SPECIFIC ACTIVITY LEVELS OF RADIONUCLIDES IN SPRING WATER, SELECTED PLANTS AND SOILS ALONG NAKIVUBO CHANNEL

BY

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DECLARATION

I Kukiriza Grace do hereby declare that this report contains the results of the research I carried out entitled "Specific Activity Levels of Radio-nuclides in Spring Water, Selected Plants and Soils along Nakivubo Channel," and it has never been submitted to any institution for an academic award.

Signed: .....

Date: 30th Jan. 2014

APPROVAL

This is to certify that this study by Kukiriza Grace was designed and carried out under our close supervision. The report is hereby cleared for submission to the Graduate School and the Senate of Kyambogo University with our due approval.

Signed .....

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Date: 30/07/2014

Signed .....

Supervisor Two: Mr. Richard Oriada

Date: .....

DEDICATION

To my beloved parents Mr. Samuel Kuteesa & Mrs. Tapenence Kuteesa Namutamba.

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LIST OF ACRONYMS

NCRP	National Council on Radiation Protection and Measurements
US EPA	United States Environmental Protection Agency
IAEA	International Atomic Energy Agency
ICRSR	International Conference on Research and Science with Radioisotopes
UNEP	United States Environmental Program
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
USNRC	United States Nuclear Regulatory Commission
NaI(TI)	Thallium-activated Sodium Iodide
PMT	Photomultiplier Tube
NEMA	National Environmental Management Authority

ABSTRACT

There is an increase in the number of industries that discharge their effluents into Nakivubo channel. It is possible that some of the industrial effluents may contain radioactive nuclides since they are widely used in hospitals, research laboratories, industries and construction for diagnosing and treating illnesses, sterilizing equipment. All these processes deposit radio-nuclides into the environment if not well handled contaminating the soil and plants grown on the soil. This in turn affects people when they ingest these crops leading to cancerous risks. This study determined the Specific activity levels of the radio-nuclides present in spring water, selected plants and soils along Nakivubo Channel and its tributaries.

The study was experimentally carried out using a Gamma Ray Spectrometer consisting of a 7.5 cm NaI(T1) GDM 20 detector used for analyzing radionuclides in the samples for a period of about 5000s. The spectral peaks of the radionuclides present in the samples were noted and their specific activity calculated.

The radio-nuclides observed in the samples are: Uranium (U-238), Thorium (Th-232) and Potassium (K-40). The highest specific activity was mainly due to K-40 with a mean value of 201162 ± 448 Bq/kg, followed by Th-232 with a mean activity of 72,7 ± 8,5 Bq/kg and the lowest was due to U-238 with a mean activity of 34,4 ± 5,9 Bq/kg. This is in agreement with a study by Anguma (1999) in water, fish and water hyacinth in Lake Victoria and Kyoga where K-40 was more abundant with a mean activity of 610 Bq/kg and the lowest mean activity levels due to U-232 of 17 Bq/kg.

From the results obtained, the concentrations of the radio-nuclides identified in the samples were within the tolerance limits and therefore the people who consumed these food crops are hardly at a high risk of developing stochastic health effects unless if they are consumed over a lifetime. However, a study investigating the concentration of radionuclides in sugarcane fibre be carried out. A study to ascertain the annual consumption of the radionuclides in foods like yam and sugarcane, spring water along Nakivubo channel and its tributaries be carried out to identify any risks if any. A high purity Germanium Spectrometer can be used in this study to improve on the accuracy and precision of the results obtained.

CHAPTER ONE: INTRODUCTION

1.1 Background of the Study

Radio-nuclides occur naturally as trace elements in rocks and soils as a consequence of the radioactive decay of uranium-238 (U^{238}) and thorium-232 (Th^{232}). Radon-222, radium-226, radium-228, and uranium-234 are decay products of the U^{238} and Th^{232} decay series. They are the most common radio-nuclides found in groundwater. Some naturally occurring radio-nuclides tend to be environmentally immobile or have a short half-life, meaning they are far less likely to be found in significant amounts in groundwater (Avison, 1989).

Due to the industrial revolution and testing of nuclear weapons especially during the cold war era, there is increased artificial radio-nuclides produced in the environment. Radioactive nuclides produced due to nuclear explosions, formed clouds that moved and settled down as radioactive fallout (Myasoedev, 1989). This contaminated the environment with long lived isotopes like Cs-137 which are more dangerous to human beings. These radioactive elements are concentrated mostly in the surface layers of soil. Plants assimilate the radioactive substances necessary for their growth and these too may be ingested by man through food.

Ionizing radiations have enough energy to remove tightly bound electrons from atoms. The examples of these radiations include X-rays, gamma rays, alpha and beta particles. These can be used to kill cancer cells and can be used in many manufacturing processes. X-ray and gamma ray radiation, which are at the upper end of the electro-magnetic radiation, have very high frequencies (in the range of 1×10^{11} hertz) and very short wavelengths of about 1 picometer (Avison, 1989). Radiations in this range have extremely high energy to at least "strip off" electrons from the atoms. Each ionization process releases approximately 33 electron volts (eV) of energy. Compared to other types of radiation that may be absorbed, ionizing radiation deposits a large amount of energy into a small area. The 33 eV, from one ionization is more than enough energy to disrupt the chemical bond between two carbon atoms (U.S EPA, 1991).

The common man-made sources of radio-nuclides include nuclear bombs, nuclear power plants, nuclear research, industrial wastes and nuclear medicine (Helmut, 2003). Everyone is known to unavoidably receive some low level of radiation resulting from natural and artificial sources in

varying proportion, depending on their geographical location, diet, occupation and lifestysle[1]. Such natural sources of radiation include radon, cosmic rays, radioactive elements in rocks and soils, as well as potassium-40 in salts. The abundance of thorium in the earth's crust is three times more than uranium. It is found in small amounts in most rocks and soils and occurs naturally as the minerals thorite, uranothorite, thorianit. Thorium is a major component of monazite and it is present in significant amounts in the minerals zircon, titanite, gadolinite and betafite. Granitile contains up to 80 ppm of thorium. World production of thorium exceeds 30000 tonnes per year. The amounts of thorium in the environment may be incidentally increased due to accidental releases of thorium processing plants. Natural sources account for the greatest share of human radiation exposure (Murkherjee, 1991).

By use of the effective dose equivalent, it is possible to compare the relative radiation hazards due to various types of radiation that impact different organs of the body. According to the United Nations Scientific Committee on the Effects of Atomic Radiation, (UNSCEAR) Report of 1988, the three main contributors to radiation doses from natural radiation in soft tissues of the human body were cosmic rays, terrestrial gamma radiation and Potassium-40 within the body itself. The radiation doses in milligray (mGy) of these sources were as follows; cosmic rays (0,3), terrestrial gamma radiation (0,3-0,5) and Potassium-40 with 0,2. The National Council on Radiation Protection and Measurements (NCRP) estimates an average radiation dose of 2,4 mSv/yr from natural sources and less than 0,024 mSv/yr from man-made sources mostly from medical procedures (U.S EPA, 2005).

Most of the terrestrial background radiation is due to potassium K-40 and the decay products of the uranium series (U^{238} to Pb^{206}), thorium series (Th^{232} to Pb^{208}), and actinium series (U^{235} to Pb^{207}). Each of these series produces many intermediate α, β and γ emitters. The amount of these radioactive nuclides in the soil and water varies greatly. In certain areas, such as in the coastal areas of Kerala in India, the average dose is about 11 mSv/year (UNSCEAR, 1997). In areas of southwestern France, Guarapari in Brazil, and Ramsar in Iran the dose may be about 17 mSv/year, and in small places within these areas the dose rate may be as high as 170 to 430 mSv per year.

[1] *www.bt.cdc gov/radiation* accessed on 24th October 2011.

These levels are caused by higher natural background levels of uranium and thorium isotopes in the soil (IAEA, 2002).

A number of accidents that involve release of radioisotopes to the environment have been recorded like the accident at the Chernobyl nuclear reactor in the USSR, which occurred on 26 April 1986. This accident caused extensive contamination in the local areas and resulted in radioactive material becoming widely dispersed and deposited in European countries and throughout the northern hemisphere. Agricultural activities were all halted and intensive monitoring was undertaken to evaluate the radiation levels. Measurements since the accident showed that the radio-nuclides contributing most significantly to doses are Iodine-131, Caesium-134 and Caesium-137, mainly by external irradiation from deposited material and by ingestion of contaminated foods (UNSCEAR, 1988). Seventy percent of the radioactive fallout from Chernobyl landed in Belarus, affecting more than 2.5 million people. The radiation contaminated the soil, which in turn was absorbed into the crops grown that people relied on for food. Many regions in Russia, Belarus and Ukraine were likely to be contaminated for decades. Radioactive fallout carried by the wind was later found in sheep in the UK and on clothing worn by people throughout Europe (Larrywest, 2011).

The most recent nuclear incident has been the March 2011 nuclear disaster in Japan. A deadly earthquake and the resulting Tsunami in Japan released radionuclides in the environment which contaminated the soils. The radioactive Cs-137 levels released into the atmosphere were approximately 1,3 x 10^{16} Bq high enough to cause concern with 4PBq discharged in the ocean and an additional deposition of 5PBq for the atmospheric fallout into a wider area of western north pacific (Kawamura et al, 2011). Food crops grown in the area were banned from sale. Based on worldwide measurements of iodine-131 and caesium-137, it was suggested that the releases of those isotopes from Fukushima are of the same order of magnitude as those from Chernobyl in 1986. Tokyo officials temporarily recommended that tap water should not be used to prepare food for infants. Plutonium contamination has been detected in the soil at two sites in the plant, although further analysis revealed that the detected density are within limits from fallout generated from previous atmospheric nuclear weapon tests (Fukushima Nuclear accident, 2011).

The most long- lived radionuclide from nuclear fallout is Cs-137. The amount of Cs-137 has a maximum in the northern hemisphere between 40-50 degrees latitude and a mean superficial activity up to 2,9 kBq m^{-2} (UNSCEAR, 1988). High concentrations of Cs-137, accumulated in the upper 10 cm of the soil can remain in the environment for many decades, with a surficial activity in the range of hundreds and thousands of Bqm^{-2} (Korun *et al*, 1993). Caesium radioisotopes are potentially more dangerous than iodine-131 in the long term, because they have longer half-lives (two years for Cs-134, thirty years for Cs-137) than I-131 with half-life of 8 days. The risk of persistence in the environment and the long-term accumulation in organisms is therefore greater (Reid, 2011).

Waste water discharge from sewage and industries are major components of water pollution, contributing to oxygen demand and nutrient loading of water bodies, promoting toxic algae blooms and leading to a destabilized aquatic ecosystem (Morrison *et al*, 2001). The disposal of waste water and industrial effluent into wetlands or water systems are potential sources of elevated heavy metal concentrations in urban wetland ecosystem (Nyangababo *et al*, 2005). Nakivubo channel is a major open drainage that runs through the centre of Kampala city. With its source at the foothills of Makerere hill, Nakivubo channel navigates the heavy populated slums of Makerere Kivulu, two busy markets (Balikuddembe and Kisekka markets) through Kampala industrial area before discharging its water at Murchison bay in Lake Victoria (Kayima et al, 2008).

With an increasing number of manufacturing and processing plants around Kampala, there is an increased pollution due to discharge from industries. Nakivubo channel contributes a very significant organic pollution load from waste water discharge resulting from many slums that receive much untreated domestic silt and heavy metals (Ssentongo, 1998). There is a high degree of pollution in Nakivubo channel caused by discharge of waste from slums, markets, schools, shops and solids carried by rain water and industrial waste. Markets, several garages and industries along the channel have the effect of introducing pollutants like solids, oils, organic matter, heavy metals, nitrogen, phosphorus and pathogenic organisms into this water way. Due to bad building practices, some builders have connected their sanitary pipe to tributaries of the

channel (Kakaire, 2009). Human waste has a lot of organic pollutants and pathogenic organism which subjects the communities along the channel to high health risk.

Small quantities of heavy metals are known to be necessary for growth of normal organisms. As trace elements, some heavy metals like copper, selenium and zinc are essential in maintaining the metabolism of the human body. However excessive levels affect the physiological processes of organisms. At higher concentrations they can lead to poisoning (Kayima *et al*, 2008). Heavy metal poisoning could result, for instance, from drinking-water that is contaminated like from lead pipes, high ambient air concentrations near emission sources. Heavy metals are also a threat to humans that utilize water from the water streams for domestic as well as agricultural purposes.

Ingesting drinking water that contains radioactive nuclides also presents a risk of internal organ cancers. Heavy metals can be accumulated in food crops hence are transferred to human beings where they cause several ailments like stomach and lung cancer and this can lead to deaths. Excessive metal pollutants also lead to increased anoxic conditions in the water and sediments which result to organism's death. Along the Nakivubo channel, heavy metals like Zinc, Chromium and Copper have been detected in the water. This is evident with the changes in the Vegetation structure in the Nakivubo wetland (Hoda et al, 2010).

The areas surrounding the Nakivubo channel and the wetland itself are regarded as prime sites for urban expansion due to their proximity to the city centre and industrial district. This is as a result of land shortage in higher areas of Kampala and also because the land prices along the channel are relatively cheap as compared to other municipalities. As a result, human settlement, industry and small scale cultivation on its fringes has therefore expanded. These activities are likely to impact on the quality of water and the wetland resources such as food obtained from the area. The industrial activities along the channel include those carried out by factories of batteries, soap, paint, metal fabrication, plastics, corrugated iron-sheets, pharmaceuticals, breweries, tanneries as well as municipal waste disposals (Campbell, 2003). All these industries pour their effluents in Nakivubo channel. Sugarcanes and yam are cultivated on the south western part of Nakivubo wetland (Kansime and Nalubega, 1999). In sediments found along the channel, high heavy metal concentrations for lead could be associated with battery and metal fabricating

industry, mercury could be associated with soap and cosmetics industry (Muwanga, 2006). It is possible that there could be mercury in the soap manufactured by some of the industries. The use of beauty creams containing high inorganic mercury concentrations, may pose a threat to high mercury exposure (Campbell, 2003). The effluents yet from the industries are directed along the channel.

Due to the long half-lives of some radio-nuclides like potassium K-40, uranium-238 and thorium-232, these can stay for a longer time in the soils and they may accumulate in the crops that are grown. If ingested, these can be passed on to man causing an increased cancer risk.

1.2 Statement of the Problem

There is an increase in the number of industries that discharge their effluents into Nakivubo Channel. These industries include Mukwano Industries, Meat packers, Sameer Agriculture, Pharmaceutical industries and the Sewage treatment plant in Bugolobi, among others and they all pollute the channel (Kansime, 1999). Joint Clinical Research Centre used radioactive material for research and the effluents (solid materials) were burnt. It is possible that some of these effluents may be directed to the channel contaminating the soils and the crops grown along the channel and its tributaries.

