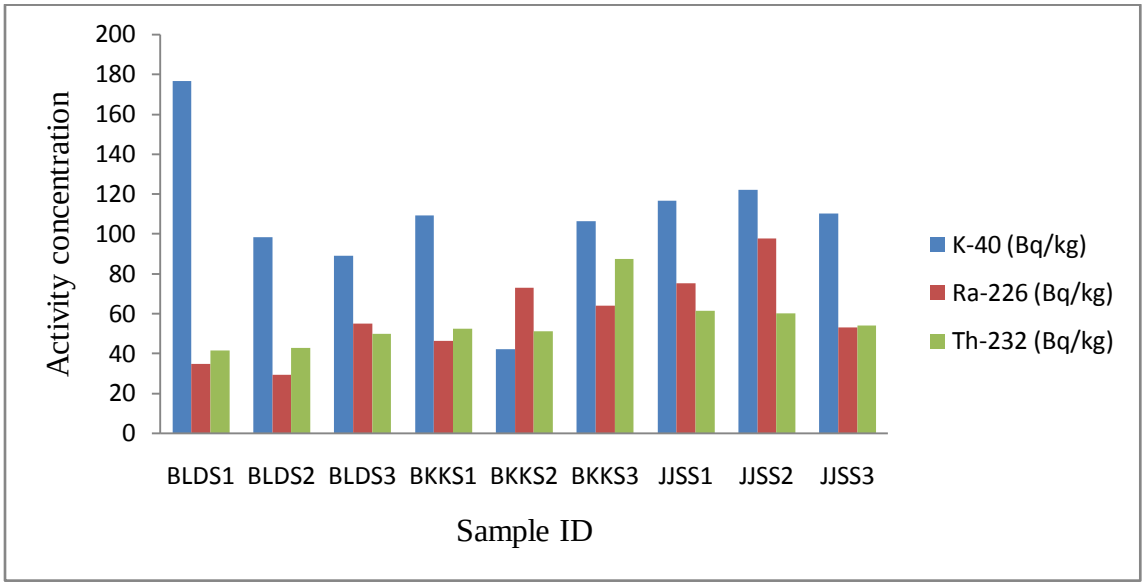


Figure 4. 1: Activity Concentration of K-40, Ra-226 and Th-232 of soils

It is observed that potassium -40 has a relatively higher concentration ranging from a mean value of 176.5163± 9.02 to 42.4573±9.02 Bq/kg in all the LGA. Radium -226 is next in activity concentration ranging from 97.6825± 4.98 to 34.9942± 2.67 Bq/kg. The least activity is recorded from thorium -236 with value ranging between 87.571 ± 3.31 to 41.7332± 2.96Bq/kg.

4.2 Absorbed Dose Rate, Effective Does Rate, Radium Equivalent and Radiological Indices of the soil samples

The calculated values of these radiological parameters were based on guidance provided by (UNSCEAR, 2000). The absorbed close rates due to gamma rays in air at 1m above the ground surface for activity concentration of Ra-226, Th-232 and K-40 in the soil samples were obtained using equation 3.4. The effective dose rates of the soil samples were obtained using equation 3.5. Equation 3.6 was used to obtain the Radium equivalent of the samples. In order to calculate the radiation hazard indices, equation 3.8 was used for external hazard and equation 3.9 for internal hazard indices.

4.2.1 Result of Absorbed Dose Rate, Effective Does Rate, Radium Equivalent and Radiological Indices of the soil samples in Barikin Ladi LGA

Table 4.5 presents the values of the calculated absorbed dose rate. Annual effective dose rate, radius equivalent, external and internal hazard indices for the soil samples obtained from Barikin Ladi L.G.As farmlands.

Table 4. 4:Absorbed Dose Rates and Hazard Indices of Soil in Barikin Ladi (BLDS) LGA

S/No.	SAMPLE CODE	Absorbed DoseRate ($nGyh^{-1}$)	Effective Dose Rate (μSvy^{-1})	Radium Equivalent R_{eq}(Bq/kg)	Radiological Indices External Hazard (H_{ex})	Internal Hazard (H_{in})
1	BLDS1	49.4444	60.6806	108.2644	0.47824	1.0979
2	BLDS2	44.4624	54.5664	98.6356	0.2667	0.6539
3	BLDS3	60.2302	73.9175	133.4838	0.2431	0.7046
	Min	44.46234	54.5664	98.6356	0.2431	0.6539
	Max	60.2302	73.9175	133.4838	0.47824	1.0979
	Mean	51.3790	63.0548	113.4613	0.3293	0.8188

The absorbed dose rate calculated values ranges from 44.4624 to 60,2302nGy/h with mean value of 51.3790 nGy/h (table 4.4). The annual effective dose rate ranges from 54.5664 to 73.9175μSv/ywith mean value of 63.0548μSv/ywhile the radium equivalent ranges from 98.6356 to 133.4838 Bqkg.$^{-1}$with mean value of 113.4613Bqkg.$^{-1}$.

The values of external and internal hazard indices range from 0.2431 to 0.4782 with mean value of 0.3293and 0.6539 to 1.0979 with mean value of 0.8188respectively. The mean values of H_{ex} and $H_{in}$of the soil from Brikin-Ladi are; 0.3293 and 0.8188 respectively which represents the risk associated from the exposure of the radionuclide ($K^{-}40$, Ra-226 and Th-232) to the soil sample.

4.2.2Result of Absorbed Dose Rate, Effective Does Rate, Radium Equivalent and Radiological Indices of the soil samples from Bokkos LGA

The absorbed dose rate effective dose rate, Radium equivalent external hazard and internal hazard and for K,-40 Ra –226and h-232 from soil sample of Bokkos L.G.A. were calculated are represented in table 4.6.

Table 4. 5:Absorbed Dose Rates and Hazard Indices of Soil in Bokkos (BKK) LGA.

SAMPLE No	SAMPLE CODE	Absorbed dose Rate ($nGyh^{-1}$)	Effective Dose Rate (μSvy^{-1})	Radium Equivalent R_{eq}(Bq/kg)	Radiological Indices	
					External Hazard (H_{ex})	Internal Hazard (H_{in})
1	BKKS1	58.6098	71.9289	129.9259	0.4850	0.7800
2	BKKS2	67.3610	82.6689	149.6449	0.4073	0.5220
3	BKKS3	88.3679	108.4495	197.3795	0.5527	0.8402
	Min	58.6098	71.9289	129.9259	0.4073	0.5220
	Max	88.3679	108.4495	197.3795	0.5527	0.8402
	Mean	71.4463	87.6824	158.9834	0.4816	0.7141

The calculated values of absorbed dose rate for the activity of the samples range from 88.3679 to 58.6098 to $nGyh^{-1}$ with mean value of 71.4463$nGyh^{-1}$(table 4.5). The value of annual effective dose rate ranged from 108.4495 to 71.9289 μSv/ywith mean value of 87.6824μSv/y. The Radium equivalent activity ranged from 129.9259 to 197.3795 Bq/kg with mean value of 158.9834Bq/kg.

The values of external (H_{ex}) and internal (H_{in}) hazard indices are (Min of 0.4073, Max of 0.5527 and Mean of 0.4816) and (Min of 0.5220, Max of 0.84017 and Mean of 0.2141) respectively.

4.2.3 Result of Absorbed Dose Rate, Effective Does Rate, Radium Equivalent and Radiological Indices of the soil samples in Jos south LGA

Table 4.6 presents the results determined absorbed dose rate, annual effective dose rate, equivalent activity and radiological hazard indices [external (H_{ex}) and internal (H_{in})] for the activity, measured of soil samples in Jos South L.G.

Table 4. 6:Absorbed Dose Rates and Hazard Indices of Soil In Jos South (JJS) LGA

SAMPLE No.	SAMPLE CODE	Absorbed Dose Rate ($nGyh^{-1}$)	Effective Dose Rate (μSvy^{-1})	Radium Equivalent R_{eq}(Bq/kg)	Radiological Indices	
					External Hazard (H_{ex})	Internal Hazard (H_{in})
1	JJSS1	77.9046	95.6084	172.3617	0.6193	0.9349
2	JJSS2	87.6138	107.5240	193.1876	0.7200	1.0504
3	JJSS3	69.2144	84.9434	153.8838	0.5168	0.8144
	Min	69.214	84.9434	153.8838	0.5168	0.8144
	Max	87.6138	107.5240	193.1876	0.7200	1.0504
	Mean	78.2443	96.0253	173.1444	0.6187	0.9332

It can be inferred (table 4.6) from the result that the calculated values of absorbed dose rate ranged from Maximumof 87.6138nGy/hr to Minimum of 69.211 with Mean value of 78.2443nGyh^{-1}. The annual effective dose rate ranged from maximum value of 107.5240 to Min of 84.9434μSvy^{-1}with mean of 96.0253 μSvy^{-1}. The Radium equivalent has Maximum value of 193.1876 Bqkg^{-1} Minimum value of 153.8838 Bqkg^{-1} and Mean value of 173.1444 Bqkg^{-1}.

The external (H_{ex}) and internal (H_{in}) has (min of 0.5168, Max of 0.7200 and Mean of 0.6187) and (Min of 0.8144, Max of 1.0542 and Mean of 0.9332) respectively.

4.3 Results of Radioactivity and Cancer Risk of Dry and Rainy Season Vegetables

The principle of radiation protection is outlined in the recommendations of ICRP publications 26 of 1977 with the emerging differentiations between the two types of effects which may be induced by ionizing radiations. The aim of radiation protection is to be able to prevent the detrimental non-stochastic effect of radiation and limit the probability of stochastic effects (Alan and Samuel, 1986)

Intake of radionuclide into the body will commit the target organ (or organs) or the whole body at risk from the radionuclide to a certain dose; the committed dose. The committed effective dose is the dose accumulated over 50 years representing the likely maximum lifespan of the individual following the intake. (Alan and Samuel, 1986)

Table 4. 7:Determined Activity concentrations and average annual committed effective doses of ^{40}K, ^{226}Ra and ^{232}Th in the cabbage dry season vegetables samples

Sample ID	K-40 (Bq/kg)	Ra-226 (Bq/kg)	Th-232 (Bq/kg)	E_{ave} mSv/yr
CABBKK	190.6687±3.42	17.7288±0.58	34.6633±1.03	0.2509±0.01
CAB JJS	605.7543±9.02	45.6547±4.28	21.77879±0.23	0.2611±0,01
CABBLD	552.8771±7.46	19.3047±4.75	15.2794±1.14	0.1945±0.01
Mean	449.7665±6.63	27.56278±3.20	23.9073±0.80	0.2355±0.01

CABBKK means cabbage of Bokkos

CAB JJS means cabbage of Jos south

CABBLD means cabbage of Barikin-Ladi

From the determined Activity concentrations and average annual committed effective doses of ^{40}K, ^{226}Ra and ^{232}Th in the cabbage dry season vegetables samples in table 4.7, it could be observed that thehighest radioactivity concentration was recorded from K-40 (605.7543±9.02Bq/kg) (CABJJS) cabbage of Jos south and the least was recorded from Th-323 (15.2794±1.14Bq/kg) (CABBLD) of the cabbage of Barikin-Ladi

The average annual committed effective dose of the cabbage samples from the study area determined was 0.2355±0.01mSv/y. The committed effective dose of a referenced man of 50years life time expectancy will be 0.2355x50 = 11.7750 mSv.

Cancer risk for the internal exposures of the NORMS = committed effective dose x risk factor

∴ Cancer risk= 11.7750 x 0.05 = 5.9 x 10^{-4}

This value is small compared with the total risk of 6.0 x 10^{-3} from all natural radiation sources based on global average annual radiation dose of 2.4 mSv/year to man.

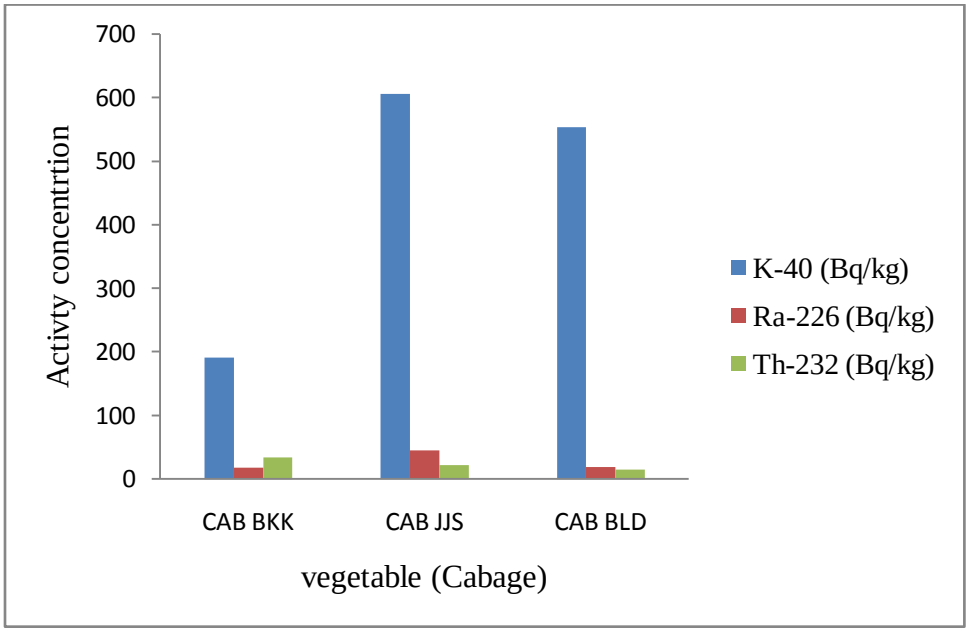


Figure 4. 2: Activity concentrations of K-40, Ra-226, and Th -232 for cabbage samples collected at dry season farming from the 3 LGA

It could be observed from figure 4.2 that the cabbage samples are rich in K-40 and very minimal of Ra-226 and Th-232. It indicated thatthe farming exercise involves the application of agrochemical fertilizers like NPK. This vegetable can be recommended for consumption especially where K-40 is required.

Table 4. 8:Determined Activity concentrations and average annual committed effective doses of ^{40}K, ^{226}Ra and ^{232}Th in the carrot vegetables samples of dry season

Sample ID	K-40 (Bq/kg)	Ra-226 (Bq/kg)	Th-232 (Bq/kg)	E_{ave} mSv/yr
CARBKK	258.1549±9.48	20.8575±1.62	29.8746±0.11	0.2354±0.00
CAR JJS	377.1384±2.48	11.3557±1.16	12.7708±0.11	0.1454±0.00
CARBLD	199.5334±5.44	62.3407±6.26	49.0308±1.05	0.3708±0.01
Mean	278.2756±5.8	31.518±3.01	30.5587±0.42	0.2505±0.01

CARBKK means carrot of Bokkos

CAR JJS means carrot of Jos south

CARBLD means carrot of Barikin-Ladi

From the determined Activity concentrations and average annual committed effective doses of ^{40}K, ^{226}Ra and ^{232}Th in the carrot vegetables samples of dry season in table 4.8, it could be observed that the highest radioactivity concentration was recorded from K-40 (377.1385±2.48 Bq/kg) (CARJJS) carrot of Jos south and the least was recorded from Ra-226 (11.3557±1.16 Bq/kg) (CARJJS) of the same of carrot of Jos-south

The determined average annual committed effective dose of the carrot samples from the study sites was 0.2505±0.01mSv/y.

The committed effective dose of a referenced man of 50years life time expectancy will be 0.2505 x 50 = 12.5250 mSv.

Cancer risk for the internal exposures of the NORMS = committed effective dose x risk factor

$\therefore$ Cancer risk = 12.5250 x 0.05 = 6.3×10^{-4}

This value is small compared with the total risk of 6.0×10^{-3} from all natural radiation sources based on global average annual radiation dose of 2.4 mSv/year to man

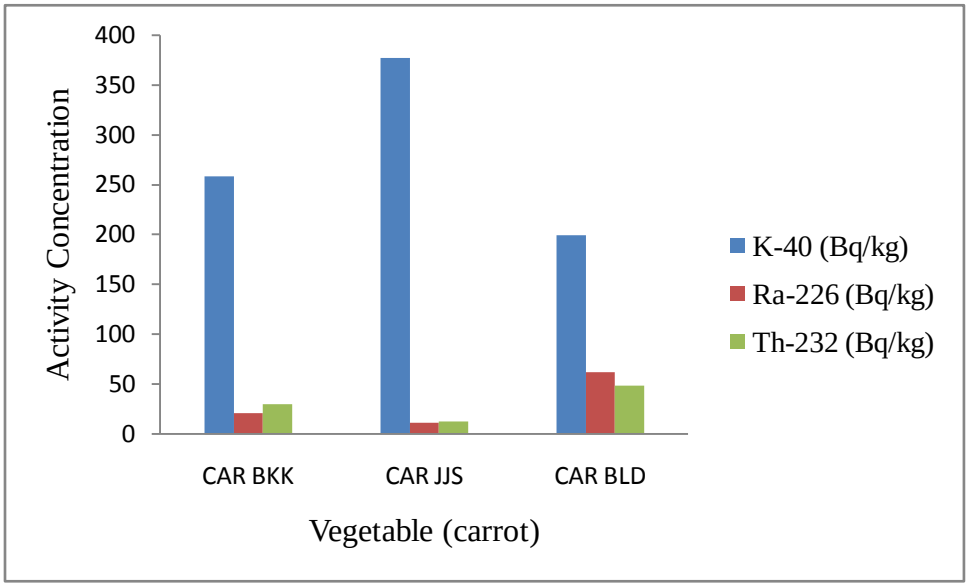


Figure 4. 3: Activity concentrations of K-40, Ra-226 and Th-232 for Carrot samples collected at dry season farming from the 3 LGA

It could be observed from figure 4.3 that the carrot samples are rich in K-40 and very minimal of Ra-226 and Th-232. It indicated thatthe farming exercise involved the application of agrochemical fertilizers like NPK. This vegetable can be recommended for consumption especially where K-40 is required.

Table 4. 9:Determined Activity concentrations and average annual committed effective doses of ^{40}K, ^{226}Ra and ^{232}Th in the potatoes vegetables samples of dry season

Sample ID	K-40 (Bq/kg)	Ra-226 (Bq/kg)	Th-232 (Bq/kg)	E_{ave} mSv/yr
POTBKK	411.5086±2.33	41.4832±10.89	17.4458±0.91	0.2009±0.01
POTJJS	266.563±8.7	21.9004±6.49	15.05131±2.05	0.1489±0.02
POTBLD	393.0016±6.22	34.299±3.48	11.0604±0.34	0.1545±0.01
Mean	357.0244±5.75	32.5608±6.95	14.5192±1.10	0.1681±0.01

POTBKK means potatoes of Bokkos

POTJJS means potatoes of Jos South

POTBLD means potatoes of Barikin-Ladi

From Table 4.9, the determined Activity concentrations and average annual committed effective doses of ^{40}K, ^{226}Ra and ^{232}Th in the potatoes vegetables samples of dry season, it could be observed that the highest radioactivity concentration was recorded from K-40 (393.0016±6.22 Bq/kg) (POTBLD) potatoes of Barikin-Ladi and the least was recorded from Th-232 (11.0604±0.34 Bq/kg) (POTBLD) of the same Potatoes of Bariki-Ladi

The determined average annual committed effective dose of the potatoes samples from the study sites was 0.16815±0.01mSv/y.

