RADIOLOGICAL HAZARD LEVELS BY THE GAMMA RAY EMITTING NATURALLY OCCURING RADIOISOTOPES IN SELECTED FISH SPECIES OF LAKE ALBERT IN UGANDA

BY

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DECLARATION

I Jimmy Kayanja declare that the work presented in this study is original and has not been presented to any University for an academic award.

Signed.....

Date.....17/10/2017.....

APPROVAL

This is to certify that the study by Jimmy Kayanja was carried out under our supervision and the report is now approved for submission to the Board of Graduate School and Senate of Kyambogo University.

Signed: .....

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Date: October 17th 2017

Signed: .....

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Date: 17th October 2017

DEDICATION

This study is dedicated to my fiancée Ms. Uwera Sharon and my lovely daughter Mitchelle Joslyn for their treasured care and encouragement during the period of the programme.

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ABSTRACT

A study was conducted for natural radioactivity in some fish samples from Lake Albert, shared by five riparian districts namely Ntoroko, Kibaale, Hoima, Buliisa and Nebbi, located in the western part of the great rift-valley. Radioactivity is a phenomenon that leads to production of ionizing radiations and these are known to trigger or induce cancer. The fish were analyzed to estimate the radioactivity (activity) concentrations due to natural radionuclides Thorium (^{232}Th), Radium (^{226}Ra) and Potassium (^{40}K).

The Gamma ray spectrometry technique was used in the spectral collection and analysis of the prepared fish samples using the Thallium activated Sodium iodide scintillator (NaI (TI)), GDM 20. The detector produced readings of Standard Deviation (S.D), Full Width at Half Maximum (FWHM) in keV, Rate(R), number of radionuclides (n) in each peak interacting with the crystal and live time (t) in seconds from which the raw data was obtained for the computation of the Activity concentrations, Dose Rates, Annual Effective Dose and Radiological Hazard Indices due to ^{232}Th, ^{226}Ra and ^{40}K in fish samples using mat lap program and Microsoft excel 2010 (spread sheet)

The result of this study showed that the activity concentrations of ^{232}Th ranged from 3.27±0.29Bqkg^{-1} to 7.64±0.46Bqkg^{-1} with an average concentration of 5.16±0.37Bq/kg, ^{226}Ra ranged from 27.22±2.13Bqkg^{-1} to 41.75±2.69Bqkg^{-1} with a mean of 33.10±2.41Bqkg^{-1} and ^{40}K ranged from 392.52±11.07Bqkg^{-1} to 465.64±13.01Bqkg^{-1} with a mean value of 435.16±12.01Bqkg^{-1}.According to the results obtained in this study, mean activity concentrations of the radionuclides increased according to the order ^{232}Th < ^{226}Ra < ^{40}K and these were lower than the worldwide maximum permissible values of 50, 50 and 481Bqkg^{-1} respectively for ^{232}Th, ^{226}Ra and ^{40}K in fish.

The absorbed dose rate for ^{232}Th in all the species analyzed ranged from 1.593nGyh^{-1} to 3.495nGyh^{-1} with the average value of 2.485nGyh^{-1}. For the dose rate due to ^{226}Ra radioisotope in the fish species ranged from 15.185nGyh^{-1} to 21.736nGyh^{-1} with the average value of 18.454nGyh^{-1}. Also the dose rate due to ^{40}K radioisotope in the species ranged from 16.368nGyh^{-1} to 19.335nGyh^{-1} with the average value of 18.149nGyh^{-1}. All of these values

obtained were lower than the world-wide permissible value which is approximately 46nGyh^{-1} and therefore pose a negligible radiological health hazard. The annual effective dose due to ^{232}Th radioisotopes in all the fish species ranged from 0.006mSvy^{-1} to 0.015mSvy^{-1} with the average value of 0.015mSvy^{-1}. That of ^{226}Ra, ranged from 0.037mSvy^{-1} to 0.053mSvy^{-1} with the average value of 0.045mSvy^{-1}. For ^{40}K radioisotope, the annual effective dose ranged from 0.041mSvy^{-1} to 0.048mSvy^{-1} with the average value of 0.045mSvy^{-1}. All of these values obtained were lower than the world-wide maximum permissible value that is approximately 0.07mSvy^{-1} thus posing negligible radiological hazards to the public.

The internal hazard index due to ^{232}Th varied from 0.012 to 0.029 with the average value of 0.020. That of ^{226}Ra, varied from 0.147 to 0.213 with the average value of 0.179. Furthermore the index due to ^{40}K radioisotopes in the samples ranged from 0.076 to 0.089 with the average value of 0.084.This average value was less than the world wide maximum permissible value of 1.0. The work showed that consumers of fish from Lake Albert have a negligible risk of radioactivity ingestion, even though no amount of radiation is assumed to be totally safe.

CHAPTER ONE: INTRODUCTION

1.1 Background to the Study

Lake Albert is currently the second most productive lake in Uganda after Lake Victoria in fish production (Walker, 1972). It's shared between Uganda (60% by area) and Democratic Republic of Congo. In Uganda, the lake is shared by five riparian districts namely Ntoroko, Kibaale, Hoima, Buliisa and Nebbi. The lake covers a total surface area of 5,270km^2 with approximately 60% within Ugandan waters. It's located in the western part of the great rift-valley at an altitude of 618m above the sea level. It's Africa's seventh largest lake. The central parts of the lake are characterized by steep escarpments whereas the northern and southern parts lie in a plain of the rift-valley. The major inflowing rivers are Semliki and Kafu in the south, and the Victoria Nile at the northern tip (Walker, 1972).

The lake has a diverse fish fauna with a gradient of multi- species fisheries in different parts of the lake and the fish species that are of most commercial and subsistence exploitation in Uganda include species of Lates (Nile perch), Oreochromis (Nile tilapia), Singidia tilapia, the herring-like Alestes, the catfishes Bagrus and Clarias, Hydrocynus (Tiger fish), Eels, Sprat, Silver fish, Lungfish (NaFIRRI, 2012).

East Africa's Albertine Rift represents significant oil reserves, specifically underneath Lake Albert. While the oil resides underneath the lake, oil companies use technology that allows drilling to occur from the shoreline at a diagonal in order to gain access to the lakebed reserves. This method of oil extraction has significant humanitarian implications since it raises the radioactive contamination in the aquatic environment. Ituri district in the DRC essentially operates as a shadow state with little oversight from the central government, hence creating a vulnerable environment for the population that lives within the oil concessionary plot. Additionally, Uganda hosts a substantial refugee population that originates from the DRC (Kathryn, 2013). This means that a large population living within the region is exposed to radiation doses following the dependence on the lake water, fish and sand. See Figure 1.1 for details of the villages within oil concessionary plot of Lake Albert.

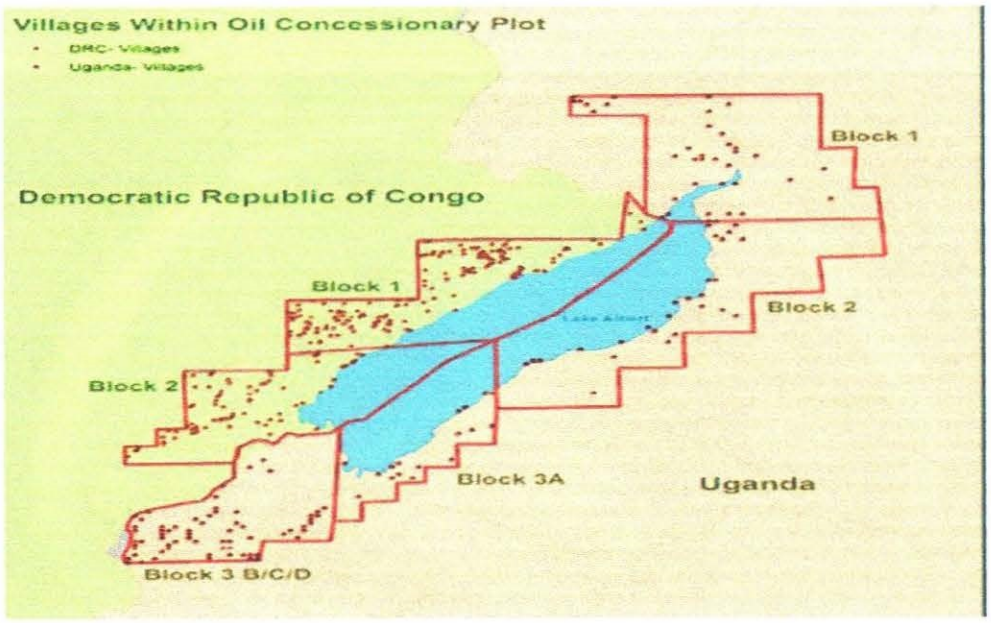


Figure 1.1: Map of Lake Albert and demarcation of blocks within oil Concessionary Area (Kathryn, 2013)

Most fish species exchange gases using gills on either side of the pharynx. Gills consist of threadlike structures called filaments and each filament contains a capillary network that provides a large surface area for exchange of oxygen and carbon dioxide. Fish exchange gases by pulling oxygen-rich water through their mouths and pumping it over their gills. In some fish species, capillary blood flows in the opposite direction to that of water inside causing countercurrent exchange. The gills push the oxygen-poor water out through its openings in the sides of the pharynx. However, bony fish have a single gill opening on each side. This opening is hidden beneath a protective bony cover called an operculum. Some fish species have evolved accessory breathing organs that extract oxygen from the air. Breathing in air is primarily of use to fish that inhabit shallow, seasonally variable waters where the water's oxygen concentration may seasonally decline and the Fish that solely depend on dissolved oxygen in water include Nile perch and cichlids which when exposed in mud quickly suffocate than the air-breathing fish species. At the most extreme, some air-breathing fish species are able to survive in damp burrows for weeks without water by entering a state of aestivation (summertime hibernation) until water returns (Mallatt and Sullivan, 1998). See Figure 1.2 for details of the gill structure.

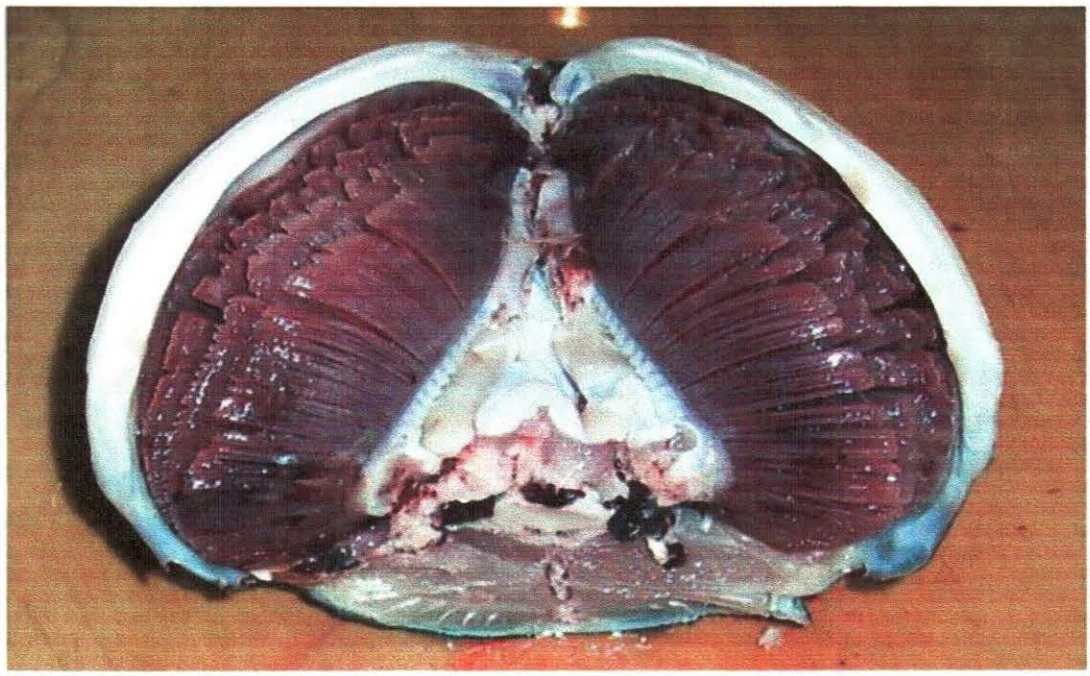


Figure 1.2: Picture of Tilapia gills (Mallatt and Sullivan,1998)

Jaws allow fish to eat a wide variety of food, including plants and other organisms and they ingest food through the mouth and break it down in the oesophagus. While in the stomach, food is further digested and in many fish, processed into finger-shaped pouches called pyloric caeca, which secrete digestive enzymes and absorb nutrients. Organs such as the liver and pancreas add enzymes and various chemicals to the food as it moves through the digestive tract. The intestine completes the process of digestion and nutrient absorption(Mallatt and Sullivan,1998).

Radioactivity is the property of spontaneous disintegration or decay of atomic nuclei accompanied by the emission of ionizing radiation. The nature, energy, charge and penetrating power of radiation is of relevance to the consequences of biological exposures. The term radionuclide applies to all radioactive isotopes of all elements. Whereas radioisotope strictly refers to the radioactive isotope of an element having other isotopes of similar chemical properties but differing nuclear properties. These may include both stable and radioactive isotopes. The major forms of ionizing radiation emitted during radioactive decay are alpha particles, which are essentially charged helium

nuclei, beta particles that are electrons and gamma rays which are photons or electromagnetic waves. Most naturally occurring radionuclides are alpha particle emitters (Uranium-231 and Radium-226), but some beta particle emitters also occur naturally (Radium-228 and Potassium-40). Man-made radionuclides are mainly beta and photon (gamma) emitters. Tritium is a beta particle emitter that may be formed naturally in the atmosphere or by human activities (OEPA, 2005).

Natural radioactivity is derived from the decay of nuclei in the Earth's crust and by the bombardment of the Earth by cosmic radiation producing radionuclides in the Earth's atmosphere. These natural radionuclides fall into three categories: the very long-lived primordial radionuclides (^{40}K, ^{238}U, ^{232}Th, ^{235}U) formed at the time the Earth was created, decay chain radionuclides (radionuclides in the uranium, thorium and actinium decay series) that are the products of decay of primordial nuclides and cosmogenic nuclides produced by the interaction of high energy cosmic radiation with the Earth's atmosphere (EPA, 2007).

Naturally occurring radionuclides namely ^{226}Ra, ^{232}Th and ^{40}K exist in the environment and releases from fertilizers, agrochemicals and research test form the bulk of radionuclides in ground and surface water (Wisser, 2005). Naturally occurring radioactivity are due to bedrock formations which are weathered, resulting in mineral leaching that leads to contamination (Martin S. et al, 1995). Artificial radioactivity is due to human activities, mainly as a result of agriculture, medicine, power production and research as well as other activities like mining and milling of mineral ores which exposes the earth surface. All this contamination may have health effects that pose great danger to human and other living organism in the biosphere (Samer *et al.*, 2008).

Biological effect starts when molecules in living cell interact with radiation energy through deposition and or exposure. If a large dose is delivered in a short period, symptoms of a cute radiation injury occurs. When delivered dose is much smaller and repeated for longer time, the biological effects may not appear for many years. These effects can be classified as direct or indirect effects. Direct effects occur when ionizing radiations cause excitation in the same molecule where the radiation is primarily deposited and absorbed. While indirect effects occur when ionizing radiation is absorbed

(for example) in water molecule in human body and produces short lived chemically reactive products i.e. radicals that react with other molecules in other parts of the body (Thermod and Maille, 2003). In an effort to minimize radiation exposure to members of the public, limits on exposure to ionizing radiation have been set (ICRP, 1991). Hence, it is necessary to measure radiation dose in order to monitor the effects of nuclear radiation on biological tissue (Shikali, 2008)

Radiation energy emitted when a radionuclide decays affects the living tissue only when it is absorbed in that tissue. Radionuclides can be more hazardous to living tissue when they are inside an organism where radiation energy released can be immediately absorbed. They can also be hazardous to an organism that is closer radioactive source through external exposure and frequent inhalation. Radionuclides move from the environment into the living tissue through different pathways: air, water (both ground water and surface water) and the food chain. Knowing these pathways make it possible to take necessary control measure to reduce their intake by aquatic animals, terrestrial animals and human beings to minimal levels (Sowole, 2014). Lake Albert's watershed geology is made up of pre-Cambrian-aged metamorphic rocks, Cretaceous sedimentary rocks, sequences of Neogene and Quaternary lacustrine and fluvial deposits that are sources of radioisotopes to the aquatic environment.

1.2 Problem Statement

In Uganda there is currently no readily available information on the Radiological hazard levels in the fish species from the natural lakes. Many of the natural water bodies in Uganda, Lake Albert inclusive have the likelihood of containing Naturally Occurring radioisotopes that are gamma emitting due to their interaction with rocks and minerals such as Thorium and Uranium and the respective progenies that constitute their basins. Lake Albert's watershed geology is made up of pre-Cambrian-aged metamorphic rocks, Cretaceous sedimentary rocks, sequences of Neogene and Quaternary lacustrine and fluvial deposits. Also the water runoff from the rocky hills of the western rift valley flows into the lake all these are sources of radioisotopes to the aquatic environment. The naturally occurring radioisotopes decay by emission of particles containing high energy gamma rays to attain stability that accumulate in the aquatic environment and this is exposed to the aquatic organisms with the fish species inclusive.

Lake Albert is of enormous importance to the local population as a source of utility water, fish, and sand. Long term exposures to radioactivity and inhalation of radioisotopes have serious health effects such as chronic lung cancer and leukemia to humans (Qureshi et al, 2014). Therefore, this study was carried out to measure and evaluate the Radiological hazard levels due to naturally occurring radioisotopes that are gamma ray emitting in the selected fish species collected from the selected fish sampling sites of Lake Albert.

1.3 Purpose of the Study

The aim of this study was to investigate the radiological hazard levels due to naturally occurring radioisotopes in the fish species collected from the selected sampling sites of Lake Albert.

1.4 Objectives of the Study

The objectives of this study were:

a) To identify the radioisotopes present in the selected fish species of Lake Albert.

b) To determine the Activity Concentrations (Specific activities) of the naturally occurring radioisotopes present in the selected fish species of Lake Albert.

c) To compute the Absorbed Dose rates of the naturally occurring radioisotopes present in the selected fish samples.

d) To compute the Annual effective dose of the naturally occurring radioisotopes present in the selected fish samples.

e) To calculate the level of health hazards based on radiological internal indices of the naturally occurring radioisotopes in the selected fish samples.

f) Compare the health hazard levels for different species of fish and locations.

1.5 Scope of the study

The study focused on the fish samples collected from the seven fishing sites on Lake Albert. The sites selected were Wanseko, Kaboolwa and Butiaba from Bulisa District and Nsonga, Kaiso, Tonya and Kibiro from Hoima District .The study also was limited to Tilapia, sliver fish, sprats, Catfish, Lungfish, Oreochromis, Clarias and Nile perch species. See Figure 1.3 for the details of the study area.