Besides, there is poor garbage disposal in Kampala by the city center dwellers and also from hospitals, and these may contain traces of radioactive material. The garbage may be washed away by rain ending up in Nakivubo channel. Radioactive materials are widely used in hospitals e.g. Radium needles which were widely used in cancer therapy in Mulago, Mengo and Rubaga hospitals were poorly disposed off (buried in the ground), research laboratories e.g. effluents from Veterinary and Botanical laboratories in Makerere University that used radiation tracers were disposed off as ordinary waste. Radio-active materials are also used for diagnosing and treating illnesses, sterilizing equipment. All these processes can deposit radio-nuclides into the environment if not well handled. Some of the crops grown along the channel and its tributaries are consumed by low income earners while others are taken to the market for sale. The inhabitants along the channel mainly use spring water in these areas for their day to day activities like washing, bathing, cooking among others.

Consuming food and water contaminated with radioactive materials increases the amount of radio-nuclides a person is exposed to and this could increase the health risks associated with exposure to radiation. The exact effect depends on the amount and/or the type of radio-nuclides that have been ingested. These can accumulate in the body and result in an increased risk of cancer (Avison, 1989). Radio-nuclides like caesium-137 can reach man by means of food chain trends. A daily intake of such radio-nuclides has a cumulative effect and it may lead to levels where dangerous neoplastic effects arise. This creates a need for not only protecting individuals from exposure to high intensity radiation but also from the low level intensity radiation that may be received over a long period of time. Findings from the study will enable us to realize the radionuclides in the soils and crops grown along the channel, together with their concentrations so that necessary measures can be taken.

1.3 Purpose of the Study

This study was aimed at determining the specific activity levels of the radio-nuclides present in spring water, selected plants and soils along Nakivubo channel and its tributaries.

1.4 Objectives of the Study

The objectives of this study were:

(i) To identify the radio-nuclides present in
   (a) spring water,
   (b) soil
   (c) Food crops (yam and sugarcane) grown along Nakivubo channel.

(ii) To determine the activity levels of the radio-nuclides present in
   (a) spring water
   (b) Soil
   (c) Food crops (yam and sugarcane) grown along Nakivubo channel.

1.5 Scope of the Study

The study was carried out at selected points in Kampala and Wakiso districts. The sampling points in Kampala district were Banda, Luzira, Kitintale, Kisaasi and Namuwongo while in Wakiso district there was only one sampling point at Lubigi. The plants sampled were: Yam

(*Dioscorea alata)* and Sugarcane *(Saccaharum officinarum)* which are the mostly grown crops by the people who live in that locality. The study was carried out in those areas because they are strategically located along the channel where the effluents from the industries located in the city center are channeled. The areas are also overpopulated with slums. Since most of the people living along the channel are low income earners, they do grow crops for their consumption and some of it is taken to the market for sale. The study was carried out for a period of five months.

1.6 Significance of the Study

This study has revealed the radio-nuclides present in the plants (yam and sugarcane) grown along the Nakivubo channel and its tributaries, the soil of growth of yam and the spring water used by the people in that locality. The radio-nuclides observed were: K-40, U-238, and Th-232. The Activity levels of these radio-nuclides were also obtained and they were within the limits of the tolerence levels and may not cause cancerous risks. These findings are important because they can be used by nationals and different stakeholders like NEMA, NW&SC among others in their daily work like environmental monitoring of the concentration levels of these radio-nuclides along damping grounds in Uganda. The information shall be used to expand knowledge about national aqua distribution of radio-nuclides in aquatic life. Finally, these findings can provide knowledge to nationals and different stakeholders to realize the concentration of the radio-nuclides in soil, yam and sugarcane grown along Nakivubo channel and its tributaries and understand the dangers associated with them.

CHAPTER TWO: REVIEW OF RELATED LITERATURE

2.1 Introduction

In this chapter, the principles of generation of radio-nuclides in the environment, radiation exposure and its absorption into the tissues of living organisms, the biological effects of the radiation and the methods of detecting radiation have been discussed. Similar studies carried out to investigate the activity levels of radio-nuclides in various areas have also been discussed.

2.2 Radioactivity

Nuclides can either be stable or unstable. The stable nuclides persist in nature while the unstable ones undergo radioactive decay until stable ones are formed. Radioactivity is the spontaneous, random transformation of an unstable nucleus to another nucleus, accompanied by the emission of one or several particles. The particles emitted include alpha and beta particles, gamma rays and neutrons. The unstable nucleus is characterized by excess energy available in the nucleus which is released on disintegration, such that it is imparted either to a newly created radiation particle from within the nucleus or to an atomic electron. The kinetic energy of the emitted particles lies in the range of 10 keV to several MeV (Knoll, 2000). The radio-nuclide, in this process, undergoes radioactive decay, and may emit gamma ray(s) and/or subatomic particles which constitute ionizing radiations.

Radio-nuclides in the environment can be either of natural origin or man-made. The main contributions to natural radioactivity are due to the primordial nuclides with half-lives of billions of years like K-40 with half-life of $1{,}3 \times 10^{9}$ years, Th^{232} of half-life of $1{,}39 \times 10^{10}$ years, U^{235} with half-life of $7{,}13 \times 10^{8}$ years and U^{238} of half-life $4{,}46 \times 10^{9}$ years (IAEA, 2003). Other nuclides like H^{3} and C^{14} are generated in the atmosphere by cosmic radiation. There are various man made activities that could deposit radio-nuclides into the environment, for example, nuclear power plants, nuclear research and nuclear medicine, poor disposal of industrial wastes, use of fertilizers and manures among others. Radioactive materials are widely used in hospitals, research laboratories, industries and construction for diagnosing and treating illnesses, sterilizing equipment, and irradiating food. All these processes can deposit radio-nuclides into the environment if not well handled.

The atomic nuclei of some isotopes which are unstable disintegrate to form more stable nuclei of a different isotope. This process is accompanied by the emission of particles or energy, termed nuclear radiation. Nuclides with this feature are called radio-nuclides, and the process is called nuclear decay or disintegration. The decay equation is given by

$$N_t = N_o e^{-\lambda t} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2.1)$$

where N_t is the number of atoms present after time t, N_0 is the number of atoms present when time $t = 0$ and λ is the decay constant of the radionuclide. A related constant, the half-life $T_{\frac{1}{2}}$, is the time taken for half the radio-nuclides to decay and it is given by

$$T_{\frac{1}{2}} = \frac{0.693}{\lambda} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2.2)$$

The product N_t gives the activity of the radionuclide. Radioactive decay is independent of other physical conditions (Avison, 1989).

Radioactive decay often occurs in a series (chain) with a number of daughter products, which are also radioactive, and terminates in a stable isotope. In a closed system, and starting with a specified amount of a parent element, the number of atoms of daughter elements and their activity grows gradually until radioactive equilibrium of the disintegration series is reached. At this point, the activities of all the radio-nuclides of the series are identical. Thus the measurement of the concentration of any daughter element can be used to estimate the concentration of any other element in the decay series. Under equilibrium conditions, this relationship can be expressed as

$$\lambda_i N_i = c \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2.3)$$

where c is a constant , $i = 1, 2, 3\ldots$ and N_i as the number of radio-nuclides that disintegrate. Examples of chain disintegration are the natural decay series U^{238}, U^{235} and Th^{232}.

Mean life time of radio-nuclide is obtained by the total lifetime of all the atoms of the element divided by the total number of atoms present initially in the sample of the element i.e.

$$\text{Mean life time} = \frac{\text{Total lifetime of all the atoms}}{\text{Total number of atoms initially}} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2.4)$$

Not all atoms of a given sample disintegrate together. Some atoms disintegrate right in the beginning for which the lifetime is zero. Therefore the lifetime of atoms, which disintegrate ranges from zero to infinity. The calculations for the number of disintegrations per unit mass of a sample are discussed in the following section

2.2.1 Specific Activity of Radio-nuclides

Activity of a sample is the number of radioactive disintegrations per second for a given sample as a whole. Specific Activity on the other hand refers to the number of disintegrations per unit mass or volume of a sample. For example, the specific activity of radium (Ra^{226}) is 1 i.e. 1 g of Ra^{226} contains $3{,}7 \times 10^{10}$ Ra^{226} atoms disintegrating every second. Kagawa (2002) stresses that the specific activity of a radionuclide is inversely proportional to its half-life (decay rate). Specific activity (S.A) of radio-nuclides can be determined using the equation

$$S.A = \frac{\Delta \frac{s}{t}}{\eta.\varepsilon.m} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2.5)$$

Where $\Delta \frac{s}{t} = \frac{s}{t} - \frac{s_f}{t_f}$, s is the radionuclide peak area obtained while measuring radionuclide activity in a sample, t is the duration of a sample measurement, s_f the peak area obtained while measuring background radiation, t_f the duration of the background radiation measurement, η the quantum yield of radionuclide decay energy, ε the efficiency of the spectrometric system and m the sample mass in kg. The S.I unit of specific activity is Bq kg^{-1}.

Radioactive decay is a statistical phenomenon. Each atomic disintegration during radioactive decay occurs completely independent of every other decay event, and the time interval between disintegrations is not constant. For a large number of randomly disintegrating atoms of a particular radionuclide, the frequency of radioactive decay is given by Poisson's distribution. If

$\bar{n}$ is the mean decay rate, the probability, $P_{(n)}$, that the number of atomic nuclei, n, will decay within a unit time is given by

$$P_{(n)} = \frac{(\bar{n})^n}{n!} \exp(-\bar{n}) \quad \text{... (2.6)}$$

For Poisson's distribution, it holds that the variance, σ^2, of a distribution is equal to its mean value. The range of $\pm 1\sigma$ about the mean encompasses 68,3 percent of the distribution, $\pm 2\sigma$ encompasses 95,5 percent of the distribution, and $\pm 3\sigma$ encompasses 99,7 percent of the distribution. The emission of particles and gamma rays in radioactive decay is proportional to the number of disintegrating atoms, and the standard deviation may be used to estimate the range of deviations and errors of the radiometric measurements (IAEA, 2003). When N counts are recorded in time t, then the standard deviation of the recorded counts is given by

$$\sigma(N) = \sqrt{\bar{N}} \quad \text{...(2.7)}$$

where $\bar{N}$ is the mathematical expectation of the number of counts (the mean count of repeated measurements). For a count rate $n = N/t$, the standard deviation is given by

$$\sigma(n) = \frac{\sqrt{N}}{t} = \sqrt{\frac{n}{t}} \quad \text{.....................................(2.8)}$$

When an individual is exposed to radiation, it may lead to various cancerous risks due to cell damage. Radiation exposure may be internal or external, and can be acquired through various exposure pathways as discussed in the following section.

2.2 Radiation Exposure and Population Risk

A human being is exposed to natural radiation from cosmic rays, particularly at high altitude. On average, 80% of the annual dose that a person receives from background radiation is due to naturally occurring terrestrial and cosmic radiation sources. Background radiation levels vary due to geological differences. Exposure in certain areas can be more than 200 times higher than the global average (Avison, 1989).

Radiation exposure is the process of being subjected to radiation from a radioactive source. The magnitude of the exposure is the amount of the radiation available at human exchange boundaries like lungs, skin, gut following intake for some specified period of time. Exposure assessment involves the study of a chain of events starting from the primary injection of radioactive material into the atmosphere and ending with the eventual irradiation of body tissues. This chain of events can be represented schematically (UNSCEAR, 1988) as shown in Figure 2.1

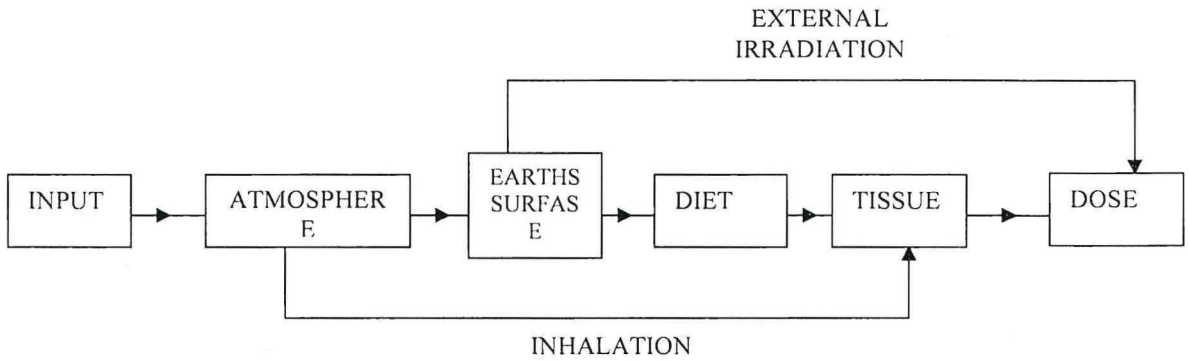

Figure 2. 1: Schematic illustration for a chain of events leading to absorbed dose

Radionuclides can enter the body by inhalation, ingestion, or dermal absorption. Gamma radiation from external nuclides can penetrate the skin and produce a dose in various tissues. Inhalation is the primary absorption mode for gaseous radio-nuclides such as radon. A fractional amount of inhaled radio-nuclides is transferred from the lungs to the blood, where it distributes to other organs. The extent of absorption is strongly dependent on the radionuclide and its chemical form (Sternhem, 1991).

Ingestion is the primary uptake mode for radio-nuclides in soil, water, and food. This includes those naturally occurring radio-nuclides such as radium and uranium in soil and groundwater, and man-made nuclides such as plutonium from radioactive fallout. A fractional amount of ingested radio-nuclides is absorbed from the gastrointestinal tract into the blood while the rest clears the body through normal biological processes via urine and feaces. Radioactivity can contaminate food after it has been discharged into the environment from industries whose wastes contain radio-nuclides. These can be incorporated into food as it is taken by plants, seafood or ingested by animals (INFOSAN, 2011).

According to a Human health factsheet (2005), the skin is generally an effective barrier against absorption of radio-nuclides and so dermal absorption is a very minor route of exposure. An exception to this is dermal absorption of tritiated water, i.e. water containing some amount of tritium (hydrogen-3) in place of a normal hydrogen atom in water molecule, which is absorbed through the skin in the same manner as ordinary water.

Although high doses of ionizing radiation are associated with catastrophic events such as nuclear weapons explosions, there have been documented cases of individuals dying from exposure to high doses of radiation resulting from workplace accidents. Some examples of deaths which have occurred as a result of occupational (worker related) accidents are: Inadvertent criticality e.g. in fuel processing plants (too much fissionable material in the right shape at the wrong time), Irradiator (accidental exposure to sterilization sources which can be more than 1×10^{7} curies) and the Chernobyl (plant workers).

According to United States Nuclear Regulatory Commission (USNRC) in the Reactor core manual, an abandoned medical therapy source (caesium) was found and cut open by people who did not know what it was. This resulted in the deaths of several members of the public and the spread of radioactive contamination over a large area. An individual's average annual dose from natural sources of radiation amounts to about 2,4 millisievert (mSv). Other sources of radiation exposure include medical diagnostic applications and the nuclear fuel cycle, which, under normal operations, is a minor source of human radiation exposure. An individual's average annual dose from the nuclear fuel cycle amounts to less than 1% of the 2,4 mSv received from natural background sources (Mukherjee *et al,* 1991, IAEA 1991). Other human activities that contribute to radiation exposure are poor disposal of industrial wastes and garbage that may be radioactive and application of fertilizers (NPK) among others.