The committed effective dose of a referenced man of 50years life time expectancy will be 0.1681 x 50 = 8.4050 mSv.

Cancer risk for the internal exposures of the NORMS = committed effective dose x risk factor

$\therefore$ Cancer risk = 8.4050 x 0.05 = 4.2 x 10^{-4}

This value is small compared with the total risk of 6.0 x 10^{-3} from all natural radiation sources based on global average annual radiation dose of 2.4 mSv/year to man

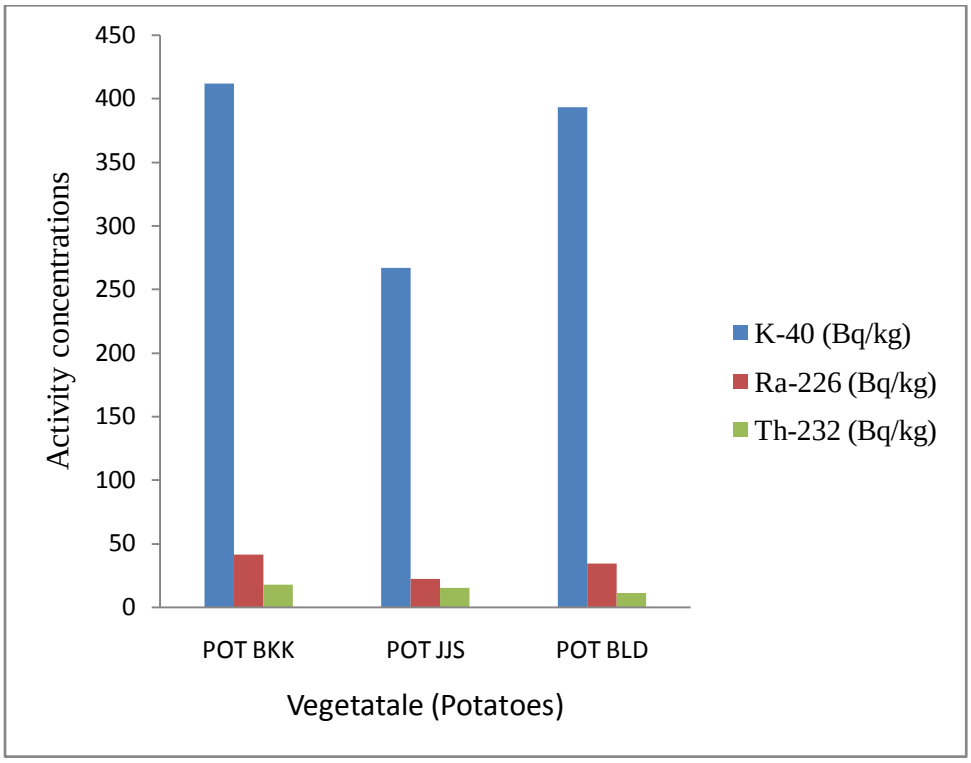


Figure 4. 4: Activity concentrations of K-40, Ra-226 and Th-232 for Potatoes collected during the dry season farming from the 3 LGA

It could be observed from figure 4.4 that the potatoes samples are rich in K-40 and very minimal of Ra-226 and Th-232. It indicated thatthe farming exercise involved the application of agrochemical fertilizers like NPK. This vegetable can be recommended for consumption especially where K-40 is required.

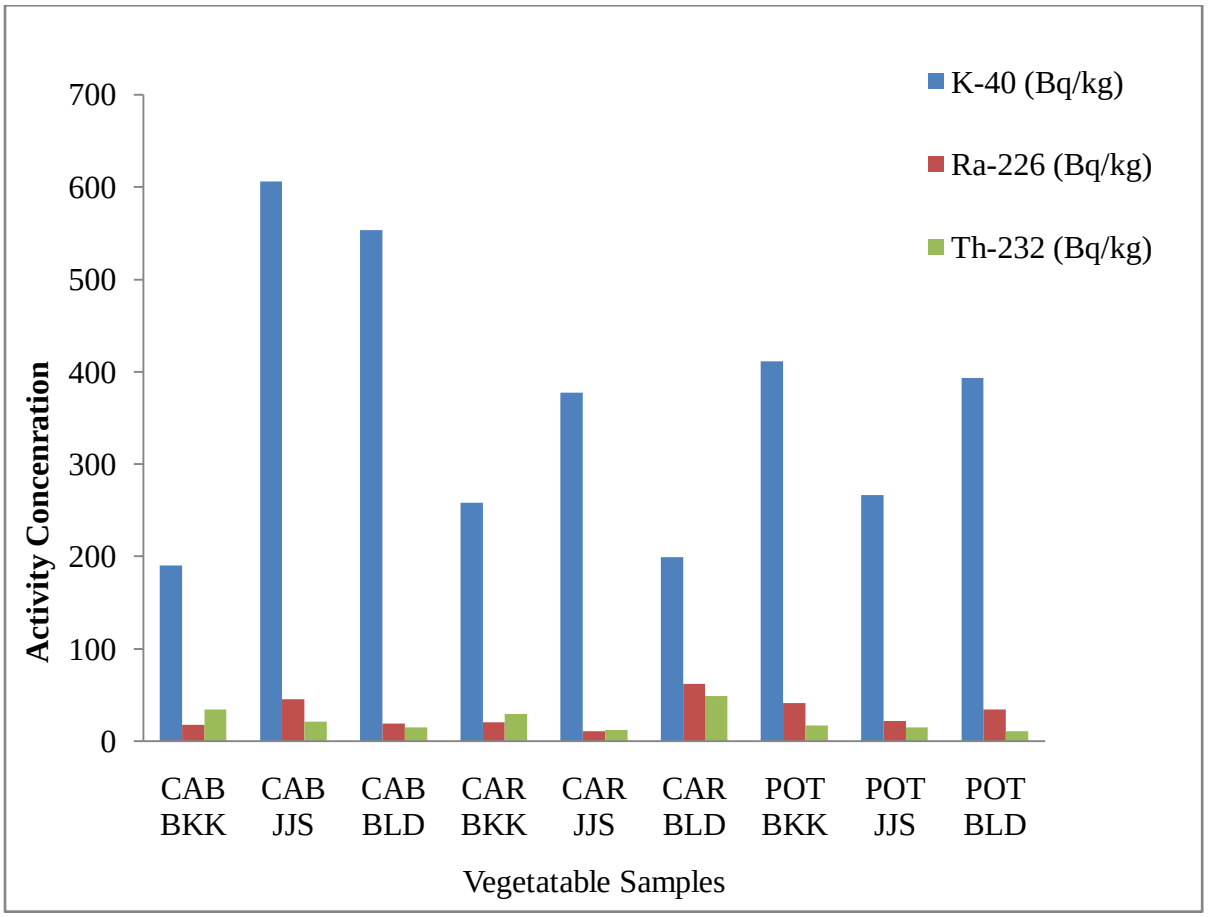


Figure 4. 5: Activity Concentrations of K-40, Ra-226 and Th-232 of Vegetables samples collected from Dry season farming.

It is observed that, from the results obtained in the whole dry season vegetable samples, activity concentration of Potassium-40 is the highest, followed by Radium -226 and the least is Thorium -236. The activity of K-40 ranges from 190.6687 ± 3.42 to 605.753 Bq/kg, Ra-226 ranges from 11.357 ± 1.16 to 62.3407 ± 6.26 $Bqkg^{-1}$ while the activity concentration of Th-232 ranges from 12.7708 ± 0.11 to 49.0308 ± 1.05$Bqkg^{-1}$.

Table 4. 10:Determined Activity concentrations and average annual committed effective doses of ^{40}K, ^{226}Ra and ^{232}Th in the cabbage vegetables samples rainy season*

Sample ID	K-40 (Bq/kg)	Ra-226 (Bq/kg)	Th-232 (Bq/kg)	E_{ave} mSv/yr
CABBKK*	161.4308±6.69	24.6813±2.32	39.6807±2.72	0.2813±0.02
CAB JJS*	81.4930±5.13	27.1147±2.55	41.8472±1.60	0.2831±0.01
CABBLD*	177.2939±5.91	38.4705±3.59	50.3991±4.79	0.3580±0.03
Mean	140.0726±5.91	30.0888±2.82	43.9757±3.04	0.3075±0.02

CABBKK* means cabbage of Bokkos

CAB JJS* means cabbage of Jos south

CABBLD* means cabbage of Barikin-Ladi

From the determined Activity concentrations and average annual committed effective doses of ^{40}K, ^{226}Ra and ^{232}Th in the cabbage vegetables samples rainy season in Table 4.10, it could be observed that the highest radioactivity concentration of the rain fed cabbage was recorded from K-40 (177.2939±5.91 Bq/kg) (CABBLD) cabbage of Barikin-Ladi and the least was recorded from Ra-226 (24.6813±2.32 Bq/kg) (CABBKK) of the Cabbage of Bokkos

The determined average annual committed effective dose of the cabbage samples from the study sites was 0.3075±0.02 mSv/y.

The committed effective dose of a referenced man of 50years life time expectancy will be 0.3075 x 50 = 15.3750 mSv.

Cancer risk for the internal exposures of the NORMS = committed effective dose x risk factor

$\therefore$ Cancer risk = $15.370 \times 0.05 = 7.7 \times 10^{-4}$

This value is relatively small and within the same range when compared with the total risk of 6.0×10^{-3} from all natural radiation sources based on global average annual radiation dose of 2.4 mSv/year to man

The relative high value of the cancer risk is due to the annual consumption rate of the vegetables (26kg/annum) considered

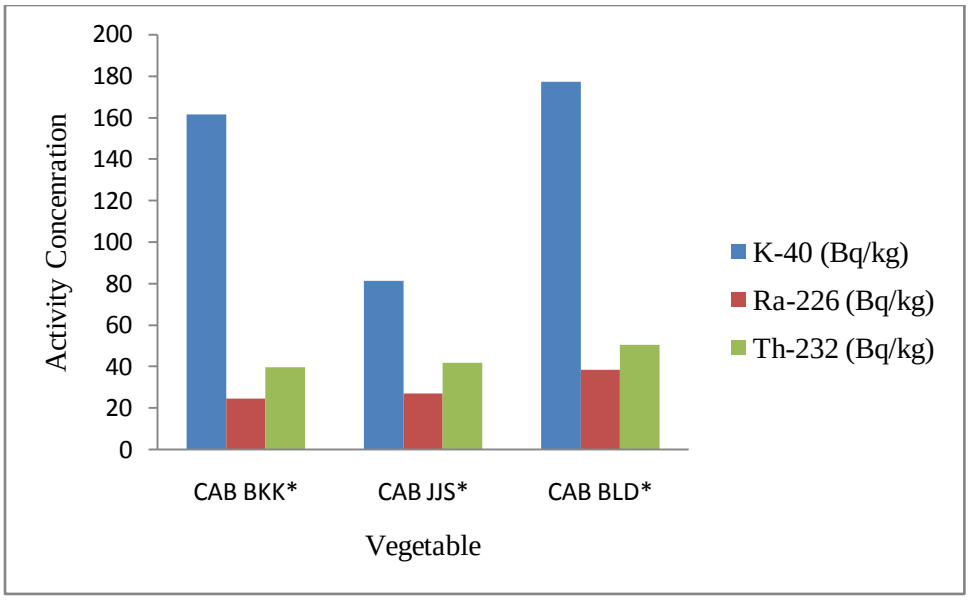


Figure 4. 6: Activity concentrations K-40, Ra-226 and Th-232 of cabbage sample collected during the rainy season farming from the 3 LGA

It could be observed from figure 4.6 that the cabbage samples have relatively high activity in K-40 and slightly elevated or increase of Ra-226 and Th-232. It indicated thatthe farming exercise involved the application of agrochemical fertilizers like NPK. This is an indication that the vegetables are grown around mining zones with soil enriched with NORMS

Table 4. 11:Determined Activity concentrations and average annual committed effective doses of ^{40}K, ^{226}Ra and ^{232}Th in the carrot vegetables samples of rainy season*

Sample ID	K-40 (Bq/kg)	Ra-226 (Bq/kg)	Th-232 (Bq/kg)	E_{ave} mSv/yr
CARBKK*	102.7994±6.53	51.2167±3.70	48.4607±3.42	0.3437±0.02
CAR JJS*	41.3686±4.20	53.6501±3.36	60.6614±3.53	0.4085±0.02
CARBLD*	89.7356±2.18	61.6454±5.10	74.3443±2.51	0.5039±0.02
Mean	77.9679±4.30	55.5041±4.05	61.1555±3.15	0.4187±0.02

CARBKK* means carrot of Bokkos

CAR JJS* means carrot of Jos south

CARBLD* means carrot of Barikin-Ladi

From the determined activity concentrations and average annual committed effective doses of ^{40}K, ^{226}Ra and ^{232}Th in the carrot vegetables samples of rainy season of table 4.11, it was observed that the highest radioactivity concentration of the rain fed carrot was recorded from K-40 (102.7994±6.53Bq/kg) (CARBKK) carrot of Bokkos and the least was recorded from Ra-226 (51.2167±3.70 Bq/kg) (CABBKK) of the same Carrot of Bokkos

The determined average annual committed effective dose of the cabbage samples from the study sites was 0.4187±0.02 mSv/y.

The committed effective dose of a referenced man of 50years life time expectancy will be 0.4187 x 50 = 20.9343 mSv.

Cancer risk for the internal exposures of the NORMS = committed effective dose x risk factor

$\therefore$ Cancer risk = 20.9343 x 0.05 = 1.05 x 10^{-3}

This value is relatively small but within the same range when compared with the total risk of 6.0 x 10^{-3} from all natural radiation sources based on global average annual radiation dose of 2.4 mSv/year to man

The relative high value of the cancer risk is due to the annual consumption rate of the vegetables (26kg/annum) considered

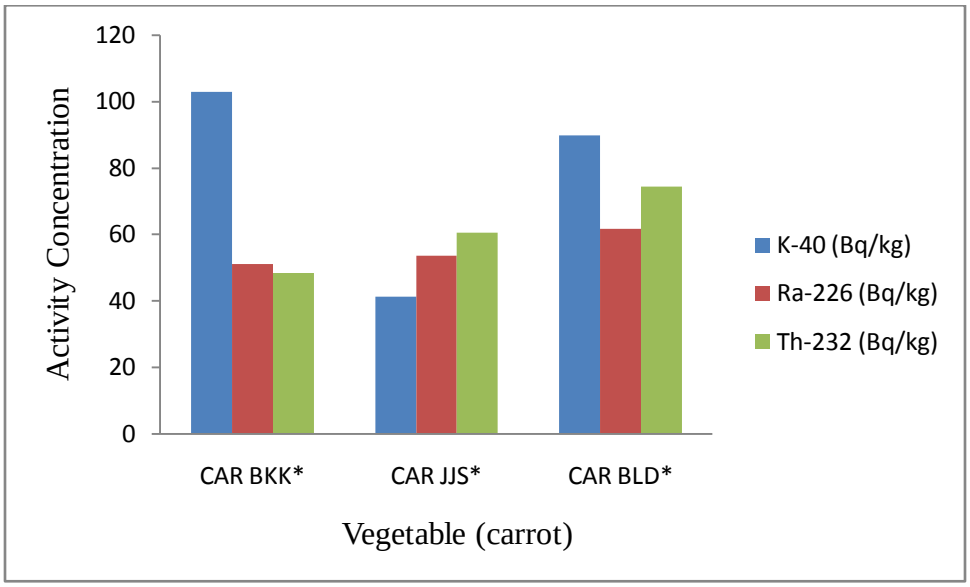


Figure 4. 7: Activity concentrations K-40, Ra-226 and Th-232 of carrot sample collected during the rainy season farming from the 3 LGA

It could be observed from figure 4.7 that the carrot samples have relatively high activity concentration in K-40 and slightly elevated or increase of Ra-226 and Th-232. It indicated thatthe farming exercise also involved the application of agrochemical fertilizers like NPK. The result is an indication that the vegetables are grown around mining zones with soil enriched with NORMS

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Table 4. 12:Determined Activity concentrations and average annual committed effective doses of ^{40}K, ^{226}Ra and ^{232}Th in the potatoes vegetables samples of rainy season*

Sample ID	K-40 (Bq/kg)	Ra-226 (Bq/kg)	Th-232 (Bq/kg)	E_{ave} mSv/yr
POTBKK*	74.9611±5.91	32.9085±4.05	48.1186±1.37	0.3238±0.01
POT JJS*	96.5785±3.42	29.4322±3.24	83.2383±2.85	0.5348±0.02
POTBLD*	94.5568±1.23	35.1101±1.23	54.732±1.25	0.3681±0.01
Mean	88.6988±3.52	32.4836±2.84	62.029±61.82	0.4089±0.37

POTBKK* means potatoes of Bokkos

POTJJS* means potatoes of Jos South

POTBLD* means potatoes of Barikin-Ladi

From table 4.12; the determined Activity concentrations and average annual committed effective doses of ^{40}K, ^{226}Ra and ^{232}Th in the potatoes vegetables samples of rainy season, it could be observed that the highest radioactivity concentration of the rain fed carrot was recorded from K-40 (96.5785±3.42Bq/kg) (POTJJS) potatoes of Bokkos and the least was recorded from Ra-226 (29.4322±3.24 Bq/kg) (POTBKK) of the potatoes of Bokkos

The determined average annual committed effective dose of the cabbage samples from the study sites was 0.4089±0.02 mSv/y.

The committed effective dose of a referenced man of 50 years life time expectancy will be 0.4089 x 50 = 20.4442 mSv.