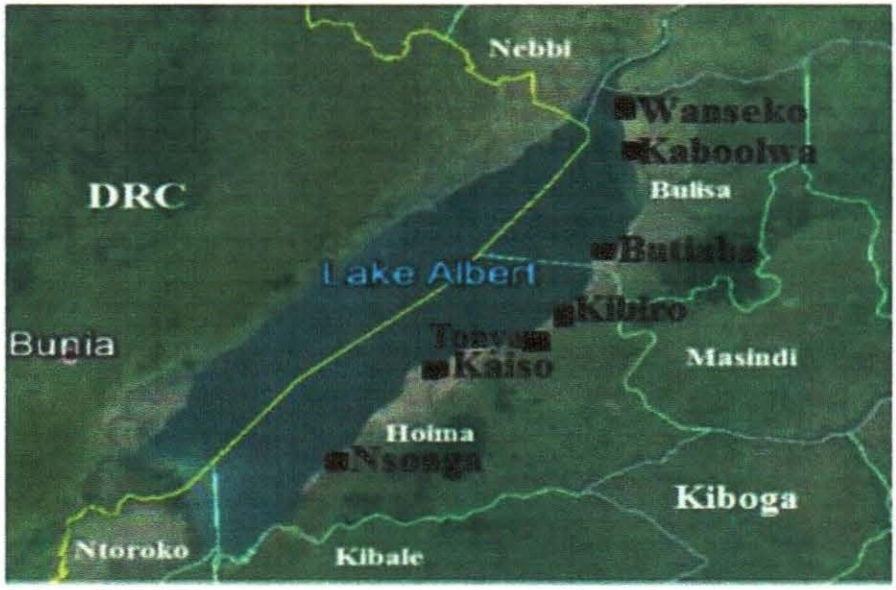


Figure 1.3: Map of Lake Albert region and the fish landing sites(Google Earth,2015)

1.6 Significance of the Study

a) The present study will establish the awareness to the public about the radioisotopes and radiological health hazards in the fish species of Lake Albert.

b) The results of the study will provide information to Uganda Atomic Energy Council (AEC), the regulatory authority mandated to implement radiation protection standards for the general population in Uganda basically in the consumption of the fish.

c) The study findings will serve as a source of reference as well as a frame of comparison by other researchers.

d) The recommendations of this study will lay a foundation for further research.

CHAPTER TWO: REVIEW OF RELATED LITERATURE

2.1 Introduction

The focus of this chapter is basically on the areas related to the study and these include the related literature, Radionuclide contamination of the Environment Impact of radioactivity products from Radioisotopes, Nuclear structure and stability, nuclear decay series and Measurement of Radioactivity.

2.2 Related literature

All living organisms are continually exposed to ionizing radiation from the naturally occurring Radionuclides in the environment. The sources of that exposure are cosmic rays that come from outer space and from the surface of the sun, terrestrial radionuclides that occur in the earth's crust, in building materials, in air, water, foods and in the human body itself. Some of the exposures are fairly constant and uniform for all individuals everywhere, for example, the dose from ingestion of potassium-40 in Foods. Other exposures vary widely depending on location. For example Cosmic rays are more intense at higher altitudes, and concentrations of uranium and thorium in soils are elevated in localized areas. Exposures can also vary as a result of human activities and practices. In particular, the building materials and design of houses and their ventilation systems strongly influence indoor levels of the radioactive gas radon and its decay products, which contribute significantly to doses through inhalation (IAEA, 2010). Some useful investigations have been carried out for assessment of public dose rates and the performance of epidemiological studies as well as keeping reference-data records to ascertain possible changes in the environmental radioactivity due to nuclear, industrial, and other human activities.

Adamu et al (2013) analyzed the activity concentrations of natural radionuclides in the fish of Kainji Lake, the activity concentration for ^{226}Ra, in all the samples collected ranged from 16.06±0.44Bqkg^{-1} to 67.39±12.34Bqkg^{-1} with an average value of 37.22±4.31Bqkg^{-1}. That of ^{232}Th ranged from 42.66±0.81Bqkg^{-1} to 200.6±10.66Bqkg^{-1} and the average value stood at 94.82±3.82 Bqkg^{-1}. The activity concentration for ^{40}K ranged between 243.3±1.56Bqkg^{-1} to 618.2±26.81Bqkg^{-1} and the average was

384.98±11.97Bqkg^{-1}. In all the fish samples analyzed, ^{40}K was observed to be higher compared to those of ^{232}Th and ^{226}Ra respectively. This could be attributed to variation in geological formations in the lake as while as the feeding habits of these fish. The work showed that consumers of fish from Kainji Lake have no risk of radioactivity ingestion, even though no amount of radiation is assumed to be totally safe.

Sowole O (2011) determined radioactivity concentrations and dose rates of ^{40}K, ^{226}Ra and ^{228}Ra in fishes as internal dose rates from major rivers in Sagamu, Ogun State Southwest of Nigeria. Fifteen samples of fishes were collected from three rivers: Majowopa, Ibu and Eruwuru. Tilapia zilli had the highest mean concentrations of ^{40}K and ^{226}Ra of values 89.13 ±6.83Bq/kg and 3.06 ± 0.26Bq/kg respectively. The highest mean concentration of ^{228}Ra was found in Papyrocranus afer with value 3.12 ± 0.29Bq/kg. The highest dose rates of ^{40}K and ^{226}Ra were obtained from Tilapia zilli with values of 0.00801mGy/yr. and 5.36 x 10^{-7}mGy/yr. respectively. For ^{228}Ra, Papyrocranus afer had the highest dose rate of value 3.50 x 10^{-13}mGy/yr. The average dose rate of the radionuclides in the fishes was calculated to be 1.74 x 10^{-3}mGy/yr. which is below the limit of 0.4mGy/h recommended by NCRP (1991) as reported by Blaylock *et al* (1993) and therefore do not pose radiological health problem to the aquatic animals.

Simon et al (2011) determined the activity concentrations of ^{238}U, ^{232}Th, and ^{40}K in water from Lake Bosumtwi and bore-holes in selected towns around the Bosumtwi basin of the Ashanti region of Ghana. The water samples from the lake contained the radionuclides with mean activity concentrations of 7.9mBq/L, 89.7mBq/L and 0.6mBq/L for ^{238}U, ^{40}K, and ^{232}Th respectively. The water samples from the boreholes recorded mean activity concentrations of 7.7mBq/L, 85.5mBq/L, and 3.3mBq/L for ^{238}U, ^{40}K and ^{232}Th, respectively. The annual effective dose calculated for the lake varied from 0.244μSv to 1.121μSv with an average of 0.763μSv and that calculated for the boreholes varied from 0.296 to 2.173μSv with an average of 1.166μSv. The radionuclides concentrations in water from the bore-holes and that of the lake, which serve as sources of water supply to the surrounding communities were negligible and pose no radiological hazards to the public.

Hosseini (2007) determined the natural radioactivity concentration in soil, drinking water and certain food items samples of Zahedan city in Iran. Also the absorbed dose was calculated across nearby five Sistan blouchestan cities in Iran. Results showed that the concentrations of ^{40}K, ^{238}U and ^{232}Th in the samples of the city varied from 396 ± 38.4 to 576 ± 57.4 Bq/kg with a mean of 473.3 ±40.7 Bq/kg for ^{40}K, whereas for ^{238}U and ^{232}Th values varied from 20.6 ± 2.3Bq/kg to 24.7 ± 3.6Bq/kg with a mean of 21.9 ± 2.8 Bq/kg and from 28.9 ± 3.3Bq/kg to 36.5 ± 3.6Bq/kg with a mean of 33 ± 3.7Bq/kg, respectively. The absorbed dose rate in the air across zahedan cities border ranged between 16±5nGyh^{-1} and 300 ±44nGyh^{-1} and the gross mean was 158.0 ± 24.5 nGyh^{-1}. It can be concluded that no risk threat the residents around and center Zahedan city and in above mentioned border.

Umar et al.(2012) determined the natural radioactivity in environmental samples (soil, vegetation and water)from the (Idu) industrial district of Federal Capital Territory (FCT) Abuja, Nigeria was measured to establish a baseline data for activity concentration of ^{40}K , ^{226}Ra and ^{232}Th. The highest activity concentration of ^{40}K, ^{226}Ra and ^{232}Th were found in soil collected from location S_2 (943.1Bq/kg), in vegetation v_c (82.3Bq/kg) and in soil collected from location s_3 (107.3Bq/Kg), respectively, where only the activity from s_2 is higher than the world average of 420Bq/kg and the highest activity concentrations of both ^{226}Ra and ^{232}Th from v_c (82.3Bq/kg) is above the world average of 50Bq/kg (UNSCEAR, 2000). Results also indicated that the activity concentration due to ^{40}K in the soil samples ranked highest against the lowest value obtained for sediments in the water samples.

Karahan et al (2000) determined the activities of eight well and five tap water samples taken in Istanbul were determined. ^{226}Ra, ^{222}Rn, ^{214}Pb, ^{214}Bi, ^{40}K, activity concentrations in four lakes, four sea water, one snow and one rain water sample were also analyzed in order to determine their radioactivity. The results obtained showed that, in general, natural activities in drinking water samples did not exceed WHO (World Health Organization) and ITS (Institution of Turkish Standards) guidelines. In sea and lake water, four samples were over WHO and ITS guidelines. Concentrations ranging from 0.007Bq L^{-1} to 0.04 Bq L^{-1} and from 0.02Bq L^{-1} to 0.1Bq L^{-1} were observed for drinking

water. An average annual effective dose equivalent of 0.84 $mSvy^{-1}$ for ^{226}Ra was calculated.

Kabir et al (2010) determined the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in water-hyacinth samples of Major water-bodies in the district of Jessore, Bangladesh. The activity concentration of ^{226}Ra range from 9.01 ± 1.08 to 96.77 ± 4.30$Bqkg^{-1}$ with mean value 31.51 ±17.22 Bq kg^{-1}. The activity concentration of ^{232}Th was found to range from 20.89 ±1.23Bq kg^{-1} to 59.10 ± 10.47Bq $kg^{-1}$with mean value of 34.74 ± 11.63 Bq kg^{-1} and that of ^{40}K from 319.29 ± 72.59 to 1227.08 ±88.74 $Bqkg^{-1}$.The mean value being 761.52± 262.54 $Bqkg^{-1}$. It is also observed that the measured activity concentration of ^{40}K exceeded markedly the values of both radium and thorium. Results showed that in all the water-hyacinth samples ^{40}K represented more than 80% of the natural radioactivity.

Kabir et al (2008) determined the activity concentrations of ^{226}Ra , ^{232}Th and ^{40}K in sediment samples collected from water-bodies of the district of Jessore Bangladesh ranged from 23.10±1.53$Bqkg^{-1}$ to 61.76±2.18$Bqkg^{-1}$, 19.71±5$Bqkg^{-1}$ to 85.36± 6.8$Bqkg^{-1}$ and 254.46 ± 43.38Bq kg^{-1} to 986.48 ± 42.86$Bqkg^{-1}$ with the average value of 42.90 ± 11.05$Bqkg^{-1}$, 47.85 ± 14.26$Bqkg^{-1}$ and 502.73±146.36$Bqkg^{-1}$ respectively. Calculated radium equivalent activity and absorbed rate were found to be 155.85±30.96$Bqkg^{-1}$ and 71.71 ± 18.48$Bqkg^{-1}$, respectively. The results were compared with those of different countries of the world and Bangladesh.

2.3 Radionuclide contamination of the Environment

Sources of radioactivity in the aquatic environment include naturally occurring radionuclides present in earth crust, runoff from watersheds that have received atmospheric deposition, radioactive effluents from medical, industrial and nuclear facilities released either accidentally or routinely. Depending upon the element and the chemical form, radionuclides may accumulate in bottom sediment or remain in the water column in the dissolved state. From either location, they can subsequently accumulate in biota and be transferred through the aquatic food chain. Contamination of the environment by radionuclides inevitably results in an increase in the radiation exposure of natural populations of organisms that occupy the contaminated area. Aquatic

organisms receive external radiation exposure from radionuclides in water, sediment, and from other biota such as vegetation. They also receive internal radiation exposure from radionuclides ingested via food and water and from radionuclides absorbed through the skin and respiratory organs (Blaylock et al, 1993).

Living organisms are continually exposed to ionizing radiation, which has always existed naturally. The sources of that exposure are cosmic rays that come from outer space and from the surface of the sun, terrestrial radionuclides that occur in the earth's crust, in building materials, in air, water, foods and in the human body itself. Some of the exposures are fairly constant and uniform for all individuals everywhere, for example, the dose from ingestion of ^{40}K in foods. Other exposures vary widely depending on location. Cosmic rays, for example, are more intense at higher altitudes and concentrations of uranium and thorium in soils are elevated in localized areas. Exposures can also vary as a result of human activities and practices. In particular, the building materials and design of houses and their ventilation systems strongly influence indoor levels of the radioactive gas radon and its decay products, which contribute significantly to doses through inhalation (IAEA, 2010).

Ionizing radiation is widely used throughout the world, particularly in medicine, industry, agriculture and research. Natural radiation in environment is augmented by artificial sources, emanating from man-made radionuclide such as those used in medical practices, nuclear power generation and also from fallout in a nuclear explosion (Larmash 1983). Most of these are not usually available to the public, but they may find their way into the environment through routine releases, accidents, thefts, loss and incorrect disposal or misuse. Unlike the natural sources of radiation which are widely distributed around the world, man-made sources are usually localized and affect only a small fraction of the population at any one time (Mettler et al, 1990).

Both naturally and artificially occurring radionuclides are found in the aquatic environment. The naturally-occurring radionuclides are primordial and of cosmogenic origin. Their presence in the aquatic environment is principally due to their solubility in water, run-off from land, exchange and removal of particulate material with the atmosphere (Pentreath 1977). In water medium of the aquatic environment, ^{40}K is the

most abundant radionuclide followed by ^{238}U. Because ^{232}Th is essentially insoluble in water, members of its series are not found in significant amount in sediments where the nuclides have been absorbed to particulate matters of the cosmogenic radionuclide. Plants and animals in the aquatic environment accumulate radionuclide to concentration greater than those of the ambient (Pentreath 1988).

The lake is the final destination of factory effluent, oil and grease and raw sewage from the urban centers, and oil spillage from transportation is considered quite significant. Important pollution components of the lake include eutrophication, microbiological pollutants, chemical pollutants, and suspended solids, which result from direct activities on the lake, untreated municipal sewage, agricultural waste brought in by inflowing rivers, maritime transport waste, and runoff and storm waters inflow (Wandiga et al, 2006)

Radionuclides and heavy metals may enter the fish body in three different ways; through the gills, digestive tract and the body surface. The gills are regarded as the most important site for uptake of heavy metals and radionuclides directly from water (Amundsen et al, 1997). To be taken up in organisms, the elements have to pass a biologic membrane, like gill membranes. The gills are a highly complex vasculature surrounded by a large surface area epithelium that provides a thin barrier between the fish's blood and the aquatic environment to ensure effective exchange of oxygen from water to blood and also get rid of carbon dioxide from the blood (Evans et al, 2005)

Some levels of radiation are naturally present in surface and ground water, but other degrees of radiation exposure come from contact with rocks and soil that have been contaminated with the artificially produced radionuclides mentioned above. Releasing of radionuclides in the environmental materials is part of the immediate pathways to commonly encountered hazardous radionuclides through accidents, poor waste disposal, or other means. Contamination of food and water sources can occur from dust transported by wind from uranium mine sites and waste deposits (Neves et al, 2008). Radiation being energy emitted when a radionuclide decays, it can affect living tissue only when the energy is absorbed in that tissue. The Figure 2.6, illustrates the pathways of radionuclides to the human.

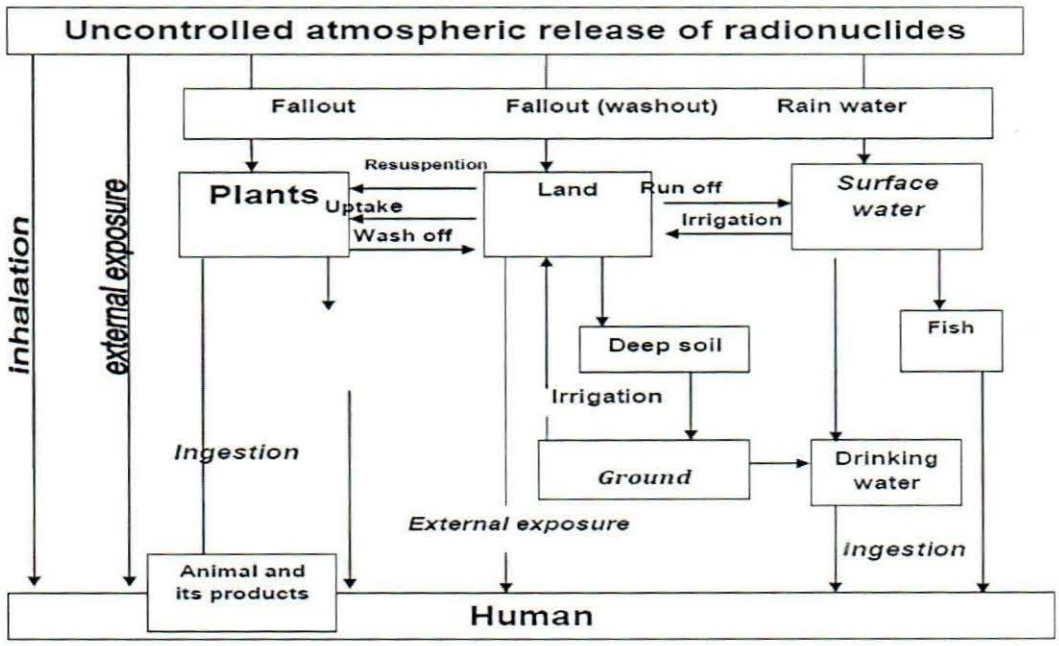


Figure 2.1: Pathways of radionuclides to the human (IAEA, 1989)

2.4 Impacts of Radioactive Radiations

The main concern about radionuclides and radiation are their adverse effects on organisms, including humans. However, it must be remembered that ionizing radiation has medical benefits in diagnosis and treatment of disease as well as in several industrial applications. Both facets of the existence and use of radionuclides and radiation have led to the creation of a major discipline called radiological protection. Other terms, such as 'radiology' and 'health physics', originally used in a wider context, are now almost exclusively used in connection with nuclear medicine. The entire focus of radiological protection is the effects of radiation on living tissues and organisms, mechanisms for the adequate protection of both deliberately and accidentally exposed humans and populations of other organisms. Natural sources of radioactivity are all around and man-made radioactive materials are a vital part of medicine and industry. Exposure to some radiation, natural or man-made is inevitable. We live with radiation every day, therefore we must understand its risks. Radiation is known to cause cancer in humans. It can also cause other adverse health effects, including genetic defects in the children of exposed parents or mental retardation in the children of mothers exposed during pregnancy (EPA, 2007)

Radioactive materials that decay spontaneously produce ionizing radiation, which has sufficient energy to strip away electrons from atoms (creating two charged ions) or to break some chemical bonds. Any living tissue in the human body can be damaged by ionizing radiation in a unique manner. When ionizing radiation strikes an organism's cells, it may injure the cells. If radiation affects a significant number of cells, it can eventually lead to cancer. At extremely high doses, this type of exposure can cause death. In general, there is no safe level of radiation exposure (EPA, 2008).