There is a high concentration of Uranium in rocks high in phosphates, and though in small amounts, may increase the load of radioactivity in agricultural soils. Plants grown on these soils absorb the radiation and they are ingested by man. Beyond certain thresholds, radiation can

impair the functioning of tissues and/or organs and can produce acute effects. These effects are discussed in the following section.

2.3 Biological Effects of Radiation

When living cells absorb ionizing radiation energy, molecules within them can be co-rugged and the cells can be destroyed as a result. The damage to living cells caused by very high doses of radiation can be so serious to either destroy or cause them to malfunction through genetic mutation. It may lead to multiplication of cells leading to cancerous cell formation. Biological effects of radiation on the cell are assumed to result from both direct and indirect action of the radiation.

Direct action of ionizing radiation is produced by the initial action of the radiation itself. In this case, the radiation energy is deposited direct on the critical targets of the cells and this may lead to biological cell damage. Direct action interaction may affect the ability of the cell to reproduce and, thus, survive (Bennet, 1983). If enough atoms are affected such that the chromosomes do not replicate properly, or if there is significant alteration in the information carried by the DNA molecule, then the cell may be destroyed by direct interference with its life-sustaining system. This occurs mainly when the body is irradiated with a single dose of 0,05 – 0,10 mSv (Sternhem, 1991).

Indirect action is caused by the later chemical actions of radicals and other radiation products. The radiation energy absorbed by water in the cells results in the production of hydroxyl free radicals which are known to be chemically toxic and highly reactive. If a cell is exposed to radiation, the probability of the radiation interacting with the DNA molecule is very small since these critical components make up such a small part of the cell. However, each cell, just as is the case for the human body, is mostly water. Therefore, there is a much higher probability of radiation interacting with the water that makes up most of the cell's volume. When radiation interacts with water, it may break the bonds that hold the water molecule together, producing fragments such as hydrogen (H) and hydroxyls (OH). These fragments may recombine or may interact with other fragments or ions to form compounds, such as water, which would not harm the cell. However, they could combine to form toxic substances, such as hydrogen peroxide (H_2O_2), which can contribute to the destruction of the cell (Sternhem, 1991). If cell damage

occurs, it may lead to stochastic and non-stochastic effects. These effects are discussed in the following section.

2.4 Dose-Effect Relationship

The effects of exposure to ionizing radiation and the amount of radiation dose received (i.e. dose-response relationship) is classified as stochastic and non-stochastic effects. The stochastic effects are delayed effects of radiation. These effects of radiation are due to continuous low-level exposure. In this case, the results may not be apparent for years. This type of exposure is likely to be the result of improper or inadequate protective measures. In any radiological situation involving the induction of cancer, there is a certain time period between the exposure to radiation and the onset of the disease (Daniels, 2005). This is known as the latency period and it is an interval in which no symptoms of disease are present. The minimum latency period for leukemia produced by radiation is two years and can be up to ten years or more for other types of cancer. One single photon or electron can produce these effects. For this reason, a stochastic effect is called a Linear or Zero-Threshold Dose-Response Effect[2].

Since everybody is exposed to natural radiation, and to other factors, stochastic effects can arise regardless of the type of work, whether or not an individual develops the effect is simply a question of chance. There is a stochastic correlation between the number of cases of cancers or genetic defects developed inside a population and the dose received by the population at relatively large levels of radiation. Attempts have been made to extrapolate the data from these levels of dose to low levels of dose (close to the levels received from background radiation). There is no scientific evidence to prove the results of these attempts (Darko, 1995).

The non-stochastic effects, also referred to as acute or deterministic effects, are specific to each exposed individual. It involves being exposed to a large, single dose of radiation, or a series of moderate doses received during a short period of time. Large acute doses can result from accidental or emergency exposures or from specific medical procedures (radiation therapy). For approved medical exposures, the benefit of the procedure may outweigh the risk from exposure (Daniels, 2005).

[2] *www.epa.gov/radiation* accessed on 18th November 2011.

In most cases, a large acute exposure to radiation causes both immediate and delayed effects. Delayed biological effects can include cataracts, temporary or permanent sterility, cancer, and harmful genetic effects. For humans and other mammals, acute exposure to the whole body, if large enough, can cause rapid development of radiation sickness, evidenced by gastrointestinal disorders, hemorrhaging, anemia, loss of body fluids, and electrolyte imbalance. Extremely high dose of acute radiation exposure can result in death within a few hours, days or weeks (US EPA, 2007).

The doses that produce such effects are characterized in three ways as follows: A certain minimum dose must be exceeded before the particular effect is observed. Because of this minimum dose, the non-stochastic effects are also called Threshold Effects, which may differ from individual to individual. The magnitude of the effect increases with the size of the dose received by the individual. There is a clear relationship between exposure to radiation and the observed effect on an individual. The larger the dose received, the greater the health effect (Dendy, 1999).

All people receive chronic exposure to background levels of ionizing radiation present in the environment. Other people receive relatively small acute exposures. For populations receiving such exposures, the primary concern is that radiation could increase the risk of cancer or harmful genetic effects. The probability of a radiation-induced cancer or harmful genetic effects is related to the total amount of radiation accumulated by an individual (Hendee, *et al*, 2005). Based on current scientific evidence, any exposure to radiation can be harmful (e.g. can increase the risk of cancer); however, at very low exposures, the estimated increase in risk is very small. For this reason, cancer rates in populations receiving very low doses of excess radiation (doses of radiation above background) may be similar to the rates for average populations (US EPA, 2007). Radiation interacts with matter in various ways and this is discussed in the following section.

2.5. Interaction of radiation with matter

Ionizing radiation is comprised of a flux of elementary particles and energy quanta, and can be classified by its physical character and energy. These determine how the radiation interacts with matter.

Alpha radiation is a flux of positively charged alpha particles. Alpha particles have an initial energy of several MeV, and an initial velocity of the order of 10^7 m s^{-1}. They exhibit high ionization, and their penetration range in matter is low. Alpha particles are absorbed by about 10^{-2} m of air, and 10^{-5} m of rock. They have a discrete energy that is specific for a particular radionuclide (IAEA, 2003). The health effects of alpha particles depend heavily upon on how exposure takes place. External exposure (external to the body) is of far less concern than internal exposure, because alpha particles lack the energy to penetrate the outer dead layer of skin. Internally exposed alpha particle can induce malignant growth. If alpha emitters are inhaled, ingested (swallowed), or absorbed into the blood stream, sensitive living tissue can be exposed to alpha radiation and they may die (US EPA, 2007). Ingested radio-nuclides accumulate in specific organs, which are irradiated over a lifelong period.

Studies by Yamamoto et al (2010) in Japan stressed why the development of malignant tumors required long-term internal exposure, on the order of decades, despite the fact that irradiation is continuous over this period. Three major factors were considered to be responsible for the long incubation time in carcinogenesis caused by internally deposited alpha-emitters: uneven distribution of radionuclides, limited range of irradiation, and dynamic movement of tumor precursor cells. It was hypothesized that target cells susceptible to malignant transformation may undergo one event by alpha particles and may then migrate outside of the range of alpha particles, thereby avoiding immediate induction of successive additional events that would lead to cell death or neoplastic changes. Based on this hypothesis, a mathematical model to predict the relationship between dose rate and incubation period of tumors induced by internally deposited alpha-emitters was proposed. The function was non-linear and included terms of both direct and indirect radiation effects and the studies showed that indirect radiation effects were independent from dose rate.

Beta radiation is a flux of electrons with a continuous energy spectrum up to a maximum energy, which depends on the particular radionuclide. The initial velocity of beta particles can approach the velocity of light. The penetration range for beta particles depends on the initial energy of the particle e.g. for an initial energy of 2 MeV, the penetration range is about 8 m in air and 1 cm in water. Beta radiation passing through matter loses its energy by ionization and generates electromagnetic radiation called bremsstrahlung (IAEA, 2003). Beta particles are more penetrating than alpha particles but are less damaging over equally traveled distances. They travel considerable distances in air but can be reduced or stopped by a layer of clothing or by a few millimeters of a substance, such as aluminum. Some beta particles are capable of penetrating the skin and causing radiation damage, such as skin burns. However, as with alpha-emitters, beta-emitters are most hazardous when they are inhaled or ingested. They damage the cells which may lead to death (US EPA, 2007).

Gamma radiation is part of the electromagnetic spectrum. Gamma rays travel at the speed of light (c), and have a discrete energy (E), and wave length (λ). These are related by

$$E = h\frac{c}{\lambda} \quad \text{..... (2.9)}$$

where h is the Planck's constant and c is the speed of light. Gamma rays comprise that part of the electromagnetic spectrum with discrete energy that is specific for a particular radionuclide. Gamma radiation is best shielded by very dense materials, such as lead, concrete, or steel. Shielding is often expressed by thicknesses that provide a certain shielding factor, such as a "Half-Value Layer" (HVL). An HVL is the thickness of a given material required to reduce the dose rate to one half the unshielded dose rate (Daniels, 2005).

Due to the high penetrating power, gamma radiation can result in radiation exposure to the whole body rather than a small area of tissue near the source. Therefore, a photon radiation has the same ability to cause dose to tissue whether the source is inside or outside the body. This is in contrast to alpha radiation, for example, which must be received internally to be a hazard. Gamma radiation is considered an external hazard. Since gamma rays are the most penetrating component of natural and man-made radiation, they are widely used in the study of the radiation environment (ICRU, 1994). Gamma rays interact with atoms of matter by three principal processes. These are Photoelectric effect, Compton scattering and Pair production.

Photoelectric effect is the predominant mode of interaction of gamma rays at relatively low energies. This results in all the energy of a gamma quantum being absorbed in a collision with an electron of an atom. In the photoelectric absorption process, a photon undergoes an interaction with an absorber atom in which the photon completely disappears. In its place, an energetic photoelectron is ejected by the atom from one of its bound shells. The interaction is with the atom as a whole and it cannot take place with free electrons. For gamma rays of sufficient energy, the most probable origin of the photoelectron is the most tightly bound or K shell of the atom. The photoelectron appears with an energy given by

$$E_i = E_b + \frac{1}{2}mv^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.10)$$

where E_b is the binding energy of the photoelectron in its original shell, m is its mass and v its speed. Since gamma rays are usually very energetic, their energy is large compared to the binding energy E_b (Knoll, 2000).

Compton scattering involves collision of an incident photon with an electron in the absorbing material. The incident photon loses part of its energy to the electron and is scattered at an angle to its original direction. In the Compton Effect, the photon of wavelength λ with the speed c, is incident upon a free or loosely bound electron. At impact, the electron recoils with a speed v at some angle ø with the direction of the photon. The incident photon surrenders its identity and a new photon of lesser energy hv' is ejected at a direction θ with the original photon. Because all angles of scattering are possible, the energy transferred to the electron can vary from zero to a large fraction of the gamma-ray energy.

Pair production is the process whereby an incident gamma photon is completely absorbed and results in the creation of an electron-positron pair in the electrostatic field of a nucleus (Cork, 1948). At least 1,02 MeV of photons energy are required for pair production, because the energy equivalent of the rest mass of the electron and positron is 0,51 MeV each. Pair production is not very probable until the photon energy exceeds about 5 MeV. Because an energy of $2m_0c^2$ is required to create the electron-positron pair, a minimum gamma ray energy of 1,02 MeV is required to make the process energetically possible. If the incident gamma ray energy exceeds

this value, the excess energy appears in the form of kinetic energy shared by the electron-positron pair. Therefore, the process consists of converting the incident gamma-ray photon energy into electron and positron kinetic energies given by the equation

$$E_{e^-} + E_{e^+} = h\nu - 2m_0c^2 \quad \text{..... (2.11)}$$

where E_{e^-} is the energy of the electron, and E_{e^+} is the energy of the positron. For typical energies, both the positron and electron travel a few millimeters at most before losing all their kinetic energy to the absorbing medium (Knoll, 2000). Gamma ray photons lose energy through successive Compton scattering events, until eventually the resulting low-energy photons are absorbed through the photoelectric effect. As a result of the interaction of gamma rays with matter, the intensity of radiation decreases with distance from the source (IAEA, 2003).

When gamma radiation is directed to the human body, cell damage occurs due to both direct and indirect actions as discussed in Section 2.3. There are various methods of measuring ionizing radiation and these are discussed in the following section.

2.6 Measurement of Ionizing Radiation

Ionizing Radiation measurement focuses on a number of factors. These include: the measurement of radiation coming from a radioactive source, the radiation dose absorbed by a person and the health effects (biological risk) a person can suffer from when exposed to radiation.

When the amount of ionizing radiation being emitted or given off by radiation source is required, the SI unit of measure used is Becquerel (Bq). The Bq is used to express the number of disintegrations of radioactive atoms in a radioactive material over a period of time. Since one Bq is equal to one disintegration per second, a Bq may be used to refer to the amount of radioactive materials released into the environment. During the Chernobyl power plant accident (1986) that took place in the former Soviet Union, an estimated total of $8{,}1 \times 10^7$ Ci of radioactive cesium was released.

When a person is exposed to ionizing radiation, energy is deposited in the tissues of the body. The amount of energy deposited per unit mass of human tissue is called the absorbed dose.

Absorbed dose is measured using the conventional radiation absorbed dose (rad) or the SI Gray (Gy). One Gy is equal to 100 rad.

A person's biological risk to suffer health effects from an exposure to radiation is measured using the conventional unit rem or the SI unit Sv. Different kinds of radiation cause damage to living cells to different extents and so to take this into account, it is necessary to multiply the absorbed dose D by a weighing factor or quality factor Q. Quality factor is a factor by which the absorbed dose must be multiplied to obtain a quantity that expresses the biological damage to the exposed tissues for all ionizing radiation (Avison, 1989). This quantity is called the Biological risk, also referred to as the Dose equivalent (H) and it can be expressed as

$$H = \mathrm{D} \times \mathrm{Q} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2.12)$$

Quality factor is also called the relative biological effectiveness of radiation.

The effective dose allows doses from external and internal exposure to be assessed on a common basis. In the calculation of effective dose, radiation weighting factors, w_R, is used to allow for the varying effectiveness of different radiations while tissue weighting factors, w_T, allows for the variations in radiation sensitivity of different tissues for the induction of stochastic effects (ICRP,2005). The quality factor for the different types of radiation is shown in Table 2.1.

Table 2. 1: Quality factor for different types of Radiations (Avison, 1989)

TYPE OF RADIATION	QUALITY FACTOR(Q)
Alpha particles	20
Neutrons	3- 10
Beta particles, X-rays and γ rays	1

Measuring the amount of ionizing radiation present can help people realize the amount of radiation from a source and hence take the necessary steps to avoid or reduce being exposed. Ionizing radiation has the potential to damage living tissues and the extent of the damage caused

depends, in part, on the type and the amount of Ionizing radiation that is absorbed by the tissue (Appleby, 1996). Radiation detection and measurement is therefore important in protecting people and the environment.

Ionizing radiation can be measured through the physical and chemical effects of its interaction with matter. Field and laboratory methods are based mainly on the ionizing properties of radiation and the use of instruments that convert the radiation to electrical signals. Ionization chambers, proportional counters, Geiger-Muller counters, scintillation counters, semiconductor detectors, thermo-luminiscence detectors and various mechanical and chemical track detectors are some of the devices used to monitor and quantify the α, β, γ and neutron radiation in the environment. In this study, a Gamma Ray Spectrometer was used and it is discussed in the following section.