Cancer risk for the internal exposures of the NORMS = committed effective dose x risk factor

∴Cancer risk = 20.9343 x 0.05 = 1.02 x 10^{-3}

This value is relatively small compared with the total risk of 6.0 x 10^{-3} from all natural radiation sources based on global average annual radiation dose of 2.4 mSv/year to man

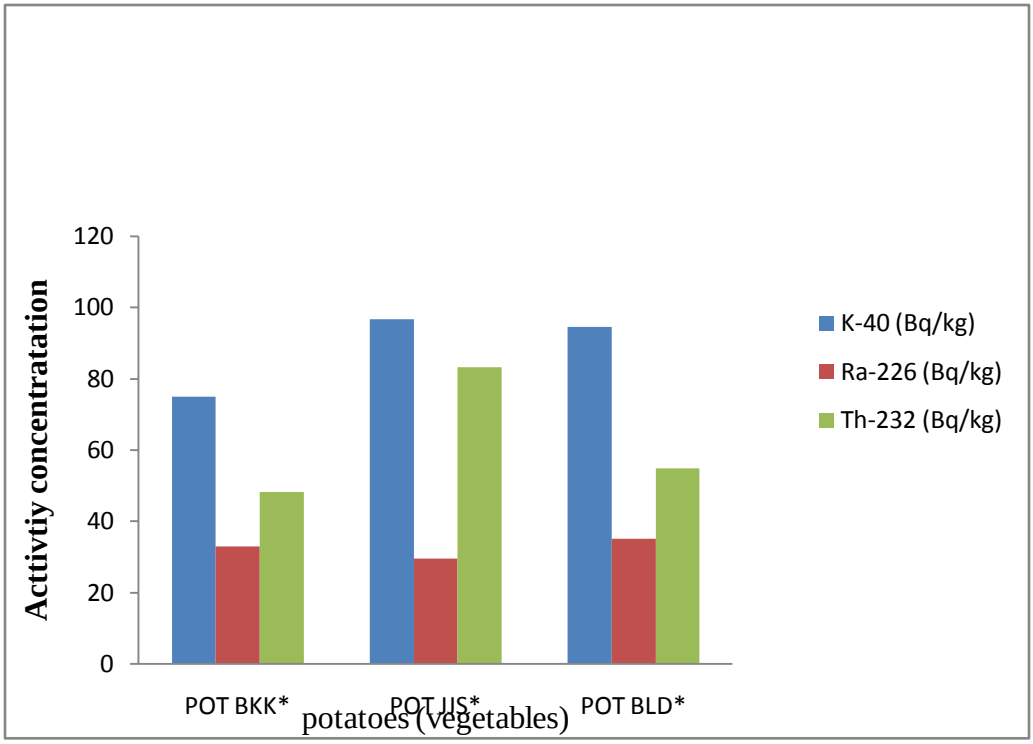


Figure 4. 8: Activity concentrations K-40, Ra-226 and Th-232 of Potatoes sample collected during the rainy season farming from the 3 LGA

It could be observed from figure 4.8 that the potatoes samples have relatively high activity concentration in K-40 and slightly elevated or increase of Ra-226 and Th-232. It indicated thatthe farming exercise also involved the application of agrochemical fertilizers like NPK. The result is an indication that the vegetables are grown around mining zones with soil enriched with NORMS

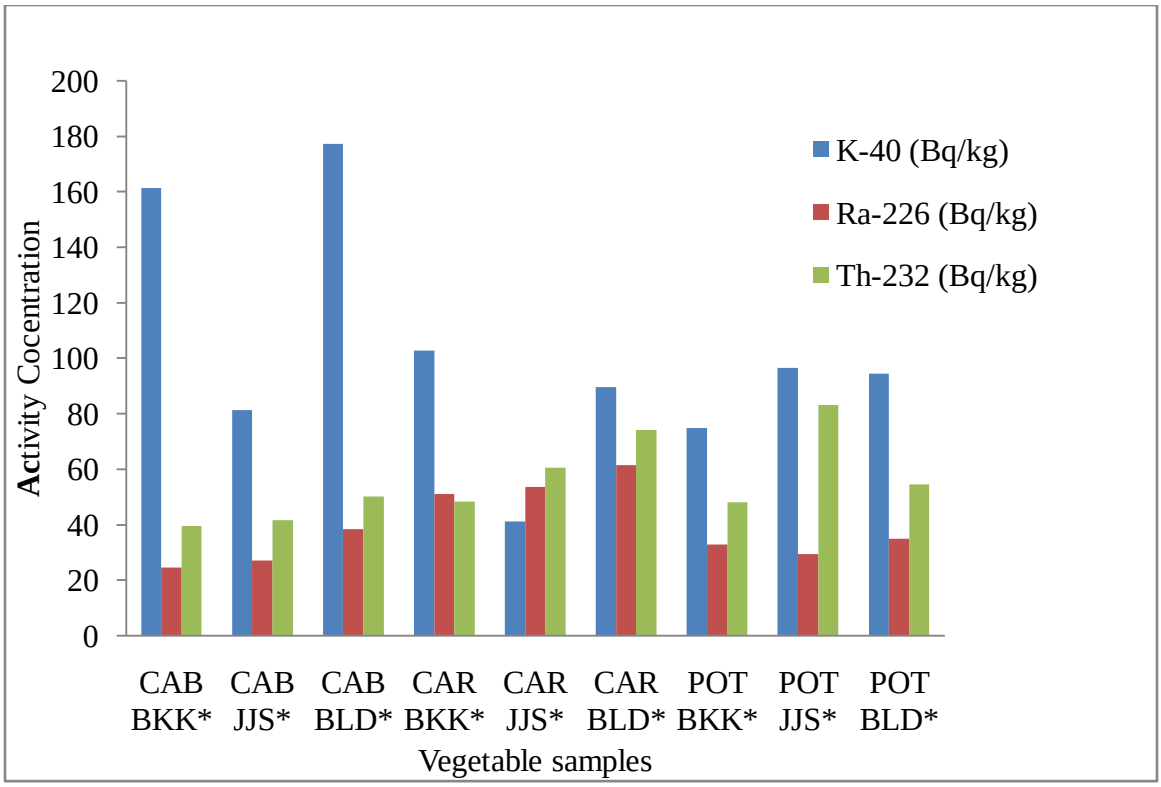


Figure 4. 9: Activity Concentrations of K-40, Ra-226 and Th-232 of Vegetables samples collected from Dry season farming.

It could be observed that the results obtained (figure 4.9) in the rainy season vegetable samples, the activity concentration of Potassium-40 (ranging from 41.3686 ± 4.20 to 177.2939 ± 5.91 Bqkg^{-1}) is relatively higher, followed by Thorium -236 (ranging from 29.6807 ± 2.74 to 83.238 ± 2.85 Bqkg^{-1}) and the least Radium -226 (ranging from 24.1150 ± 2.55 to 61.6454 ± 5.10 Bq/kg)

4.4 INAA results

4.4.1 Essential and non-essential elements identified in the samples

A total of 34 (for soil) and 25 (for vegetables) elements of interest were identified with the Nigeria research reactor-1 (NRR-1) after the usage of all the 4 irradiation schemes. The elements identified includes Mg, Al, Cl, Ca, V, Se,Mn, Sr, Na, K, La, Sm, U, Sc, Cr, Fe, Co, Zn, Br, Rb, Sb, Eu, Tb,Yb and Th. They were also found to be at various concentrations as computed from the WINSPAN 2004 sheet spectrum of the elements. The area under the spectral graph of each element is directly proportional to the concentration of the elements at the specific energy (in MeV) of irradiation. The main essential elements needed in man's diet Na, K, Ca, Mg and CI were detected in all the vegetables samples. Phosphorus and sulphur were however not detected in all the samples (soil and vegetable). Minor essential elements that are required in man's food in concentrations less than 50mg/day such as Fe, Zn, and Mn, were also detected in all the samples after using all the channels. Also ultra-trace non-essential elements such as Al, As, Br, Sm, were detected in some of the samples also at various ranges. Other such as Bi, B, Ge, Hg, Li, Pb, Sn, Tl, and W were not detected in all the samples. This observation was expected because in the same raw food material content can fluctuate greatly depending on genetic, climate factors, agricultural procedures, and composition of soil and ripeness of the harvested crops among other factors (Belitz et al., 2004)

4.4.2 Description ofNAA data analysis

Some statistical tools were used in order to interpret the results, these include:

i) Regrouping, this is used to rearrange the data for proper interpretation and calculations

ii) Statistical range, correlation t-test were used for inference, showing relationship and proper test of significant levels.

iii) Equation 3.11 was used to determine the Daily intake of elements (DIM)

iv) Equation 3.12 was used to determine the Health Risk index (H_Q)

v) Equation 3.13 was used to determine the soil element transfer ration (T_f)

4.4.3 Results of NAA Elemental Concentration of the Soil

Table 4. 13: Mean Elemental Concentration of Soil from the Tree LGA in ppm

Elements	Barikin-Ladi	Bokkos	Jos south	AVERAGE
Mg	6532.67±621.00	9253.00±820.50	7362.50±919.00	7716.06±786.83
Al	5356.33±159.67	50120.67±519.67	29406.67±549.33	28294.56±409.56
Ca	36649.33±2056.67	74140.00±1803.50	62200.00±3121.00	57663.11±2327.06
Ti	BDL	4163.67±439.33	5507.00±338.00	4835.33±259.11
V	7.00±2.00	101.67±4.67	51.33±4.00	53.33±3.56
Mn	352.67±2.00	667.33±2.33	885.33±3.00	635.11±2.44
Dy	BDL	3.10±0.43	7.60±0.40	5.35±0.28
Na	152.43±1.13	576.67±2.67	552.33±3.33	427.14±2.38
K	9637.00±92.67	10563.33±148.33	3530952.67±212.00	1183717.67±151.00
As	5.20±0.20	3.50±0.07	4.73±0.25	4.48±0.17
Br	0.82±0.02	0.67±0.03	0.57±0.03	0.69±0.03
Cd	BDL	BDL	BDL	BDL
La	30.36±0.08	33.30±0.17	50.87±0.20	38.18±0.15
Sm	3.21±0.02	5.18±0.02	6.72±0.03	5.04±0.02
Ho	7.30±0.30	2.50±0.20	3.67±0.23	4.49±0.24
U	13.90±0.20	5.60±0.20	8.33±0.20	9.28±0.20
Sc	1.97±0.04	5.58±0.07	9.50±0.10	5.68±0.07
Cr	58.00±3.00	264.00±10.67	82.67±3.33	134.89±5.67
Fe	12095.67±155.67	23604.33±248.67	42740.00±380.33	26146.67±261.56
Co	4.10±0.27	10.30±0.30	7.83±0.33	7.41±0.30
Zn	41.67±5.00	99.00±7.00	128.50±11.00	89.72±7.67
Rb	64.21±3.02	104.33±5.00	61.67±6.00	76.74±4.67
Sb	BDL	3.80±0.70	4.33±1.00	4.07±0.57
Cs	3.39±0.32	3.70±0.30	3.37±0.50	3.49±0.37
Ba	72.50±19.50	213.00±29.00	202.33±34.67	162.61±27.72
Nd	954.00±4.00	51.50±2.00	59.67±4.00	355.06±3.33
Eu	1.20±0.20	0.80±0.10	1.27±0.17	1.09±0.16
Tb	2.10±1.00	1.20±0.07	1.10±0.13	1.47±0.40
Tm	11.00±1.00	5.65±0.50	17.97±0.67	11.54±0.72
Yb	7.30±0.08	5.05±0.10	6.93±0.23	6.43±0.14
Lu	1.69±0.01	0.53±0.02	28.84±0.03	10.35±0.02
Hf	BDL	18.50±0.20	29.83±0.40	24.17±0.20
Ta	281.00±1.00	9.93±0.23	60.13±0.57	117.02±0.60
Th	0.25±0.07	20.40±0.23	27.77±0.30	16.14±0.20

BDL→ below Detection Limits

From table 4.13 it could be seen that the mean Elemental Concentration of some metals from the soil obtained from each of thethree LGA **in** mg/kg were high. For Barikin-Ladi**,** Bokkos**,** Jos south the values were: Ca; (36649, 74140, 62200), K; (9637, 10563, 353095), Fe; (12096, 23604, 42740), Mg; (6533, 9253, 7362), Al; (5356, 50121, 29407) respectively

(i) Concentration of Major Element (Ba, Al, K, Ca, Mg and Fe) in the Soil with Location

The determined elemental concentration of Ba, Al, K, Ca, Mg and Feof the soil collected from the three LGA is presented in figure 4.10

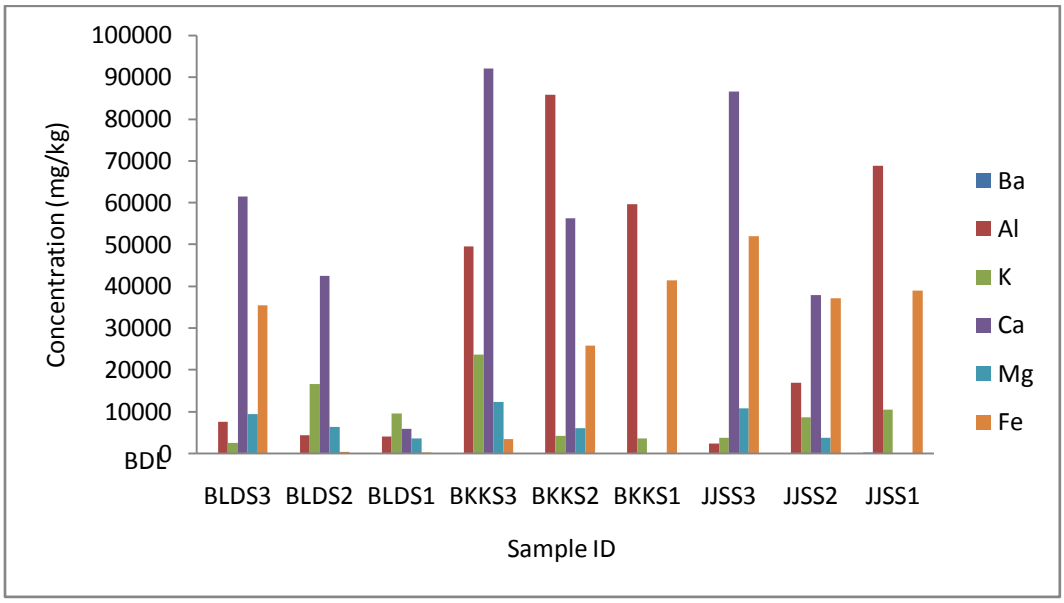


Figure 4. 10: Variation of Concentration of Major Element (Ba, Al, K, Ca, Mg and Fe) in the Soil with Location

From figure 4.10 the elemental concentration of Ba in the soil ranged from BDL to 273±42 in ppm (mg/kg)

The elemental concentration of As in the soil ranged from 4117±115 to 6881±757 in ppm (mg/kg)

Patassium-41 (k-41) is present in the entire sample in relatively large quantity. Its concentration values ranges from 2608±110 to 2367 ±118 in ppm (mg/kg)The elemental concentration of Ca, Mg and Fe in the soil ranged from BDL to 91990±376, BDL to 12420±832 and 367±64 to 52050±416 respectively

(ii) Element concentration (Ti, Mn and Rb) in the Soil

The determined elemental concentration of Ti, Mn and Rb of the soil collected from the three LGA is presented in figure 4.11

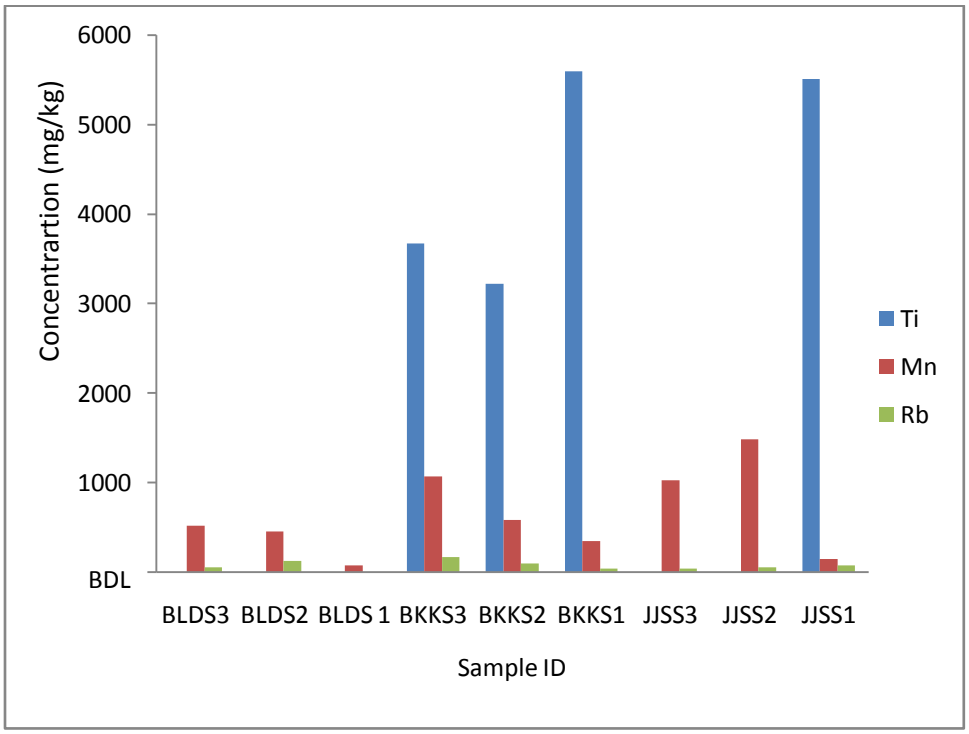


Figure 4. 11: Variation of Element (Ti, Mn and Rb) in the Soil with Location

The elemental concentration of Tin (Ti) presents in only four samples (BKKS1, BKKS2, BKKS3 and JJS1) range from 3221±457 to 5507±358 in ppm (mg/kg)

The elemental concentration of Mn and Rb ranged from 81±1 to 1483±5 and 0.63±0.05 to 131±4 in ppm (mg/kg) respectively

(iii) Elemental Concentration of Radioactive (Th-232, Ra-226 and U-238)

The determined elemental concentration of Th-232, Ra-226 and U-238 of the soil collected from the three LGA is presented in figure 4.12

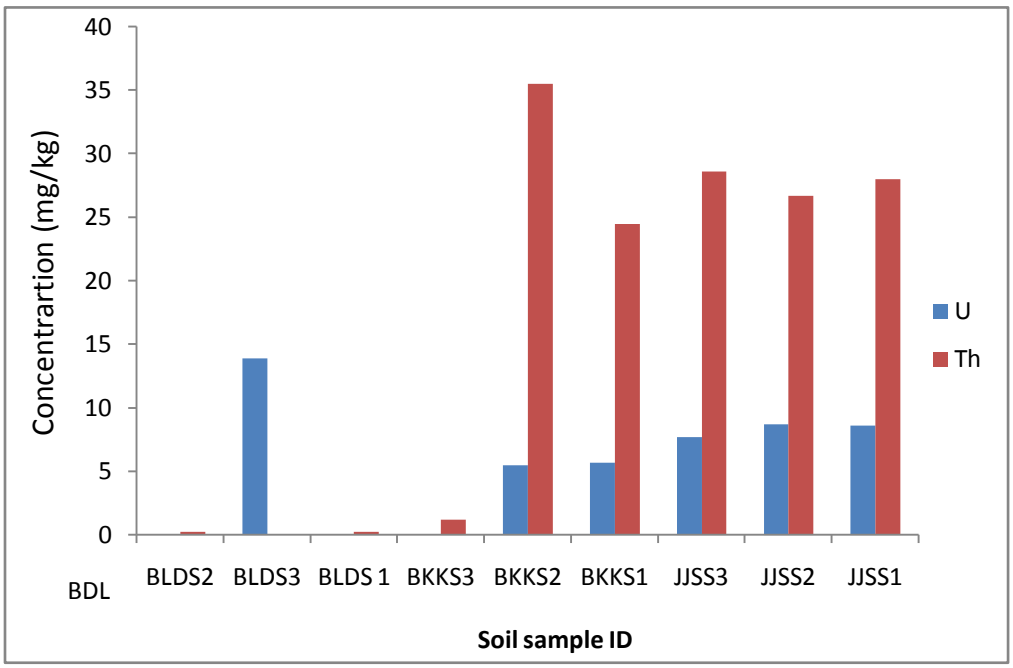


Figure 4. 12: The determined elemental concentration of Th-232, Ra-226 and U-238 of the soil collected from the three LGA

Radon-226 (Ra-226) was not detected in all the samples probably due it short half-life

Thorium-232 (Th-232) has its elemental concentration ranging from 0.24±0.07 to 35.5±0.3 in ppm (mg/kg) and present in all the samples.