Uranium mining and the use of nuclear reactors are common sources of radionuclides, which are primarily contained within radioactive wastes, which present serious threats to human health. Additionally, Uranium has two primary isotopes ^{238}U and ^{235}U in the proportion of (99.3% to 0.7%) respectively. Although ^{235}U has a small environmental significance, it forms the basis of nuclear energy production. ^{238}U has a greater number of decay products, several of which are long-lived and it is more radiotoxic. ^{226}Ra (Radium) is a member of the ^{238}U natural decay series, which has a half-life of 1600 years (Andrew and Dan Becker, 2010), and is the most hazardous radionuclide released from uranium mining and milling. Chronic exposure to radium through the inhalation pathway can lead to leucopenia (a decrease in the number of white blood cells). ^{222}Ra (Radon) comes from the natural decay of radium that is found in nearly all rocks and soils, which is a human lung carcinogen. It also causes the lung cancer death in uranium miners. Long-term exposure to radon leads to an elevated risk of leukemia (Yablokov, 2009)

Exposure to radiation can also cause detrimental health effects. At large acute doses, radiation effects – such as opacities in the lens of the eye sometimes leading to cataract, temporary or permanent sterility, in severe cases of whole body irradiation, acute syndromes (such as damage to bone marrow, gastrointestinal tract, lungs and the nervous system) – can lead to death within a short period of time after exposure. Large chronic dose rates also cause clinically detectable deleterious effects. These various effects are called deterministic because they are certain to occur if the dose exceeds certain threshold levels. At low doses, radiation exposure can also plausibly induce severe health effects, such as malignancies, which are statistically detectable in a population, but cannot be

unequivocally associated with individual exposures. Hereditary effects due to radiation exposure have been statistically detected in mammals and are presumed to occur in humans as well. All these statistically detectable effects are called stochastic effects because of their random (i.e., probabilistic) nature. These effects are expressed after a latency period, presumably over the entire range of doses without a threshold level. In addition, there is a possibility of health effects in children exposed to radiation in utero during certain periods of pregnancy, including a greater likelihood of leukaemia and severe mental retardation (UNSCEAR, 2000).

2.5 Nuclear structure and stability

A radionuclide is an unstable chemical element that radioactively decays resulting into the emission of ionizing radiation. Radionuclide has excess nuclear energy that makes it unstable can either create and emit from the nucleus, new radiation (gamma radiation) or a new particle (alpha particle or beta particle) or transfer this excess energy to one of its electrons causing it to be ejected. The unstable nucleus is more stable following the emission, but will sometimes undergo further decay. Radioactive decay is a random process at the level of single atoms.

Alpha (α) Particle emission occurs when a positive α-Particle (He) leaves the nucleus. Since the α-particle is simply the nucleus of a helium atom with mass number 4, the daughter nuclide which results from this type of decay has a mass number 4 atomic mass units and an atomic number 2 less than the parent nuclide

$$^{238}_{92}U \longrightarrow {}^{234}_{90}Th + {}^{4}_{2}He \qquad (2.1)$$

In the equation 2.1 above, the isotope of uranium with mass number 238 (the parent nuclide) decays to the isotope of thorium with mass number 234 (the daughter nuclide) and an α-particle. This type of radioactive decay occurs frequently with heavy elements or elements that have too many protons for stability. Plutonium-239, ^{239}Pu, and americium-241, ^{241}Am, are pure α-emitters. α-Particles are not very penetrating, having a range of only a few centimeters in air.

Beta (β) Particle emission occurs when one neutron in the nucleus is converted to a proton and a high-energy electron, called a β-particle. Since the mass of the β-particle is negligibly small compared to nucleons, this type of decay does not change the mass number, but as the number of protons increases by 1, the daughter nuclide will have an atomic number 1 larger than the parent nuclide as in the equation 2.2 below.

$$^{14}_{6}C \longrightarrow {}^{14}_{7}N + {}^{0}_{-1}e \qquad (2.2)$$

Many isotopes of light elements that have too many neutrons for stability are subject to this type of decay. β-Particles are fairly penetrating, and may have a range in air up to several metres.

Gamma (γ) ray emission, certain radioactive nuclides emit very penetrating electromagnetic radiation known as γ-rays. These rays are in fact very high energy photons. For example cobalt-60 decays by losing a β-particle, leaving a nickel-60 nucleus in a high energy state, shown as ^{60}Ni as shown in the equation 2.3 below. The nickel nucleus then very rapidly loses 2 γ-photons to stabilize its nucleus to the normal (ground) state.

$$^{60}Co \xrightarrow{\beta^-} {}^{60}Ni \xrightarrow{2\gamma} {}^{60}Ni \qquad (2.3)$$

Radionuclides both occur naturally and are artificially made using nuclear reactors, cyclotrons, particle accelerators or radionuclide generators. Most naturally occurring radionuclides are alpha particle emitters (uranium-231 and radium-226), but some beta particle emitters also occur naturally (radium-228 and potassium-40). Manmade radionuclides are mainly beta and photon (gamma) emitters. Tritium is a beta particle emitter that may be formed naturally in the atmosphere or by human activities (OEPA, 2005).

2.6 Natural Decay Series

Uranium, radium, and thorium occur in three natural decay series, headed by ^{238}U, ^{232}Th and ^{235}U respectively. In nature the radionuclides in these three series are approximately in a state of secular equilibrium, in which the activities of all radionuclides within each

series are nearly equal. Two conditions are necessary for secular equilibrium. First, the parent radionuclide must have a half-life much longer than that of any other radionuclide in the series. Second, a sufficiently long period of time must have elapsed, for example ten half-lives of the decay product having the longest half-life, to allow for ingrowth of the decay products. Under secular equilibrium, the activity of the parent radionuclide undergoes no appreciable changes during many half-lives of its decay products (ANL, 2005).

Radioactive decay occurs when an unstable (radioactive) isotope transforms to a more stable isotope, generally by emitting a subatomic particle such as an alpha or beta particle. Radionuclides that give rise to alpha and beta particles are shown in the Figures 2.2 and 2.3. Gamma radiation is not a mode of radioactive decay (such as alpha and beta decay), rather, it is a mechanism by which excess energy is emitted from certain radionuclides, that is as highly energetic electromagnetic radiation emitted from the nucleus of the atom. For simplicity, only significant gamma emissions associated with the major decay modes are shown in Figures 2.4 and 2.5 that is radionuclides listed are those for which the radiation dose associated with gamma rays may pose a health concern. The gamma component is not shown for those radionuclides whose gamma emissions do not generally represent a concern (ANL, 2005).

From the two conditions noted above for secular equilibrium, the first is generally met for the ^{238}U, ^{232}Th and ^{235}U decay series in naturally occurring ores, while the second condition may not be met for all ores or other deposits of uranium and thorium (given the extremely long half-lives for the radionuclides involved and the geological changes that occur over similar time scales), it is reasonable to assume secular equilibrium for naturally occurring ores to estimate the concentrations of the various daughter radionuclides that accompany the parent. The state of secular equilibrium in natural uranium and thorium ores is significantly altered when they are processed to extract specific radionuclides. After processing, radionuclides with half-lives less than one year will reestablish equilibrium conditions with their longer-lived parent radionuclides within several years. For this reason, at processing sites what was once a single, long decay series (for example the series for ^{238}U) may be present as several smaller decay series

headed by the longer-lived decay products of the original series (that is, headed by ^{238}U, ^{234}U, ^{230}Th, ^{226}Ra, and ^{210}P in the case of ^{238}U). Each of these sub-series can be considered to represent a new, separate decay series (ANL, 2005). Understanding the physical and chemical processes associated with materials containing uranium, thorium, and radium is important when addressing associated radiological risks. It may be necessary to add the radiological risk identified for a given radionuclide to that of its parent radionuclide to properly represent the total risk (ANL, 2005).

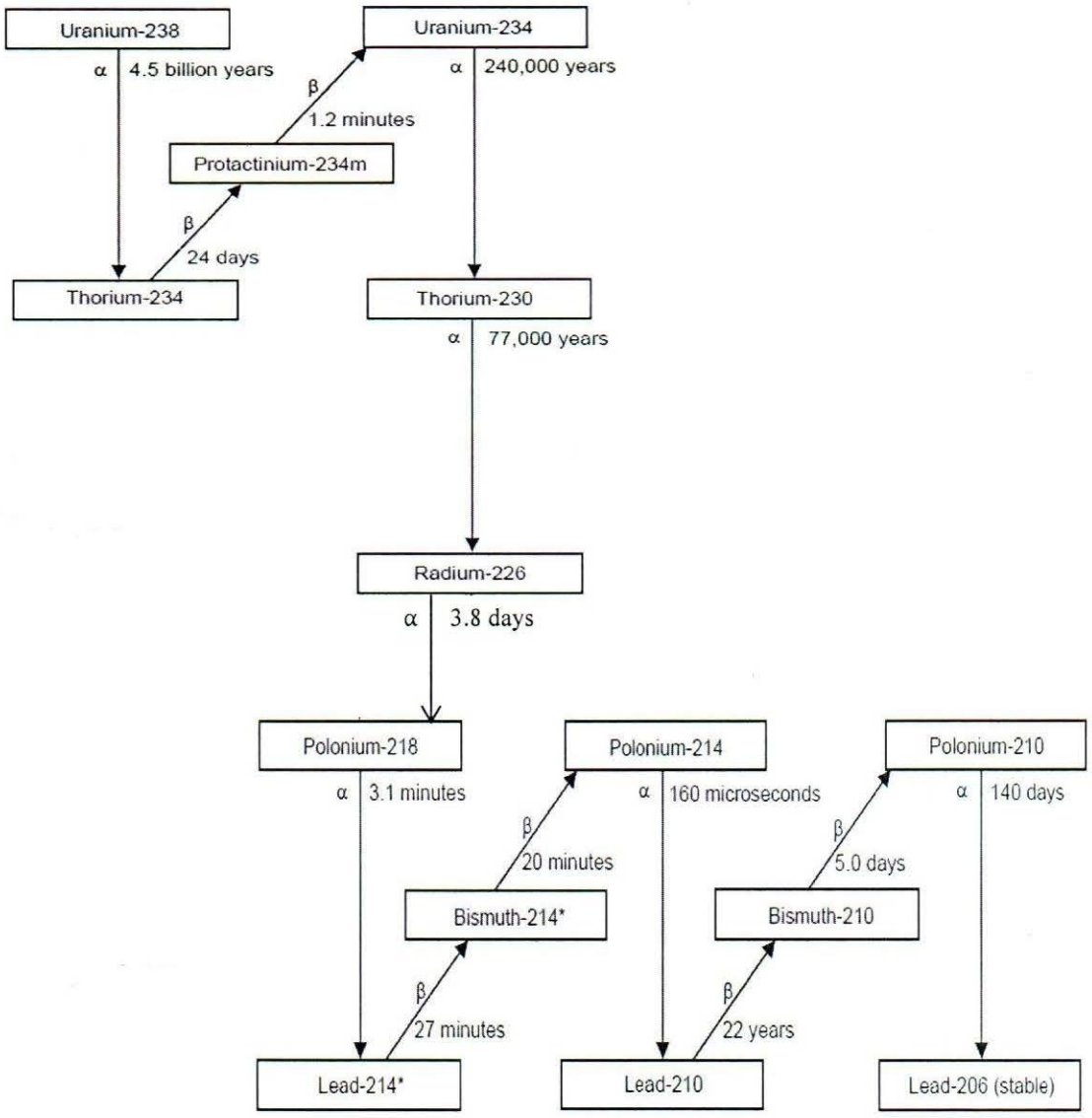


Figure 2.2: Natural decay series of Uranium-238

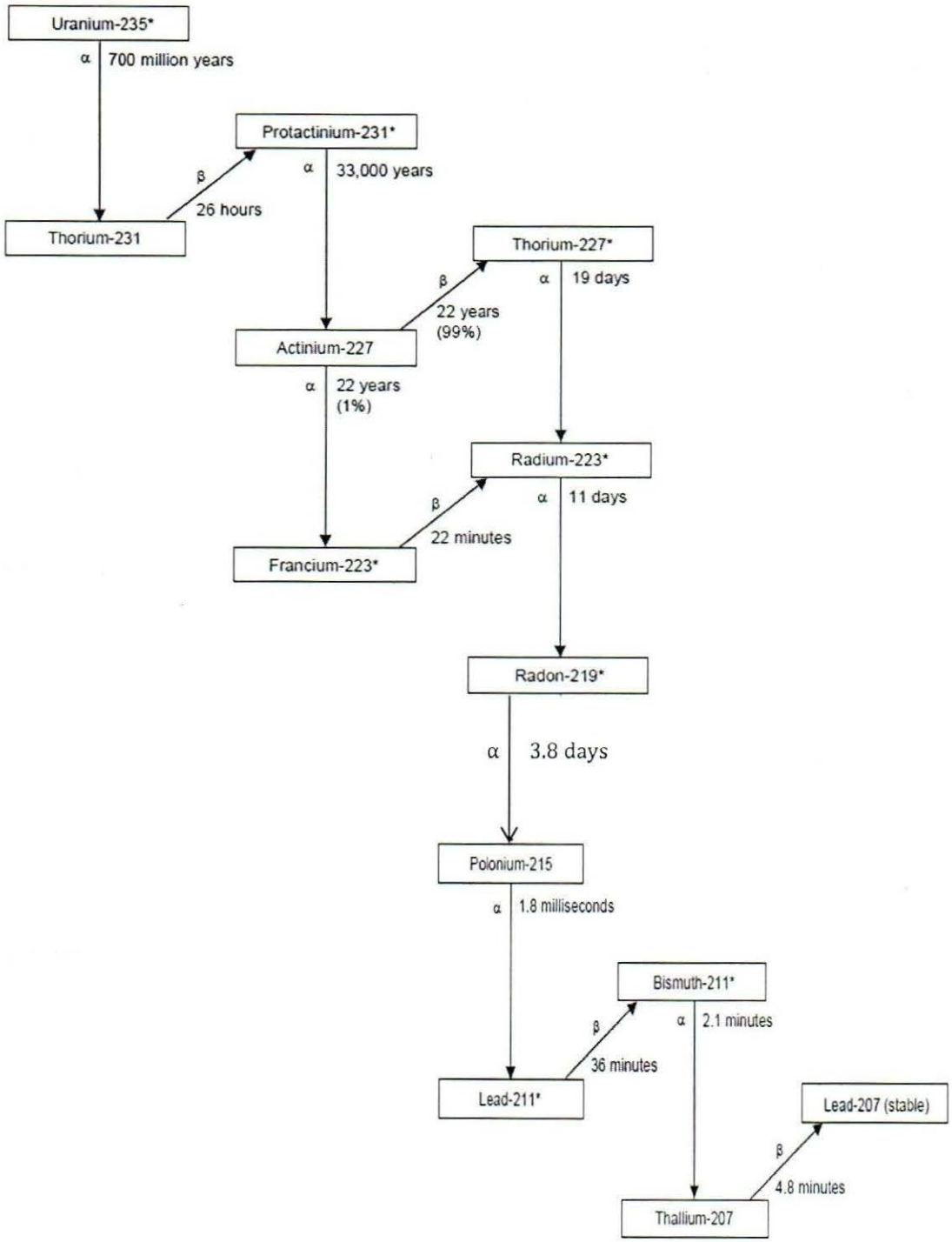


Figure 2.3: Natural decay series of Uranium-235

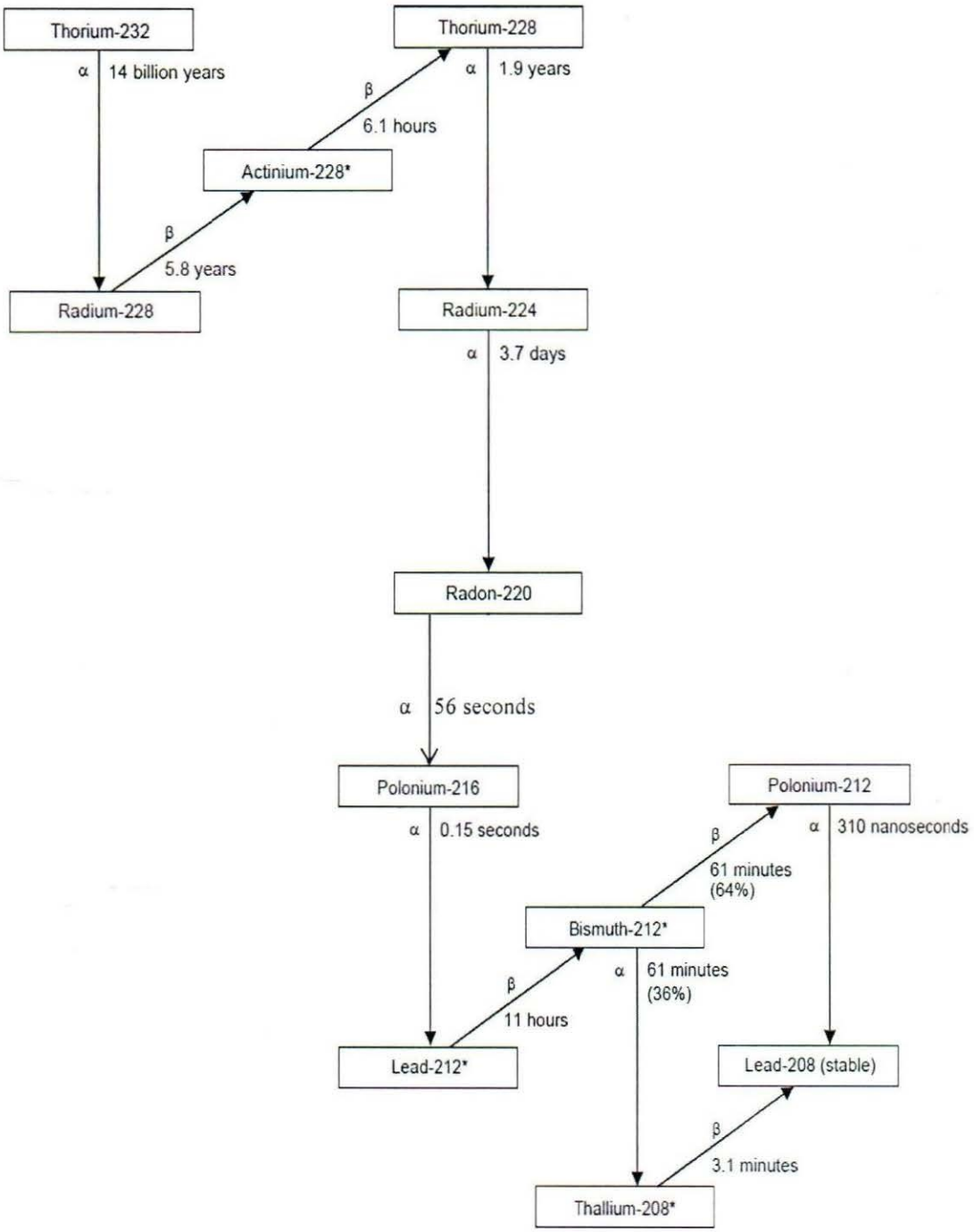


Figure2.4: Natural Decay Series of Thorium-232

Potassium is a soft, silver-white metal. An important constituent of soil, it is widely distributed in nature and is present in all plant and animal tissues. Potassium-40 is a naturally occurring radioactive isotope of potassium. Two stable (nonradioactive) isotopes of potassium exist, potassium-39 and potassium-41. Potassium-39 comprises most (about 93%) of naturally occurring potassium, and potassium-41 accounts for essentially all the rest. Radioactive postassium-40 comprises a very small fraction (about 0.012%) of naturally occurring potassium. The half-life of potassium-40 is 1.3 billion years, and it decays to calcium-40 by emitting a beta particle with no attendant gamma radiation (89% of the time) and to the gas argon-40 by electron capture with emission of an energetic gamma ray (11% of the time). Potassium-40 is an important radionuclide in terms of the dose associated with naturally occurring radionuclides (ANL, 2005).