2.7 Gamma Ray Spectrometer

A typical laboratory scintillation gamma ray spectrometer consists of a NaI(Tl) scintillation detector with a minimum size of 76 × 76 mm NaI(Tl), a preamplifier, a multichannel analyzer (1024-4096 channels), a stabilized high voltage supply, a display unit, and a data recording unit. The sample and detector are enclosed within 6 -10 cm of lead shielding to reduce the background radiation. A 5 mm thick brass plate is installed inside the lead shielding to minimize the effect of induced X-ray radiation in the lead shielding. The performance characteristics of a particular laboratory spectrometer should be known, as this affects the selection of the best method for analyzing the samples. The energy resolution of the detector can be measured using the Cs-137 peak at 662 keV. This can be used to select an appropriate channel width setting (IAEA, 2003). Figure 2.2 shows the components of a Gamma ray spectrometer.

Gamma ray spectrometers use the direct proportionality between the energy of an incoming gamma ray and the pulse amplitude at the output of the detector. The voltage pulse produced by the detector (or by the photomultiplier in a scintillation detector) is shaped by a Multi-Channel Analyzer (MCA). The multichannel analyzer takes the very small voltage signal produced by the detector, reshapes it into a Gaussian or trapezoidal shape, and converts that signal into a digital signal. In some systems, the analog-to-digital conversion is performed before the peak is

reshaped. The analog-to-digital converter (ADC) also sorts the pulses by their height. ADCs have specific numbers of bins into which the pulses can be sorted; these bins represent the channels in the spectrum. The number of channels can be changed in most modern gamma spectroscopy systems by modifying software or hardware settings. The number of channels is typically a power of two; common values include 512, 1024, 2048, 4096, 8192, or 16384 channels. The choice of number of channels depends on the resolution of the system and the energy range being studied. The multichannel analyzer output is sent to a computer, which stores, displays, and analyzes the data.

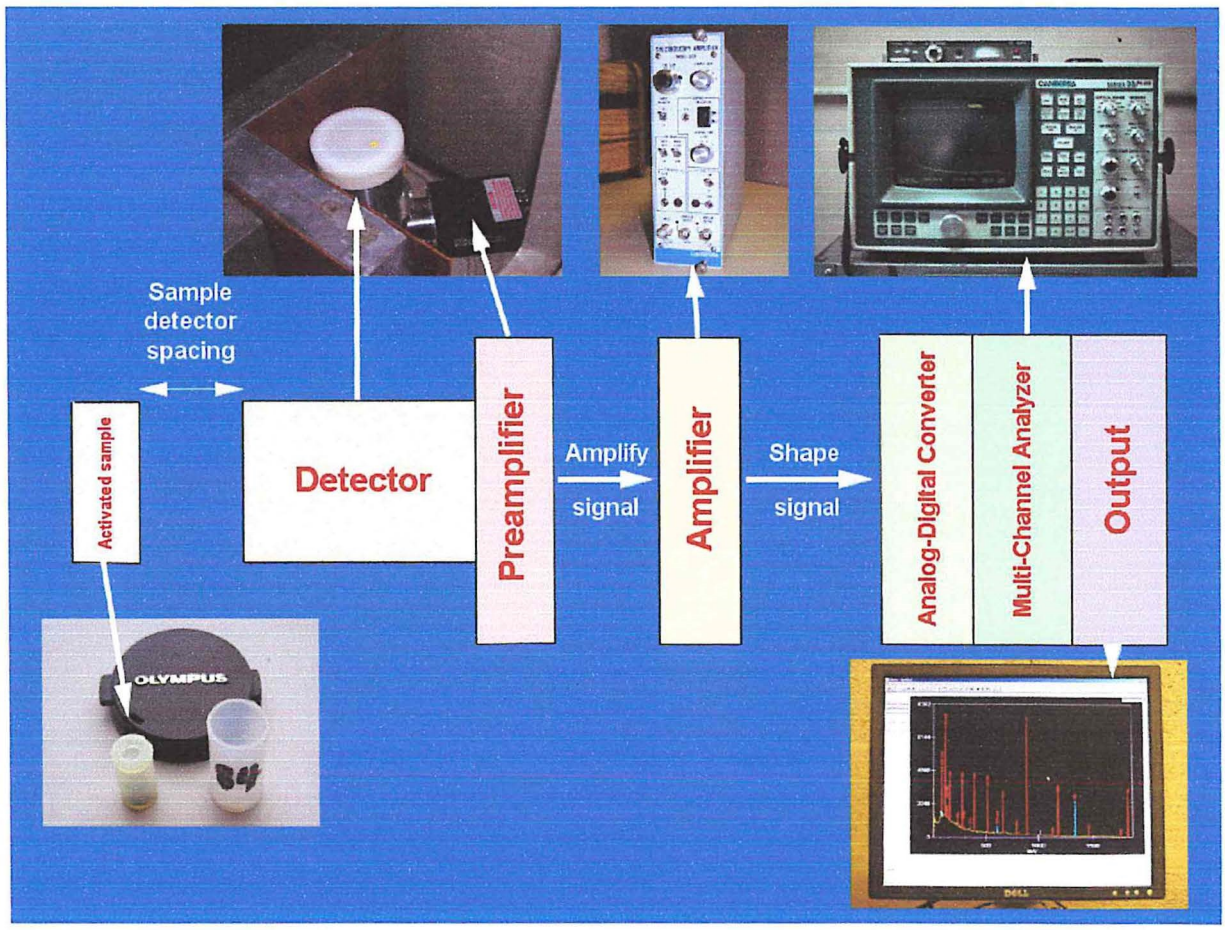

Figure 2. 2: Components of a Gamma Ray Spectrometer

After amplification and digitization, the pulse amplitudes are analyzed, and the output of the spectrometer is an energy spectrum of detected radiation. Since individual radio-nuclides emit specific gamma ray energies, gamma ray spectra can be used to diagnose the source of the radiation (IAEA, 2003). The nature and character of radiation governs the selection of a suitable detector. The major components of a Gamma Ray Spectrometer are discussed in the following section.

2.6.1 The Detector System

The detector system of a Gamma ray spectrometer consists of a Thallium-activated sodium iodide [NaI(Tl)] crystal and a photomultiplier Tube (PMT) to which a tube base is connected. A preamplifier is connected to the detector in order to amplify the signals from the photomultiplier tube which are of small amplitude. After pre-amplification the signals are sent to the amplifier (pulse shaper) and from here to the multichannel analyzer (spectral analyzer).

This analyzer sorts all incoming electrical signals according to their amplitudes and sorts the detected photons in channels covering small energy intervals. The energy range of each channel depends on the gain settings of the multichannel analyzer and the high voltage across the photomultiplier tube. NaI(TI) is the most commonly used scintillator for gamma rays. This is because it is produced in large crystal, yielding high efficiency. It also produces intense bursts of light compared to other spectroscopic scintillators. It has been produced in single crystal of up to 0,75 m in diameter and thickness of 0,25 m.

The properties of NaI(TI) are:

(i) NaI(TI) crystal has a very high efficiency as a gamma ray detector due to its relatively high density of 3,67 x 10^3 kg/m^3 and the high atomic number combined with its large volume.

(ii) The emission spectrum of NaI(TI) has peaks at 410 nm, and it's light conversion efficiency is the highest of all the inorganic scintillators.

(iii) It is brittle and sensitive to temperature gradient and thermal shocks. NaI(TI) is also hygroscopic that it should be encapsulated at all times. NaI(TI) always contains a small

amount of potassium which creates a certain background because of the radioactive Potassium, K-40.

The NaI(TI) crystal is sealed in a cylindrical aluminum container with a face of beryllium or Mylar to prevent it from absorbing atmospheric moisture and to permit low energy radiation entry.

Modern gamma ray spectrometers typically record 256 (or 512) channels of information in the energy range 0-3,0 MeV. Each channel thus records all gamma rays absorbed by the detector that have energy within a 11,7 keV range. The Count rates are usually low. An airborne gamma ray spectrometer with 32 litres of NaI(TI) detectors will record perhaps one or even zero counts in some high energy channels during a one-second counting period. The precision to which a spectrometer can measure the energy of a gamma ray is known as the spectrometer energy resolution. Typical spectrometer resolutions for large-volume NaI(TI) detectors are 10% for Cs-137 at 0,662 MeV and 7% for Tl-208 at 2,61 MeV (IAEA, 2003).

The efficiency of a detector is a measure of the probability that an incident photon will be absorbed in the detector. It is usually quoted as the ratio of recorded counts to incident photons. The energy resolution of a detector is a measure of its ability to distinguish between two gamma rays of only slightly different energies. This is usually defined as the full width of a photo peak at half the maximum (FWHM) amplitude divided by the mean pulse height H_o corresponding to the same peak. The energy resolution R is expressed as

$$R = \frac{FWHM}{H_O} \quad \text{...} \quad (2.13)$$

The energy resolution of scintillators is the poorest of any commonly used detector; therefore the spectra have relatively broad peaks (Knoll, 2000). Figure 2.3 shows the energy resolution of a gamma ray spectrometer.

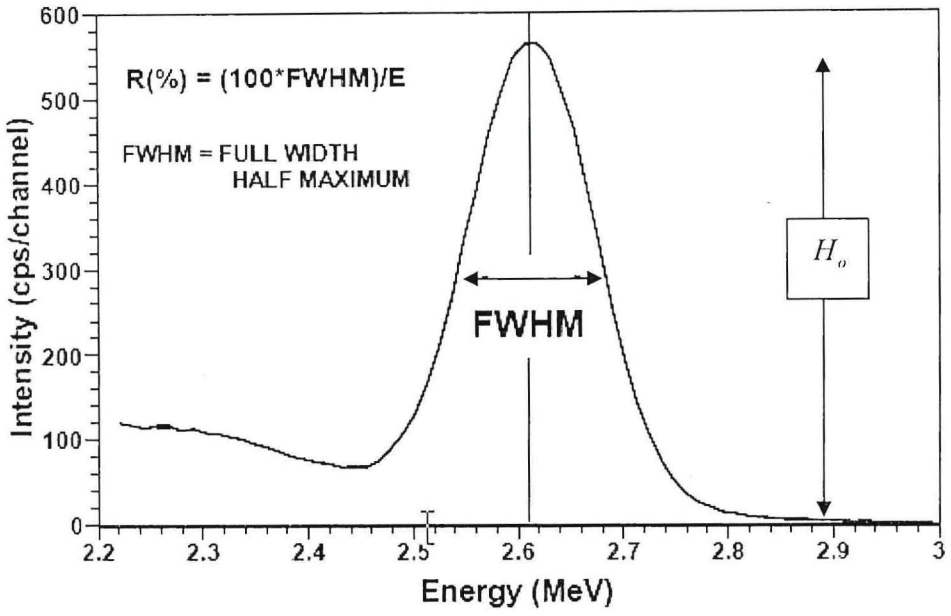

Figure 2. 3: The energy resolution of a gamma ray spectrometer (IAEA, 2003).

Dead time refers to the finite time required for a detector to process an individual particle of radiation. During this time all incoming pulses are ignored. Dead time should thus be as small as possible (IAEA, 2003). The detector is connected to a Photomultiplier Tube and it is discussed in the following subsection.

2.8.2 The Photomultiplier Tube

The Photomultiplier Tube (PMT) is an integral part of a scintillation counter. It consists of an evacuated glass tube in which photons are admitted through a window backed by a photocathode material. The window material must have very low absorption and the photo cathode must have a very high absorption towards the scintillation light. The emitted electrons from the cathode are focused onto a series of dynodes held at an increasingly high positive potential with respect to the cathode. At the photocathode, a proportion of the optical photons are absorbed by the dynodes where electron multiplication takes place by secondary emission. The rate of secondary emission depends on the type of surface the dynodes have and also on the voltage applied to them. The secondary electrons from the first dynode move towards the second, to the third e.t.c

and these can generate up to 10^7 electrons at the anode. Typical phototubes have up to 15 dynodes. The Figure 2.4 shows the schematic of a PMT.

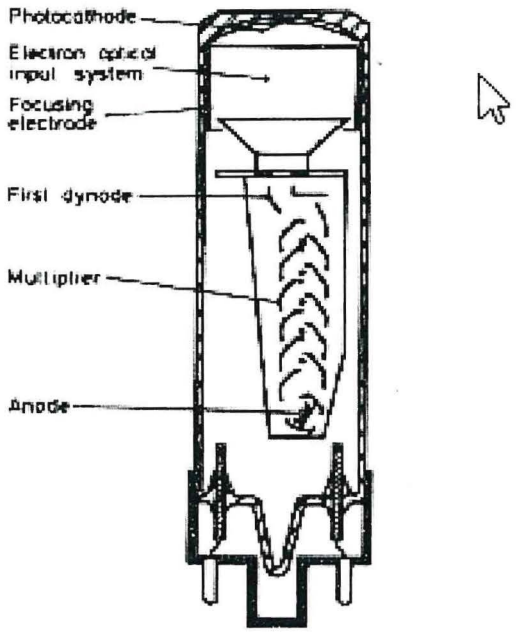

Figure 2. 4: Schematic of a PMT (Knoll, 2000)

The multiplier portion of a PMT is based on the phenomenon of secondary electron emission. Electrons from the photocathode are accelerated and caused to strike the surface of an electrode, called a dynode. If the dynode material is properly chosen, the energy deposited by the incident electron can result in the re-emission of more than one electron from the same surface. The process of secondary emission is similar to that of photoemission discussed earlier. In this case however, electrons within the dynode material are excited by the passage of the energetic electron originally incident on the surface rather than by an optical photon. Electrons leaving the photocathode have a kinetic energy of the order of 1 eV or less. Therefore if the first dynode is held at a positive potential of several hundred volts, the kinetic energy of electrons on arrival at the dynode is determined almost entirely by the magnitude of the accelerating voltage. The creation of an excited electron within the dynode material requires energy at least to the band gap, which typically may be of the order of 2-3 eV. Therefore, it is possible for one incident

electron to create electrons of order of 30 excited electrons per 100 V of accelerating voltage. Because the direction of motion of these electrons is essentially random, many will not reach the surface of the dynode before their de-excitation. Others that do arrive at the surface of the dynode will have lost sufficient energy so that they cannot overcome the potential barrier at the surface and are therefore incapable of escaping. Therefore, only a small fraction of the excited electrons ultimately contribute to the secondary electron yield from the dynode surface. If a relatively low- energy electron strikes the dynode surface, little energy is available for transfer to electrons in the dynode material, and relatively few electrons will be excited across the gap between the valence and conduction bands. At the same time, because the distance of penetration is not large, most of these excited electrons will be formed near the surface. For incident electrons of higher energy, more excited electrons will be created within the dynode but at greater average depth (Knoll, 2000). The overall multiplication factor for a single dynode is given by:

$$\sigma = \frac{N_s}{N_p} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2.14)$$

where N_s is the number of secondary electrons emitted and N_p is the number of primary incident electrons. The overall multiplication factor should be as large as possible for maximum amplification per stage in the Photomultiplier tube.