Uranium-238 (U-238) was present in the entire samples except in BLDS2, BLDS1, and BKKS1where as the elemental concentration of BKKS3 ranged from BLD to 13.9±0.2 in ppm (mg/kg)

(iv)Concentration of Toxic Element (As, Zn,Cr, and V)

The variation of concentration toxic element As, Zn, Cr and V is presented in figure 4.13

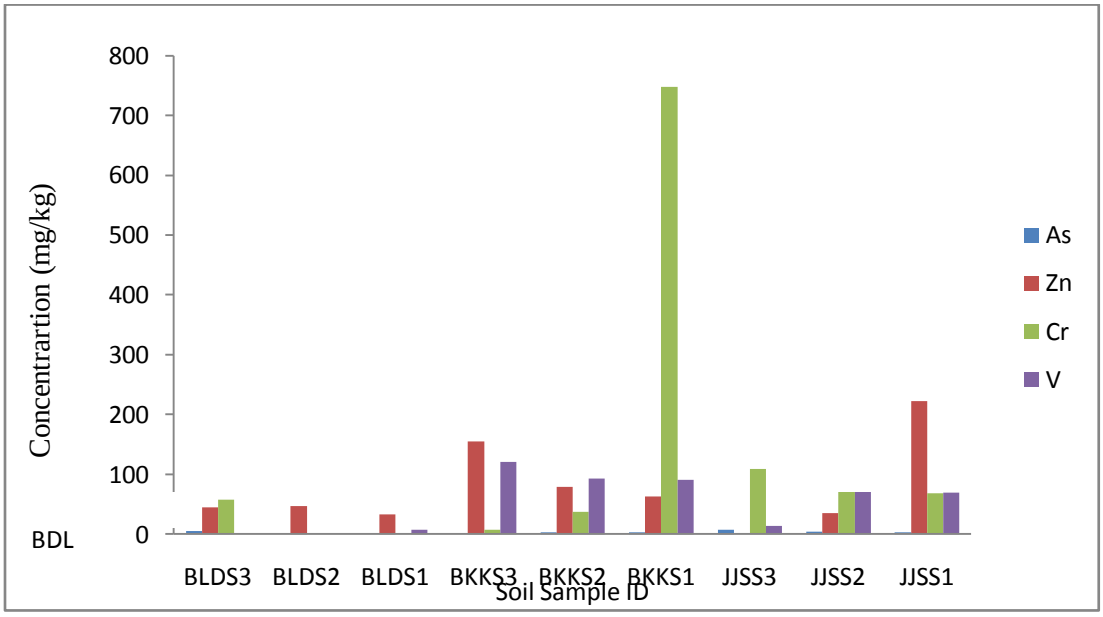


Figure 4. 13: Variation Of Concentration Of Toxic Element (As, Zn,Cr, and V) In The Soil With Location

The soil samples JJSS1, JJSS2, JJSS3, BLDS3, KKS1 AND BKKS2 contained Arsenic (As) elemental concentrations ranging from 3.12±0.2 to 7.3±0.2 in ppm (mg/kg)

Zinc (Zn) elemental concentration contained in the soil sample ranged from 33±4 to 222±15 in ppm (mg/kg) for all the soil except JJSS3

Chromium (Cr) elemental concentration contained in the soil sample ranged from 7±1 to 748±28 in ppm (mg/kg) except in BLDS1 and BLDS2. Highest in BKKS1

Vanadium (V) elemental concentration contained in the soil sample ranged from 7±2 to 121±5 in ppm (mg/kg) except in BLDS2 and BLDS3

4.4.4 Results showing seasonal elemental concentration of Cabbage, Potatoes and carrots

The Determined Seasonal Elemental concentrations (mg/kg) reaction and half-lives of BLD (Barikin Ladi LGA) Cabbage using NAA is presented in table 4.13

Table 4. 14: Determined Seasonal Elemental concentrations in ppm of BLD Cabbage using NAA

Elements	Reaction	Half-lives ($t_{1/2}$)	CBBLDD	CBBLDR
Mg	$^{26}Mg(n,\gamma)^{27}Mg$	9.46min	5306±356	2777±308
Al	$^{27}Al(n,\gamma)^{28}Al$	4min	3338±27	296±12
Cl	$^{37}Cl(n,\gamma)^{38}Cl$	37.5min	6935±62	4149±50
Ca	$^{48}Ca(n,\gamma)^{49}Ca$	8.8min	11650±443	5394±307
V	$^{51}V(n,\gamma)^{51}V$	3.75min	16±1	BDL
Se	$^{75}Se(n,\gamma)^{76}Se$	17,45s	BDL	BDL
Mn	$^{55}Mn(n,\gamma)^{56}Mn$	2.85hrs	211±1	97.4±0.4
Na	$^{23}Na(n,\gamma)^{24}Na$	15.0hrs	281±1	80.7±0.3
K	$^{41}K(n,\gamma)^{42}K$	12.5hrs	7080±35	4870±29
As	$^{75}As(n,\gamma)^{76}As$	1.1d	BDL	BDL
Br	$^{81}Br(n,\gamma)^{82}Br$	353hrs	1702±41	4.71±0.04
La	$^{139}La(n,\gamma)^{140}La$	40.3hrs	1.00±0.92	0.18±0.01
Sm	$^{152}Sm(n,\gamma)^{153}Sm$	46.26hrs	0.182±0.005	0.026±0.003
U	$^{238}U(n,\gamma)^{239}U$	2.36d	DBL	DBL
Sc	$^{45}Sc(n,\gamma)^{46}Sc$	83.81d	0.40±0.02	0.06±0.01
Cr	$^{50}Cr(n,\gamma)^{51}Cr$	27.8d	0.89±0.15	BDL
Fe	$^{58}Fe(n,\gamma)^{59}Fe$	45d	1474±56	303±37
Co	$^{59}Co(n,\gamma)^{60}Co$	5.27yrs	0.66±0.03	0.20±0.02
Zn	$^{64}Zn(n,\gamma)^{65}Zn$	243d	107±5	32.2±3.2
Rb	$^{85}Rb(n,\gamma)^{86}Rb$	1.04min	100±3	74.2±2.5
Sb	$^{121}Sb(n,\gamma)^{122}Sb$	60.3d	BDL	BDL
Ba	$^{130}Ba(n,\gamma)^{132}Ba$	11.8d	BDL	BDL
Eu	$^{151}Eu(n,\gamma)^{152}Eu$	13.3yr	BDL	BDL
Tb	$^{159}Tb(n,\gamma)^{60}Tb$	72.3d	0.15±0.03	BDL
Yb	$^{174}Yb(n,\gamma)^{175}Yb$	4.19d	BDL	BDL
Th	$^{232}Th(n,\gamma)^{233}Th$	27.0d	0.028±0.008	0.029±0.009

BDL~ Below Detection Limit, Correlation coefficient = 0.6372: significant difference

CBBLDR~ Cabbage of Barikin-Ladi Local Government Area; rainy season

CBBLDD~ Cabbage of Barikin-Ladi Local Government Area; dry season

Se is BDL and Cr is present in small quantity. The highly toxic element Cd is not detected and Ca, K Mg and Cl are relatively high showing that agro chemicals are applied in the farming exercises

Table 4. 15: Determined Seasonal Elemental concentrations in ppm of BKK Cabbage using NAA

Elements	Reaction	Half-lives ($t_{1/2}$)	CBBKKD	CBBKKR
Mg	$^{26}Mg(n,\gamma)^{27}Mg$	9.46min	3945±292	2574±183
Al	$^{27}Al(n,\gamma)^{28}Al$	4min	497±12	223±6
Cl	$^{37}Cl(n,\gamma)^{38}Cl$	37.5min	6452±58	2260±34
Ca	$^{48}Ca(n,\gamma)^{49}Ca$	8.8min	7575±356	3852±239
V	$^{51}V(n,\gamma)^{51}V$	3.75min	BDL	BDL
Se	$^{75}Se(n,\gamma)^{76}Se$	17,45s	BDL	0.48±0.06
Mn	$^{55}Mn(n,\gamma)^{56}Mn$	2.85hrs	74.0±0.4	31.1±0.2
Na	$^{23}Na(n,\gamma)^{24}Na$	15.0hrs	244±1	172±1
K	$^{41}K(n,\gamma)^{42}K$	12.5hrs	4434±31	40170±241
As	$^{75}As(n,\gamma)^{76}As$	1.1d	BDL	BDL
Br	$^{81}Br(n,\gamma)^{82}Br$	353hrs	0.56±0.03	67.8±0.2
La	$^{139}La(n,\gamma)^{140}La$	40.3hrs	0.22±0.02	0.33±0.02
Sm	$^{152}Sm(n,\gamma)^{153}Sm$	46.26hrs	0.03±0.003	0.051±0.006
U	$^{238}U(n,\gamma)^{239}U$	2.36d	BDL	BDL
Sc	$^{45}Sc(n,\gamma)^{46}Sc$	83.81d	0.07±0.008	0.045±0.005
Cr	$^{50}Cr(n,\gamma)^{51}Cr$	27.8d	BDL	BDL
Fe	$^{58}Fe(n,\gamma)^{59}Fe$	45d	272±28	352±35
Co	$^{59}Co(n,\gamma)^{60}Co$	5.27yrs	0.1±0.01	0.14±0.02
Zn	$^{64}Zn(n,\gamma)^{65}Zn$	243d	95±15	27±2
Rb	$^{85}Rb(n,\gamma)^{86}Rb$	1.04min	191±3	179±6
Sb	$^{121}Sb(n,\gamma)^{122}Sb$	60.3d	BDL	BDL
Ba	$^{130}Ba(n,\gamma)^{132}Ba$	11.8d	BDL	BDL
Eu	$^{151}Eu(n,\gamma)^{152}Eu$	13.3yr	BDL	BDL
Tb	$^{159}Tb(n,\gamma)^{60}Tb$	72.3d	BDL	BLD
Yb	$^{174}Yb(n,\gamma)^{175}Yb$	4.19d	BDL	BDL
Th	$^{232}Th(n,\gamma)^{233}Th$	27.0d	BLD	BDL

BDL~ Below Detection Limit, Correlation coefficient = 0.7672

CBBKKR~ cabbage of Bokkos LGA; Rainy season

CBBKKD~ cabbage of Bokkos LGA; Dry season

From table 4.15 the Determined Seasonal Elemental concentration (mg/kg) of BKK Cabbage using NAA in Bokkos LGA reveals that both V and U are below detection limit. The highly toxic element Cd is not detected and Ca, K Mg and Cl are relatively high showing that agro chemicals are applied in the farming exercises

Table 4. 16:Determined Seasonal Elemental concentrations in ppm of JJS Cabbage using NAA

Elements	Reaction	Half-lives ($t_{1/2}$)	CBJJSSD	CBJJSR
Mg	$^{26}Mg(n,\gamma)^{27}Mg$	9.46min	4447±382	3210±270
Al	$^{27}Al(n,\gamma)^{28}Al$	4min	1592±57	508±12
Cl	$^{37}Cl(n,\gamma)^{38}Cl$	37.5min	12370±87	6350±57
Ca	$^{48}Ca(n,\gamma)^{49}Ca$	8.8min	10460±471	6047±302
V	$^{51}V(n,\gamma)^{51}V$	3.75min	2±1	BDL
Se	$^{75}Se(n,\gamma)^{76}Se$	17,45s	BDL	0.25±0.07
Mn	$^{55}Mn(n,\gamma)^{56}Mn$	2.85hrs	190±1	69.9±0.4
Na	$^{23}Na(n,\gamma)^{24}Na$	15.0hrs	378±1	766±2
K	$^{41}K(n,\gamma)^{42}K$	12.5hrs	8746±44	32200±225
As	$^{75}As(n,\gamma)^{76}As$	1.1d	BDL	BDL
Br	$^{81}Br(n,\gamma)^{82}Br$	353hrs	13.6±0.1	17.5±0.1
La	$^{139}La(n,\gamma)^{140}La$	40.3hrs	0.64±0.03	0.43±0.03
Sm	$^{152}Sm(n,\gamma)^{153}Sm$	46.26hrs	0.123±0.006	0.059±0.005
U	$^{238}U(n,\gamma)^{239}U$	2.36d	BDL	
Sc	$^{45}Sc(n,\gamma)^{46}Sc$	83.81d	0.25±0.01	BDL
Cr	$^{50}Cr(n,\gamma)^{51}Cr$	27.8d	BDL	BDL
Fe	$^{58}Fe(n,\gamma)^{59}Fe$	45d	747±40	212±42
Co	$^{59}Co(n,\gamma)^{60}Co$	5.27yrs	0.48±0.03	0.19±0.02
Zn	$^{64}Zn(n,\gamma)^{65}Zn$	243d	84±5	23±3
Rb	$^{85}Rb(n,\gamma)^{86}Rb$	1.04min	137±4	219±6
Sb	$^{121}Sb(n,\gamma)^{122}Sb$	60.3d	BDL	BDL
Ba	$^{130}Ba(n,\gamma)^{132}Ba$	11.8d	BDL	BDL
Eu	$^{151}Eu(n,\gamma)^{152}Eu$	13.3yr	0.11±0.03	BDL
Tb	$^{159}Tb(n,\gamma)^{60}Tb$	72.3d	BDL	BLD
Yb	$^{174}Yb(n,\gamma)^{175}Yb$	4.19d	BDL	BDL
Th	$^{232}Th(n,\gamma)^{233}Th$	27.0d	0.09±0.01	0.032±.008

BDL~ Below Detection Limit, Correlation coefficient = 0.8772

CBJJSR~ Cabbage of Jos south Local Government Area; rainy season

CBJJSD~ Cabbage of Jos south Local Government Area; dry season

From table 4.16 the Determined Seasonal Elemental concentration (mg/kg) of JJS (Jos South) LGA Cabbage using NAA reveals that Se is BDL though present in small quantity at rainy season and Cr is present in small quantity. The highly toxic element Cd is not detected and Ca, K Mg and Cl are relatively high showing that agro chemicals are applied in the farming exercises.

Table 4. 17: Determined Seasonal Elemental concentrations in ppm of BLD Potatoes using NAA

Elements	Reaction	Half-lives ($t_{1/2}$)	PTBLDD	PTBLDR
Mg	$^{26}Mg(n,\gamma)^{27}Mg$	9.46min	1939.00±312.00	1555.00±157.00
Al	$^{27}Al(n,\gamma)^{28}Al$	4min	486.00±28.00	232.00±11.00
Cl	$^{37}Cl(n,\gamma)^{38}Cl$	37.5min	7587.00±68.00	1745.00±31.00
Ca	$^{48}Ca(n,\gamma)^{49}Ca$	8.8min	500.00±110.00	888.00±124.00
V	$^{51}V(n,\gamma)^{51}V$	3.75min	BDL	BDL
Se	$^{75}Se(n,\gamma)^{76}Se$	17.45s	BDL	BDL
Mn	$^{55}Mn(n,\gamma)^{56}Mn$	2.85hrs	312.00±0.20	17.10±0.20
Na	$^{23}Na(n,\gamma)^{24}Na$	15.0hrs	45.40±0.40	38.80±0.50
K	$^{41}K(n,\gamma)^{42}K$	12.5hrs	22050.00±88.00	22030.00±154.00
As	$^{75}As(n,\gamma)^{76}As$	1.1d	BDL	0.02±0.01
Br	$^{81}Br(n,\gamma)^{82}Br$	353hrs	0.71±0.01	1.79±0.04
La	$^{139}La(n,\gamma)^{140}La$	40.3hrs	1.44±0.05	0.29±0.02
Sm	$^{152}Sm(n,\gamma)^{153}Sm$	46.26hrs	0.30±0.01	0.08±0.00
U	$^{238}U(n,\gamma)^{239}U$	2.36d	DBL	BDL
Sc	$^{45}Sc(n,\gamma)^{46}Sc$	83.81d	0.10±0.01	0.06±0.01
Cr	$^{50}Cr(n,\gamma)^{51}Cr$	27.8d	BDL	0.52±0.15
Fe	$^{58}Fe(n,\gamma)^{59}Fe$	45d	192.00±0.02	1144.00±55.00
Co	$^{59}Co(n,\gamma)^{60}Co$	5.27yrs	0.21±0.02	BDL
Zn	$^{64}Zn(n,\gamma)^{65}Zn$	243d	25.00±3.00	19.00±3.00
Rb	$^{85}Rb(n,\gamma)^{86}Rb$	1.04min	43.00±2.00	149.00±5.00
Sb	$^{121}Sb(n,\gamma)^{122}Sb$	60.3d	BDL	BDL
Ba	$^{130}Ba(n,\gamma)^{132}Ba$	11.8d	BDL	BDL
Eu	$^{151}Eu(n,\gamma)^{152}Eu$	13.3yr	BDL	BDL
Tb	$^{159}Tb(n,\gamma)^{60}Tb$	72.3d	BDL	BLD
Yb	$^{174}Yb(n,\gamma)^{175}Yb$	4.19d	BDL	BDL
Th	$^{232}Th(n,\gamma)^{233}Th$	27.0d	0.03±0.01	BDL

BDL~ Below Detection Limit

CBBLDR~ Cabbage of Jos south Local Government Area; rainy season

CBBLDD~ Cabbage of Jos south Local Government Area; dry season

Correlation coefficient = 0.9772

From table 4.17 the Determined Seasonal Elemental concentration (mg/kg) of BLD (Barikin Ladi LGA) Potatoes using NAA, it could be seen that V and Se are BDL,As and Cr are present in small quantity rainy season only. The highly toxic element Cd is not detected and Ca, K Mg and Cl are relatively high showing that agro chemicals are applied in the farming exercises.