Potassium-40 is present as a very small fraction of naturally occurring potassium, which is an element found in large amounts throughout nature. Potassium is the seventh most abundant element in the crust of the earth. It is present in mineral waters and brines, and in various minerals such as carnallite, feldspar, saltpeter, greensand, and sylvite. Potassium is an important constituent of fertile soil and is an essential nutrient for plant growth and in the human diet. The white solid potassium carbonate is used to make glass and soft soap. The white solids potassium sulphate and potassium chloride are used to fertilize soil, because potassium (along with nitrogen and phosphorous) is an essential element for plant growth. Potassium is also an essential element for humans, as a key electrolyte for maintaining basic cardiovascular functions, many people take potassium supplements as capsules or tablets. There are no specific commercial or medical uses associated with the radioactive properties of potassium-40 ANL (2005).

Potassium-40 can be taken into the body through drinking water, eating food, or breathing air. Once taken in, potassium-40 behaves in the body in the same manner as other potassium isotopes. Humans require potassium to sustain biological processes, with most (including potassium-40) being almost completely absorbed upon ingestion, moving quickly from the gastrointestinal tract to the bloodstream. The potassium-40 that enters the bloodstream after ingestion or inhalation is quickly distributed to all organs and

tissues. Potassium-40 is eliminated from the body with a biological half-life of 30 days. The potassium content of the body is under strict homeostatic control and it is not influenced by variations in environmental levels. Hence, the potassium-40 content in the body is constant, with an adult male having about 0.1micro curie or 100,000 pCi. Each year this isotope delivers doses of about 18 millirem (mrem) to soft tissues of the body and 14mrem to bone (ANL, 2005).

Potassium-40 can be present both an external and an internal health hazard. The strong gamma radiation associated with the electron-capture decay process (which occurs 11% of the time) makes external exposure to this isotope a concern. While in the body, potassium-40 poses a health hazard from both the beta particles and gamma rays. The health hazard of potassium-40 is associated with cell damage caused by the ionizing radiation that results from radioactive decay, with the general potential for subsequent cancer induction. Lifetime cancer mortality risk coefficients have been calculated for nearly all radionuclides, including potassium-40. While ingestion is generally the most common type of exposure, the risk coefficients for this route are lower than those for inhalation. As for other radionuclides, the risk coefficient for tap water is about 70% of that for dietary ingestion. In addition to risks from internal exposures, an external gamma exposure risk also exists for potassium-40 (ANL 2005).

With the Radioactive Decay Progenies, Naturally occurring radioactive nuclei undergo a combination of α, β and γ emission. Artificially produced nuclei may also decay by spontaneous fission, neutron emission and even proton and heavy-ion emission (NTEC, 2009). Any decay process is subject to the same *basic radioactive decay law,* "The rate of decay (number of disintegrations per unit time) is proportional to *N,* the number of radioactive nuclei in the sample"

$$\frac{dN}{dt}\alpha - \lambda N \qquad (2.4)$$

The negative sign signifies that N is *decreasing* with time. λ Called the *decay constant* - probability per unit time that a given radioactive nucleus will decay

Large $\lambda \longrightarrow$ rapid decay, small $\lambda \longrightarrow$ slow decay, on integration equation 2.4, then

$$N(t) = N_O \exp(-\lambda t) \tag{2.5}$$

The activity, the number of disintegrations per unit time is

$$A(t) = \lambda N(t) = N_o \exp(-\lambda t) = A_o \exp(-\lambda t) \tag{2.6}$$

Radioactive decay leads to the emission of energetic particles and rays. The decay products are alpha and beta particle and gamma rays. The gamma ray photons are quantum electromagnetic energies of range 0.1-10 Mev (Krane, 1998). Transitions resulting into gamma emission leave mass number (A) and atomic number (Z) unchanged and are isomeric. In the gamma decay, an excited parent nuclide attains its ground state through emission of one or several gamma photons (Nelson, 2014). In most alpha and beta decays, the daughter de-excitation is instantaneous and it's thus apparent that the gamma rays are produced by the parent nuclide. If the daughter nucleus de-excites with a time delay, its excited state is referred to as metastable and the process of de-excitation is referred to as isometric transformation (NTEC, 2009). The parent and daughter in this case become isomers.

2.7 Measurement of radioactivity

There are a lot of methods and techniques applied in the determination of the naturally occurring radionuclide in the geological, biological and environmental media such as rocks, soil, air and natural wastewater. However, Quantitative gamma-ray spectroscopy is a powerful technique available for the nondestructive analysis of samples from such media (Youssef et al., 2007)

Identification and assessment of low radioactivity levels in different samples emitting gamma rays by High purity Germanium detectors (HPGe) requires two types of calibration including, energy calibration and photo peak detection efficiency calibration. Energy calibration is necessary to identify different isotopes from respective gamma ray energy lines; while photo peak detection efficiency determination is necessary for quantitative assessment of the radioactivity levels for each radioisotope (Knoll, 1989).

Energy calibration is simply to assign the correct energy value to the corresponding channel number. The pulse height is assumed to be proportional to the energy of the

incident particle. This enables the linearly to find the energies of gamma lines emitted by unknown source. In gamma-ray spectroscopy with germanium detectors, the pulse height scale must be calibrated in terms of absolute gamma-ray energy if various peaks in the spectrum are to be properly identified. In many applications, the gamma-rays expected to appear in the spectrum are well known in advance and the corresponding peaks can be identified by inspection. In other applications, unknown gamma-ray spectra may occur and hence a spectra calibration gamma ray (Knoll, 1989).

Source is used to supply peaks of known energy in the spectrum. Accurate calibration should involve a standard source with gamma-ray energies that are not widely different from those to be measured in the unknown spectrum. Because even the best spectrometer systems often show nonlinearities of a channel or two over a full range of several thousand channels, it is also useful to have multiple calibration peaks at various points along the measured energy range of interest. The selection of standards to be used for germanium spectrometer calibration depends on the energy range of interest (Gilmore & Hemingway, 1995).

Detection efficiency, all detectors give rise to an output pulse or signal for a quantum of radiation, which interacts within its active volume. Radiation such as gamma ray must first undergo a considerable interaction in the detector crystal before detection is possible. Because gamma photons can travel large distance between interactions, detectors are often less than 100% efficient. It then becomes necessary to have a precise figure for the detector efficiency in order to relate the number of pulses counted to the number of photons incident on the detector (Gilmore & Hemingway, 1995).

Intrinsic efficiency,

$$\varepsilon_{int} = \frac{\text{number of pulses at the detector output}}{\text{number of radiation quanta incident on detector}} \qquad (2.7)$$

The intrinsic efficiency of a detector is a detector property and independent of the geometry, therefore it is much more convenient to tabulate values for intrinsic efficiencies. The intrinsic efficiency of a detector depends on the detector material, the

radiation energy, and the physical thickness of the detector in the direction of the incident radiation (Gilmore & Hemingway, 1995).

Absolute Efficiency (photo peak),

$$\varepsilon_{abs} = \frac{\text{number of pulses recorded in photopeak}}{\text{number of radiation quanta emitted by source}} \tag{2.8}$$

The absolute efficiency is dependent not only on detector properties but also on the details of the counting geometry such as the distance from the source to the detector (Gilmore & Hemingway, 1995).

The activity concentration of the naturally occurring radionuclides in the sample can be calculated using the equation 2.9 (Matteknik, 1995, Martin et al, 2013)

$$A_i(Bqkg^{-1}) = \frac{N}{MtC} \tag{2.9}$$

Where M is the mass per sample in kilograms, N is the number of radionuclides/ protons present under the region of interest, t the time in seconds taken to run the sample in the detector (it's the acquisition time) and C is the correction coefficient for the detector. The error, σ, associated with the determination of the activity concentration can be obtained using the equation 2.10 (Mattetnik, 1995).

$$\sigma = \frac{\sqrt{N}}{MtC} \tag{2.10}$$

The correction coefficient, C, of the NaI (TI) detector is calculated using the equation 2.11 (Mattetnik, 1995)

$$C = \varepsilon\eta \tag{2.11}$$

Where ε is the detector efficiency and η branching ratio of the radionuclides. The correction coefficients of NaI (TI) detector are given in the Table 2.1

Table 2.1: Values of Correction coefficients for NaI (TI) detector (Mattetnik, 1995)

Energy(keV)	Decay series	Coefficient
84	Th (Th -228)	0.0286
185	U (Ra -226)	0.0043
205-238	Th (Pb - 212)	0.0608
242	U (Pb - 214)	0.0104
295	U (Pb - 214)	0.0237
309-352	U (Pb - 214)	0.3000
538-580	Th(Tl - 208)	0.0101
610	U(Bi-214)	0.0210
780	Eu-512	0.0296
860.58	Th(TI-208)	0.0013
1170	Co-60	0.0200
1460	K - 40	0.0023

Intake of ionizing radiation through exposure to a radiation pathway is quantified by computing the radiation dose. The absorbed dose rate and the annual effective dose rates dose equivalent of ionizing radiation can be computed using the appropriate criteria. Radiological clinical effects of ionizing radiation are directly related to the absorbed dose rate (D_i) since the severity depends on the dose level(Ramasamy et al, 2004).The measured activity concentrations are converted into doses by applying the conversion factors for uranium, thorium and potassium respectively (UNSCEAR, 2000) as shown in the equation 2.12

$$D_i(nGyh^{-1}) = 0.462A_{Ra} + 0.604A_{Th} + 0.0417A_K \qquad (2.12)$$

Where D is the dose rate, A_{Ra}, A_{Th}, and A_K are the activity concentrations (in $Bqkg^{-1}$) of ^{226}Ra, ^{232}Th and ^{40}k in the sample respectively. The level must be below $46nGyh^{-1}$ to pose no radiological hazards to the public (NCRP, 1991).

The annual effective dose equivalent, H_i (in $mSvy^{-1}$) is computed with the aid of dose criterion (UNSCEAR, 2000)

$$H_i(mSvy^{-1}) = \frac{A_{Ra}}{740} + \frac{A_{Th}}{520} + \frac{A_K}{9620} \tag{2.13}$$

The annual effective dose equivalent must be less than $0.07mSvy^{-1}$as the maximum permissible value (UNSCEAR, 2000) to pose negligible radiological hazards to the public.

The level of health hazard associated with the exposure to ionizing radiation following the different pathways is assessed by use of Radium equivalent activity and the hazard indices (IJST, 2013). The value of any index must be less than one in order to be safe from exposure hazard (UNSCEAR, 2000). The internal hazard index (H_{in}) gives the internal exposure to carcinogenic radon in the fish samples and is given by equation 2.14 (Ibeanu.I.et al, 1999, (Beretka J. et al, 1985) and (M.O. Isinkaye et al, 2015).

$$H_{in} = \frac{A_{Ra}}{185Bqkg^{-1}} + \frac{A_{Th}}{259Bqkg^{-1}} + \frac{A_K}{4810Bqkg^{-1}} \tag{2.14}$$

For radiological safety precautions, the internal hazard index should individually be less than one in order for the radiation hazard to have negligible hazardous effects to the respiratory organs of the public (Beretka et al, 1985).

CHAPTER THREE: METHODOLOGY OF STUDY

3.1 Introduction

This chapter constitutes the Research Design and Variables involved, Sample Collection, Sample Preparation, Measurement, Presentation of Data, Data Analysis and Treatment in line with the objectives of the study.

3.2 Research Design

This study used exploratory and descriptive research design, in order to get the samples that give results of significant importance. There was a need to survey to identify the commonly harvested fish species, the legalized fishing methods and tools, size and age of the fish for proper sample collection. This was followed by sampling the study area and sample collection from various locations of the Lake. Data collected was analyzed and then related to the existing international reference levels.

The study had both dependent and independent variables. The independent variable included the type of fish and size commonly harvested in a given sampling site. In this case the fish species that were used include Tilapia, Oreochromis, Catfish, Lungfish, Clarias, sliver fish, sprats and Nile perch. See the Figures 3.1 and 3.2 showing the Tilapia and Nile perch fish species respectively that were among samples for this study.

The fish samples were collected from seven (7) selected sites namely Wanseko, Kaboolwa and Butiaba from Bulisa district and Nsonga, Kaiso, Tonya and Kibiro from Hoima district. The dependent variables of the study were the centroid of the spectrum (kev), Rate(R) of photon interaction with the detector, Sum between the markers (n) Gamma emitting radionuclides, Standard Deviation (S.D in kev), Full width at half maximum (FWHM in kev), Activity concentration (A_i in $Bqkg^{-1}$), absorbed dose rates (in $nGyh^{-1}$), Annual Effective dose equivalent (H_i in $mSvy^{-1}$) and radiological internal hazard indices (H_{in}).

Figure 3.1: Picture of tilapia fish species

Figure 3.2: Picture of Nile perch fish species

3.3 Sample collection

Samples were collected by the use of fishing nets of fishermen randomly from the selected sampling sites on cluster basis for investigation and analysis. The fish were then packaged into polyethylene bags, labeled and placed into ice container (Akinloye et al, 1999). This was done in line with the permissible guidelines of International Commission on Radiological Protection (ICRP), the National Committee on Radiation Protection and Measurements (NCRP, 1991). Seven (7) fish sampling sites were selected for the study

and these include Nsonga, Kaiso, Tonya, Kibiro, Butiaba, Wanseko and Kaboolwa because these selected sites were in the vicinity of the water runoff from the rocky hills of the western rift valley. Eight commonly harvested fish species from all the sites were collected and these include Tilapia, Oreochromis, Catfish, Lungfish, Clarias, sliver fish, sprats and Nile perch. The Table 3.1 shows the mass (grams) per fish species that was collected from the selected sampling sites.

Table 3.1: The mass (grams) per fish sample from the selected sites

	SELECTED SAMPLING SITES							
Species	Butiaba	Nsonga	Tonya	Wanseko	Kaboolwa	Kaiso	Kibiro	TOTAL
Tilapia	800	800	800	800	800	800	800	5600
Sprat	800	800	800	800	800	800	800	5600
Oreochromis	800	800	800	800	800	800	800	5600
Catfish	800	800	800	800	800	800	800	5600
Nile perch	800	800	800	800	800	800	800	5600
Lung fish	800	800	800	800	800	800	800	5600
Sliver fish	800	800	800	800	800	800	800	5600
Clarias	800	800	800	800	800	800	800	5600
TOTAL	6400	6400	6400	6400	6400	6400	6400	44800

3.4 Sample preparation

The samples of Tilapia, Oreochromis, Catfish, Lungfish, Clarias and Nile perch fish collected were dissected with the use of a knife, washed and placed on filthy wooden platforms whereas the sprats and silver fish samples were only washed and placed on the non-radioactive interlocked platforms raised from the ground surface to avoid contamination from ground soil. See the figures 3.3, 3.4 and 3.5 showing the dissected fish species. The samples were then dried at a temperature ranging 40-70^{0}C with the oven. The dried samples were grounded to fine powder using the mortar, sieved with a mesh of unit inch and packed into fill labeled cylindrical plastic non-radioactive containers of height 7cm by 6cm diameter. This satisfied the selection of optimal sample container height (Ibeanu, 1999). Each container accommodated approximately 800g of fine grounded and sieved fish powder. They were then carefully sealed (using Vaseline, candle wax and masking tape) to prevent radon escape and store for a minimum of 30 days (Ramasamy et al ,2004).This allowed the establishment of secular radioactive equilibrium between the natural radionuclides and their respective progenies (Isinkaye & Oyedele,2014).

Figure 3.3: Picture of dissected samples of Tilapia species

Figure 3.4: Picture of dissected samples of Nile perch species

Figure 3.3: Picture of dissected samples of Tilapia species

Figure 3.4: Picture of dissected samples of Nile perch species

Figure 3.5: Picture of dissected samples of Sliver fish species

3.5 Measurement

Gamma ray spectrometry technique was employed in the spectral collection and analysis of the prepared fish samples using the Thallium activated Sodium iodide scintillator (NaI (TI)), GDM 20. GDM 20 is a measurement system for detection and energy determination of gamma radiation from radioactive sources or samples. It makes use of IBM compatible computer. The detector consists of a cylindrical NaI crystal with a height and a diameter of 7.5cm. When the gamma radiation hits the crystal it creates a weak light. The light is collected and converted to electrical pulses by the photomultiplier tube (PM). The pulses are amplified in an amplifier. The analog/ digital convertor converts the size of the pulses to digital information that is processed by the computer. The result is presented on the screen of the computer in form of a spectrum (frequency diagram of the energy distribution of the detected gamma quanta). Figure 3.6 below shows the picture of the detector system. The net area under the corresponding photo peaks in the energy spectrum was computed by subtracting the count due to Compton scattering of the background source from the total area of the photo peaks (Matteknik, 1995).

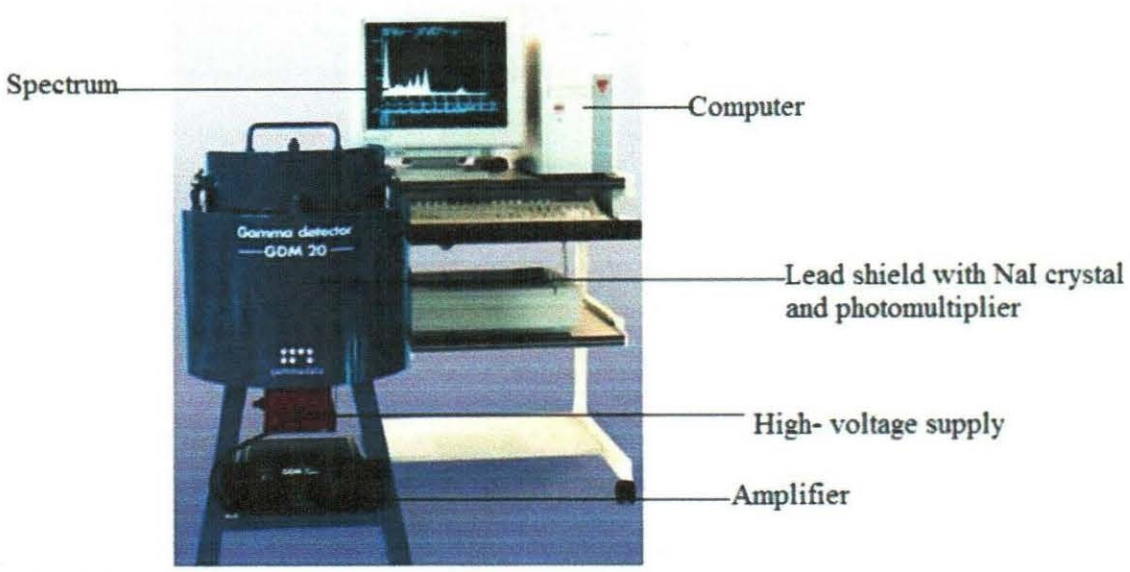


Figure 3.6: Picture of the spectrometer system GDM 20(Gamma data, 2004)

The background radiation distribution in the environment due to different sources in the room and the components of the detector was measured by running the empty sealed marinelli beaker for the same 6000 seconds as the samples. The spectrum obtained was stored as background and this was subtracted from each spectrum before analysis. Mass of each sample was measured using a triple beam balance in kilograms to an error limit of ±0.0005kg and recorded to five significant figures. The sample was then filled in a marinelli beaker before loading into the gamma ray detector. The 6000 seconds was the minimum acquisition time as some studies considered it long enough for the detector to interact with beaker and the samples (Lemeriga (1998), Anguma (1999)). This time frame is appropriate for the gamma rays to interact with the NaI crystal.