The pulse amplifier is normally positioned very close to the photomultiplier tube arrangement. This is to sustain the low signal levels which may get attenuated before reaching the amplifier. The primary purpose of the pulse amplifier section is to provide an optimum coupling between the detector and the rest of the counting system. The secondary purpose is to minimize any sources of noise, which may be transmitted along with the pulse and therefore this degrades the energy resolution of the system. This is very important with semiconductors which offer the best resolution (Knoll, 2000).

A multichannel analyzer is used to detect, analyze and display gamma rays emitted by rock samples. Quantitative analysis is essentially comparative: the radiation from a rock sample is compared with the radiation from known standards. The accuracy and precision of the results

depends on many factors: the size and energy resolution of the detector, the mass and geometry of the sample, the shielding of laboratory background, counting time, data processing procedures, and the quality of the radioactive standards. High-resolution Germanium laboratory spectrometers can be used for more sophisticated applications. These include the identification of environmental isotopic pollution, the identification of unknown gamma radiation sources, and detailed studies of radioactive equilibrium and the distribution of radio-nuclides in soil and rock samples (IAEA, 2003).

2.9 Review of Related Studies

Studies by Lameriga (1998) measuring the activity levels of Cs, K, U and Th in tea, coffee, beans and simsim and their corresponding soils of Growth in selected districts (Hoima, Soroti, Mukono and Mbale) revealed that the mean activities were highest in Tea (584 Bq/kg) followed by Beans (520,5 Bq/kg) and lowest in Coffee with mean activity of 190,9 Bq/kg. Much of the activity was due to K-40 in both the soils and the plants. This is because K-40 is naturally available in the lithosphere and it is a requirement for plant growth. Cs was not detected in any of the samples possibly because the huge fission products released during the Chernobyl nuclear accident had not been carried and deposited by rain in the four districts sampled. In the soils samples, K-40 had the highest mean activity 0f 241,95 Bq/kg, followed by Th-232 (173,88Bq/kg) and the lowest activity was due to U-238 (23,97 Bq/kg). From the study, there was a low correlation coefficient between the activity of beans, coffee, simsim and their corresponding soils of growth, and these were 0,24, 0,42 and 0,1 respectively. He stressed that this could be due to the mineral nutrient uptake by plants being affected by not only the concentration of the radionuclides in the soil, and also due to other factors like pH, metabolic activity, temperature, and the presence of other elements with which the elements may compete. There are also possibilities that some of these elements in the soils are not forms that are absorbable by plants but rather are in non-exchangeable form.

Ssozi (1995) research on processed food showed that the activity levels in tinned (processed) beans were in the range of 0 – 85 Bq/kg which was relatively low in relation to activity in unprocessed beans (392,48 Bq/kg) according to Lameriga (1998). The study stressed that this

could possibly be due to leaching out of the radio-nuclides as a result of the cooking process. This was in line with results by Lameriga (1998) for both washed and unwashed beans were the total activity of the washed beans (379,46 Bq/kg) was less than that for unwashed beans (392,48 Bq/kg). From the results therefore, the way in which beans and other plants are handled between harvest and storage before they are prepared for sample analysis has an effect on the mean activity of the radio-nuclides present.

Anguma (1999) measured the activity levels of K-40, U-238, Th-232 and C-137 in water, fish and Water hyacinth from Lake Victoria and Lake Kyoga. From the study, no traces of Cs-137 were observed in all samples probably because these lakes are located far away from the main sources from which most of the Ceasium would be expected to come from i.e. the Chernobyl nuclear accident. All the samples had measurable amounts of K-40, Th-232 and U-238 though K-40 was more abundant with a mean activity of 610 Bq/kg and the activities were lowest due to U-232 with a mean activity of 17 Bq/kg. The study stressed that the presence of Th-232 and U-238 in the lakes and in their biota may be attributed to the content of these isotopes being trace elements in the basement rock structure of the lake basins and their catchment areas.

Azua (1994) found that Ugandan clays have about 18,38 mg/g of Thorium and 2,96 mg/g of Uranium. This contributes to the presence of these isotopes in the soils and thus a need to monitor the concentration of these radio-nuclides in various places in Uganda. The method that is used to determine the concentration of radio-nuclides in soils and plant species is discussed in the following chapter.

CHAPTER THREE: METHODOLOGY

3.1 Introduction

In this chapter, the methods used to investigate the radio-nuclides present in plants, soil and spring water samples are presented. The procedures followed in sample collection and preparations are discussed. The method used to investigate the activity levels of the radio-nuclides present is also presented. In the following section, the procedure of sample collection is presented.

3.2 Sample Collection

The samples were collected at selected points in Kampala and Wakiso districts. The sampling points in Kampala district were Banda, Luzira, Kitintale, Kisaasi and Namuwongo while in Wakiso district, there was only one sampling point at Lubigi. These sampling sites were chosen because they are in the vicinity of Kampala city, which is an industrial centre. These sampling sites are along Nakivubo channel where most of the wastes from the industries and hospitals are directed. The areas along the Channel are highly populated with low income earners who mainly feed on some food crops grown along the channel. In addition, the people who live along these areas use spring water in the area for domestic purposes. Some of the food crops grown in these areas e.g. Yam, Sugarcane, Maize and Vegetables are taken to the market for sale. Consuming food contaminated with radio-nuclides increases the risk of cancer. Sugarcane and Yam were obtained for this study because they are widely grown throughout the year. The sugarcane obtained from Banda area was not mature enough.

Soil samples were obtained from the area where Yam was uprooted, and unwanted materials like roots, worms and plastics were manually removed from the soil samples in order to ensure a uniform mixture. The samples were collected from each of the six study sites. The collected samples were labeled and taken to the laboratory. From each area, two samples were obtained and in total, ninety six (96) samples were collected for the study. The Samples were prepared in order to create a uniform mixture. This is discussed in the following section.

3.3 Sample Preparation

In order to increase the surface area of the yam, the root tuber of yam was cut into small pieces and then placed in an oven until it became brittle dry. The dry samples were then cooled, placed on a manila paper crushed and ground into fine particles. This was done so that the samples placed in the marinelli beaker completely cover the detector so that more accurate results are obtained.

The peeled sugarcane samples were cut into smaller parts, placed in a metallic mortar, and then pounded to extract juice from it. The juice extracted from the sugarcane was used for the study because it is the juice that is actually consumed by man.

The soil samples were sun-dried. They were then crushed into fine particles using a metallic cylinder in order to increase the surface area and create a uniform sample.

After preparing the samples, they were each placed in marinelli beakers, labelled and their weights determined using a beam balance. The labelled samples were kept in separate places to prevent cross- contamination. The weights obtained were used in the calculation of the specific activity of the radio-nuclides present. This is discussed in section 3.5.

3.4 Determination of Radio-nuclides present in the Samples

To cater for the background radiation that would arise from the environment where the samples were to be run, a background spectrum was created by acquiring a spectrum with no sample placed in the GDM 20 detector (see Figure 3.1) that was used for this study. This was run for a period of about 24 hours. GDM 20 is a measurement system for energy detection and determination of gamma radiation from a radioactive source. When the different parts of a GDM 20 were assembled and connected to a computer, a spectrum was collected and stored. The details for the mode of operation of the detector system were discussed in section 2.6.1. The system makes use of an IBM compatible computer. The samples to be analyzed were run for a time interval of about 5000s. After this time period, a spectrum consisting of different spectral peaks corresponding to different mean gamma energies was obtained. Each spectral peak obtained was analyzed by first placing the cross at the left edge of the peak, and then typed letter

l in order to define the cross of the lower marker. The cross of the upper marker was similarly placed at the right edge of the same peak and defined it by using the command *u*. The command *cen* was written which gives the energy position of the centre of mass of the peak. This procedure was done for all the peaks obtained on the spectrum. This is a standard procedure that can be obtained from a GDM 20 detector manual[3]. The spectrum was calibrated by retrieving an already saved spectrum which was obtained after inserting a standard source of ^{152}Eu in the GDM 20 detector.

The background radiation was subtracted from each spectrum created and the new resulting spectrum formed was used for analysis. The mean energy of the samples was obtained from a computer that was connected to a GDM 20 detector system that used a Thallium-activated Sodium Iodide (NaI) crystal and the Autodas software program. The results were presented on the screen of the computer in form of a frequency diagram of the energy distribution of the detected gamma quanta or spectrum.

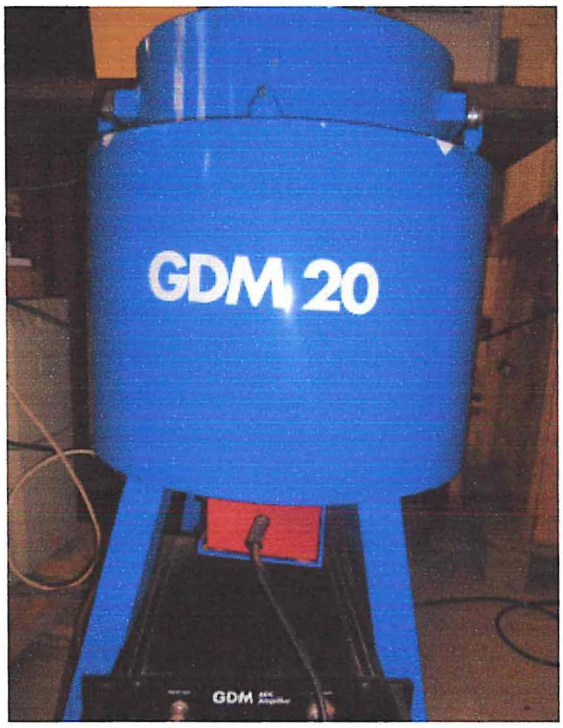

Figure 3. 1: Structure of a GDM 20 Detector System

[3] www.gammadata.net accessed on 16th October 2011.

The analysis of the samples was done using Gamma ray spectrometric techniques. The gamma ray spectrometer consists of a detector system, Photomultiplier tube (pulse amplifier) and a multi-channel analyzer where the small voltage peak is reshaped into a digital signal.

These were discussed in details in chapter 2. The multi-channel analyzer sorts the pulses by height. After amplification and digitization, the pulse amplitudes are analyzed and the output is an energy spectrum of the detected radio-nuclide which is displayed on the computer. The samples were then analyzed for the concentration of radio-nuclides present. This is discussed in the following section.

3.5 Determination of the Specific Activity Levels

The radio-nuclides present were identified based on the most prominent gamma energies of the peaks shown in Table 3.1. The Specific Activities (SA) of the radio-nuclides in each sample were then calculated using the expression

$$SA = \frac{dN}{dt}.\frac{1}{m}.\frac{1}{\eta} \quad \text{..} \quad (3.1)$$

where $\frac{dN}{dt}$ is the rate of disintegration or activity of the radio-nuclide, m is the mass of the sample in kg and η the detector efficiency.

The rate of disintegration of the radio-nuclide was obtained direct from the computer using the standard procedure that is found in the GDM 20 detector manual. The detector efficiency for each radio-nuclide and the experimental photon energy (See Table 3.1) was used to calculate the Specific Activity of the radio-nuclides using Equation 3.1.

Table 3. 1: Energy of a Photon and Overall Detector Efficiency (**www.ias.ac.in**)

Experimental photon energy (keV)	Theoretical photon energy (keV)	Detector efficiency
54 ± 11	88 (Pb-x-rays)	-
213 ± 7 (Pb-214)	242 (U)	0,01044
262 ± 9 (Pb-214)	295 (U)	0,23169
317 ± 12* (Pb-214)	351 (U)	0,03000
552± 23* (Bi-214)	610 (U)	0,02100
58 ± 11 (Th-228)	84 (Th)	0,02856
210 ± 9* (Pb-212)	238 (Th)	0,06075
544 ± 22* (Tl-208)	580 (Th)	0,01012
1460 (K-40)	1460	$2,34 \times 10^{-6}$

The radio-nuclides with gamma energies having an asterisk (*) are the ones corresponding to the most prominent peaks. A list of other commonly observed gamma energies can be obtained from www.csupomona.edu/pbsiegel/bio431/genergies.html. The results obtained in this study are presented in the following chapter.

CHAPTER FOUR: RESULTS OF THE STUDY

4.1 Introduction

The main purpose of this study was to investigate the specific activity concentrations of radio-nuclides present in selected plants, soil and spring water samples along Nakivubo channel and its tributaries. The radio-nuclides present were first determined and then their specific activity concentrations calculated. In the following section, the results of the radio-nuclides present in the samples are presented.

4.2 Radio-nuclides Present in the Samples

The radio-nuclides present were identified for each sample from a spectrum obtained basing on the most prominent spectral peaks. The mean energy of the spectral peaks was determined and this was used to identify the radio-nuclides present. This was done using the standard procedure found in the GDM 20 detector manual. A typical spectrum for a water sample obtained from Banda (opposite plot 703 Jinja road) is shown in Figure 4.1. Seven (7) spectral peaks were observed from the spectrum (see Figure 4.1). Referring to Table 3.1, the gamma energies for these peaks obtained correspond to specific radio-nuclides as shown in Table 4.1.

Table 4. 1: Radio-nuclides found in water samples obtained from Banda Area A

Mean energy/keV	Radio-nuclide present
211,584	Th(Pb-212)
261,970	U(Pb-214)
317,225	U(Pb-214)
552,369	U(Bi-214)
1016,234	Th
1267,051	U(Bi-214)
1579,519	K-40

This procedure was followed for all the samples in this study

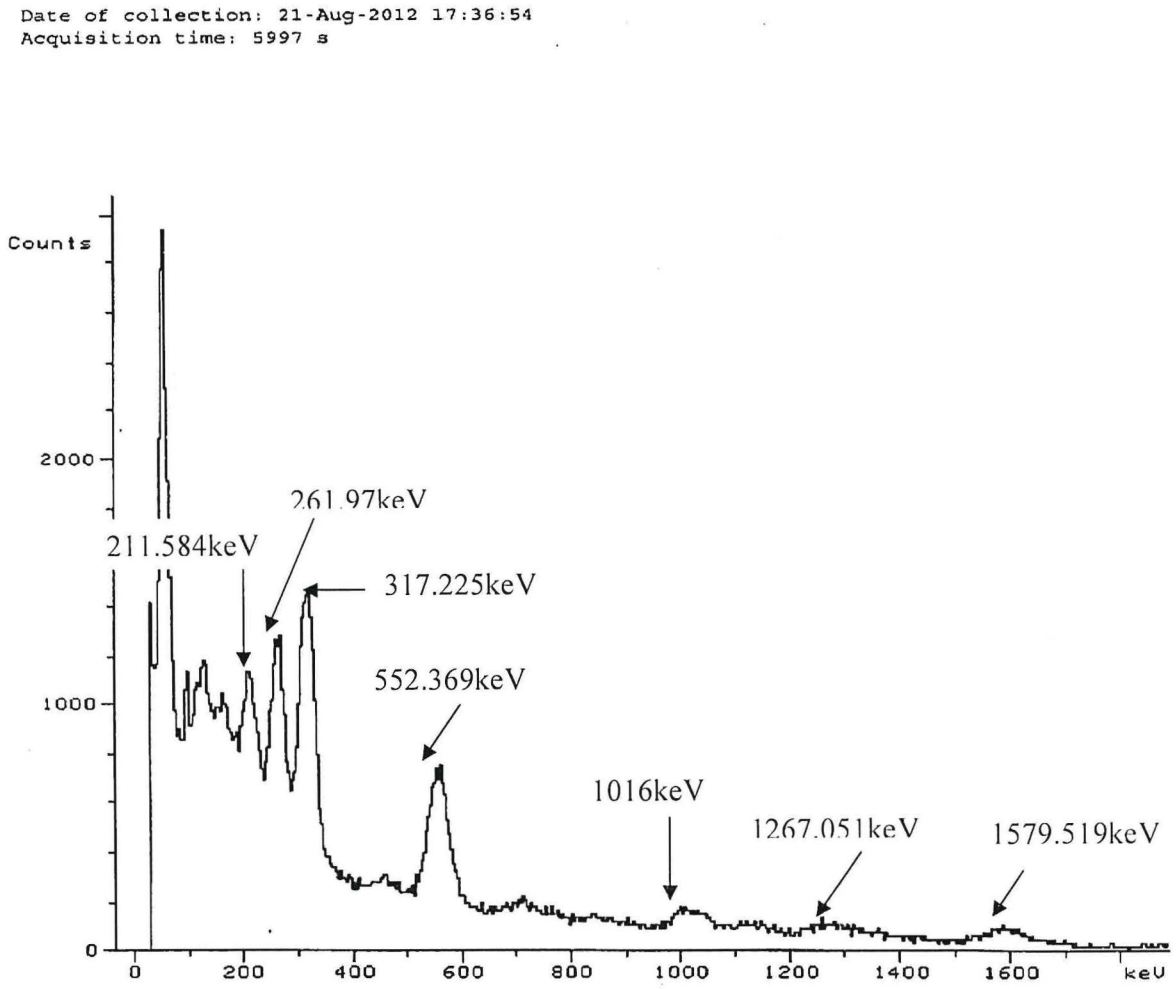

Figure 4.1: Typical spectrum of a water sample from Banda

The Mean Energies of the radio-nuclides identified in the different spectral peaks of the different samples are shown in the appendix A. The radio-nuclides identified in all the water samples are summarized in Table 4.2.