Table 4. 18: Determined seasonal elemental concentration of Potatoes in ppm Jos south LGA

Elements	Reaction	Half-lives ($t_{1/2}$)	PTJJSD	PTJJSR
Mg	$^{26}Mg(n,\gamma)^{27}Mg$	9.46min	1620.00±198.00	994.00±162.00
Al	$^{27}Al(n,\gamma)^{28}Al$	4min	370.00±10.00	1309.00±64.00
Cl	$^{37}Cl(n,\gamma)^{38}Cl$	37.5min	4954.00±50.00	3042.00±40.00
Ca	$^{48}Ca(n,\gamma)^{49}Ca$	8.8min	798±115	646.00±109.00
V	$^{51}V(n,\gamma)^{51}V$	3.75min	10.00±0.20	BDL
Se	$^{75}Se(n,\gamma)^{76}Se$	17.45s	BDL	BDL
Mn	$^{55}Mn(n,\gamma)^{56}Mn$	2.85hrs	15.50±0.20	11.70±0.10
Na	$^{23}Na(n,\gamma)^{24}Na$	15.0hrs	10.2±0.2	22.30±0.20
K	$^{41}K(n,\gamma)^{42}K$	12.5hrs	2856±20	13610.00±68.00
As	$^{75}As(n,\gamma)^{76}As$	1.1d	BDL	BDL
Br	$^{81}Br(n,\gamma)^{82}Br$	353hrs	1.16±0.04	0.44±0.01
La	$^{139}La(n,\gamma)^{140}La$	40.3hrs	0.20±0.01	0.26±0.03
Sm	$^{152}Sm(n,\gamma)^{153}Sm$	46.26hrs	0.04±0.00	0.04±0.01
U	$^{238}U(n,\gamma)^{239}U$	2.36d	BDL	BDL
Sc	$^{45}Sc(n,\gamma)^{46}Sc$	83.81d	0.085±0.01	BDL
Cr	$^{50}Cr(n,\gamma)^{51}Cr$	27.8d	BDL	BDL
Fe	$^{58}Fe(n,\gamma)^{59}Fe$	45d	150.00±26.00	79.00±21.00
Co	$^{59}Co(n,\gamma)^{60}Co$	5.27yrs	0.13±0.02	0.10±0.02
Zn	$^{64}Zn(n,\gamma)^{65}Zn$	243d	23.00±3.00	13.00±3.00
Rb	$^{85}Rb(n,\gamma)^{86}Rb$	1.04min	47.00±2.00	42.00±2.00
Sb	$^{121}Sb(n,\gamma)^{122}Sb$	60.3d	BDL	BDL
Ba	$^{130}Ba(n,\gamma)^{132}Ba$	11.8d	BDL	BDL
Eu	$^{151}Eu(n,\gamma)^{152}Eu$	13.3yr	BDL	BDL
Tb	$^{159}Tb(n,\gamma)^{60}Tb$	72.3d	BDL	BLD
Yb	$^{174}Yb(n,\gamma)^{175}Yb$	4.19d	0.17±0.05	BDL
Th	$^{232}Th(n,\gamma)^{233}Th$	27.0d	0.03±0.01	BDL

BDL~ Below Detection Limit

PTJJSR~ potatoes of Jos south; rainy season

PTJJSD~ potatoes of Jos south; dry season

Correlation coefficient = 0.9772

It could be obtained from table 4.18, The determined seasonal elemental concentration of JJS (Jos south LGA) potatoes using NAA that V and Se are BDL, As and Cr are present in small quantity rainy season only. The highly toxic element Cd is not detected and Ca, K Mg and Cl are relatively high showing that agro chemicals are applied in the farming exercises

Table 4. 19: Determined Seasonal Elemental concentrations in ppm of BKK Potatoes using NAA

Elements	Reaction	Half-lives ($t_{1/2}$)	PTBKKD	PTBKKR
Mg	$^{26}Mg(n,\gamma)^{27}Mg$	9.46min	2442.00±254.00	1431.00±165.00
Al	$^{27}Al(n,\gamma)^{28}Al$	4min	2476.00±32.00	149.00±10.00
Cl	$^{37}Cl(n,\gamma)^{38}Cl$	37.5min	3253.00±46.00	2310.00±37.00
Ca	$^{48}Ca(n,\gamma)^{49}Ca$	8.8min	950.00±137.00	650.00±112.00
V	$^{51}V(n,\gamma)^{51}V$	3.75min	5.3.00±0.40	BDL
Se	$^{75}Se(n,\gamma)^{76}Se$	17,45s	BDL	BDL
Mn	$^{55}Mn(n,\gamma)^{56}Mn$	2.85hrs	41.00±0.30	16.90±0.20
Na	$^{23}Na(n,\gamma)^{24}Na$	15.0hrs	66.00±1.00	33.00±0.50
K	$^{41}K(n,\gamma)^{42}K$	12.5hrs	23480.00±141.00	19170.00±153.00
As	$^{75}As(n,\gamma)^{76}As$	1.1d	BDL	BDL
Br	$^{81}Br(n,\gamma)^{82}Br$	353hrs	0.29±0.01	2.44±0.04
La	$^{139}La(n,\gamma)^{140}La$	40.3hrs	2.4±0.1	0.094±0.009
Sm	$^{152}Sm(n,\gamma)^{153}Sm$	46.26hrs	0.50±0.01	0.02±0.00
U	$^{238}U(n,\gamma)^{239}U$	2.36d	BDL	BDL
Sc	$^{45}Sc(n,\gamma)^{46}Sc$	83.81d	0.27±0.01	0.03±0.00
Cr	$^{50}Cr(n,\gamma)^{51}Cr$	27.8d	BDL	BDL
Fe	$^{58}Fe(n,\gamma)^{59}Fe$	45d	1022.00±42.00	151±30
Co	$^{59}Co(n,\gamma)^{60}Co$	5.27yrs	0.18±0.02	0.26±0.02
Zn	$^{64}Zn(n,\gamma)^{65}Zn$	243d	38.00±3.00	14.00±2.00
Rb	$^{85}Rb(n,\gamma)^{86}Rb$	1.04min	56.00±2.00	64.00±4.00
Sb	$^{121}Sb(n,\gamma)^{122}Sb$	60.3d	BDL	BDL
Ba	$^{131}Ba(n,\gamma)^{132}Ba$	11.8d	BDL	BDL
Eu	$^{151}Eu(n,\gamma)^{152}Eu$	13.3yr	BDL	BDL
Tb	$^{159}Tb(n,\gamma)^{60}Tb$	72.3d	BLD	BLD
Yb	$^{174}Yb(n,\gamma)^{175}Yb$	4.19d	BDL	BDL
Th	$^{232}Th(n,\gamma)^{233}Th$	27.0d	0.07±0.01	BDL

BDL~ Below Detection Limit PTBKKR~ potatoes of Bokkos LGA; rainy season

PTBKKD~ potatoes of Bokkos LGA; dry seson

Correlation coefficient = 0.9772

From the Determined Seasonal Elemental concentration (mg/kg) of BKK Potatoes using NAA of table 4.20 it could be seen that V and Se are BDL, As and Cr are present in small quantity rainy season only. The highly toxic element Cd is not detected and Ca, K Mg and Cl are relatively high showing that agro chemicals are applied in the farming exercises

The Determined Seasonal Elemental concentrations in ppm of BLD Carrot using NAA is presented in table 4.22

Table 4. 20: Determined Seasonal Elemental concentrations (ppm) of BLD Carrot using NAA

Elements	Reaction	Half-lives ($t_{1/2}$)	CRBLDD	CRBLDR
Mg	$^{26}Mg(n,\gamma)^{27}Mg$	9.46min	2556.00±340.00	2345.00±183.00
Al	$^{27}Al(n,\gamma)^{28}Al$	4min	5685.00±46.00	766.00±11.00
Cl	$^{37}Cl(n,\gamma)^{38}Cl$	37.5min	9362.00±75.00	3376.00±44.00
Ca	$^{48}Ca(n,\gamma)^{49}Ca$	8.8min	7012.00±358.00	3830.00±230.00
V	$^{51}V(n,\gamma)^{51}V$	3.75min	12.00±1.00	0.57±0.08
Se	$^{75}Se(n,\gamma)^{76}Se$	17,45s	BDL	BDL
Mn	$^{55}Mn(n,\gamma)^{56}Mn$	2.85hrs	112.00±1.00	77.60±0.30
Na	$^{23}Na(n,\gamma)^{24}Na$	15.0hrs	648.00±1.00	982.00±2.00
K	$^{41}K(n,\gamma)^{42}K$	12.5hrs	6232.00±37.00	43350.00±260.00
As	$^{75}As(n,\gamma)^{76}As$	1.1d	BDL	BDL
Br	$^{81}Br(n,\gamma)^{82}Br$	353hrs	3.20±0.10	6.31.00±0.08
La	$^{139}La(n,\gamma)^{140}La$	40.3hrs	5.70±0.10	134.00±0.04
Sm	$^{152}Sm(n,\gamma)^{153}Sm$	46.26hrs	0.88±0.01	0.16±0.01
U	$^{238}U(n,\gamma)^{239}U$	2.36d	0.01±0.00	
Sc	$^{45}Sc(n,\gamma)^{46}Sc$	83.81d	0.85±0.02	0.08±0.01
Cr	$^{50}Cr(n,\gamma)^{51}Cr$	27.8d	0.70±0.20	BDL
Fe	$^{58}Fe(n,\gamma)^{59}Fe$	45d	1397.00±50.00	432.00±40.00
Co	$^{59}Co(n,\gamma)^{60}Co$	5.27yrs	0.20±0.04	0.30±0.02
Zn	$^{64}Zn(n,\gamma)^{65}Zn$	243d	109.00±5.00	35.00±3.00
Rb	$^{85}Rb(n,\gamma)^{86}Rb$	1.04min	169.00±4.00	221.00±6.00
Sb	$^{121}Sb(n,\gamma)^{122}Sb$	60.3d	DBL	0.154±0.01
Ba	$^{130}Ba(n,\gamma)^{132}Ba$	11.8d	230.00±18.00	168.00±19.00
Eu	$^{151}Eu(n,\gamma)^{152}Eu$	13.3yr	BDL	BDL
Tb	$^{159}Tb(n,\gamma)^{60}Tb$	72.3d	BDL	BLD
Yb	$^{174}Yb(n,\gamma)^{175}Yb$	4.19d	0.89±0.99	BDL
Th	$^{232}Th(n,\gamma)^{233}Th$	27.0d	0.66±0.02	0.04±0.01

BDL~ Below Detection Limit CRBLDR~ Carrot of Barikin- Ladi LGA; rainy season

CRBLDD~ Carrot of Barikin -Ladi LGA; dry season

Correlation coefficient = 0.6872

Th element is present in both rainy season and dry season but in small quantity. V and Se are BDL, As and Cr are present in small quantity rainy season only. The highly toxic element Cd is not detected and Ca, K Mg and Cl are relatively high showing that agro chemicals are applied in the farming exercises

Determined Seasonal Elemental concentrations (mg/kg) of BKK Carrot using NAA is presented in Table 4.23

Table 4. 21: Determined Seasonal Elemental concentrations (ppm) of BKK Carrot using NAA

Elements	Reaction	Half-lives ($t_{1/2}$)	CRBKKD	CRBKKR
Mg	$^{26}Mg(n,\gamma)^{27}Mg$	9.46min	2117.00±500.00	BDL
Al	$^{27}Al(n,\gamma)^{28}Al$	4min	3818.00±73.00	1301.00±14.00
Cl	$^{37}Cl(n,\gamma)^{38}Cl$	37.5min	7897.00±71.00	BDL
Ca	$^{48}Ca(n,\gamma)^{49}Ca$	8.8min	6391.00±395.00	BDL
V	$^{51}V(n,\gamma)^{51}V$	3.75min	19.00±1.00	4.20±0.30
Se	$^{75}Se(n,\gamma)^{76}Se$	17,45s	BDL	BDL
Mn	$^{55}Mn(n,\gamma)^{56}Mn$	2.85hrs	210.00±1.00	55.700±0.30
Na	$^{23}Na(n,\gamma)^{24}Na$	15.0hrs	4485.00±14.00	1228.00±1.00
K	$^{41}K(n,\gamma)^{42}K$	12.5hrs	45690.00±914.00	25130.00±101.00
As	$^{75}As(n,\gamma)^{76}As$	1.1d	BDL	BDL
Br	$^{81}Br(n,\gamma)^{82}Br$	353hrs	1.09±0.03	1.04±0.02
La	$^{139}La(n,\gamma)^{140}La$	40.3hrs	13.70±0.20	1.90±0.10
Sm	$^{152}Sm(n,\gamma)^{153}Sm$	46.26hrs	2.04±0.04	0.204±0.02
U	$^{238}U(n,\gamma)^{239}U$	2.36d	DBL	DBL
Sc	$^{45}Sc(n,\gamma)^{46}Sc$	83.81d	BDL	0.09±0.01
Cr	$^{50}Cr(n,\gamma)^{51}Cr$	27.8d	BDL	BDL
Fe	$^{58}Fe(n,\gamma)^{59}Fe$	45d	693.00±44.00	165.00±32.00
Co	$^{59}Co(n,\gamma)^{60}Co$	5.27yrs	0.34±0.03	BDL
Zn	$^{64}Zn(n,\gamma)^{65}Zn$	243d	92.00±5.00	40.00±4.00
Rb	$^{85}Rb(n,\gamma)^{86}Rb$	1.04min	101.00±3.00	80.00±2.00
Sb	$^{121}Sb(n,\gamma)^{122}Sb$	60.3d	BDL	BDL
Ba	$^{130}Ba(n,\gamma)^{132}Ba$	11.8d	425.00±20.00	128.00±13.00
Eu	$^{151}Eu(n,\gamma)^{152}Eu$	13.3yr	DBL	BDL
Tb	$^{159}Tb(n,\gamma)^{60}Tb$	72.3d	DBL	BDL
Yb	$^{174}Yb(n,\gamma)^{175}Yb$	4.19d	0.50±0.10	BDL
Th	$^{232}Th(n,\gamma)^{233}Th$	27.0d	0.13±0.01	0.041±0.01

BDL~ Below Detection Limit

CRBKKR~ Carrot of Bokkos LGA; rainy season

CRBKKD~ Carrot of Bokkos LGA; dry season

Correlation coefficient = 0.7365

From table 4.11, Th is present at in both rainy season and dry season but in small quantity. V and Se are BDL, As and Cr are present in small quantity rainy season only. The highly toxic element Cd is not detected and Ca, K Mg and Cl are relatively high showing that agro chemicals are applied in the farming exercise.

The Determined Seasonal Elemental concentration (mg/kg) of JJS Carrot using NAA is presented inTable 4.24

Table 4. 22: Determined Seasonal Elemental concentrations (ppm) of JJS Carrot using NAA

Elements	Reaction	Half-lives ($t_{1/2}$)	CRJJSD	CRJJSR
Mg	$^{26}Mg(n,\gamma)^{27}Mg$	9.46min	4338.00±460.00	2323.00±253.00
Al	$^{27}Al(n,\gamma)^{28}Al$	4min	4000.00±48.00	933.00±17.00
Cl	$^{37}Cl(n,\gamma)^{38}Cl$	37.5min	14110.00±99.00	2129.00±36.00
Ca	$^{48}Ca(n,\gamma)^{49}Ca$	8.8min	11010.00±484.00	5032.00±239.00
V	$^{51}V(n,\gamma)^{51}V$	3.75min	10.00±1.00	0.50±0.11
Se	$^{75}Se(n,\gamma)^{76}Se$	17,45s	BDL	BDL
Mn	$^{55}Mn(n,\gamma)^{56}Mn$	2.85hrs	148.00±1.00	751.00±4.00
Na	$^{23}Na(n,\gamma)^{24}Na$	15.0hrs	8908.00±18.00	445.00±2.00
K	$^{41}K(n,\gamma)^{42}K$	12.5hrs	49210.00±1132.00	4168000±250.00
As	$^{75}As(n,\gamma)^{76}As$	1.1d	BDL	BDL
Br	$^{81}Br(n,\gamma)^{82}Br$	353hrs	1.53.00±0.03	5.55±0.07
La	$^{139}La(n,\gamma)^{140}La$	40.3hrs	12.00±0.20	1.55±0.03
Sm	$^{152}Sm(n,\gamma)^{153}Sm$	46.26hrs	1.73±0.03	0.204±0.01
U	$^{238}U(n,\gamma)^{239}U$	2.36d	BDL	BDL
Sc	$^{45}Sc(n,\gamma)^{46}Sc$	83.81d	0.67±0.02	0.074±0.01
Cr	$^{50}Cr(n,\gamma)^{51}Cr$	27.8d	0.9±0.2	0.75±0.18
Fe	$^{58}Fe(n,\gamma)^{59}Fe$	45d	2146.00±62.00	487.00±42.00
Co	$^{59}Co(n,\gamma)^{60}Co$	5.27yrs	0.27±0.03	0.07±0.02
Zn	$^{64}Zn(n,\gamma)^{65}Zn$	243d	113.00±4.00	38.00±3.00
Rb	$^{85}Rb(n,\gamma)^{86}Rb$	1.04min	166.00±4.00	170.00±6.00
Sb	$^{121}Sb(n,\gamma)^{122}Sb$	60.3d	BDL	BDL
Ba	$^{130}Ba(n,\gamma)^{132}Ba$	11.8d	313.00±20.00	159.00±19.00
Eu	$^{151}Eu(n,\gamma)^{152}Eu$	13.3yr	BDL	0.09±0.03
Tb	$^{159}Tb(n,\gamma)^{60}Tb$	72.3d	BDL	BLD
Yb	$^{174}Yb(n,\gamma)^{175}Yb$	4.19d	0.28±0.07	0.33±0.09
Th	$^{232}Th(n,\gamma)^{233}Th$	27.0d	0.32±0.02	BDL

BDL~ Below Detection Limit

CRJJSD ~Carrot of Jos South LGA; dry season

CRJJSD ~Carrot of Jos South LGA; rainy season

Correlation coefficient = 0.7578

Th is BDL at rainy season but present in small quantity at dry season. V and Se are BDL, As and Cr are present in small quantity rainy season only. The highly toxic element Cd is not detected and Ca, K Mg and Cl are relatively high showing that agro chemicals are applied in the farming exercises

4.4.5 Results showing mean elemental concentration of Cabbage collected during the rainy and dry season farming from all the three LGA in ppm (mg/kg)

Mean elemental concentration of Cabbage collected during the rainy and dry season farming from all the three LGA in ppm (mg/kg) is presented in Table 4.25

Table 4. 23: Mean elemental concentration of Cabbage collected during the rainy and dry season farming from all the three LGA in ppm

Elements	CABBAGE	CABBAGE*
Mg	4176.67±348.67	2853.67±253.67
Al	1742.00±32.00	342.33±10.00
Cl	7818.00±66.33	4253.00±47.00
Ca	9168.00±407.00	5097.67±282.67
V	6.00±0.67	BDL
Se	BDL	0.24±0.04
Mn	166.13±0.80	358.33±0.33
Na	246.57±0.77	339.57±0.43
K	6898.67±35.33	25746.67±97.33
As	BDL	BDL
Br	573.44±13.71	30.00±0.11
La	0.61±0.32	0.31±0.02
Sm	0.11±0.02	0.04±0.03
U	BDL	BDL
Sc	0.24±0.01	0.04±0.01
Cr	29.67±0.05	BDL
Fe	841.33±44.33	289.00±38.00
Co	0.45±0.03	0.18±0.02
Zn	49.07±4.40	27.40±1.73
Rb	103.73±3.17	157.40±12.33
Sb	BDL	BDL
Ba	BDL	BDL
Eu	0.04±0.01	BDL
Tb	0.05±0.01	BDL
Yb	BDL	BDL
Th	0.05±0.01	0.02±2.67

BDL~ Below Detection Limit

CABAGE, CABBAGE* ~ Dry and Rainy Season Respectively

Correlation coefficient = 0.97

V and Se were atBDL whileAs and Cr are present in small quantity rainy season only. The highly toxic element cd is not detected and Ca, K Mg and Cl are relatively high showing that agro chemicals are applied in the farming exercises and the elemental concentrations of dry season cabbage is higher than the rainy season ones