For energy calibration, system energy axis was calibrated at two selected peaks of standard sample in this case ^{152}Eu solution was used. The ^{152}Eu is selected for ideal use because it has been used in many studies as the only available calibration solution at hand. The radionuclides present in the counted samples were identified from their individual photo peaks. The activity of ^{226}Ra during the equilibrium was assumed to be the same as that of the parent ^{238}U (Jabbar et al, 2009). The efficiency of the NaI (TI) detector was calculated using the equation 3.1 (Matteknik, 1995)

$$\varepsilon = \frac{Y}{Bt} \tag{3.1}$$

where Y is the number of pulses corresponding to the area under the photo peak, B is the number of gamma quanta emitted per second and t is the time taken to measure the activity, A , of the radionuclides. For the analysis of ^{40}K, ^{226}Ra and ^{232}Th, the 185kev energy for U was used in assessment of the activity concentration of ^{226}Ra while 84kev energy of ^{228}Th was used for ^{232}Th and the single 1460kev energy was used in evaluation of ^{40}K (Matteknik, 1995).

3.6 Presentation of Data

The detector produced readings of Standard Deviation (S.D), Full Width at Half Maximum (FWHM) in keV, Rate(R), number of radionuclides (n) in each peak interacting with the crystal, live time (t) in seconds. These results were tabulated for each sampling site to avail the primary data of the study as shown in appendix A.

3.7 Data analysis and treatment

It's from the primary data the Activity concentration, Dose Rates, Annual Effective Dose and Radiological Hazard Indices were computed using mat lap program and Microsoft excel 2010 (spread sheet)

The primary data from the spectrum was used to determine the Activity Concentration (A_i) of the radionuclides that were identified in the fish samples using the equation (3.2) (Matteknik, 1995, Martin et al, 2013)

$$A_i(Bqkg^{-1}) = \frac{N}{MtC} \tag{3.2}$$

where M is the mass per sample in kilograms, N is the number of radionuclides/ protons present under the region of interest, t the time in seconds taken to run the sample in the detector (it's the acquisition time) and C is the correction coefficient for the detector. The error, σ, associated with the determination of the Activity Concentration was obtained using the equation 3.3 (Mattetnik, 1995).

$$\sigma = \frac{\sqrt{N}}{MtC} \tag{3.3}$$

The data was tabulated where each radionuclide was entered into one column for the respective fish species from all the selected sites and hence the range and average values of the respective radionuclides were stated. The average Activity Concentration level for each radionuclide in the fish species

The Absorbed Dose Rates (D_i) were calculated using equation (3.4),

$$D_i(nGyh^{-1}) = 0.462A_{Ra} + 0.604A_{Th} + 0.0417A_K \tag{3.4}$$

Where D_i is the dose rate, A_{Ra}, A_{Th}, and A_K are the activity concentrations ($Bqkg^{-1}$) of ^{226}Ra, ^{232}Th and ^{40}k in the given sample respectively (UNSCEAR, 2000). Results were tabulated from which the range and average values of the Dose Rates of the fish species from all the selected sites were stated.

The Annual Effective Dose Equivalent (H_i) was computed using the equation (3.5) UNSCEAR (2000)

$$H_i(mSvy^{-1}) = \frac{A_{Ra}}{740} + \frac{A_{Th}}{520} + \frac{A_K}{9620} \tag{3.5}$$

Results were tabulated from which the range and the average values of the Annual Effective Dose Equivalent of the species from all the selected sites.

The Radiological Internal Hazard Indices (H_{in}) were calculated using the equation (3.6), (Beretka J. et al, 1985) and (M.O. Isinkaye et al, 2015).

$$H_{in} = \frac{A_{Ra}}{185Bqkg^{-1}} + \frac{A_{Th}}{259Bqkg^{-1}} + \frac{A_K}{4810Bqkg^{-1}} \tag{3.6}$$

Results were tabulated from which the range and average values of the Radiological Internal Hazard Indices of the species from all the selected sites were stated. The activity concentration levels, dose rates and dose equivalents, the hazard indices of this study were compared with those in the literature review, viable explanations, conclusions and recommendations were given accordingly in chapter four and five respectively

CHAPTER FOUR: RESULTS AND DISCUSION

4.1 Introduction

This chapter covers the four major results and discussion connected to naturally occurring radioisotopes that are gamma ray emitting in the fish species of Lake Albert as specified in the research objectives. It examined activity concentrations, absorbed dose rates, annual effective doses and the radiological hazard indices of the samples due to the naturally occurring radioisotopes (^{232}Th, ^{226}Ra and ^{40}K) in the fish species collected from all the seven selected sampling sites that is Nsonga, Kaiso, Tonya, Kibiro, Butiaba, Wanseko and Kaboolwa. The respective ranges and average values for the samples due to concentration of the radioisotopes were obtained. The tables as well as the bar graphs were used respectively for illustration, presentation and analysis.

4.2: Activity concentration of naturally Occurring Radioisotopes in the fish species of Lake Albert.

The activity concentrations of the samples under investigation in Bqkg^{-1} were determined from the photo peaks of the gamma spectra corresponding to ^{232}Th, ^{226}Ra and ^{40}K. Radioactive concentrations in different fish samples were tabulated (see the Tables 4.1 to 4.3) respectively where the range and average values of ^{226}Ra, ^{232}Th and ^{40}K concentration levels in the fish species were determined. The activity concentration due to ^{232}Th, ^{226}Ra and ^{40}K radioisotopes in all the fish samples collected from various locations in Lake Albert line region varied by site and specie type.

Table 4.1: The Activity Concentration due to ^{232}Th radioisotope in the selected fish species of Lake Albert

Activity Concentration due ^{232}Th radioisotope in $Bqkg^{-1}$								
Fish species	The selected sampling sites							Average
	Butiaba	kaboolwa	kaiso	kibiro	Nsonga	Tonya	Wanseko	
Tilapia	4.57±0.29	4.96±0.33	3.31±0.29	3.86±0.36	3.45±0.29	3.45±0.29	5.17±0.32	4.24±0.32
Sprat	2.93±0.24	3.53±0.29	2.91±0.29	3.29±0.33	3.17±0.29	3.17±0.29	5.96±0.39	3.39±0.30
Sliver fish	2.43±0.22	3.09±0.30	2.98±0.29	3.95±0.37	2.67±0.27	2.67±0.27	2.97±0.26	3.27±0.29
Oreochromis	5.87±0.35	4.30±0.36	4.43±0.35	3.56±0.32	4.89±0.32	4.89±0.32	6.44±0.39	4.89±0.35
Catfish	5.14±0.39	5.70±0.44	4.09±0.34	5.97±0.42	5.47±0.40	5.47±0.40	6.08±0.39	5.31±0.40
Nile perch	6.19±0.36	5.54±0.42	4.34±0.33	3.76±0.32	3.93±0.33	3.93±0.33	6.17±0.39	5.98±0.41
Lungfish	5.32±0.42	6.14±0.42	7.85±0.43	8.04±0.47	9.15±0.50	9.15±0.50	10.74±0.51	7.64±0.46
Clarias	8.67±0.53	6.12±0.40	6.22±0.41	5.80±0.40	8.10±0.49	8.10±0.49	9.58±0.48	6.54±0.41
Average	5.14±0.35	4.92±0.37	4.52±0.34	4.78±0.37	5.10±0.36	5.10±0.36	6.64±0.39	5.16±0.37
Maximum	8.67±0.53	6.14±0.42	7.85±0.43	8.04±0.47	9.15±0.50	9.15±0.50	10.74±0.51	7.64±0.46
Minimum	2.43±0.22	3.09±0.30	2.91±0.29	3.29±0.32	2.67±0.27	2.82±0.28	2.97±0.26	3.27±0.29

From Table 4.1 above the results showed Lungfish species had the highest Activity concentration due to ^{232}Th radioisotope with the average value of 7.64±0.46 $Bqkg^{-1}$ followed by Clarias species with the average value of 6.54±0.41$Bqkg^{-1}$and then Nile perch species with the average value of 5.98±0.41$Bqkg^{-1}$ while Sliver fish and Sprats species had the lowest activity concentration levels with the average values of 3.27±0.29$Bqkg^{-1}$and 3.39±0.30$Bqkg^{-1}$ respectively. The fish species collected from Wanseko sampling site had the highest Activity concentration level that ranged from 2.97±0.26$Bqkg^{-1}$ to 10.74±0.51$Bqkg^{-1}$ with the average value of 6.64±0.39$Bqkg^{-1}$ this was followed by the samples from Butiaba site that ranged from 2.43±0.22$Bqkg^{-1}$ to 8.67±0.53$Bqkg^{-1}$ with the average value of 5.14±0.35$Bqkg^{-1}$ whereas those collected from Kibiro site had the lowest Activity concentration level that ranged from 3.29±0.32 $Bqkg^{-1}$ to 8.04±0.47$Bqkg^{-1}$ with the average value 4.78±0.37$Bqkg^{-1}$.The Activity concentration due to ^{232}Th radioisotope in the fish species collected from all the selected sites ranged from 3.27±0.29$Bqkg^{-1}$ to 7.64±0.46 $Bqkg^{-1}$ with an average concentration of 5.16±0.37$Bqkg^{-1}$

Table 4.2: The Activity Concentration due to ^{226}Ra radioisotope in the fish species of Lake Albert

Activity Concentration due ^{226}Ra radioisotope in $Bqkg^{-1}$								
Fish species	The selected sampling sites							Average
	Butiaba	kaboolwa	kaiso	kibiro	Nsonga	Tonya	Wanseko	
Tilapia	32.93±1.99	16.93±1.58	17.13±1.70	38.07±2.96	16.81±1.67	30.92±2.77	37.75±2.22	27.22±2.13
Sprat	24.34±1.81	29.48±2.13	20.68±2.00	42.20±3.04	26.86±2.16	31.60±2.37	61.59±3.24	41.75±2.69
Sliver fish	42.77±2.37	50.35±3.08	36.90±2.60	40.72±3.08	38.28±2.63	17.20±1.75	26.92±2.01	28.23±2.20
Oreochromis	55.46±2.76	44.42±2.95	14.37±1.62	33.37±2.52	52.66±2.71	45.68±3.14	31.52±2.24	39.64±2.56
Catfish	39.07±2.76	43.88±3.17	16.60±1.77	19.27±1.93	22.63±2.09	34.73±2.88	52.82±2.93	32.71±2.50
Nile perch	26.47±1.91	15.94±1.82	27.32±2.15	24.64±2.12	20.29±1.92	32.45±2.66	45.71±2.77	38.10±2.63
Lungfish	27.38±2.47	29.61±2.37	18.13±1.67	25.76±2.20	22.72±2.11	25.19±2.42	32.01±2.27	29.51±2.35
Clarias	63.39±3.73	42.11±2.70	36.11±2.52	40.30±2.72	33.95±2.50	43.06±2.81	32.34±2.26	27.66±2.18
Average	38.98±2.48	34.09±2.48	23.41±2.00	33.04±2.57	29.28±2.22	32.60±2.60	40.08±2.49	33.10±2.41
Maximum	63.39±3.73	50.35±3.17	36.90±2.60	42.20±3.08	52.66±2.71	8.52±0.40	61.59±3.24	41.75±2.69
Minimum	24.34±1.81	15.94±1.58	14.37±1.62	19.27±1.93	16.81±1.67	17.20±1.75	26.92±2.01	27.22±2.13

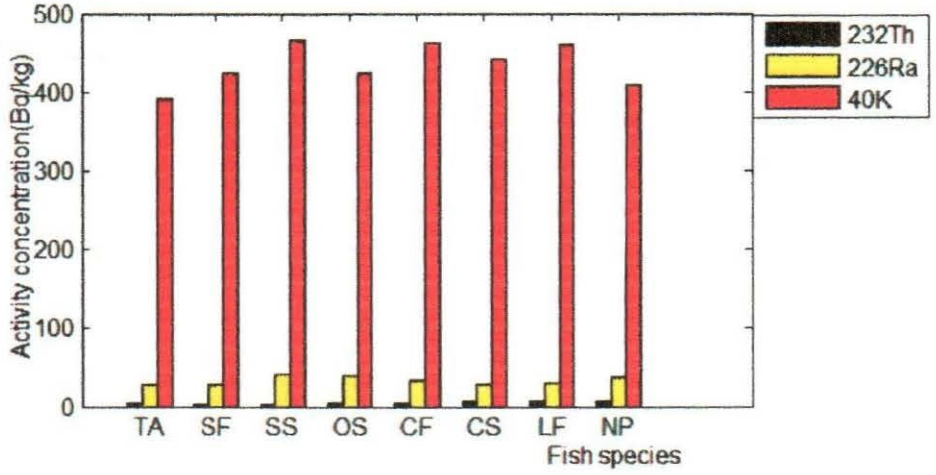
From Table 4.2 above the results showed sprat species had the highest Activity concentration due to ^{226}Ra radioisotope with the average value of 41.75±2.69$Bqkg^{-1}$ followed by Oreochromis species with the average value of 39.64±2.56$Bqkg^{-1}$and then Nile perch species with the average value of 38.10±2.63$Bqkg^{-1}$ while Tilapia and Clarias species had the lowest activity concentration levels with the average values of 27.22±2.13$Bqkg^{-1}$and 27.66±2.18$Bqkg^{-1}$ respectively. The fish species collected from Wanseko sampling site had the highest Activity concentration level that ranged from 26.92±2.01$Bqkg^{-1}$ to 61.59±3.24$Bqkg^{-1}$ with the average value of 40.08±2.49$Bqkg^{-1}$ this was followed by the samples from Butiaba site that ranged from 24.34±1.81$Bqkg^{-1}$ to 63.39±3.73$Bqkg^{-1}$ with the average value of 38.98±2.48$Bqkg^{-1}$ whereas those collected from Kaiso site had the lowest Activity concentration level that ranged from 14.37±1.62$Bqkg^{-1}$ to 36.90±2.60$Bqkg^{-1}$ with the average value 23.41±2.00$Bqkg^{-1}$.The Activity concentration due to ^{226}Ra radioisotope in the fish species collected from all the selected sites ranged from 27.22±2.13$Bqkg^{-1}$ to 41.75±2.69 $Bqkg^{-1}$ with an average concentration of 33.10±2.41$Bqkg^{-1}$.

Table 4.3: The Activity Concentration (A_i) due to ^{40}K radioisotope in the fish species of Lake Albert

Activity Concentration due ^{40}K radioisotope in $Bqkg^{-1}$								
Fish species	The selected sampling sites							Average
	Butiaba	kaboolwa	kaiso	kibiro	Nsonga	Tonya	Wanseko	
Tilapia	406.59±9.48	406.93±10.49	405.42±11.24	423.99±13.37	394.19±10.98	350.42±12.62	360.09±9.30	392.52±11.07
Sprat	420.56±10.19	414.70±10.82	371.48±11.49	487.83±14.00	440.13±11.88	496.00±12.76	442.06±11.76	465.64±12.32
Sliver fish	453.22±10.45	486.88±12.99	453.38±12.37	544.27±15.25	418.67±11.81	345.99±10.62	461.66±11.26	425.25±11.63
Oreochromis	434.83±10.46	404.16±12.06	431.45±12.01	376.66±11.46	334.50±9.240	518.71±14.33	484.51±11.91	425.12±11.64
Catfish	537.89±13.86	434.23±13.50	476.06±12.85	465.20±12.83	372.51±11.51	489.06±14.67	470.69±11.86	463.23±13.01
Nile perch	453.67±10.69	419.22±12.63	456.81±11.90	412.52±11.76	367.54±11.06	410.25±12.81	492.56±12.33	408.81±12.20
Lungfish	425.83±13.20	405.67±11.90	378.31±10.33	467.56±12.55	436.67±12.17	449.11±13.87	477.93±11.89	459.98±12.27
Clarias	604.60±15.61	370.06±10.86	373.89±11.00	398.11±11.73	409.61±12.14	496.42±12.96	451.18±11.46	440.72±11.93
Average	417.15±11.74	417.73±11.91	418.35±11.65	447.02±12.87	396.73±11.35	444.50±13.11	455.09±10.22	435.16±12.01
Maximum	604.60±15.61	486.88±13.50	476.06±12.85	544.27±15.25	440.13±12.17	345.99±10.62	492.56±11.91	465.64±13.01
Minimum	420.56±9.48	370.06±10.49	371.48±10.33	376.66±11.46	334.50±9.24	518.71±14.67	360.09±2.33	392.52±11.07

From Table 4.3 above the results showed sprat species had the highest Activity concentration due to ^{40}K radioisotope with the average value of 465.64±12.32$Bqkg^{-1}$ followed by Catfish species with the average value of 463.23±13.01$Bqkg^{-1}$and then Lungfish species with the average value of 459.98±12.27$Bqkg^{-1}$ while Tilapia and Nile perch species had the lowest activity concentration levels with the average values of 392.52±11.07$Bqkg^{-1}$and 408.81±12.20$Bqkg^{-1}$ respectively. The fish species collected from Wanseko sampling site had the highest Activity concentration level that ranged from 360.09±2.33 $Bqkg^{-1}$ to 492.56±11.91$Bqkg^{-1}$with the average value of 455.09±10.22$Bqkg^{-1}$ this was followed by the samples from Kibiro site that ranged from 376.66±11.46$Bqkg^{-1}$ to 544.27±15.25$Bqkg^{-1}$ with the average value of 447.02±12.87$Bqkg^{-1}$ whereas those collected from Nsonga site had the lowest Activity concentration level that ranged from 334.50±9.24$Bqkg^{-1}$ to 440.13±12.17$Bqkg^{-1}$ with the average value 396.73±11.35$Bqkg^{-1}$.The Activity concentration due to ^{40}K radioisotope in the fish species collected from all the selected sites ranged from 392.52±11.07$Bqkg^{-1}$to 465.64±13.01$Bqkg^{-1}$ with an average concentration of 435.16±12.01$Bqkg^{-1}$.