Table 4. 2: Radio-nuclides found in the spring water

Sample Area	**Radio-nuclide detected**
BANDA	K-40,Pb-212,Tl-208,Pb-214,Bi-214
LUZIRA	K-40,Pb-212,Tl-208,Pb-214,Bi-214
LUBIGI	K-40,Pb-212,Tl-208,Pb-214,Bi-214
NAMUWONGO	K-40,Pb-212,Tl-208,Pb-214,Bi-214
KITINTALE	Pb-212,Pb-214
KISAASI	K-40,Pb-212,Tl-208,Pb-214

From Table 4.2, it is observed that the radio-nuclides present in the spring water samples are; Pb-214, Bi-214, Pb-212, Tl-208 and K-40. Traces of K-40 were not observed in the water samples from Kitintale area. Similarly, the radio-nuclides obtained in sugarcane are shown in Table 4.3.

Table 4.3: Radio-nuclides found in the sugarcane

Sample Area	**Radio-nuclide detected**
BANDA	K-40
KITINTALE	K-40
LUZIRA	K-40,Pb-212,Pb-214
LUBIGI	K-40,Pb-212,Tl-208,Pb-214
NAMUWONGO	K-40,Tl-208,Pb-214
KISAASI	K-40,Pb-212,Tl-208,Pb-214,Bi-214

In all the samples, K-40 was observed. Pb-212 was identified in samples from Kisaasi, Luzira and Lubigi areas, but Pb-214 was not observed in the samples from Banda and Kitintale. Bi-214 was observed from Kisaasi only.

Table 4. 4: Radio-nuclides found in yam

Sample Area	Radio-nuclides detected
BANDA	K-40,Pb-212, Tl-208; Pb-214, Bi-214
KITINTALE	K-40,Pb-212, Tl-208; Pb-214, Bi-214
KISAASI	K-40,Pb-212, Tl-208; Pb-214, Bi-214
LUZIRA	K-40,Pb-212, Tl-208; Pb-214, Bi-214
LUBIGI	K-40,Pb-212 ,Tl-208; Pb-214
NAMUWONGO	K-40, Pb-212,Tl-208; Pb-214

Table 4.4 shows the radio-nuclides observed in the Yam samples. In most of the samples, K-40, Pb-212, Tl-208, Pb-214 and Bi-214 were observed. In Lubigi and Namuwongo areas, Bi-214 was not observed. Similarly, the radio-nuclides obtained in the soil samples are shown in Table 4.5.

Table 4. 5: Radio-nuclides obtained in the Soil

Sample Area	Radio-nuclides detected
BANDA	K-40,Pb-212, Tl-208; Pb-214, Bi-214
KITINTALE	K-40, Tl-208; Pb-214, Bi-214
KISAASI	K-40,Pb-212, Tl-208; Pb-214
LUZIRA	K-40,Pb-212, Tl-208; Pb-214
LUBIGI	K-40,Pb-212 ,Tl-208; Pb-214, Bi-214
NAMUWONGO	K-40, Pb-212,Tl-208; Pb-214, Bi-214

The radio-nuclides obtained in the soil samples are K-40, Pb-212, Tl-208 and Pb-214. However, for soil from Kitintale area, there were no traces of Pb-212 observed. Bi-214 was also obtained in all the areas except for Luzira and Kisaasi.

In all the samples, the nuclides Pb-214 and Bi-214 are decay products of uranium (U-238) series, while Pb-212 and Tl-208 are decay products of Thorium (Th-232) series. After identifying the radio-nuclide present in all the samples, the specific activity of each radio-nuclide was calculated. This is discussed in the following section.

4.3 Specific Activity of the Radio-nuclides

The specific activity (SA) of the radio-nuclides was calculated using Equation 3.1 i.e.

$$SA = \frac{dN}{dt} \cdot \frac{1}{m} \cdot \frac{1}{\eta}$$

where $\frac{dN}{dt}$ is the rate of disintegration or activity of the radio-nuclide, m is the mass of the sample in kg and η the detector efficiency. The parameters that were used to calculate Specific Activity are: the rate of disintegration of the radio-nuclide, the mass of the sample and the detector efficiency. The detector efficiency is given in Table 3.1, while the rate of disintegration of the radio-nuclide for each individual sample is shown in Appendix B. The mean values of the specific activity of the radio-nuclides present are presented in the Table 4.6 for spring water, Table 4.7 for sugarcane, Table 4.8 for yam and Table 4.9 for soil samples.

Table 4. 6: Mean Specific Activities of Radio-nuclides in spring water

Sample	**Mass(kg)±0,001**	**Mean Specific Activity (Bq/kg)**		
		U-238	**Th-232**	**K-40 (x10^5)**
BANDA	0,496	84 ± 9,17	56 ± 7,48	2,19412 ± 468
NAMUWONGO	0,423	63 ± 7,94	11 ± 3,32	1,71748 ± 414
KISAASI	0,434	55 ± 7,42	70 ± 8,37	1,91180 ±437
KITINTALE	0,405	02 ± 1,41	02 ± 1,41	0,00000 ± 0,0
LUBIGI	0,371	17 ± 4,12	222 ± 14,89	0,00020 ± 4,47
LUZIRA	0,458	27 ± 5,19	19 ± 4,36	0,88067 ± 296

The Mean Specific activities of the radio-nuclides present in the samples are shown graphically in Figure 4.2 for U-238, Figure 4.3 for Th-232 and Figure 4.4 for K-40.

Table 4. 7: Mean Specific Activities of Radio-nuclides in Sugarcane samples

Sample area	**Mass(kg)** ±0,001	**Mean Specific Activity (Bq/kg)**		
		U-238	**Th-232**	**K-40 ($x10^5$)**
NAMUWONGO	0,457	3,5 ± 1,87	5,5 ± 2,35	0,28152 ± 168
LUZIRA	0,486	01 ± 1,00	01 ± 1,00	0,44437 ± 211
BANDA	0,520	00 ± 0,00	00 ± 0,00	0,19968 ± 141
KISAASI	0,443	01 ± 1,00	27 ± 5,19	0,39367 ± 198
KITINTALE	0,426	00 ± 0,00	00 ± 0,00	0,24863 ± 158
LUBIGI	0,369	02 ± 1,41	03 ± 1,72	0,40700 ± 201

Table 4. 8: Mean Specific Activity of Radio-nuclides in Yam samples

Sample	**Mass(kg)** ±0,001	**Mean Specific Activity (Bq/kg)**		
		U-238	**Th-232**	**K-40** $\times 10^5$
BANDA	0,177	34 ± 5,83	109 ± 10,44	4,15872 ± 645
NAMUWONGO	0,237	05 ± 2,24	13 ± 3,61	4,52107 ± 672
LUBIGI	0,275	17 ± 4,12	14 ± 3,74	3,14710 ± 177
KITINTALE	0,295	09 ± 3,00	10 ± 3,16	5,18648 ± 720
LUZIRA	0,309	09 ± 3,00	10 ± 3,16	3,73148 ± 611
KISAASI	0,415	03 ± 1,72	08 ± 2,83	3,74495 ± 612

Table 4.9: Mean Specific Activities of Radio-nuclides in Soil

Sample	**Mass(kg)** ±0,001	**Mean Specific Activity/(Bq kg^{-1})**		
		U-238	**Th-232**	**K-40 (x10^5)**
BANDA	0,383	68 ± 8,25	199 ± 14,11	2,34025± 484
KITINTALE	0,353	161 ± 12,69	269 ± 16,40	2,82915± 532
LUBIGI	0,443	66 ± 8,12	283 ± 16,82	2,08560± 144
KISAASI	0,498	110 ± 10,49	181 ± 13,45	2,67601± 517
NAMUWONGO	0,275	67 ± 8,19	161 ± 12,69	2,70965± 521
LUZIRA	0,371	22 ± 4,69	69 ± 8,31	2,46933± 497

Figure 4.2 shows the variation of the mean specific activities of U-238 in spring water, soil, yam and sugarcane.

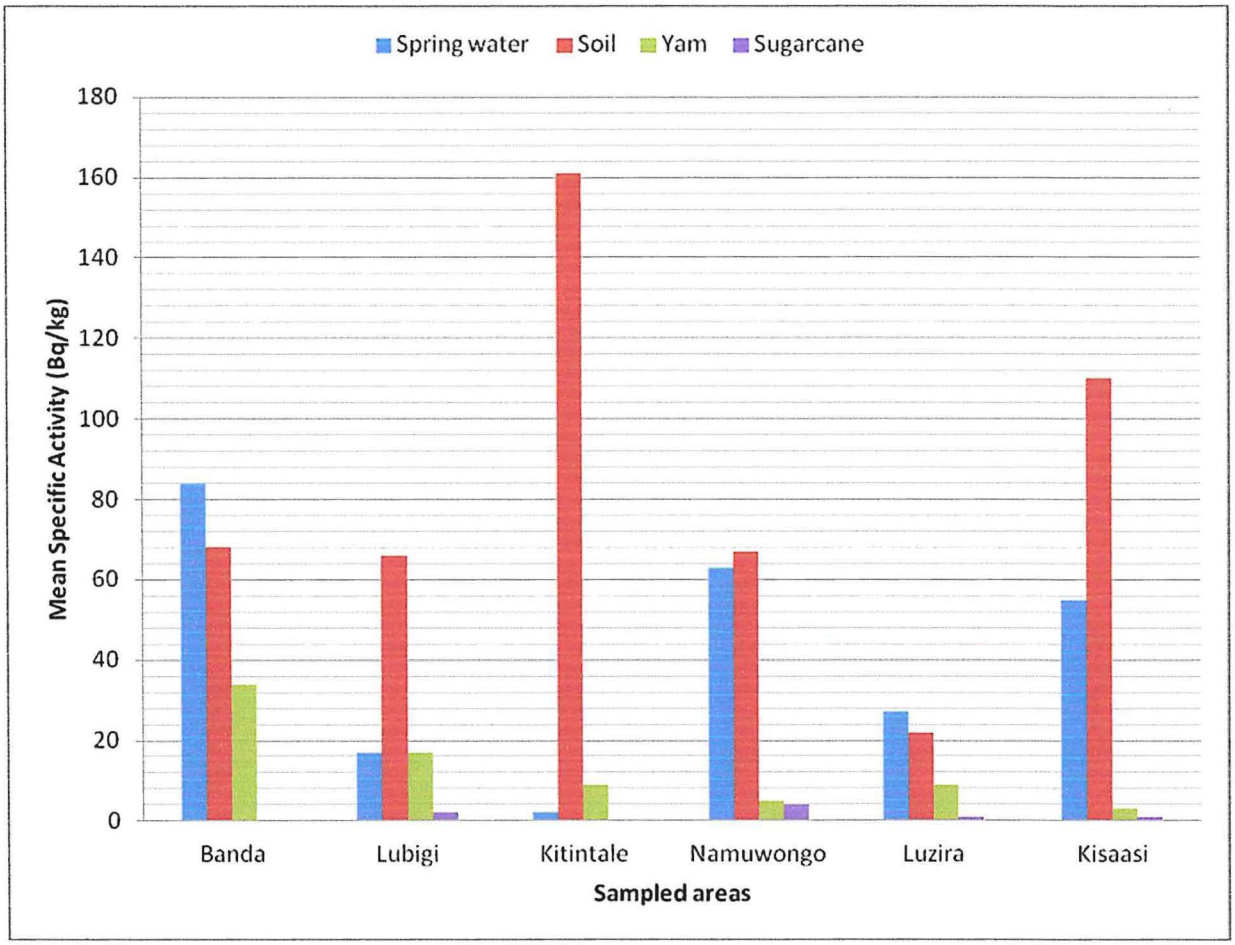

Figure 4. 2: Mean Specific Activity of U-238 in Spring water, Soil, Yam and Sugarcane

From the results presented in Figure 4.2, the soil samples had the highest mean specific activities due to U-238 with the highest values obtained from Kitintale (161 Bq/kg) while the lowest was from Luzira with a mean value of 22 Bq/kg. However, Sugarcane samples had the lowest mean specific activities. The highest value for the specific activity of U-238 in sugarcane sample was 3,5 Bq/kg in Namuwongo while the lowest was 1 Bq/kg in Luzira and Kisaasi. There were no traces observed in the sugarcane samples obtained from Banda.

Figure 4.3 shows the variation of Th-232 in the different samples obtained from specific

sampling points.