4.4.6 Comparism of Mean elemental concentration of Cabbage collected during therainy and dry (*) season farming from all the three LGA

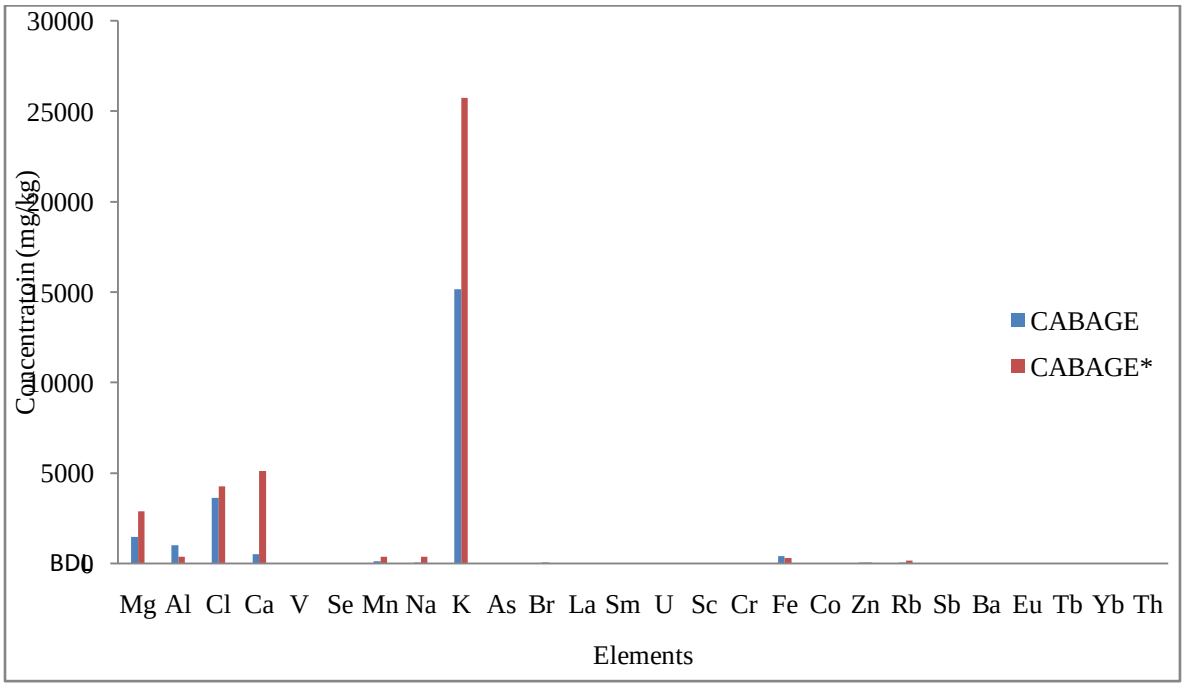


Figure 4. 14: Conparism of mean elemental concentration of Cabbage collected during the rainy and dry season farming from all the three LGA

The determined elemental concentration of Potassium (K) is high with values 25747±97 in ppm at rainy season and 6898±35 in ppm (mg/kg) at the dry season followed by Cl with values 7818±66 in ppm at the dry season and 4253±47 in ppm while U,V,Sb,Ba,Eu,Tb and Yb range from BDL to 0.04±0.01 in ppm

The result of Mean elemental concentration of Potatoes collected during the rainy and dry season farming from all the three LGA in ppm is presented in Table 4.24

Table 4. 24: Mean elemental concentrations of Potatoes collected during the rainy and dryseason farming from all the three LGA in ppm

Elements	POTATOES	POTATOES*
Mg	2000.33±254.67	1326.67±161.33
Al	1110.67±23.33	170.33±10.00
Cl	5264.67±54.67	2365.67±36.00
Ca	749.33±120.67	728.00±115.00
V	BDL	BDL
Se	BDL	BDL
Mn	122.83±0.23	15.23±0.10
Na	40.53±0.53	31.37±0.40
K	16128.67±83.00	18270.00±125.00
As	BDL	0.01±0.00
Br	0.72±0.35	1.56±0.03
La	1.35±0.05	0.21±0.02
Sm	0.28±0.01	0.05±0.01
U	BDL	BDL
Sc	0.15±0.01	0.03±0.00
Cr	BDL	0.17±0.05
Fe	454.67±22.67	BDL
Co	0.17±0.02	BDL
Zn	28.67±3.00	15.33±2.67
Rb	48.67±2.00	85.00±3.67
Sb	BDL	BDL
Ba	BDL	BDL
Eu	BDL	BDL
Tb	BDL	BDL
Yb	BDL	BDL
Th	0.04	BDL

BDL~ Below Detection Limit

POTATOSE, POTATOES* Dry and Rainy Season Respectively

Correlation coefficient = 0.77

From table 4.24, potatoes, potatoes* each contained K (16129, 18270) and Mg (2000, 1327), Al (1111, 170), Cl (5265, 2366), Ca, (749, 728). The elemental concentrations of dry season cabbage is higher than the rainy season ones and the relative high values may beshowing that agro chemicals are applied in the farming exercises

4.4.7 Comparism of mean seasonal elemental concentration of Potatoes collected during the rainy and dry season farming from all the three LGA

The mean seasonal elemental concentration of potatoes collected in all the three local Government areas are presented in figure 4.15

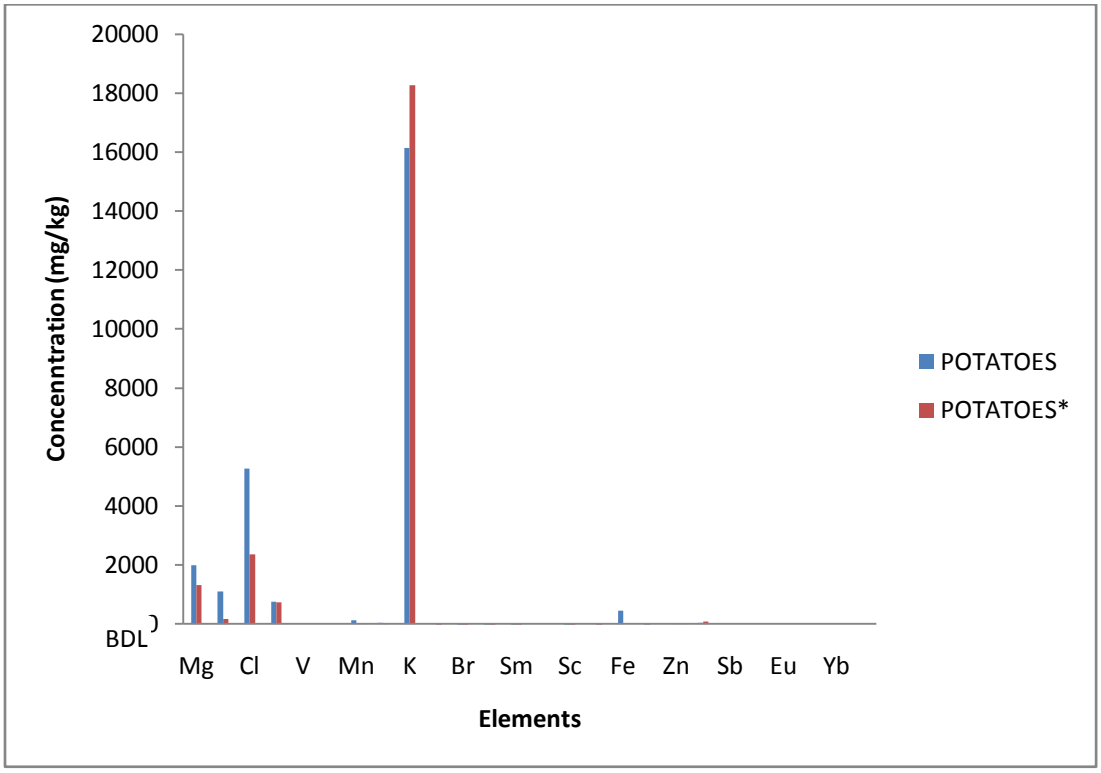


Figure 4. 15: Comparism of mean elemental concentration of Potatoes collected during the rainy and dry season farming from all the three LGA

The determined elemental concentration of Potassium (K-40) is high with values 18270±125 in ppm (mg/kg)at rainy season and 16128±83 in ppm (mg/kg) at the dry season followed by Cl with values 5264±54 in ppm (mg/kg) at the dry season and 2365±36 in ppm (mg/kg)while U,V,Sb,Ba,Eu,Tb and Yb range from BDL to 0.04±0.01 in ppm (mg/kg)

The Mean seasonal elemental concentration of carrot collected during the rainy and dry season farming from all the three LGA in ppm (mg/kg)is presented in Table 4.25

Table 4. 25: Mean elemental concentration of carrot collected during the rainy and dry season farming from all the three LGA in ppm

Elements	CARROT	CARROT*
Mg	3003.67±433.33	1556.00±145.33
Al	4501.00±55.67	1000.00±145.33
Cl	10456.33±81.67	1835.00±26.67
Ca	8137.67±	2954.00±156.33
V	13.67±1.00	1.76±0.16
Se	BDL	BDL
Mn	156.67±1.00	294.77±1.53
Na	4680.33±11.00	885.00±1.67
K	33710.67±694.33	36720.00±203.67
As	BDL	BDL
Br	1.94±1.04	4.30±0.06
La	10.47±0.47	45.82±0.06
Sm	1.55±1.68	0.19±0.01
U	BDL	BDL
Sc	0.03	0.08
Cr	0.17	0.25±0.06
Fe	1412.00±52.00	361.333±8.00
Co	0.27±0.03	0.12±0.01
Zn	104.67±4.67	37.67±3.33
Rb	145.33±3.67	157.00±4.67
Sb	BDL	0.05±0.001
Ba	322.67±19.33	151.67±17.00
Eu	BDL	0.03±0.01
Tb	BDL	BDL
Yb	0.56±0.39	0.11±0.03
Th	0.37±0.01	0.03±0.01

BDL~ Below Detection Limit

CARROT, CARROT* Dry and Rainy Season Respectively

Correlation coefficient = 0.62

4.4.8 Comparism of Mean seasonal elemental concentration of Carrot collected during the rainy and dry season farming from all the three LGA

The mean seasonal elemental concentration the Carrot vegetable for all the three local Government areas is presented in figure 4.16

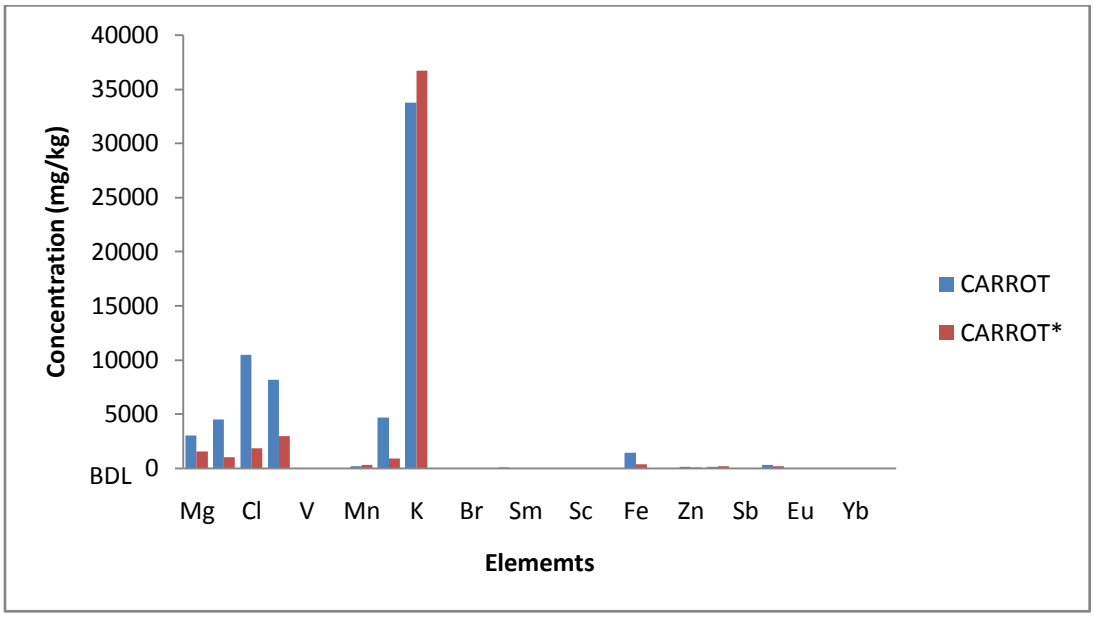


Figure 4. 16: Conparism of Mean elemental concentration of Carrot collected during the rainy and dry season farming from all the three LGA

The mean value K at rainy season (36720 in ppm is higher than its dry season value of 33710 in ppm.this may be due to the agro- chemical applications in the farming exercises. However Cl is relatively high with mean value elemental concentration of 10456 in ppm at rainy season compared to its dry season value of 1835in ppm

4.5 Average Concentration of Three vegetables ppm (mg/kg), daily intake and health risk

Table 4.28 shows the calculated average elemental Concentration of Three vegetables ppm (mg/kg), estimated daily intake and health risk

Table 4. 26: Average Concentration, Daily intake of Metal (DIM) and Health risk index (H_Q) of the vegetables ppm

Elements	Average Concentration of Three vegetables Ppm	DIM (g)	H_Q
Mg	7362.50	2208.75	24.5417
Al	27883.33	8365.00	92.9444
Cl	62200.00	18660.00	207.3333
Ca	3947.20	16.20	13.1573
V	55.00	16.50	0.1833
Se	918.67	275.60	3.0622
Mn	45.00	0.20	0.1500
Na	676.67	203.00	2.2556
K	6551.00	1965.30	2.1837
As	4.80	1.44.00	0.020
Br	0.56	0.17	0.0019
La	2.43	NIL	NIL
Sm	50.47	15.14	0.1700
U	6.95	2.08	0.0232
Sc	3.37	1.01	0.0112
Cr	7.85	2.36	0.0262
Fe	9.58	2.88	0.03319
Co	196.00	58.80	0.6533
Zn	43160.00	12948.00	143.8667
Rb	9.45	2.84	0.0315
Sb	75.50	22.65	0.2517
Ba	55.00	16.50	0.1833
Eu	4.50	1.35	0.0200
Tb	3.03	0.91	0.0101
Yb	192.33	57.70	0.6411
Th	56.67	17.00	0.1900

NIL means the result is not possible

Fe, Cu, Co, Cr, V, , Mn, Zn and are classified as toxic elements Charya,et al (2008)

For Fe, Cu, Co, Cr, V, , Mn and Zn, H_Q were calculated which showed a decreasing order of Mn>Zn>Cu>Fe>V>Co>Cr. Highest H_Q values found were Cl (207.333mg/kg), Zn(143.8667mg/kg), Al(92.9444), and Mg(24.5417mg/kg) which were above the safe valueCharya,et al (2008)

4.6 Mean Concentration in ppm and Transfer Factor of Soils and Vegetables

Table 4. 27: Mean concentration in ppm and transfer factor of soils and vegetables

Elements	Mean Concentration				T_f	
	Soil	Cabbage	potatoes	Carrot	Cabbage	Potatoes	Carrot
Mg	7547.00	10910.00	7362.50	3815.00	1.4456	0.9756	0.5055
Al	33246.56	31070.00	9705.00	42875.00	0.9345	0.2919	1.2896
Cl	BDL	86530.00	62200.00	37870.00	NIL	NIL	NIL
Ca	44995.00	5596.00	738.60	5507.00	0.1244	0.0164	0.1224
V	66.57	52.50	42.50	70.00	0.7886	0.6384	1.0515
Se	BDL	686.50	12540.00	815.50	NIL	NIL	NIL
Mn	635.11	4.70	45.00	7.60	0.0074	0.0708	0.0120
Na	444.91	405.00	939.00	686.00	0.9103	2.1105	1.5419
K	9301.22	3712.00	6265.00	9676.00	0.3991	0.6736	1.0403
As	4.27	5.40	5.55	3.45	1.2656	1.3008	0.8086
Br	0.70	0.69	0.57	0.43	0.9857	0.8143	0.6143
La	BDL	0.078	0.78	28.14	NIL	NIL	NIL
Sm	5.04	52.00	46.65	52.75	10.3175	9.2560	10.4663
U	8.35	7.50	6.38	6.965	0.8976	0.7641	0.8341
Sc	5.68	3.50	2.85	3.75	0.6162	0.5018	0.6602
Cr	156.86	6.70	8.20	8.65	0.0427	0.0523	0.0551
Fe	26146.67	10.40	9.20	9.15	0.0004	0.0004	0.0003
Co	7.41	428.50	90.00	69.50	57.8273	12.1457	9.3792
Zn	26146.67	46780.00	44615.00	38085.00	1.7891	1.7063	1.4566
Rb	76.74	13.25	6.40	8.70	0.1727	0.0834	0.1134
Sb	4.20	63.00	35.00	128.50	15.0000	8.3333	30.5952
Ba	160.83	42.00	52.00	71.00	0.2611	0.3233	0.4415
Eu	1.06	5.00	4.50	4.00	4.7170	4.2453	3.7736
Tb	1.30	2.60	2.55	3.95	2.0000	1.9615	3.0385
Yb	6.50	161.50	167.00	248.50	24.8462	25.6923	38.2308
Th	2.80	49.00	55.00	66.00	17.5000	19.6429	23.5714

Cl, Se and La concentration in the soil samples were not determined (BDL) and hence their T_f values are undetermined.