According to the results obtained in this study, ^{40}K was highly concentrated in the fish samples compared to ^{232}Th and ^{226}Ra. This could be attributed to water runoff from the rocky hills of the western rift valley that flow into the aquatic environment, fertilizer application on the nearby gardens and the rocky watershed geology of the lake. The samples collected from Wanseko site had the highest Activity concentration values compared to those from the other selected sampling sites, this is because wansenko is at the exit point of the lake and there high concentration of mineral ore deposits at this site. The mean activity concentrations of the radioisotopes in all the samples analyzed increased in the order $^{232}Th < ^{226}Ra < ^{40}K$ as shown in the Figure 4.1



TA-Tilapia, SS-Sprat, SF-Sliver fish, OS-Oreochromis, CF- Catfish, NP- Nile perch, LF- Lung fish, CS-Clarias

Figure 4.1: Distribution of activity concentrations of ^{232}Th, ^{226}Ra and ^{40}K radioisotopes in the fish species

4.3: Absorbed Dose Rate due to ^{232}Th, ^{226}Ra and ^{40}K radioisotopes in the fish species from the selected sites of Lake Albert

The Absorbed dose rates depend on the Activity concentrations of various radionuclides in the given samples. The absorbed dose rate for all the fish species from all the selected sampling sites were calculated using the Activity concentration of ^{232}Th, ^{226}Ra and ^{40}K in the species from which the range and average values were stated and these varied by site and specie type. The obtained results were tabulated as in the Tables from 4.4 to 4.6. The

illustration of the absorbed dose rate distributions due to concentration of radioisotopes in the samples was done with the aid of bar graph as shown in the Figure 4.2

Table 4.4: Absorbed Dose Rate due to ^{232}Th radioisotope in the fish species from the selected sites of Lake Albert

Absorbed Dose Rates due ^{232}Th radioisotope in (nGyh^{-1})								
Fish species	The selected sampling sites							Average
	Butiaba	kaboolwa	kaiso	kibiro	Nsonga	Tonya	Wanseko	
Tilapia	2.111	2.292	1.529	1.783	1.594	2.609	3.123	2.149
Sprat	1.354	1.631	1.344	1.520	1.465	1.703	3.600	1.802
Sliver fish	1.123	1.428	1.377	1.825	1.234	2.368	1.794	1.593
Oreochromis	2.712	1.987	2.047	1.645	1.594	2.857	3.890	2.390
Catfish	2.375	2.633	1.890	2.758	1.234	2.851	3.672	2.488
Nile perch	2.860	2.559	2.005	1.737	1.234	4.216	3.727	2.620
Lungfish	2.458	2.837	3.627	3.714	1.594	3.751	6.487	3.495
Clarias	4.006	2.827	2.874	2.680	1.465	3.763	5.786	3.343
Average	2.375	2.274	2.087	2.208	2.358	3.015	4.010	2.485
Maximum	4.006	2.837	3.627	3.714	4.227	4.216	6.487	3.495
Minimum	1.123	1.428	1.344	1.520	1.234	1.703	1.794	1.593

From the Table 4.4 above absorbed dose rate (D_i) due to ^{232}Th radioisotopes in the fish species was highest in the Lungfish species with the average value of 3.495nGyh^{-1} followed by Clarias species with the average value of 3.343nGyh^{-1} and it was lowest in Sliver fish species with the average value of 1.593nGyh^{-1}. Furthermore the fish species collected from Wanseko site had the highest dose rate that ranged from 1.794nGyh^{-1} to 6.487nGyh^{-1} with the average value of 4.010nGyh^{-1}followed by those from Tonya that ranged from 1.703nGyh^{-1}to 4.216nGyh^{-1} with the average value of 3.015nGyh^{-1} whereas the species collected from Kaiso site had the lowest dose rate and ranged from 1.344nGyh^{-1} to 3.627nGyh^{-1} with the average value of 2.087nGyh^{-1}.The gamma-absorbed dose rate for the fish species due to the Activity concentration of ^{232}Th from all the selected sampling sites ranged from 1.593nGyh^{-1} to 3.495nGyh^{-1} with the average value of 2.485nGyh^{-1}.

Table 4.5: Absorbed Dose Rate due to ^{226}Ra radioisotope in the fish species from the selected sites of Lake Albert

Fish species	Absorbed dose rates due to ^{226}Ra radioisotope in ($nGyh^{-1}$)							
	The selected sampling sites							Average
	Butiaba	Kaboolwa	Kaiso	Kibiro	Nsonga	Tonya	Wanseko	
Tilapia	19.890	16.969	10.347	22.994	10.153	14.285	17.441	16.011
Sprat	14.701	17.806	12.491	25.489	16.223	14.599	28.455	18.538
Sliver fish	25.833	30.411	22.288	24.595	23.121	7.946	12.437	20.947
Oreochromis	33.498	26.83	8.679	20.155	10.153	21.104	14.562	19.283
Catfish	23.598	26.504	10.026	11.639	23.121	16.045	24.403	19.334
Nile perch	15.988	9.628	16.501	14.883	23.121	14.992	21.118	16.604
Lung fish	16.538	17.884	10.951	24.341	10.153	11.638	14.789	15.185
Clarias	38.288	25.434	21.810	15.559	16.223	19.894	14.941	21.736
Average	23.542	22.071	14.137	19.957	17.682	15.063	18.518	18.454
Maximum	38.288	30.411	22.288	25.489	31.807	21.104	28.455	21.736
Minimum	14.701	9.628	8.679	11.639	10.153	7.946	12.437	15.185

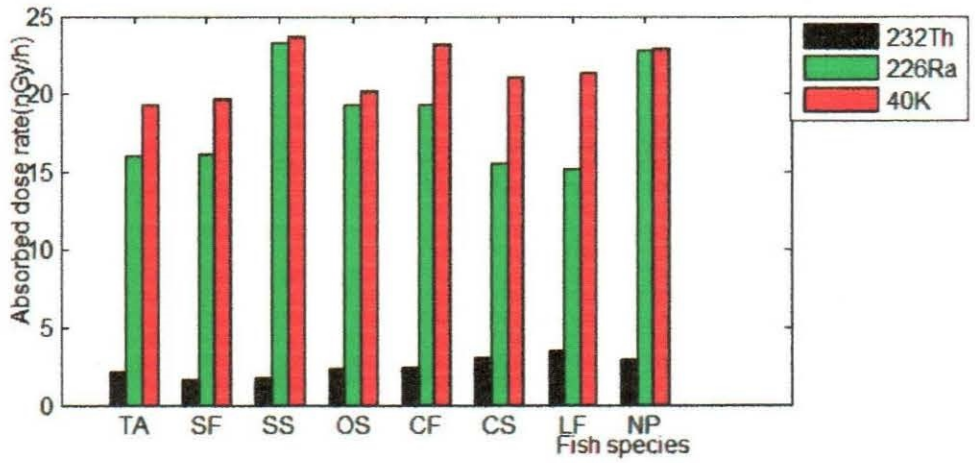
From the Table 4.5 above absorbed dose rate (D_i) due to ^{226}Ra radioisotopes in the fish species was highest in the Clarias species with the average value of 21.736$nGyh^{-1}$ followed by Sliver fish species with the average value of 20.947$nGyh^{-1}$ and it was lowest in Lung fish species with the average value of 15.185$nGyh^{-1}$.Furthermore the fish species collected from Butiaba site had the highest dose rate that ranged from 14.701$nGyh^{-1}$ to 38.288$nGyh^{-1}$ with the average value of 23.542$nGyh^{-1}$followed by those from Kaboolwa that ranged from 9.628$nGyh^{-1}$to 30.411$nGyh^{-1}$ with the average value of 22.071$nGyh^{-1}$ whereas the species collected from Kaiso site had the lowest dose rate and ranged from 8.679$nGyh^{-1}$ to 22.288$nGyh^{-1}$ with the average value of 14.137$nGyh^{-1}$.The gamma-absorbed dose rate for the fish species due to the Activity concentration of ^{226}Ra from all the selected sampling sites ranged from 15.185$nGyh^{-1}$ to 21.736$nGyh^{-1}$ with the average value of 18.454$nGyh^{-1}$.

Table 4.6: Absorbed Dose Rate (D_i) due to ^{40}K radioisotope in the fish species from the selected sites of Lake Albert

Fish species	Absorbed dose rates due to ^{40}K radioisotope in ($nGyh^{-1}$)							
	The selected sampling sites							Average
	Butiaba	Kaboolwa	Kaiso	Kibiro	Nsonga	Tonya	Wanseko	
Tilapia	16.955	16.969	16.906	17.680	16.438	14.613	15.016	16.368
Sprat	17.537	17.293	15.491	20.343	18.353	20.683	18.434	18.305
Sliver fish	18.899	20.303	18.906	17.202	17.459	14.428	19.251	18.064
Oreochromis	18.132	16.853	17.991	15.707	13.949	21.63	20.204	17.781
Catfish	22.430	18.107	19.852	19.399	15.534	20.394	19.628	19.335
Nile perch	18.918	17.481	19.049	22.696	15.326	17.107	20.540	18.731
Lung fish	17.757	16.916	15.776	19.497	18.209	18.728	19.930	18.116
Clarias	25.212	15.432	15.591	16.601	17.081	20.701	18.814	18.490
Average	19.480	17.419	17.445	18.641	16.544	18.535	18.977	18.149
Maximum	25.212	20.303	19.852	22.696	18.353	21.630	20.540	19.335
Minimum	16.955	15.432	15.491	15.707	13.949	14.428	15.016	16.368

From the Table 4.6 above absorbed dose rate (D_i) due to ^{40}K radioisotopes in the fish species was highest in the Catfish species with the average value of 19.335$nGyh^{-1}$ followed by Nile perch species with the average value of 18.731$nGyh^{-1}$ and it was lowest in Tilapia species with the average value of 16.368$nGyh^{-1}$.Furthermore the fish species collected from Butiaba site had the highest dose rate that ranged from 16.955$nGyh^{-1}$ to 25.212$nGyh^{-1}$ with the average value of 19.480$nGyh^{-1}$followed by those from Wanseko that ranged from 15.016$nGyh^{-1}$to 20.540$nGyh^{-1}$ with the average value of 18.977$nGyh^{-1}$ whereas the species collected from Nsonga site had the lowest dose rate and ranged from 13.949$nGyh^{-1}$ to 18.353$nGyh^{-1}$ with the average value of 16.544$nGyh^{-1}$.The gamma-absorbed dose rate for the fish species due to the Activity concentration of ^{40}K from all the selected sampling sites ranged from 16.368$nGyh^{-1}$ to 19.335$nGyh^{-1}$ with the average value of 18.149$nGyh^{-1}$.

From all the analyzed fish samples in this study, the absorbed dose rates due to ^{226}Ra and ^{40}K were highest compared to those due to ^{232}Th radioisotope as shown in the figure 4.2. This could be attributed to feeding habit of these fish species, water runoff from the rocky hills of the western rift valley that flows into the aquatic environment, fertilizer application on the nearby gardens and the rocky watershed geology of the lake.



TA-Tilapia, SS-Sprat, SF-Sliver fish, OS-Oreochromis, CF- Catfish, NP- Nile perch, LF- Lung fish, CS-Clarias

Figure 4.2: Distribution of absorbed dose rates due to the ^{232}Th, ^{226}Ra and ^{40}K radioisotopes in the fish species

4.4: Annual Effective dose due to ^{232}Th, ^{226}Ra and ^{40}K radioisotopes in the fish species from the selected sites of Lake Albert

The Annual Effective dose depends on the Activity concentrations of various radionuclides in the given samples. The Annual Effective dose for all the fish species from all the selected sampling sites were calculated using the Activity concentration of ^{232}Th, ^{226}Ra and ^{40}K in the species from which the range and average values were stated and these varied by site and specie type. The obtained results were tabulated as in the Tables from 4.7 to 4.9. The illustration of the Annual effective dose distributions due the concentration of the ^{232}Th, ^{226}Ra and ^{40}K radioisotopes in samples was done with the aid of bar graph as shown in the Figure 4.3.

Table 4.7: The Annual effective dose due to ^{232}Th radioisotopes in the fish species from the selected sites of Lake Albert

Fish species	Annual effective dose rates due to ^{232}Th radioisotope in ($mSvy^{-1}$)							
	The selected sampling sites							Average
	Butiaba	Kaboolwa	Kaiso	Kibiro	Nsonga	Tonya	Wanseko	
Tilapia	0.009	0.010	0.006	0.007	0.007	0.008	0.010	0.008
Sprat	0.006	0.007	0.006	0.008	0.005	0.005	0.011	0.008
Sliver fish	0.005	0.006	0.006	0.006	0.006	0.008	0.006	0.005
Oreochromis	0.011	0.008	0.009	0.007	0.009	0.009	0.012	0.009
Catfish	0.009	0.011	0.008	0.011	0.011	0.009	0.012	0.009
Nile perch	0.012	0.011	0.008	0.011	0.016	0.013	0.012	0.012
Lung fish	0.010	0.012	0.015	0.015	0.018	0.012	0.021	0.012
Clarias	0.017	0.012	0.012	0.007	0.008	0.012	0.018	0.013
Average	0.009	0.010	0.009	0.009	0.010	0.010	0.013	0.010
Maximum	0.017	0.012	0.015	0.015	0.018	0.013	0.021	0.015
Minimum	0.005	0.006	0.006	0.006	0.005	0.005	0.006	0.006

From the Table 4.7 above Annual Effective Dose (H_i) due to ^{232}Th radioisotopes in the fish species was highest in the Clarias species with the average value of 0.013mSv/y followed by Lung Fish and Nile perch species each with the average value of 0.012mSv/y and it was lowest in Sliver fish species with the average value of 0.005mSv/y. Furthermore the fish species collected from Wanseko site had the highest Annual effective dose that ranged from 0.006mSv/y to 0.021mSv/y with the average value of 0.013mSv/y followed by those from Kaboolwa that ranged from 0.006mSv/y to 0.012mSv/y with the average value of 0.010mSv/y whereas the species collected from Butiaba site had the lowest dose and ranged from 0.005mSv/y to 0.017mSv/y with the average value of 0.010mSv/y. The gamma-annual effective dose for the fish species due to the Activity concentration of ^{232}Th from all the selected sampling sites ranged from 0.006mSv/y to 0.015mSv/y with the average value of 0.015mSv/y.

Table 4.8: The Annual effective dose due to ^{226}Ra radioisotopes in the fish species from the selected sites of Lake Albert

Fish species	Annual effective dose rates due to ^{226}Ra radioisotope in ($mSvy^{-1}$)							
	The selected sampling sites							Average
	Butiaba	Kaboolwa	Kaiso	Kibiro	Nsonga	Tonya	Wanseko	
Tilapia	0.045	0.023	0.023	0.051	0.023	0.042	0.051	0.037
Sprat	0.033	0.040	0.028	0.055	0.052	0.043	0.083	0.048
Sliver fish	0.058	0.068	0.050	0.057	0.036	0.023	0.036	0.047
Oreochromis	0.075	0.057	0.019	0.045	0.071	0.062	0.043	0.053
Catfish	0.053	0.059	0.022	0.026	0.031	0.047	0.071	0.044
Nile perch	0.036	0.022	0.037	0.035	0.031	0.044	0.062	0.038
Lung fish	0.037	0.040	0.025	0.054	0.046	0.034	0.043	0.040
Clarias	0.086	0.060	0.049	0.033	0.027	0.058	0.044	0.051
Average	0.053	0.046	0.032	0.045	0.040	0.044	0.054	0.045
Maximum	0.086	0.068	0.050	0.057	0.071	0.062	0.083	0.053
Minimum	0.033	0.022	0.019	0.026	0.023	0.023	0.036	0.037

From the Table 4.8 above Annual Effective Dose (H_i) due to ^{226}Ra radioisotopes in the fish species was highest in the Oreochromis species with the average value of 0.053mSv/y followed by Clarias species with the average value of 0.051mSv/y and it was lowest in Tilapia species with the average value of 0.037mSv/y. Furthermore the fish species collected from Wanseko site had the highest Annual effective dose that ranged from 0.036mSv/y to 0.053mSv/y with the average value of 0.054mSv/y followed by those from Butiaba site that ranged from 0.033mSv/y to 0.086mSv/y with the average value of 0.053mSv/y whereas the species collected from Kaiso site had the lowest dose and ranged from 0.019mSv/y to 0.050mSv/y with the average value of 0.032mSv/y. The gamma-annual effective dose for the fish species due to the Activity concentration of ^{226}Ra from all the selected sampling sites ranged from 0.037mSv/y to 0.053mSv/y with the average value of 0.045mSv/y.

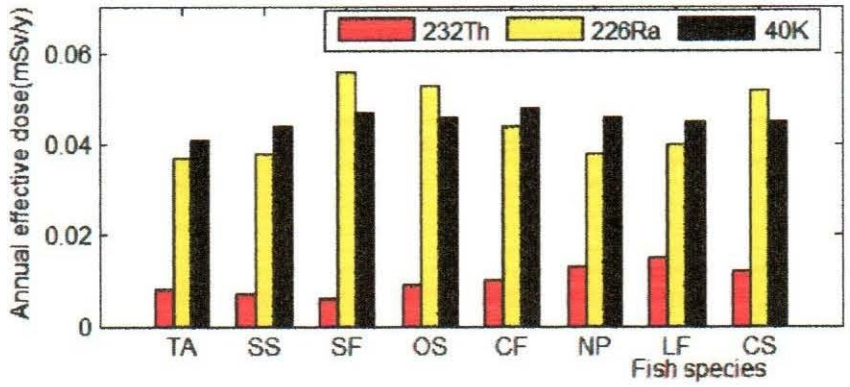
Table 4.9: The Annual effective dose due to ^{40}K radioisotopes in the fish species from the selected sites of Lake Albert

Fish species	Annual effective dose rates due to ^{40}K radioisotope in ($mSvy^{-1}$)							
	The selected sampling sites							Average
	Butiaba	Kaboolwa	Kaiso	Kibiro	Nsonga	Tonya	Wanseko	
Tilapia	0.042	0.042	0.042	0.044	0.041	0.036	0.037	0.041
Sprat	0.044	0.043	0.039	0.057	0.044	0.052	0.046	0.046
Sliver fish	0.047	0.042	0.047	0.051	0.046	0.036	0.048	0.045
Oreochromis	0.045	0.051	0.045	0.039	0.035	0.054	0.050	0.046
Catfish	0.063	0.038	0.049	0.048	0.039	0.051	0.049	0.048
Nile perch	0.047	0.044	0.047	0.041	0.043	0.043	0.051	0.045
Lung fish	0.044	0.042	0.039	0.049	0.045	0.047	0.050	0.045
Clarias	0.056	0.045	0.039	0.043	0.038	0.052	0.047	0.046
Average	0.049	0.043	0.043	0.046	0.041	0.046	0.047	0.045
Maximum	0.063	0.051	0.049	0.057	0.046	0.054	0.051	0.048
Minimum	0.043	0.038	0.039	0.039	0.035	0.036	0.037	0.041

From the Table 4.9 above Annual Effective Dose (H_i) due to ^{40}K radioisotopes in the fish species was highest in the Catfish species with the average value of 0.048mSv/y followed by Clarias, Oreochromis and sprats species each with the average value of 0.046mSv/y and it was lowest in Tilapia species with the average value of 0.041mSv/y. Furthermore the fish species collected from Butiaba site had the highest Annual effective dose that ranged from 0.043mSv/y to 0.063mSv/y with the average value of 0.049mSv/y followed by those from Wanseko site that ranged from 0.037mSv/y to 0.051mSv/y with the average value of 0.047mSv/y whereas the species collected from Nsonga site had the lowest dose and ranged from 0.035mSv/y to 0.046mSv/y with the average value of 0.041mSv/y. The gamma-annual effective dose for the fish species due to the Activity concentration of ^{40}K from all the selected sampling sites ranged from 0.041mSv/y to 0.048mSv/y with the average value of 0.045mSv/y.