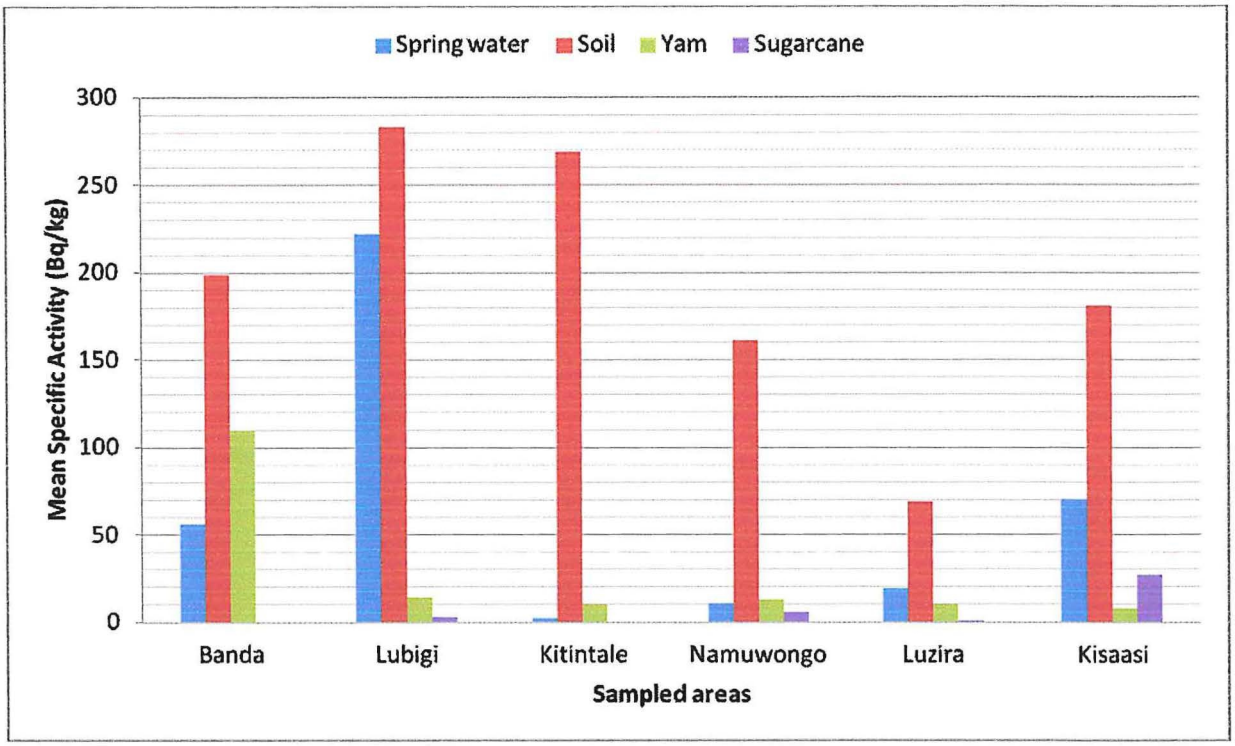

Figure 4. 3: Mean Specific Activity of Th-232 in Spring water, Soil, Yam and Sugarcane

Traces of Th-232 were obtained highest in the soil samples from Lubigi (283 Bq/kg) and the lowest obtained from Luzira with a mean specific activity of 69 Bq/kg. The specific activities in the spring water were obtained highest from Lubigi area with a mean value of 222 Bq/kg while the lowest mean specific activity was from Kitintale (2 Bq/kg). Sugarcane had the lowest mean specific activities, with the highest values obtained from Kisaasi (27 Bq/kg) and the lowest obtained from Luzira (1 Bq/kg). Kitintale and Banda areas had no traces of Th-232 observed in the sugarcane samples.

The variation of the mean specific activity of K-40 in the various samples for the different sampling areas is shown in Figure 4.4.

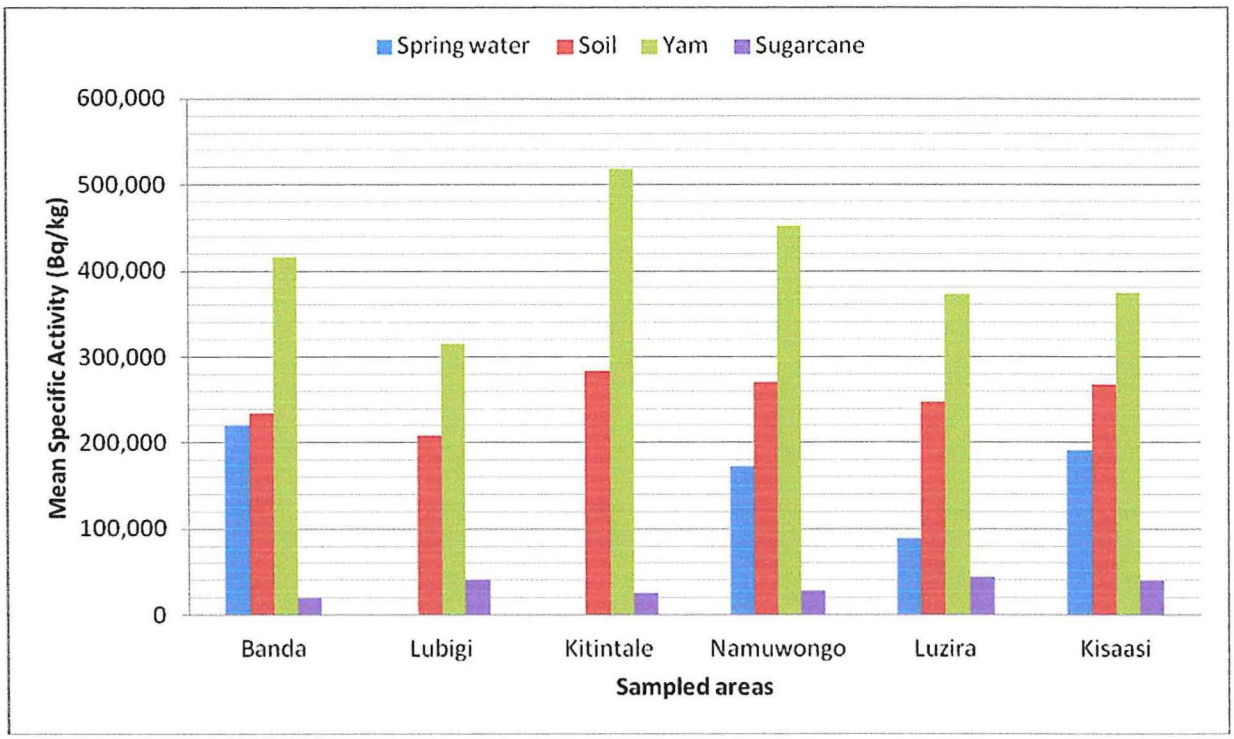

Figure 4. 4: Mean Specific Activity of K-40 in Spring water, Soil, Yam and Sugarcane.

From the results presented, K-40 had the highest mean specific activities in Yam from Kitintale (518648 Bq/kg), and the lowest activities obtained from Lubigi (314710 Bq/kg). Sugarcane samples had the lowest specific activities with the highest values observed from Luzira (44437 Bq/kg) and the least obtained from Banda (19968 Bq/kg). Lubigi and Kitintale had insignificant traces of K-40 in the spring water samples.

Using the values of mean specific activity of the radio-nuclides obtained for all the samples, the average value of the specific activity was determined for each sample i.e. spring water, sugarcane, soil and yam. This is presented in Table 4.10.

Table 4. 10: Mean specific activities of U-238, Th-232 and K-40 in the samples

Sample	Average Specific Activity(Bq/kg)		
	U-238	Th-232	K-40 ($x10^5$)
Spring water	41,3 ± 6,43	63,3 ± 7,96	1,11738 ± 334
Sugarcane	1,25 ± 1,12	6,08 ± 2,47	0,32915 ± 56,7
Soil	82,3 ± 9,07	194 ± 13,93	2,51833 ± 502
Yam	12,8 ± 3,58	27,3 ± 5,22	4,08163 ± 638

The Figure 4.5 shows the average specific activities of U-238 and Th-232, while Figure 4.6 is for K-40 in the soil, spring water, yam and the sugarcane samples carried out.

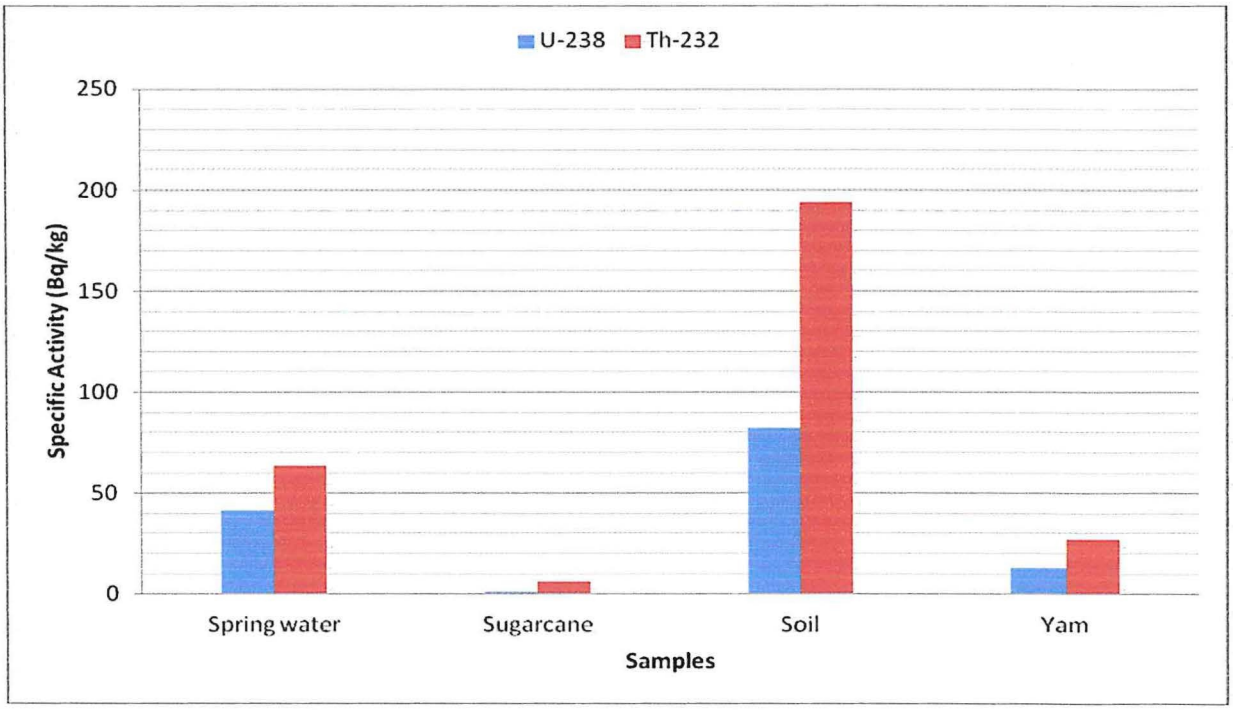

Figure 4. 5: Mean Specific Activities of U-238 and Th-232 in the samples

From the results presented in Figure 4.5, the highest mean specific activity due to Th-232 and U-238 was in the soil samples with mean specific activities of 194 Bq/kg and 82,3 Bq/kg while the lowest was in sugarcane with mean specific activities of 6,08 Bq/kg and 1,25 Bq/kg respectively.

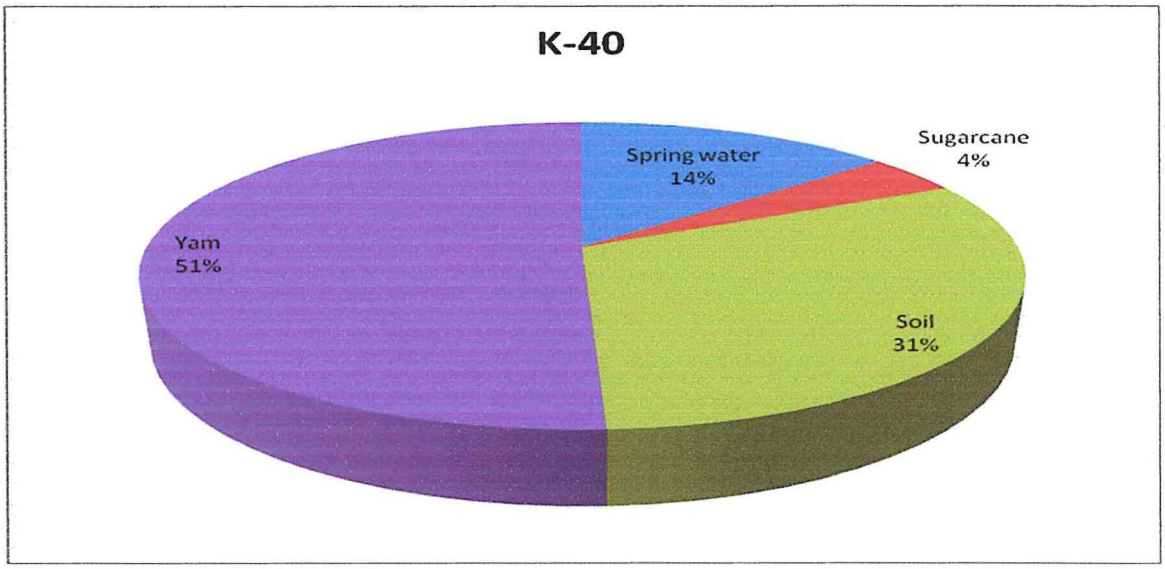

Figure 4. 6: Mean specific activities of K-40 in the samples

In all the samples, the mean specific activities of K-40 were observed highest in yam with 51% and lowest in sugarcane with 4%. However, basing on the various industrial activities that take place in the city centre and in the vicinity of the channel e.g. industries of soap, batteries, paint, plastics, pharmaceuticals among others, nuclides of mercury, zinc and chromium would be expected but these were not found because they are not radioactive. These heavy pollutants can be analyzed chemically using other methods like X-ray fluorescence, atomic absorption spectroscopy e.t.c. It is therefore possible that there is no pollution of the channel by radioactive material from the industries. This chapter mainly involved presentation of results obtained in the study together with the observations. The discussion of the results is presented in the following chapter.

CHAPTER FIVE: DISCUSSION, CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

Samples of yam, sugarcane, soil and spring water were collected and the radionuclides present in these samples were identified. The radio-nuclides identified in the samples were K-40, U-238 and Th-232. The specific activities of the radio-nuclides varied from one area to another and from one sample to another, and the mean specific activities are discussed in the following section.

5.2 Discussion

The mean specific activity due to K-40 was notably very high in all the samples carried out. The high values were attributed to the abundance of potassium in the lithosphere and thus it can be passed on to the plants through bio-accumulation and precipitation. Besides, Potassium is required for plant growth and reproduction. It is a highly soluble element and it is a requirement for protein synthesis due to its catalytic effect on enzymes used in protein synthesis (Bowen, 1981). This leads to a high K-40 content in the plants, soil and spring water. The details are discussed in the subsections that follow.

5.2.1 Mean Specific Activities due to K-40.

From Figure 4.6, it was observed the mean specific activity of K-40 was highest in the yam (408163 Bq/kg) and lowest in sugarcane (32915). Despite its use in metabolism and protein synthesis in plants, sugarcane had the lowest activities of K-40 probably because mineral nutrient uptake by plants is not only affected by the concentration of the radionuclide in the soil, but also on the plant species and the part sampled. Some traces of this element could have remained in the fibre from which the juice was extracted. A study by Anguma (1999) in the three parts of a mature and a young water hyacinth plant revealed that K-40 concentration was greatest in the petiole of a mature plant (2570 Bq/kg) followed by the leaves (960,11 Bq/kg) for the mature plant and least amounts obtained from the roots (424 Bq/kg). This clearly shows that the part of the plant sampled is equally an important factor.