The determined seasonal transfer factor for the vegetables could be seen from table 4.17. High values of (transfer of element from soil to vegetables) Transfer factor (T_f) determine from the work cabbage , carrot and potatoes were; Co(57,12 and 09), Yb(25,26 and 38), Th(18, 20 and 24), Sb(15, 08 and 31) and Sm(10. 9 and 11)

4.7 Discussion of the Results

The results of radioactivity concentration of the radionuclides measurement using NaI detector and the calculated values of radiological indices are discussed in this chapter. Possible radiological health effects are further discussed and suggestions were made at the end. The results of elemental concentration using the NAA were also discussed in this chapter. Recommendations and conclusion were also presented in this chapter

4.7.1 Discussion on Measurement of Activity Concentration of the TENORMradionuclides

General discussion of radioactivity concentration of the radionuclides measurement and the calculated values of radiological indices are discussed. Possible radiological health effects are further discussed

4.7.2 The Specific activities of the TENORM of soil samples

The Specific activities of the concerned radionuclides (K-40, Ra-226, Th-232) measured through laboratory-based NaI(Tl) scintillation spectrometer analyses of soil samples compared to Worldwide values is presented in Table 4.18

Table 4. 28: Average Specific activities of TENORMmeasured through laboratory-basedNaI(Tl) scintillation spectrometer analyses of soil samples compared to Worldwide values

Location	Mean Activity		
	^{40}K (Bqkg^{-1})	^{226}Ra (Bqkg^{-1})	^{232}Th (Bqkg^{-1})
Barikin Ladi	121.3060±6.40	39.8200±4.01	44.4640±2.39
Bokkos	86.0027±6.58	61.1043±4.37	63.8160±7.53
Jos South	116.3813±8.30	75.4343±4.83	62.0620±2.87
Average	107.8967±7.07	58.7862±4.40	56.7807±4.26
Worldwide*	**420**	**33**	**45**

*Adapted from UNSCEAR (2000)

The mean value of potassium-40 measured from the soil samples is far below the estimated worldwide value hence no possible radiological health implication. However the mean value of radium-226 and thorium-232 of Bokkos (40 Bq/kg) and Jos-south (61 Bq/kg)and Barikin-Ladi (45 Bq/kg same) are slightly greater than the worldwide estimated value.s

4.7.3 Assessment of radiological health hazards of the soil

The calculated values of the verge absorbed dose, effective dose, radium equivalent external hazard and internal hazard indices of the soil samples as compared with the average Worldwide values is presented in table 4.19

Table 4. 29: Comparism between Averages absorbed dose rate, effective dose rate, radium equivalent external hazard and internal hazard of the soil with the average worldwide values

Location	Mean Dose rate ($nGyh^{-1}$)	Computed Effective Dose rate (μSvy^{-1})	Values Radium Equivalent ($Bqkg^{-1}$)	External Hazard (H_{ex})	Internal Hazard (H_{in})
Barikin Ladi	51.3790	63.0548	113.4613	0.3293	0.8188
Bokkos	71.4463	87.6824	158.9834	0.4816	0.7146
Jos South	78.2443	96.0253	173.1444	0.6187	0.9332
Average	67.0232	82.2542	148.5297	0.4765	0.8220
Worldwide*Mean	**57**	**70**	**<370**	**<1**	**<1**

*Adapted from UNSCEAR (2000)

From the results (table 4.19), the soil average absorbed dose rate is slightly higher than the world wide average ($57nGh^{-1}$) value(Barikin-Ladi 51, less, Bokkos 71 high and Jos south 78 high)

Theaverage effective annual dose rate (Barikin-Ladi 63 lower, Bokkos 87 higher and Jos-south 96 higher than the world wide mean of 70 $82\mu Svy^{-1}$) of the soil samples.

For radiological assessment The external (H_{ex}) and internal (H_{in}) hazard indices (averaged 0.5 and 0.8 respectively), which represent the risk associated exposure to these radionuclides in the soil samples indicated that the associated risk to the samples is below the limit set by ICRP,(2000) and reported by UNSCEAR, (2000) For all radiation exposure, the radiological indices for H_{ex} and H_{in} should not exceed unity ($1mSvy^{-1}$) Barikin-Ladi, and Jos-south (0.8 and 0.9) slightly near unity with H_{in}, this may be due to the fact that they are located at the area with high level of radiation. In areas of high background radiation, the values of these radiological indices may exceed unity however; care should be taken since it is believed that radiation at any given level could pose risk that is there is no “safe dose.”

4.7.4 Assessment of The radioactivity concentration of TENORMs from the dry season vegetables samples

Table 4. 30:Determined mean Activity concentrations, average annual committed effective doses and Cancer risk of ^{40}K, ^{226}Ra and ^{232}Th in the vegetable samples of dry season

S/No	Vegetables	K-40 (Bq/kg)	Ra-226 (Bq/kg)	Th-232 (Bq/kg)	E*ave* (mSv/yr)	Dose to Man (50)yr (mSv)	Cancer risk $x10^{-3}$
1.	**Cabbage**	449.7665±6.63	27.56278±3.2	23.9073±0.8	0.2355±0.01	11.7767	0.58
2.	**Carrot**	278.2756±5.8	31.518±3.01	30.5587±0.42	0.2505±0.01	12.5272	0.63
3.	**Potatoes**	357.0244±5.75	32.5608±6.95	14.5192±1.10	0.1681±0.01	8.4041	0.42

The mean Activity concentrations, average annual committed effective doses Dose to man (50yrs) and Cancer risk factor of ^{40}K, ^{226}Ra and ^{232}Th determined in the vegetable samples of dry season is presented in table

It could be observed that there is no risk of cancer due to consumption of vegetables grown on the dry season farming system when compared with 6.0×10^{-3} and the risk is about 10% less.

Also it is important to note that the relative high value of the cancer risk is due to the annual consumption rate of the vegetables (26kg/annum) considered

4.7.5 Assessment of The radioactivity concentration of NORMs from the rainy season vegetables samples

Table 4. 31:Determined mean Activity concentrations, average annual committedeffective doses and Cancer risk of ^{40}K,^{226}Ra and ^{232}Th and in the vegetable samples of rainy season

S/No	Vegetables	K-40 (Bq/kg)	Ra-226 (Bq/kg)	Th-232 (Bq/kg)	E_{ave} mSv/yr	Dose to Man (50)y mSv	Cancer Risk $x10^{-3}$
1.	**Cabbage***	140.0726±0.91	30.0888±2.82	43.9757±3.04	0.3075c0.02	15.3730	0.77
2.	**Carrot***	77.9679±4.30	55.5041±4.05	61.1555±3.15	0.4187±0.02	20.9343	1.05
3.	**Potatoes***	88.6988±3.52	32.4836±2.84	62.0296±1.82	0.4089±0.02	20.4442	1.02

There is relatively no risk to cancer due to ingestion the NORSM front the vegetables consumed which are grown on the rainy season. Cancer risk coefficient determined was within the range of 6.0×10^{-3} which shows that area of study is in relatively high radiation zone.(Table 4.21)

The relative high value of the cancer risk is due to the annual consumption rate of the vegetables (26kg/annum) considered

4.7.6 The Chart of Mean Activity Concentration of the Seasonal Vegetables

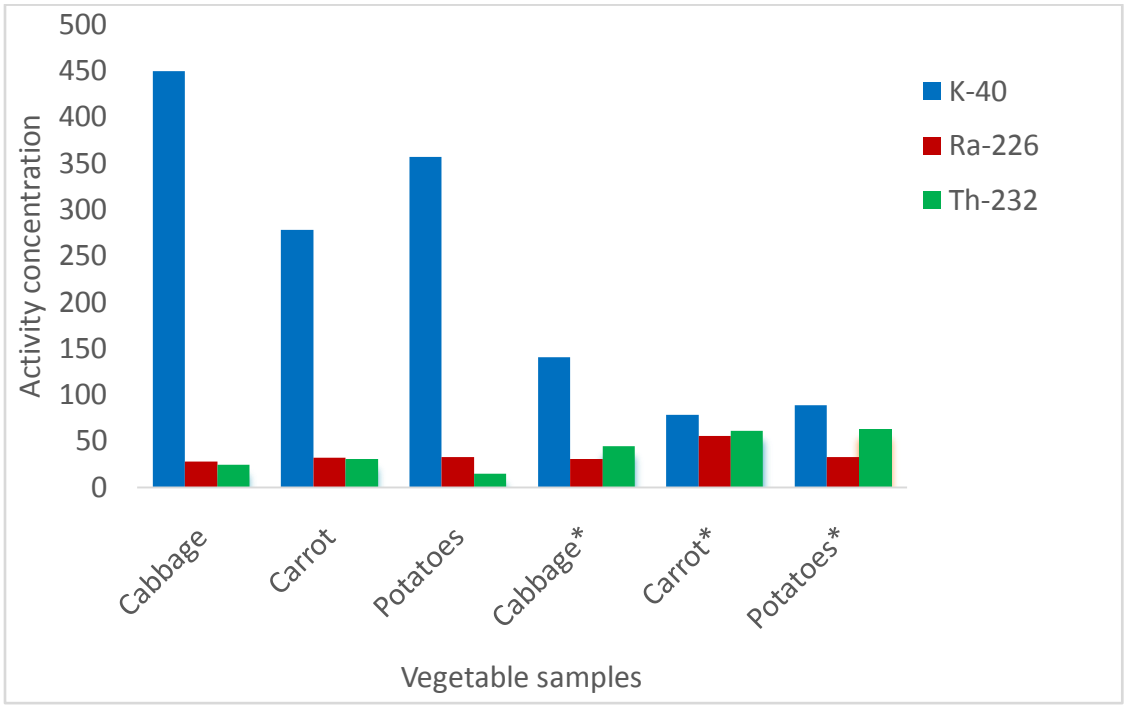


Figure 4. 17: Mean activity concentration of the seasonal vegetables

The average annual committed effective dose, $E_{ave,}$ for cabbage and carrot of dry seasons are 0.25 and 0.26 (mSv/yr) respectively which are within the recommended value of 0.30 mSv/yr received per head worldwide (UNSCEAR,2000) whereas the E_{ave} of potatoes for the dry season (0.18 mSv/yr) was below the recommended value. The average annual committed effective dose, $E_{ave,}$ for cabbage of rainy season, (0.30 mSv/yr) was found to be same with the recommended value. The carrot and potatoes of the rainy season, (having $E_{ave,}$ value of 0.43 and 0.41 mSv/yrrespectively) were slightly higher than the world wide recommended value of 0.30 mSv/yr

The resultsobtained were an overwhelmed projection to cover all anticipation and possibilities of ingestion of the NORMs. It is not likely a man could take any of the vegetables either at dry or rainy season for 12 month in his life time of about 50 years. If this is possible, then a consumption of 26 kg could not be possible over every year throughout the man's life time.

4.8 Discussions on INAA Elemental Concentrations Results

It could be seen that the result of the elemental concentration of soil for radioactive uranium Th-232 ranged from 5.5±0.2 to 13.9 ±0.2 mg/kg. This value is within the world value of

^{232}Th with $T_{½}$ = 1.41x10^{9} yrand natural radioactivity of 1.6 to 20 ppm in the common rock type with crystal average of 10.7ppmSource; (ISU Home, 2012)This clearly indicated that it is a mining zone and extra care should be taken to avoid unnecessary exposure in other to reduce cancer risk to the populace. This is because it decays by emitting both α and β particles with associated γ-rays thereby posing the health implication.

The elemental concentration of K-40 being 2608±110 to 2368±118ppm indicated a high measured value when compared with the world wide K-40 of $T_{½}$ = 1.28 x10^{9} yrwith natural radioactivity of Soil – 1-30pCi/g (0.037 – 1.1 Bq/g)(ISU Home, 2012)K-40 decays by emission of β-particles hence could pose a lot of radiological health implication if exposed to it.

Radium – 226 elemental concentration may be present in very small quantity at the below detection limit. The measured concentration of Radium -226 of $T_{½}$ = 1.6x10^{3} yr with natural activity of0.42 pCi/g (16Bq/kg) in limestone and 1.3 pCi/g (48 Bq/kg) in gaseous rock (ISU Home, 2012)

Concentration of some trace, toxic and radioactive elements in Jos Plateau soils with comparison data from China and World is presented in table 4.28 (in the data, values are in Arithmetic mean ± arithmetic standard deviation)

Table 4. 32: Concentration of some trace elements in Jos Plateau soils (mg kg^{-1} except for "Hg, which is µg kg^{-1}) with comparison data from China and World

Elements	Jos Plateau soils	*China soils	$World soils
Ag	NA	0.105	NA
As	0.69±0.03	9.200	(11.30)
Ba	162.61±27.72	450.000	NA
Be	NA	1.820	6.00
Cd	BDL	0.074	0.40 (0.62),
Cr	134.89±5.67	53.900	50.00
Ca	57663.11±2327.06	20.000	12.00
Hg	NA	40.000	60.00 (98),
Mn	635.11±2.44	482.000	450.00
Mo	NA	1.200	1.50
Ni	NA	23.400	25.00
Pb	NA	23.6000	15.00 (29.2),
Sb	4.07±0.57	1.060	(<0.90)
Se	NA	0.220	(0.40),
Zn	89.72±7.67	67.700	40.00
U	9.28±0.20	NA	**0.50-4.70
Th	16.14±0.20	NA	**1.60-20.00
V	53.33±3.56	NA	NA
K	1183717.67±151.00	NA	NA
Ti	4835.33±259.11	NA	NA
Rb	76.74±4.67	NA	NA
Mg	7716.06±786.83	NA	NA
Fe	26146.67±261.56	NA	NA
Al	28294.56±409.56	NA	NA

BDL; Below Detection Limit

NA; Data not available

**ISU, Home (2012)

***$**Ming Chen, et al (1999) {Geometric mean reported by Berrow and Reaves, 1984, and arithmetic mean reported by Fergusson, 1990 (in bracket)}

From table 4.28, the elemental concentration mg/kg of the soil of Jos,Plateau , Nigeria revealed that; Ca,(57663) is high compared with (20 and 12,China and world soils), As, (0.69) is low compared with (9 and (11),China and world soils), Ba (162)is low compared with (450.000 and NA,China and world soils), Cr (135) is highcompared with (54 and50,China and world soils), Mn (635) is highcompared with (482 and 450,China and world soils)Zn (90) is relatively high compared with (67 and 40,China and world soils), Sb (4) also highcompared with (1 and (<0.90),China and world soils)

Also elemental concentrations of radioactive U (9) and have higher values than the world one (4) while Th (16) had value less the worldwide values (20)

The mean concentration of macro and micronutrients and toxic elements showed variations among different vegetables collected from the sites. Macronutrients (K, Ca and Fe) are abundant in all the three type of vegetables. Calcium is present in higher concentration in leafy vegetables than others. Iron is present in small quantities in all types of samples compared to other macronutrient and lowest concentration is found in Br. Among the micronutrient Cu and Zn are abundant in all varieties and concentration of zinc is high compared to Manganese (Mn) and Selenium (Se). Mn is present in all the vegetable samples with moderate concentration (4.7-7.6 mg/kg). Vanadium is present in all the vegetables, Cabbage, Potatoes and Carrot while Cr is present in all, and in lower concentration. Co and Na are found in all the vegetables with lower concentration and within the permissible limit (Codex General Standard for Contaminants and Toxins in Food and Feed 1995).Toxic element like As (3.45-5.55mg/kg), Tb (2.95-2.6 mg/kg)Se (686.5-1254 mg/kg) and Al(9705-42875 mg/kg) are present in almost all varieties of samples but concentration of As and Tb is very low to contribute any toxic effect.

On the other hand potassium element K (1183717.67±151.00 mg/kg) showed comparatively higher value than the others which may be attributed to plants grown on the agricultural lands located near high ways. Cadmium is a dangerous element and not detected (BDL) because it can be absorbed via alimentary tract; penetrate through placenta during pregnancy and damage membranes and DNA. (Wagner 1993) reported that vegetables may contribute to about 70% of Cd intake by human varying according to the level of consumption

CHAPTER FIVE

5.0 SUMMARY, CONCLUSION AND RECOMMENDATION

5.1 Summary

Radioactivity concentrations of TENORMs from the soil of the degraded mine tailing, vegetables grown on the soil and vegetables grown away from the mine tailings were successfully determined in the work using gamma ray spectroscopy with NaI(Tl) detector. The elemental concentrations of the same set of samples were also successfully determined using NAA (NIRR-1) techniques. The following summary can be derived from the research:

i) The soil activity concentration of TENORM in Barikin-Ladi determination was K-40>Th-232>Ra-226 in decreasing order, in Bokkos, the decreasing order activity concentration of TENORM was K-40>Th-232>Ra-226 while in Jos south, K-40>Ra-226>Th-232

ii) The highest total activity concentration of all the TENORM in the soil determined was at Jos south (K-40, 177 Bq/kg) with the least at Barikin-Ladi (Ra-226, 35 Bq/kg)

iii) The absorbed dose rate and effective dose rate and Radium equivalent of the soil were found to be slightly higher (67 and 82) than the average worldwide values (57 and 70) ‘ nGy/h, µSv/y’ respectively

iv) and Radium equivalent of the soil were found to be highly less (148) than the average worldwide (370) values ‘Bq/kg’

v) The internal health risk index for the soil of BLDS1 is about 10% higher than 1, the recommended value and this may be due to high activity of K-40 (177Bq/kg) There is no potential cancer risk since K-40 did not exceed the recommended value of 420 Bq/kg and potassium is required for maintenance and building of cells in the bodies.

vi) The internal health risk index for the soil of JJS2 is about 5% higher than 1, the recommended value and this may be due to high activity of K-40 (122 Bq/kg) and Ra-226 (98Bq/kg) There is no potential cancer risk since K-40 did not exceed the recommended value of 420 Bq/kg and potassium is required for maintenance and building of cells in the bodies

vii) The activity concentration of TENORM from the vegetable collected during the dry season farming revealed that K-40>Ra-226>Th-232 in decreasing order (362 > 31 > 23 Bq/kg) with highest concentration of the leafy cabbage (450 Bq/kg)

viii) The activity concentration of the TENORMs (rainy season) in the potatoes was K-40>Ra-226>Th-232 (140 > 43 > 30) while that of carrot was K-40>Ra-226>Th-232 (78 > 61 > 56) The activity concentration of TENORMs of cabbage(K-40 > Th-232 > Ra-226: 89 > 62 > 32) 'Bq/kg'

ix) The determined average annual committed effective dose, $E_{ave,}$ for cabbage and carrot of dry seasons were; 0.25 and 0.26 (mSv/yr) respectively whereas the E_{ave} of potatoes for the same season was (0.18 mSv/yr)

x) For the rainy season vegetables the determined average annual committed effective dose, $E_{ave,}$ for cabbage, carrot and potatoes were; (0.30 mSv/yr), (0.43 mSv/yr) and (0.41 mSv/yr) respectively.

xi) The determined Cancer risk of dry season vegetables, cabbage, carrot and potatoes (0.58, 0.63 and 0.42 $x10^{-3}$ Sv respectively) were below recommended value 6.0 $x10^{-3}$ Sv

xii) The determined Cancer risk of rainy season vegetables, cabbage, carrot and potatoes (0.77, 1.05 and 1.02Sv respectively) were below recommended value 6.0 $x10^{-3}$ Sv

xiii) Although the activity concentration of Ra-226 and Th-232 are slightly above the recommended value from the soil, the radiological indices are below unity hence the soil of the degraded tin mine field has low or no health hazard risk.

xiv) Small amount of thorium (< 1.0 mg/kg) was detected in the soil was at below detection limit (BDL) in both the dry and rainy season vegetables

xv) Uranium elemental concentration was at below detection limit (BDL)in all the samples and Radon was not detected in all the samples.

xvi) High concentration of tin, non-essential element (5507 mg/kg)was recorded in the soil butwas at below detection limit (BDL) in the vegetables.

xvii) Potassium, a major element and indispensable to living cells was found in all the samples and highest at dry season vegetables (361 Bq/kg) and low in rainy season vegetables (102 Bq/kg)

xviii) Arsenic was below detection level at dry season but determined in small quantities from the soil and rainy season vegetables.