From all the analyzed fish samples in this study, the annual effective dose rates due to ^{226}Ra were highest followed by those due to ^{40}K and least due to ^{232}Th radioisotope in the all the samples as shown in the figure 4.3. This could be attributed to feeding habit of these fish species, water runoff from the rocky hills of the western rift valley that flows into the aquatic environment, fertilizer application on the nearby gardens and the rocky

watershed geology of the lake. All these are potential radiological contamination pathways to the aquatic environment



TA-Tilapia, SS-Sprat, SF-Sliver fish, OS-Oreochromis, CF- Catfish, NP- Nile perch, LF- Lung fish, CS-Clarias

Figure 4.3: Distribution of annual effective dose due to the ^{232}Th, ^{226}Ra and ^{40}K radioisotopes in the fish species

4.5: Internal Hazard Indices due to ^{232}Th, ^{226}Ra and ^{40}K radioisotopes in the fish species from the selected sites of Lake Albert

The Internal Hazard Index (H_{in}) depends on the Activity concentrations of various radionuclides in the given samples. The Internal Hazard Index for all the fish species from all the selected sampling sites were calculated using the Activity concentration of ^{232}Th, ^{226}Ra and ^{40}K in the species from which the range and average values were stated and these varied by site and specie type. The obtained results were tabulated as in the Tables from 4.10 to 4.12. The illustration of the Internal hazard indices for the species due to ^{232}Th, ^{226}Ra and ^{40}K radioisotopes in the samples was done with the aid of bar graph as shown in the Figure 4.4.

Table 4.10: The Internal hazard index of the fish species due to ^{232}Th radioisotopes in the fish species from the selected sites of Lake Albert

Fish species	Internal hazard indices due to ^{232}Th radioisotope							
	The selected sampling sites							Average
	Butiaba	Kaboolwa	Kaiso	Kibiro	Nsonga	Tonya	Wanseko	
Tilapia	0.018	0.019	0.013	0.015	0.013	0.017	0.020	0.016
Sprat	0.011	0.014	0.011	0.015	0.010	0.015	0.011	0.014
Sliver fish	0.009	0.012	0.012	0.013	0.012	0.011	0.023	0.012
Oreochromis	0.023	0.017	0.017	0.014	0.019	0.018	0.025	0.019
Catfish	0.020	0.022	0.016	0.023	0.021	0.018	0.023	0.020
Nile perch	0.024	0.021	0.017	0.022	0.031	0.024	0.037	0.024
Lung fish	0.021	0.024	0.030	0.031	0.035	0.024	0.041	0.029
Clarias	0.033	0.024	0.024	0.015	0.015	0.027	0.024	0.025
Average	0.020	0.019	0.018	0.018	0.020	0.019	0.026	0.020
Maximum	0.033	0.024	0.030	0.031	0.035	0.027	0.041	0.029
Minimum	0.009	0.012	0.011	0.013	0.010	0.011	0.011	0.012

From the Table 4.10 above Internal hazard index (H_{in}) due to ^{232}Th radioisotopes in the fish species was highest in the Lungfish species with the average value of 0.029 followed by Clarias species each with the average value of 0.025 and it was lowest in Sprat species with the average value of 0.014. Furthermore the fish species collected from Wanseko site had the highest index that ranged from 0.011 to 0.041 with the average value of 0.026 followed by those from Nsonga site that ranged from 0.010 to 0.027 with the average value of 0.019 whereas the species collected from Kaiso site had the lowest index and ranged from 0.011 to 0.030 with the average value of 0.018. The Internal hazard index for the fish species due to the Activity concentration of ^{40}K from all the selected sampling sites ranged from 0.012 to 0.029 with the average value of 0.020.

Table 4.11: The Internal hazard index of the fish species due to ^{226}Ra radioisotopes in the fish species from the selected sites of Lake Albert

Fish species	Internal hazard indices due to ^{226}Ra radioisotope							
	The selected sampling sites							Average
	Butiaba	Kaboolwa	Kaiso	Kibiro	Nsonga	Tonya	Wanseko	
Tilapia	0.178	0.092	0.093	0.206	0.091	0.167	0.204	0.147
Sprat	0.132	0.159	0.112	0.220	0.207	0.093	0.146	0.191
Sliver fish	0.231	0.272	0.199	0.228	0.145	0.171	0.333	0.188
Oreochromis	0.300	0.228	0.078	0.180	0.285	0.247	0.170	0.213
Catfish	0.211	0.237	0.090	0.104	0.122	0.188	0.286	0.177
Nile perch	0.143	0.086	0.148	0.139	0.123	0.233	0.175	0.152
Lung fish	0.148	0.160	0.098	0.218	0.184	0.136	0.173	0.160
Clarias	0.343	0.240	0.195	0.133	0.110	0.175	0.247	0.204
Average	0.211	0.184	0.127	0.179	0.158	0.176	0.217	0.179
Maximum	0.343	0.272	0.199	0.228	0.285	0.247	0.333	0.213
Minimum	0.132	0.086	0.078	0.104	0.091	0.093	0.146	0.147

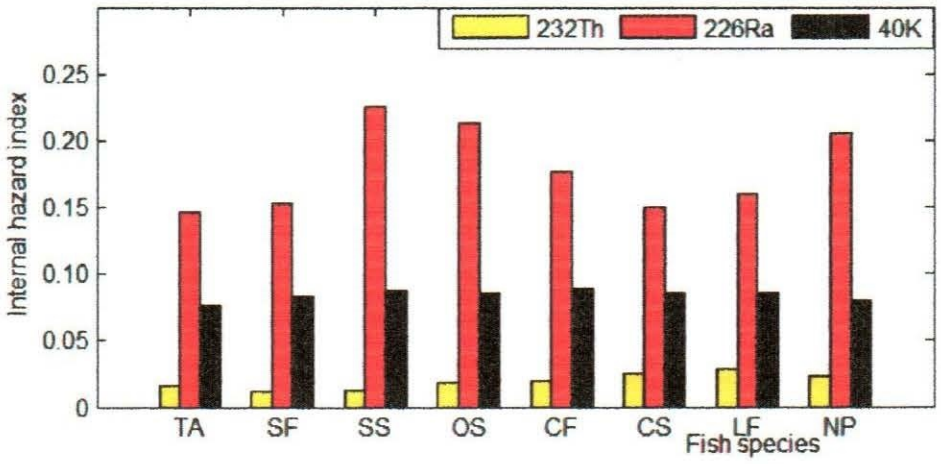
From the Table 4.11 above Internal hazard index (H_{in}) due to ^{226}Ra radioisotopes in the fish species was highest in the Oreochromis species with the average value of 0.213 followed by Clarias species each with the average value of 0.204 and it was lowest in Tilapia species with the average value of 0.147. Furthermore the fish species collected from Wanseko site had the highest index that ranged from 0.146 to 0.333 with the average value of 0.217 followed by those from Butiaba site that ranged from 0.132 to 0.343 with the average value of 0.211 whereas the species collected from Kaiso site had the lowest index and ranged from 0.078 to 0.199 with the average value of 0.127. The Internal hazard index for the fish species due to the Activity concentration of ^{226}Ra from all the selected sampling sites ranged from 0.147 to 0.213 with the average value of 0.179.

Table 4.12: The Internal hazard index of the fish species due to ^{40}K radionuclides in the fish species from the selected sites of Lake Albert

Fish species	Internal hazard indices due to ^{40}Th radioisotope							
	The selected sampling sites							Average
	Butiaba	Kaboolwa	Kaiso	Kibiro	Nsonga	Tonya	Wanseko	
Tilapia	0.085	0.085	0.042	0.088	0.082	0.073	0.075	0.076
Sprat	0.087	0.086	0.039	0.113	0.087	0.072	0.096	0.087
Sliver fish	0.094	0.084	0.047	0.101	0.092	0.103	0.092	0.084
Oreochromis	0.090	0.101	0.045	0.078	0.070	0.108	0.101	0.085
Catfish	0.126	0.077	0.049	0.097	0.077	0.102	0.098	0.089
Nile perch	0.094	0.087	0.047	0.083	0.085	0.103	0.094	0.079
Lung fish	0.089	0.084	0.039	0.097	0.091	0.093	0.099	0.085
Clarias	0.112	0.090	0.039	0.086	0.076	0.085	0.075	0.086
Average	0.097	0.087	0.043	0.093	0.082	0.092	0.102	0.084
Maximum	0.126	0.101	0.049	0.113	0.092	0.108	0.095	0.089
Minimum	0.085	0.077	0.039	0.078	0.070	0.072	0.102	0.076

From the Table 4.12 above Internal hazard index (H_{in}) due to ^{40}K radioisotopes in the fish species was highest in the Sprats species with the average value of 0.087 followed by Clarias species each with the average value of 0.086 and it was lowest in Tilapia species with the average value of 0.076. Furthermore the fish species collected from Wanseko site had the highest index that ranged from 0.102 to 0.095 with the average value of 0.102 followed by those from Butiaba site that ranged from 0.085 to 0.126 with the average value of 0.097 whereas the species collected from Kaiso site had the lowest index and ranged from 0.039 to 0.049 with the average value of 0.043. The Internal hazard index for the fish species due to the Activity concentration of ^{40}K from all the selected sampling sites ranged from 0.076 to 0.089 with the average value of 0.084.

From all the analyzed fish samples in this study, the internal hazard indices due to ^{226}Ra were highest followed by those due to ^{40}K and least due to ^{232}Th radioisotope in the all the samples as shown in the figure 4.4. This could be attributed to feeding habit of these fish species, water runoff from the rocky hills of the western rift valley that flows into the aquatic environment, fertilizer application on the nearby gardens and the rocky watershed geology of the lake which are potential exposure sources to aquatic environment.



TA-Tilapia, SS-Sprat, SF-Sliver fish, OS-Oreochromis, CF- Catfish, NP- Nile perch, LF- Lung fish, CS-Clarias

Figure 4.4: Radiological internal hazard indices due to the ^{232}Th, ^{226}Ra and ^{40}K radioisotopes in the fish species

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

According to the results obtained in this study, mean Activity concentrations of the radionuclides increased according to the order $^{232}Th < ^{226}Ra < ^{40}K$. The results showed that the mean Activity concentrations of the three radioisotopes were lower than worldwide maximum permissible values of 50, 50 and 481Bqkg^{-1} respectively for ^{232}Th, ^{226}Ra and ^{40}K in fish (IAEA, 2006). This could be attributed to variation in geological formations in the lake, water run-off from the rocky hills of valley into the lake, oil exploration activities in the lake vicinity as well as the feeding habits of these fish.

The average absorbed dose rates due to ^{232}Th, ^{226}Ra and ^{40}K radioisotopes in the fish species analyzed in this study were all below the maximum permissible value of 46nGyh^{-1}in the fish (UNSCEAR, 2000). Similarly the average Annual Effective Doses due to ^{232}Th, ^{226}Ra and ^{40}K in the fish species, all the values obtained were lower than the world-wide average annual effective dose permissible value that is approximately 0.07mSvy^{-1} (UNSCEAR, 2000). For the Internal Hazard indices due to the radioisotopes in the selected were all less than the maximum permissible value of 1.0 (ICRP, 1991).

The fish species from Lake Albert therefore do pose negligible hazardous effects to the public since the results showed that the Radiological Hazard levels were lower than the worldwide permissible values as stipulated above. The consumers of fish from Lake Albert have a negligible risk of radioactivity ingestion, even though no amount of radiation is assumed to be totally safe.

5.2 Recommendations

The following work is suggested for further research on the;

Determination of the Radiological hazard levels by the ^{210}pb and ^{210}po radionuclides in fish species from Lake Albert. The present study only focused on radiological hazard levels by the gamma ray emitting natural occurring radioisotopes ^{232}Th, ^{226}Ra and ^{40}K in the fish using gamma-ray spectroscopy method and Wanseko had the highest hazard levels compared to other sites selected.

An independent study Wanseko site should be done to determine the radiological hazard levels by the gamma ray emitting natural occurring radioisotopes ^{232}Th, ^{226}Ra and ^{40}K since in the present study the results showed that in all the samples collected from the seven selected sites, those collected from Wanseko had the highest concentration values.

Determination of the radiological hazard levels in the water from the inflowing rivers of Lake Albert that is Semliki, Kafu and Victoria Nile. This will help to ascertain the percentage radiological leakage to aquatic environment of Lake Albert by these inflowing rivers.

APPENDIX A

RAW DATA OF RESEARCH

Table 1: Primary data for the fish samples from Butiaba (B) sampling site

Sample ID	Peak	M(Kg)	T(S)	n	R	Centroid	SD(Kev)	FWHM	R.ND
B_1	1	0.19935	6002	176	0.03	80.905	5.791	13.608	Th
	2			201	0.03	144.701	6.652	15.631	Ra
	3			1506	0.25	1277.602	28.237	66.358	K
B_2	1	0.28810	6003	145	0.02	90.210	3.463	8.137	Th
	2			181	0.03	133.434	4.754	11.171	Ra
	3			1702	0.28	1270.590	27.710	65.118	K
B_3	1	0.29535	6002	123	0.02	74.656	2.860	6.720	Th
	2			326	0.05	144.283	6.278	14.753	Ra
	3			1880	0.31	1271.55	27.382	64.347	K
B_4	1	0.28300	6001	285	0.05	81.888	5.600	13.159	Th
	2			405	0.07	145.979	7.089	16.659	Ra
	3			1728	0.29	1272.237	26.257	61.704	K
B_5	1	0.32245	6001	253	0.04	80.803	6.639	15.602	Th
	2			274	0.05	145.330	7.328	17.222	Ra
	3			1841	0.31	1272.300	27.906	65.579	K
B_6	1	0.28250	6002	300	0.05	80.847	6.352	14.927	Th
	2			193	0.03	145.264	5.566	13.079	Ra
	3			1800	0.30	1276.472	25.329	59.523	K
B_7	1	0.17265	6051	159	0.03	82.347	5.910	13.889	Th
	2			123	0.02	174.636	2.404	5.649	Ra
	3			1041	0.17	1271.278	27.350	64.271	K
B_8	1	0.17665	6002	263	0.04	81.101	6.235	14.653	Th
	2			289	0.05	146.613	5.801	13.631	Ra
	3			1500	0.25	1273.198	25.494	59.910	K

R.ND: Radionuclide

S.D: Standard Deviation

T: Acquisition (counting) time

n: Number of radionuclides present in a given sample

M: Mass of the sample

FWHM: Full Width at Half Maximum

R: Rate

Table 2: Primary data for the fish samples from Kaboolwa(X) sampling site

Sample ID	Peak	M(Kg)	T(S)	n	R	Centroid	SD(Kev)	FWHM	R.NCD
X_1	1	0.16935	6009	166	0.03	83.187	6.428	16.246	Th
	2			192	0.03	144.691	6.817	15.887	Ra
	3			1034	0.17	1269.655	27.337	64.535	K
X_2	1	0.19805	6001	146	0.02	84.653	3.451	8.111	Th
	2			227	0.04	184.581	9.498	22.321	Ra
	3			1124	0.19	1262.822	22.579	53.060	K
X_3	1	0.18980	6455	215	0.03	80.642	6.637	15.597	Th
	2			156	0.02	147.455	4.692	11.027	Ra
	3			1163	0.18	1269.726	27.644	64.964	K
X_4	1	0.18695	6009	178	0.03	84.129	5.713	13.426	Th
	2			77	0.01	177.171	5.846	13.739	Ra
	3			1102	0.18	1271.851	24.834	58.360	K
X_5	1	0.22350	6004	235	0.04	82.681	6.119	14.380	Th
	2			243	0.04	147.728	4.252	9.993	Ra
	3			1162	0.19	1267.313	26.341	61.901	K
X_6	1	0.24915	6080	153	0.03	87.251	2.628	6.175	Th
	2			192	0.03	179.503	7.493	17.609	Ra
	3			1470	0.24	1271.012	27.167	63.843	K
X_7	1	0.26250	6017	224	0.04	81.888	6.207	14.587	Th
	2			115	0.02	175.774	2.755	6.474	Ra
	3			1504	0.25	1270.733	26.890	63.192	K
X_8	1	0.20540	6004	109	0.02	88.711	1.766	4.150	Th
	2			267	0.04	147.372	6.085	14.300	Ra
	3			1405	0.23	1269.493	27.305	64.166	K

R.NCD: Radionuclide

S.D: Standard Deviation

T: Acquisition (counting) time

n: Number of radionuclides present in a given sample

M: Mass of the sample

FWHM: Full Width at Half Maximum

R: Rate

Table 3: Primary data for the fish samples from Kaiso (Y) sampling site

Sample ID	Peak	M(Kg)	T(S)	n	R	Centroid	SD(Kev)	FWHM	R.NCD
Y_1	1	0.20035	6006	100	0.02	73.316	2.505	5.887	Th
	2			107	0.02	173.824	1.774	4.169	Ra
	3			1046	0.17	1266.562	27.709	65.116	K
Y_2	1	0.2475	6116	340	0.06	82.817	5.791	13.608	Th
	2			118	0.02	143.125	5.926	13.927	Ra
	3			1340	0.22	1272.016	25.163	59.134	K
Y_3	1	0.22615	6064	130	0.02	76.743	1.876	4.409	Th
	2			101	0.02	146.648	5.635	13.242	Ra
	3			1301	0.21	1268.559	25.504	59.935	K
Y_4	1	0.21305	6002	162	0.03	83.924	5.133	12.062	Th
	2			79	0.01	176.078	2.695	6.332	Ra
	3			1291	0.22	1274.003	25.753	60.521	K
Y_5	1	0.20535	6002	144	0.02	82.928	6.867	16.137	Th
	2			88	0.01	174.694	3.526	8.286	Ra
	3			1373	0.23	1271.548	28.958	68.051	K
Y_6	1	0.20950	6047	108	0.02	89.290	3.265	7.673	Th
	2			201	0.03	147.751	4.510	10.598	Ra
	3			1344	0.22	1272.141	27.930	65.635	K
Y_7	1	0.22440	6145	171	0.03	78.159	5.543	13.026	Th
	2			162	0.03	176.107	3.101	7.288	Ra
	3			1474	0.24	1272.436	25.005	58.761	K
Y_8	1	0.21995	6002	235	0.04	83.240	5.875	13.807	Th
	2			205	0.03	142.246	7.343	17.256	Ra
	3			1155	0.19	1279.296	22.507	52.891	K