xix) Other toxic elements like chromium and vanadium were detected ranging from below detection level to small valuesinall samples. V ; 53, Cr; 135 soil, V;19, Cr;1 mg/kg vegetables)

xx) Higher daily intakes of metals (DIM) are determined with highest chlorine and least (0.17 mg/kg) Bromine: (Cl > Zn> Al >Mg> K > Se; 18660, 12948, 8365, 2208, 1965, 276 mg/kg)

xxi) The determined health risk index (H_Q) have higher values of Cl (207.333mg/kg), Zn(143.8667mg/kg), Al(92.9444), and Mg(24.5417mg/kg) which were above the safe value Charya,et al (2008)

xxii) Toxic element like As (3.45-5.55mg/kg), Tb (2.95-2.6 mg/kg)Se (686.5-1254 mg/kg) and Al(9705-42875 mg/kg) are present in almost all varieties of samples but concentration of As and Tb is very low to contribute any toxic effect

xxiii) High values of Transfer factor (T_f) determine from the work cabbage , carrot and potatoes were; Co(57,12 and 09), Yb(25,26 and 38), Th(18, 20 and 24), Sb(15, 08 and 31) and Sm(10. 9 and 11)

5.2 Conclusion

It can be concluded from this work that:

i) The mean absorbed dose rate of the soil measured 1m above the ground slightly higher, indicated increase of absorbed dose rate from the soil to the head (containing delicate organs) as farmers bow down to weed in the degraded farm land (determined 67 and recommended 57 Bq/kg) from UNSCEAR (20000).

ii) There is slightly high effective radiation dose rate on the soil of the degraded mine field farm land than the recommended values (determined 82 and recommended 70 Bq/kg) from UNSCEAR (20000).

iii) The average annual committed effective dose, $E_{ave,}$ for cabbage and carrot of dry seasons are 0.25 and 0.26 (mSv/yr) respectively which are within the recommended value of 0.30 mSv/yr received per head worldwide (UNSCEAR,2000) whereas the E_{ave} of potatoes for the dry season (0.18 mSv/yr) was below the recommended value.

iv) The average annual committed effective dose, $E_{ave,}$ for cabbage of rainy season, (0.30 mSv/yr) was found to be same with the recommended value. The carrot and potatoes of the rainy season, (having $E_{ave,}$ value of 0.43and 0.41 mSv/yrrespectively) were slightly higher than the world wide recommended value of 0.30 mSv/yr

v) The proportions of some radionuclides were incorporated via the roots into the vegetables by chemical similarities with other element that plants need for their growth.

vi) High potassium elemental content is observed on vegetables of dry season and

vii) There is no potential cancer risk to consume vegetables grown in both the dry and rainy season

viii) The elemental health risks of major element were above the safe value. This result agreed with a similar finding by Charya et al,(2008)

ix) High values of Transfer factor (T_f) of non-essential elements were determined from the work for the vegetables (cabbage , carrot and potatoes)

5.3 Recommendation

i) Farmers should use long Implement to maintain distance to head >1m so as to reduce exposure to the delicate tissue the eye.Therefore extra care should be taken to avoid unnecessary gamma radiationabove the ground uniformly distributed from the TENORM.

ii) Similar studies should be carried out to assess the radioactivity and elemental concentrationon some more stable food crops eaten in most Nigerian home, such as guinea-corn, maize, rice, millet sweet potatoes, yam, and cassava. This should be done in areas particularly that have witnessed one form of mining or the other.

iii) It will also be of great importance to extend such work to other vegetables like cucumber, lettuce, tomatoes green beans, garden eggs and water melons that are produced of the newly reclaimed farm land during both farming seasons that are marketed all over Nigeria.

iv) Methods of further enhancing the uptake of essential elements by crops grown during wet season should be sought for

v) Type of fertilizers and agro chemicals required for growing of vegetables should be looked into

vi) Radiation protection is routinely carried out as such similar research especially on the degraded mine field should be carried out in future

vii) Farm land containing arsenic Zinc, Chromium and Vanadium should be discouraged in the use of agricultural crop production

viii) The vegetables of the dry season can be recommended to persons that require more potassium content

ix) A similar work should also be carried out with yet different measuring techniques apart from those used to find out if the results could vary

x) The vegetables of the dry season can be recommended to persons that require more potassium content

xi) Radiation protection officers should take advantage to advice on the advantages and implication of these TENORM and how their concentrations could constitute to human health.

xii) NIS, SON and NAFDAC should take advantage of this research and other similar data to develop a standard for Nigerian agricultural produce. Such standard should conformto internal standards advocated by specialized and recognized bodies like NCRP, IAEA and UNSCEAR.

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APPENDICES

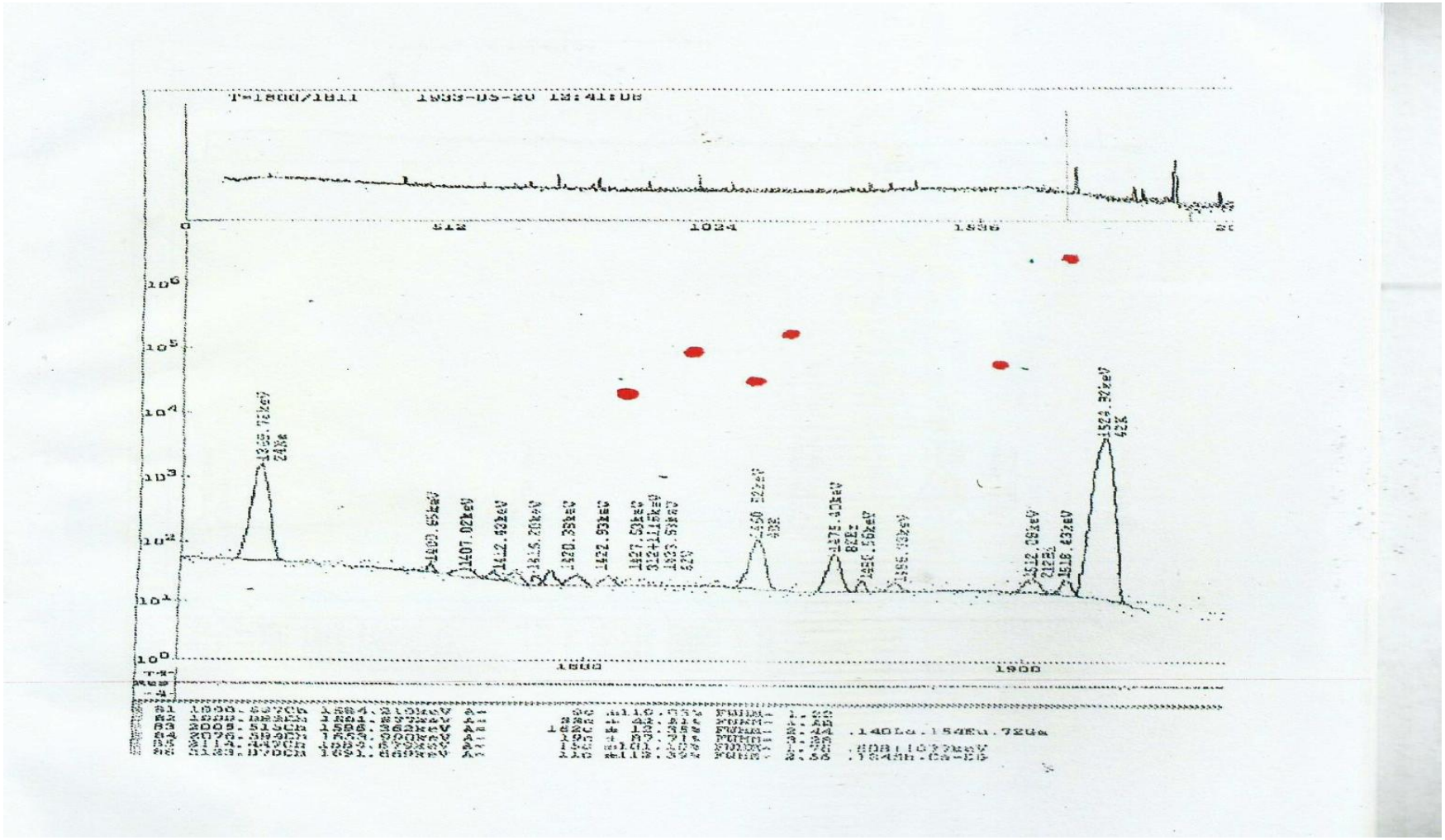


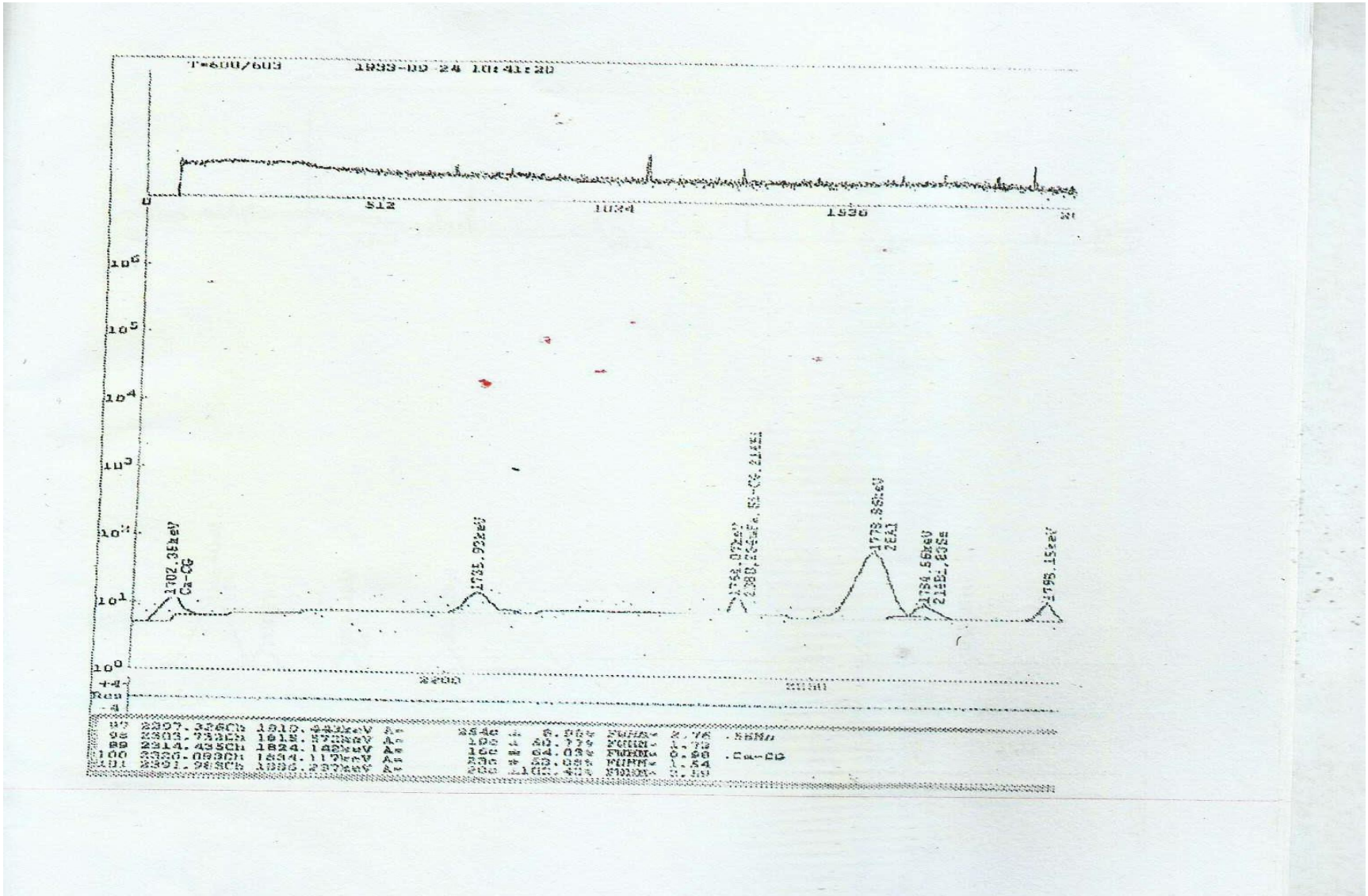
Plate VIV:A newly reclaimed minefield farmland in Jos-Plateau

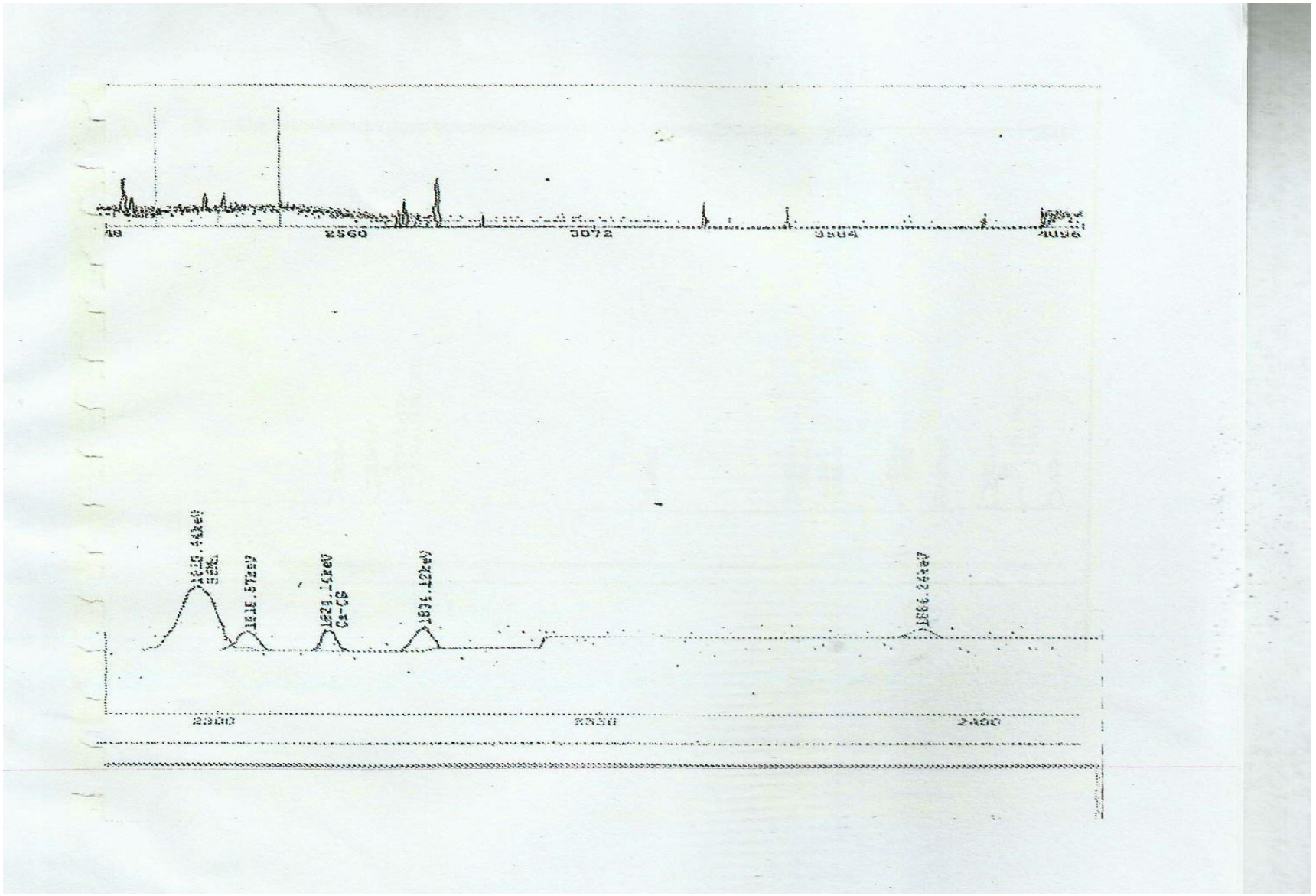


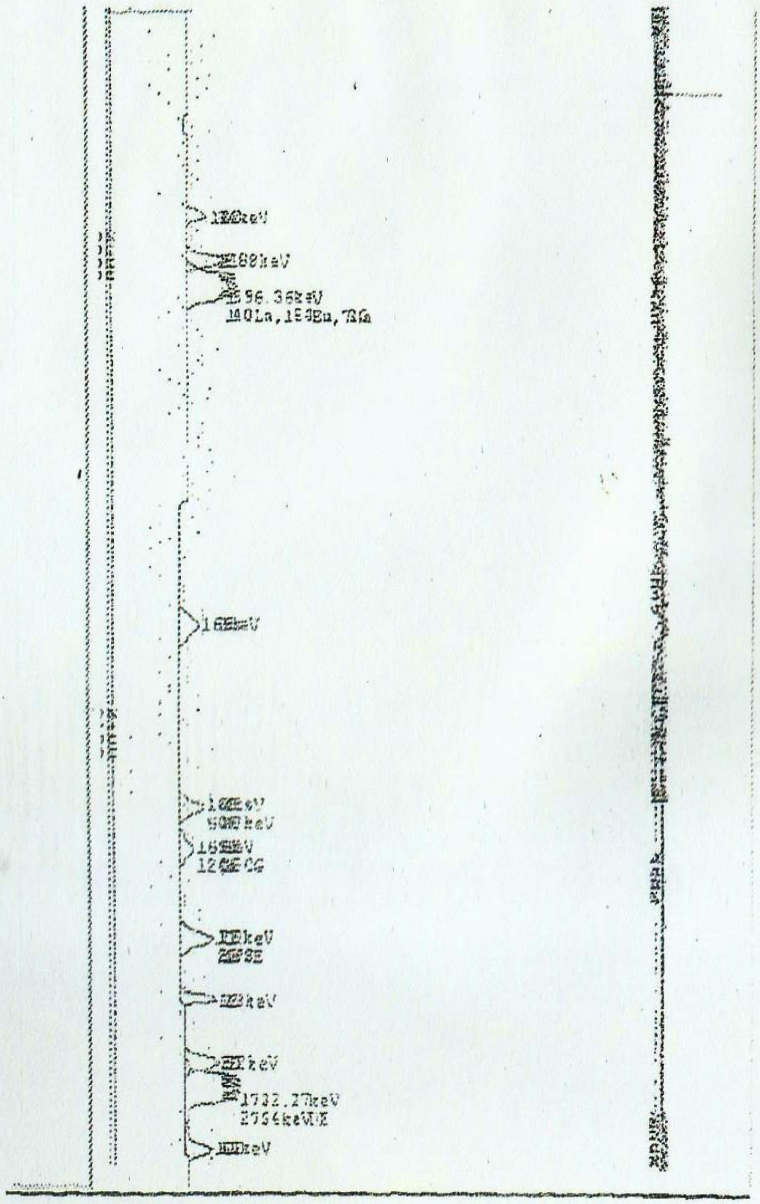
Plate VIVI:A reclaimed minefield farmland close to a mining pond in Jos-Plateau

Appendix III: CABBLD Spectrum




T=600/600
1999-09-24 10:41:20
512
1024
1536
2048
10^6
10^5
10^4
10^3
10^2
10^1
10^0
1702.35keV
Ca-CO
1735.92keV
1778.88keV
2EA1
1784.56keV
2118Z,60Se
1795.15keV
Ca-CO


2560
3072
1630.44keV
1631.57keV
1629.15keV
1631.12keV
1636.99keV
2300
2550


96.36keV
140La,149Eu,TBa
1732.27keV
2754keV