R.NCD: Radionuclide

S.D: Standard Deviation

T: Acquisition (counting) time

n: Number of radionuclides present in a given sample

M: Mass of the sample

FWHM: Full Width at Half Maximum

R: Rate

Table 4: Primary data for the fish samples from Kibiro (Z) sampling site

Sample ID	Peak	M(Kg)	T(S)	n	R	Centroid	SD(Kev)	FWHM	R.NCD
Z_1	1	0.16835	6023	112	0.02	82.843	5.685	13.360	Th
	2			166	0.03	143.267	6.961	16.358	Ra
	3			1006	0.17	1282.733	25.659	60.299	K
Z_2	1	0.16375	6104	113	0.02	86.993	3.477	8.172	Th
	2			175	0.03	139.431	4.167	9.792	Ra
	3			1273	0.21	1282.788	30.240	71.063	K
Z_3	1	0.17710	6005	100	0.02	73.874	8.175	19.211	Th
	2			193	0.03	145.633	5.306	12.469	Ra
	3			1214	0.20	1282.931	25.562	60.070	K
Z_4	1	0.20350	6027	125	0.02	82.801	5.608	13.180	Th
	2			176	0.03	181.542	6.662	15.655	Ra
	3			1081	0.18	1281.271	26.069	61.263	K
Z_5	1	0.20115	6001	206	0.03	83.790	5.716	13.434	Th
	2			100	0.03	176.636	2.615	6.146	Ra
	3			1314	0.22	1279.366	26.537	62.362	K
Z_6	1	0.20600	6003	205	0.02	90.171	3.005	7.062	Th
	2			137	0.02	174.287	4.693	11.029	Ra
	3			1152	0.19	1287.549	22.383	52.600	K
Z_7	1	0.21145	6004	292	0.05	80.564	6.180	14.524	Th
	2			220	0.04	147.453	6.239	14.662	Ra
	3			1389	0.23	1283.778	26.741	62.841	K
Z_8	1	0.20290	6280	137	0.02	85.894	3.079	7.236	Th
	2			135	0.02	175.778	3.030	7.120	Ra
	3			1230	0.20	1280.741	24.814	58.313	K

R.NCD: Radionuclide

S.D: Standard Deviation

T: Acquisition (counting) time

n: Number of radionuclides present in a given sample

M: Mass of the sample

FWHM: Full Width at Half Maximum

R: Rate

Table 5: Primary data for the fish samples from Nsonga (N) sampling site

Sample ID	Peak	M(kg)	T(s)	n	R	Centroid	S.D(Kev)	FWHM	R.NCD
N_1	1	0.27875	6004	234	0.04	69.122	5.006	11.906	Th
	2			379	0.06	148.406	10.009	23.552	Ra
	3			1310	0.22	1276.015	21.204	49.828	K
N_2	1	0.23275	6004	138	0.02	74.215	2.906	6.829	Th
	2			101	0.02	118.640	1.802	6.371	Ra
	3			1289	0.21	1281.285	22.858	53.716	K
N_3	1	0.2138	6004	146	0.02	82.368	6.6169	15.555	Th
	2			112	0.02	149.963	3.328	7.820	Ra
	3			1104	0.18	1278.471	23.982	56.358	K
N_4	1	0.19775	6004	275	0.04	81.082	6.212	14.598	Th
	2			116	0.02	151.131	5.101	11.986	Ra
	3			1138	0.19	1281.681	24.286	57.073	K
N_5	1	0.21005	6001	330	0.05	82.475	6.121	14.385	Th
	2			184	0.03	151.275	3.961	9.309	Ra
	3			1288	0.21	1277.006	25.886	60.832	K
N_6	1	0.22215	6001	121	0.02	63.883	4.859	11.418	Th
	2			154	0.03	173.675	1.719	4.032	Ra
	3			1373	0.23	1276.807	24.872	58.449	K
N_7	1	0.21360	6002	98	0.02	83.134	5.012	11.778	Th
	2			211	0.04	145.635	6.518	15.318	Ra
	3			1256	0.21	1279.697	26.525	62.335	K
N_8	1	0.20035	6001	188	0.03	88.814	4.911	11.540	Th
	2			117	0.02	144.960	4.793	11.264	Ra
	3			1048	0.17	1272.993	24.548	57.689	k

R.NCD: Radionuclide

S.D: Standard Deviation

T: Acquisition (counting) time

n: Number of radionuclides present in a given sample

M: Mass of the sample

FWHM: Full Width at Half Maximum

R: Rate

Table 6: Primary data for the fish samples from Tonya (T) sampling site

Sample ID	Peak	M(Kg)	T(S)	n	R	Centroid	SD(Kev)	FWHM	R.NCD
T_1	1	0.21855	6002	147	0.02	80.142	6.659	15.659	Th
	2			97	0.02	176.431	3.255	7.650	Ra
	3			1062	0.18	1274.797	27.670	65.05	K
T_2	1	0.16615	6002	177	0.03	89.336	2.651	6.231	Th
	2			108	0.02	178.506	5.761	13.539	Ra
	3			1048	0.17	1277.891	28.359	66.644	K
T_3	1	0.17495	6103	213	0.03	83.816	5.116	12.023	Th
	2			149	0.02	151.921	2.348	5.517	Ra
	3			1025	0.17	1280.735	25.004	58.758	K
T_4	1	0.21705	6002	105	0.02	74.985	2.845	6.685	Th
	2			177	0.03	176.379	2.808	6.598	Ra
	3			1512	0.25	1278.472	28.137	66.121	K
T_5	1	0.21045	6005	225	0.04	77.518	9.454	22.217	Th
	2			234	0.04	145.586	6.088	14.307	Ra
	3			1468	0.24	1275.005	27.863	65.477	K
T_6	1	0.17985	6001	146	0.02	78.892	5.974	14.039	Th
	2			212	0.04	144.557	4.289	10.080	Ra
	3			1310	0.22	1279.160	28.262	66.417	K
T_7	1	0.16175	6002	131	0.02	85.651	2.371	5.573	Th
	2			145	0.02	176.574	3.076	7.229	Ra
	3			1111	0.19	1278.720	29.154	68.513	K
T_8	1	0.15640	6012	117	0.01	78.578	6.286	14.773	Th
	2			125	0.02	148.498	6.303	14.812	Ra
	3			771	0.13	1285.739	23.044	54.154	K

R.NCD: Radionuclide

S.D: Standard Deviation

T: Acquisition (counting) time

n: Number of radionuclides present in a given sample

M: Mass of the sample

FWHM: Full Width at Half Maximum

R: Rate

Table 7: Primary data for the fish samples from Wanseko (W) sampling site

Sample ID	Peak	M(Kg)	T(S)	n	R	Centroid	SD(Kev)	FWHM	R.NCD
W_1	1	0.23060	6001	244	0.04	80.964	5.462	12.835	Th
	2			272	0.05	183.508	6.452	15.162	Ra
	3			1595	0.27	1272.407	26.774	62.918	K
W_2	1	0.23840	6002	249	0.04	79.003	6.643	15.610	Th
	2			325	0.05	145.779	6.604	15.520	Ra
	3			1576	0.26	1270.999	27.177	63.866	K
W_3	1	0.22775	6002	233	0.04	79.121	5.964	14.016	Th
	2			362	0.06	185.264	8.155	19.165	Ra
	3			1414	0.24	1270.202	26.443	62.918	K
W_4	1	0.24340	6001	269	0.04	82.985	5.472	12.860	Th
	2			198	0.03	147.110	5.312	12.483	Ra
	3			1656	0.28	1272.082	28.417	66.780	K
W_5	1	0.25915	6001	132	0.02	86.879	2.688	6.317	Th
	2			180	0.03	180.321	5.600	13.159	Ra
	3			1680	0.28	1270.847	27.904	65.575	K
W_6	1	0.29665	6001	263	0.04	81.101	6.235	14.653	Th
	2			289	0.05	146.613	5.801	13.631	Ra
	3			1500	0.25	1273.198	25.494	59.910	K
W_7	1	0.24445	6002	402	0.07	84.538	6.818	16.021	Th
	2			204	0.03	145.171	5.479	12.876	Ra
	3			1549	0.26	1269.247	26.953	63.339	K
W_8	1	0.24090	6002	444	0.07	84.335	6.913	15.106	Th
	2			199	0.03	179.167	6.761	16.020	Ra
	3			1617	0.27	1269.474	27.462	64.241	K

R.NCD: Radionuclide

S.D: Standard Deviation

T: Acquisition (counting) time

n: Number of radionuclides present in a given sample

M: Mass of the sample

FWHM: Full Width at Half Maximum

R: Rate

APPENDIX B

GAMMA RAY SPECTRA FOR THE FISH SAMPLES

Figure 1: Gamma ray spectrum for the Nile perch fish sample from Wanseko sampling site

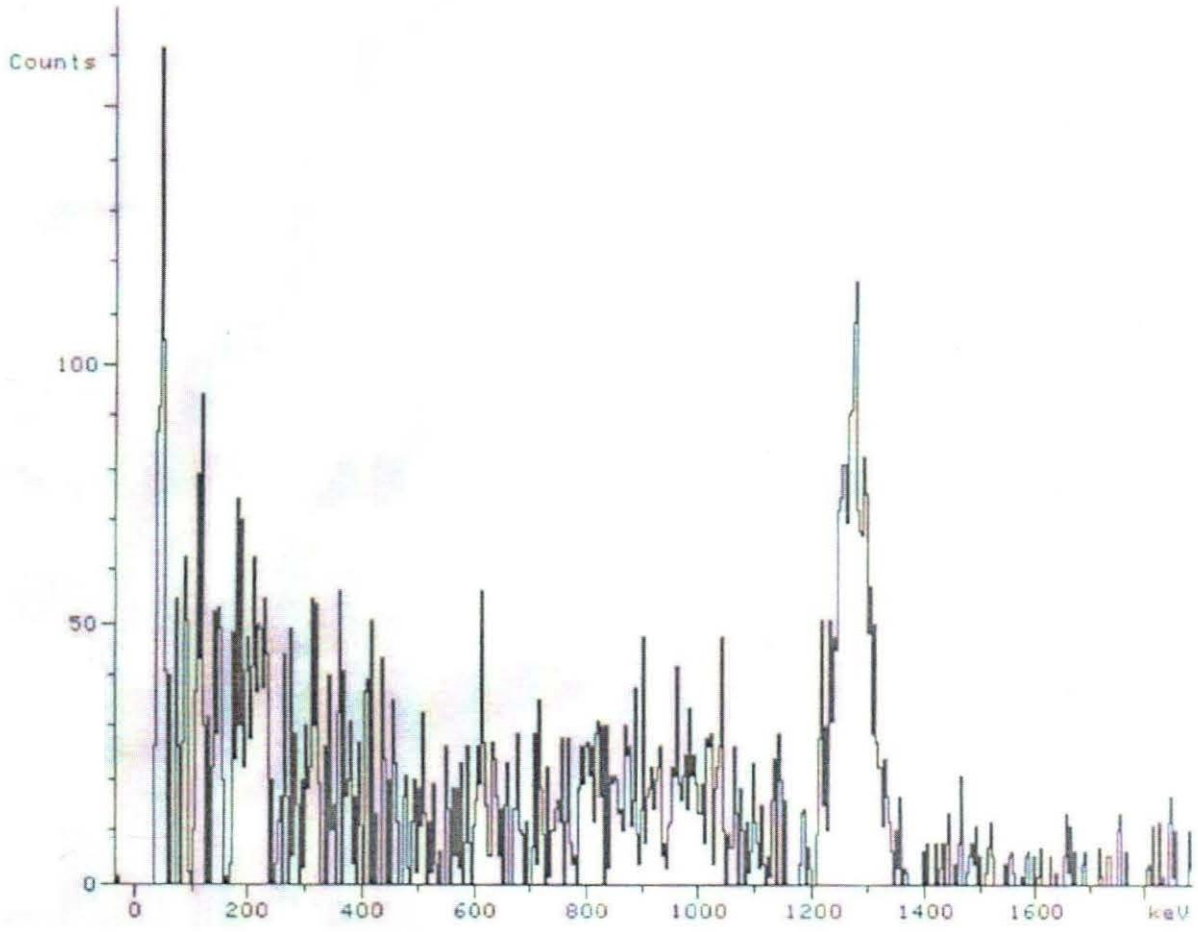


Figure 2: Gamma ray spectrum for the clarias fish sample from Butiaba sampling site

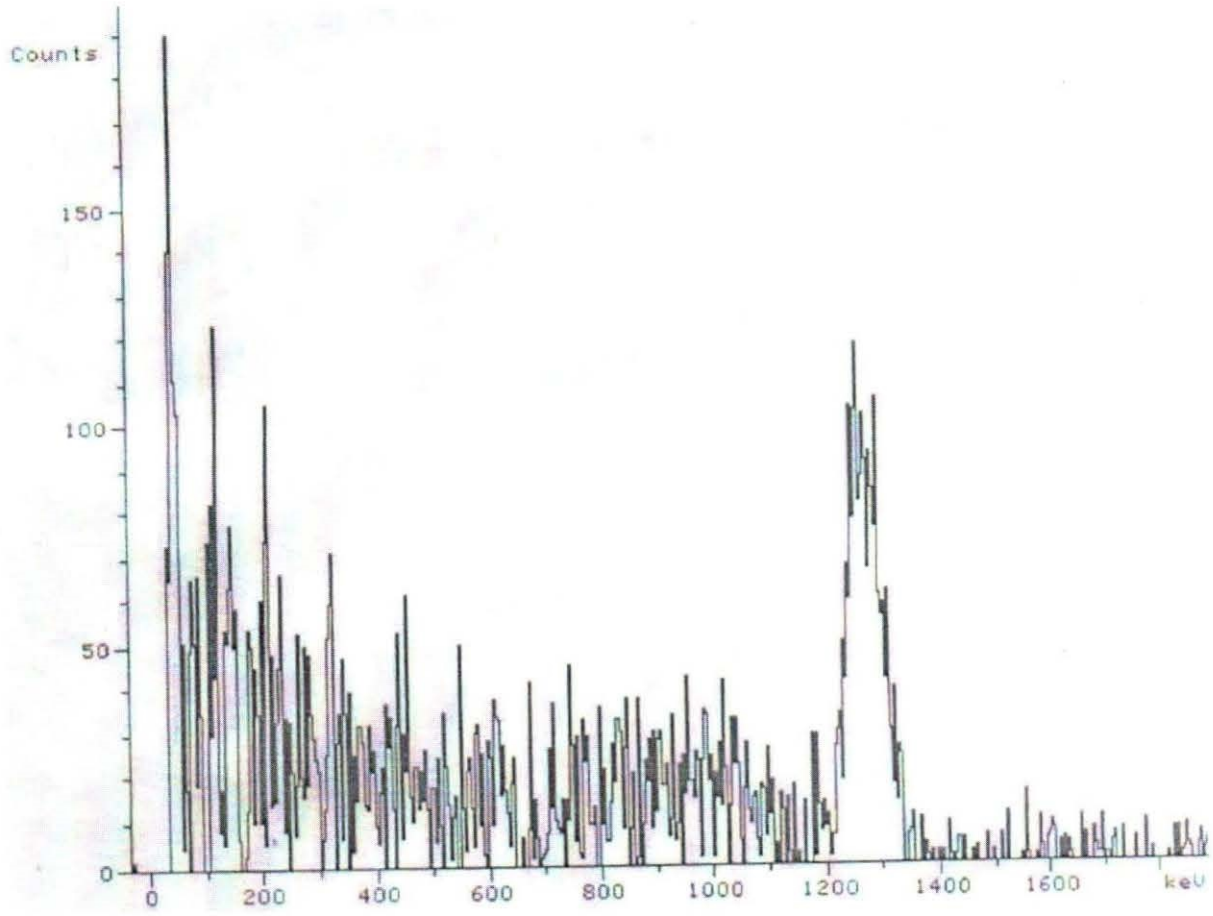
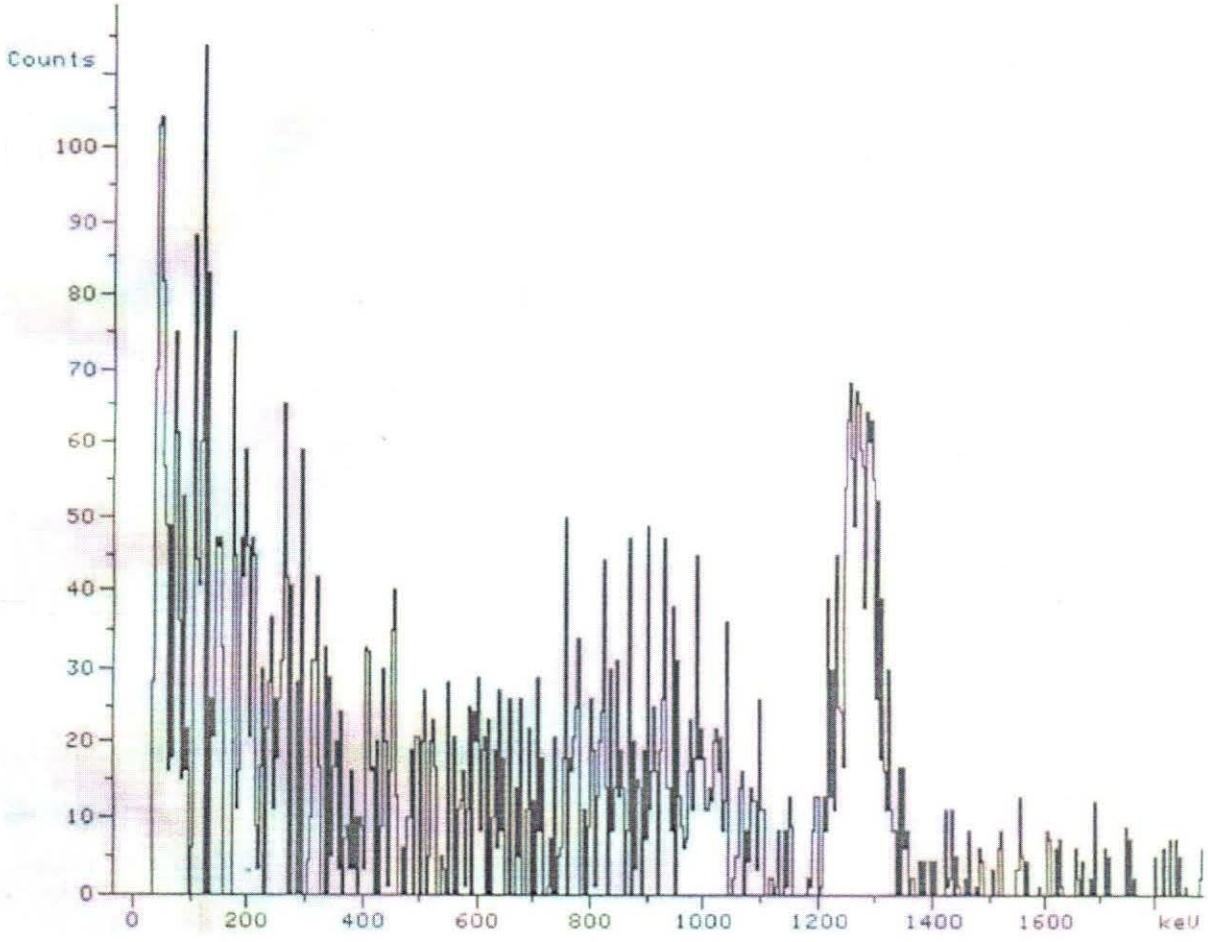


Figure 3: Gamma ray spectrum for the Tilapia fish sample from Kaiso sampling site



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