From Figure 4.4, K-40 was abundant in all the soil sampled. However, the high levels of K-40 in the yam could be attributed to the fact that potassium is an essential element for plant growth and reproduction. The Potassium content that is required for optimal plant growth is about 2-5% of the dry weight of the vegetative plants, fleshy fruits and tubers (Black, 1957). Potassium has a number of functions like enzyme action, phloem transport and cation- anion balance in the cytoplasm and it is known to be the most abundant cation in the cytoplasm compared to that in the chloroplast (Chobowski, 1999). These high concentrations in the cytoplasm are required to neutralize soluble and insoluble macromolecular anions and to stabilize the pH to an optimum level favourable for enzyme reaction (Gilbert, 1953). All these processes lead to a high concentration of K-40 in the plants (yam) than in the soils.

Lubigi and Kitintale areas had insignificant traces of K-40 in the water samples (see Figure 4.4). This may not be enough to conclude that the water samples had no traces of K-40 but probably the levels where below the Low Level Detection of the machine used. This low level could also possibly be due to the imbalance with other cation elements in the soil that also affected its availability in the water. In areas where there is a significant imbalance between available K^+ and the other major cations primarily calcium, magnesium, and sometimes hydrogen, aluminum, or sodium, the availability of K^+ may be affected. For example, in many high pH soils there is an excess of Ca^{2+}. Competition from this Ca^{2+} could reduce uptake of K^+. Strongly acidic soils will often have an excess of H^+, Al^{2+}, Fe^{3+}, and possibly other cation elements. These excess elements can compete with K^+ for entry into the plant, and/or set up soil conditions that are unfavorable to efficient K^+ utilization (Horst, 1986). This could have resulted into insignificant traces of K-40 in the water sampled from Lubigi and Kitintale.

Besides the concentration of elements in the soils, uptake of elements from the soil is also determined by the soil type. The potassium available in the soil is in ionic (electrically charged) form represented as K^+. Cations are attracted to, and held by negatively charged colloids (primarily clay and organic matter) that make up the Cation Exchange Capacity (CEC) of the soil. The larger the CEC, the more K^+ that can be held by the soil (Huble, 1970). Other factors that affect availability and uptake of K^+ include; Soil moisture, pH and soil drainage. Potassium is transported within the soil and it is absorbed by plant roots in the soil water. Water deficiency in the soil therefore results into less absorption of K^+. Reduction in the soil pH (increasing soil

acidity) also reduces the availability of K^+. Soil compaction and temperature also affects the availability of K^+ i.e. compacted and cold soils often reduce the availability of K^+ to be absorbed by the plants. As the soil drainage (aeration) is improved, uptake of K^+ typically improves (Huble, 1970). Saline soils often have excess sodium (Na). One of the negative effects of excess Na is that it reduces the availability of K^+. All the mentioned factors in one way or the other contributed to the variation of K-40 in the soil and water as well.

5.2.2 Mean Specific Activity Levels due to Th-232 and U-238.

In the yam samples (see Figures 4.2 and 4.3), Banda had the highest specific activity values for both Th-232 and U-238 compared to the other sampling areas. This could possibly be due to the fertilizers that had been earlier used. Alan (1996) stresses that fertilizers (phosphate) contain high concentrations of uranium, and though in small amounts, this could have increased the U-238 levels in these soils. However, Banda and Kitintale had insignificant traces of Th-232 and U-238 in the sugarcane samples. This could be possibly because these radio-nuclides remained in the fibre as discussed earlier in section 5.2.1. However, Kisaasi had a higher concentration of Th-232 of 27 Bq/kg in the sugarcane possibly because of its abundance in the soil and also due to the nature of the soils from where the samples were obtained. The soils had some clay in it and studies show that clay soils have a higher percentage of Th-232 than U-238 (Azua, 1994).

In the water samples (Figures 4.2 and 4.3), there was a slight variation in the specific activities of Th-232 and U-238 except for Lubigi whose specific activity of Th-232 (222 Bq/kq) was very high compared to the other areas. The area in Lubigi had clay soils while the other areas had general (Loam) soils. Studies by Azua (1994) showed that Ugandan clay soils have about 18,38 mg/g of thorium and 2,96 mg/g of uranium. Basing on these findings, it is possible that the high specific activities due to Th-232 levels in Lubigi area were attributed to the nature of soil i.e. clay soil.

Figure 4.2 and Figure 4.3 show that the mean specific activities of Th-232 and U-238 were highest in soil (194 Bq/kg and 82,3 Bq/kg) respectively and the lowest specific activities in sugarcane with mean values of 6,08 Bq/kg and 1,25 Bq/kg respectively. The low specific

activities in Th-232 and U-238 could be due to much of the traces remaining in the fibre. In the Earth's crust, Thorium is three times more abundant than uranium (Frisch, 1958). It is found in small amounts in most rocks and soils and it occurs naturally as the minerals thorite, uranothorite, thorianite. Ugandan clays have about 18,38 mg/g of thorium and 2,96 mg/g of uranium. This clearly indicates the variation in the amount of thorium and uranium in the soils and thus in the plants (Azua, 1994).

The activity in the soils due to Th-232 in the four districts was in the range 111-286 Bq/kg with an average value of 173,88 Bq/kg (Lameriga,1998). This value lies within the 69-283 Bq/kg obtained in this study as shown in Figure 4.4. However for U-238 in the soils, the average value 82,3 Bq/kg was far much greater than the average value (23,97 Bq/kg) obtained by Lameriga in the soils of the four districts of Mukono, Soroti, Mbale and Hoima. The concentration of these radio-nuclides differs from one geographical area to another and the variation in the average value obtained could be due to the differences in the soil types along Nakivubo channel and in these four districts. The rate of uptake of these radio-nuclides from the soil to the plants is characterized by factors like the plant genotype where there are distinct uptake characteristics for different plant species (Marschner, 1986). In some plants, certain mineral elements are taken up preferably while others are discriminated against.

The Specific Activity levels of the radio-nuclides obtained in the samples were within the recommended limits and therefore no stochastic health effects are likely to arise. However, excess of these radio-nuclides e.g. Potassium is harmful in the human body for it may interfere with nerve pulses and thus affecting the proper functioning of the heart.

5.3 Conclusion

All the samples tested contained the radionuclides; K-40, U-238 and Th-232. K-40 had the highest mean specific activity of 201162 ± 448 Bq/kg, followed by Th-232 with a mean value of 72,7 ± 8,5 Bq/kg and U-238 had the lowest mean value of 34,4 ± 5,9 Bq/kg. The mean specific activity of K-40 was highest in yam (408163 ± 638 Bq/kg), soil with 251833 ± 501 Bq/kg, spring water with 117738 ± 343 Bq/kg and lowest in sugarcane samples with 32915 ± 181 Bq/kg. On the other hand, both U-238 and Th-232 activity levels were highest in soil samples (82,3 ± 9,0

Bq/kg and 194 ± 13,9 Bq/kg) respectively and lowest in the sugarcane samples with 1,25 ± 1,11 Bq/kg and 6,08 ± 2,46 Bq/kg respectively. All the areas had measurable activity levels and they are in the limit of the tolerance values. Ingesting these plants for over a long period of time may lead to stochastic health effects. Based on these results, the radio-nuclides identified in the soil, spring water and plants are naturally found in the earth's crust and hence there is no contamination of the soils along Nakivubo channel with radioactive material. The government should therefore keep monitoring damping grounds of industrial wastes and garbage.

5.3 Recommendations

1. A study investigating the concentration of radio-nuclides in the sugarcane fibre as be carried out.
2. The estimates of the annual consumption of these radionuclides in plants (yam and sugarcane) by individuals living along the channel per year be carried out in order to estimate the risks of ingesting them.
3. The activity levels of the radio-nuclides present in the soils around damping grounds of industrial wastes and garbage needs to be carried out in order to investigate the extent of contamination if any.
4. A study of the activity levels of radio-nuclides present in soils categorized into general soils, sand, clay and rocky soil should be carried out to boost the data bank for individuals carrying out research on the environment.

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APPENDIX A
MEAN ENERGY OF RADIO-NUCLIDES

For the samples in the appendix, SG represents Sugarcane, W represent Water, S represents soil, Y represents Yam. BAN represents Banda, NAM for Namuwongo, KINT represents Kitintale, LUZ for Luzira, KIS for Kisaasi and LUB for Lubigi areas. a and b are the different sampling points taken in a particular area.

Table 1: Mean Energy of Radio-nuclides in Water samples

Sample (Peak number)	Mean energy/keV	Nuclide present
BANWa (i)	211.584	Th(Pb-212)
(ii)	261.970	U(Pb-214)
(iii)	317.225	U(Pb-214)
(iv)	552.369	U(Bi-214)
(v)	1016.234	Th
(vi)	1267.051	U(Bi-214)
(vi)	1579.519	K-40
BANWb(i)	210.226	Th(Pb-212)
(ii)	262.972	U(Pb-214)
(iii)	319.111	U(Pb-214)
(iv)	557.264	Th(Tl-208)
(v)	846.107	Th(Tl-208)
(vi)	1027.62	Th
(vii)	1274.975	U(Bi-214)
(viii)	1595.352	K-40
KINTWa(i)	199.426	Th(Pb-212)
(ii)	258.687	U(Pb-214)
(iii)	308.206	U(Pb-214)
KISWa (i)	213.430	U(Pb-214)
(ii)	316.975	U(Pb-214)
(iii)	551.908	Th(Tl-208)
(iv)	1578.283	K-40
LUBWa (i)	212.613	Th(Pb-212)
(ii)	255.156	U(Pb-214)
(iii)	313.602	U(Pb-214)
(iv)	551.219	Th(Tl-208)
(v)	1263.785	U(Bi-214)
(vi)	1569.705	K-40
NAMWa (i)	210.565	Th(Pb-212)
(ii)	263.366	U(Pb-214)
(iii)	319.063	U(Pb-214)
(iv)	555.416	U(Bi-214)

(v)	856.936	Th(Tl-208)
(vi)	1585.744	K-40
LUBWb (i)	221.731	Th(Pb-212)
(ii)	260.487	U(Pb-214)
(iii)	310.036	U(Pb-214)
(iv)	549.272	Th(Tl-208)
(v)	1267.266	U(Bi-214)
LUZWa (i)	210.712	Th(Pb-212)
(ii)	263.987	U(Pb-214)
(iii)	316.881	U(Pb-214)
(v)	555.531	U(Bi-214)
(vi)	1599.340	K-40
LUZWb (i)	210.829	Th(Pb-212)
(ii)	260.968	U(Pb-214)
(iii)	315.621	U(Pb-214)
(iv)	553.592	Th(Tl-208)
(vi)	1266.363	U(Bi-214)
(vii)	1587.256	K-40
KISWb (i)	219.681	Th(Pb-212)
(ii)	279.284	U(Pb-214)
(iii)	337.409	U(Pb-214)
(iv)	578.745	Th(Tl-208)
(v)	1375.481	K-40
(vi)	1699.267	U(Bi-214)

Table 2: Mean Energy of the Radio-nuclides Present in Yam.

Sample (Peak number)	Mean energy/ keV	Nuclide present
BANYa (i)	211.081	Pb-212(Th)
(ii)	262.991	Pb-214(U)
(iii)	319.668	Pb-214(U)
(iv)	555.159	Bi-214(U)
(v)	1324.054	K-40
BANYb (i)	546.806	Tl-208(Th)
(ii)	1322.054	K-40
KINTYb (i)	132.857	
(ii)	213.379	Th(Pb-212)

(iii)	558.580	U(Bi-214)
(iv)	1005.711	U(Bi-214)
(v)	1321.331	K-40
LUZYb (i)	168.521	U(Pb-214)
(ii)	216.057	Th(Pb-212)
(iii)	297.640	U(Pb-214)
(iv)	414.757	U
(v)	1311.316	K-40
LUBYa (i)	163.704	U(Pb-214)
(ii)	213.381	U(Pb-214)
(iii)	299.423	U(Pb-214)
(iv)	441.740	Th(Tl-208)
(v)	529.747	Th(Tl-208)
(vi)	1311.456	K-40
LUBYb (i)	191.933	U(Th-227)
(ii)	303.142	U(Pb-214)
(iii)	428.274	Th(Tl-208)
(iv)	762.904	Th(Tl-208)
(v)	928.045	Th(Tl-208)
(vi)	1314.736	K-40
NAMYb (i)	202.849	Th(Pb-212)
(ii)	303.945	U(Pb-214)
(iii)	544.730	Th(Tl-208)
(iv)	1311.642	K-40
NAMYa (i)	206.938	Th (Pb-212)
(ii)	218.192	U (Pb-214)
(iii)	317.131	U (Pb-214)
(iv)	569.194	Th (Tl-208)
(v)	1334.92	K-40
KINTYa (i)	217.785	Th (Tl-212)
(ii)	329.649	U (Pb-214)
(iii)	549.594	Th(Tl-208)

(iv)	1308.702	K-40
LUZYa	199.894	Th (Pb-212)
	307.702	U (Pb-212)
	548.384	Th (Tl-208)
	852.113	Th (Tl-208)
	1312.204	K-40

Table 3: Mean Energy of the Radio-nuclides found in Sugarcane Samples

Sample(peak number)	Mean energy/kev	Radio-nuclide
BANSGa(i)	1324.813	K-40
BANSGb(i)	None	
LUBSGa (i)	161.546	U(Pb-214)
	221.546	Th(Pb-212)
	344.905	U(Pb-214)
	423.751	Th(Tl-208)
	1301.882	K-40
LUBSGb	170.319	U(Pb-214)
	209.176	Th(Pb-212)
	300.249	U(Pb-214)
	529.269	Th(Tl-208)
	1301.012	K-40
KINTSGb(i)	1315.051	K-40
KINTSGa(i)	1298.534	K-40
KISSGa	161.403	U(Pb-214)
	198.331	Th(Pb-212)
	248.750	Th(Tl-208)
	530.544	Th(Tl-208)
	992.370	U(Bi-214)
	1306.558	K-40

LUZSGa	227.254	Th(Pb-212)
	335.044	U(Pb-214)
	1306.362	K-40
LUZSGb	194.779	Th(Pb-212)
	232.323	Th(Pb-212)
	350.115	U(Pb-214)
	1307.913	K-40
NAMSGa	280.809	U(Pb-214)
	432.477	Th(Tl-208)
	1311.661	K-40
NAMSGb	357.512	U(Pb-214)
	450.389	Th(Tl-208)
	1298.493	K-40
KISSGb	200.645	Th (Pb-212)
	302.320	U (Pb-214)
	1381.014	K-40

Table 4: Mean Energy of the Radio-nuclides in Soil samples

Sample (Peak number)	Mean energy/keV	Radio-nuclide
LUBSa (i)	114.286	
(ii)	206.978	Th(Pb-212)
(iii)	262.210	U(Pb-214)
(iv)	315.203	U(Pb-214)
(v)	545.918	Th(Tl-208)
(vii)	859.123	Th(Tl-208)
(viii)	1027.069	Th
(ix)	1325.203	K-40
(x)	1472.397	K-40
(xi)	1604.225	Bi-214(U)
LUBSb (i)	165.073	Pb-214(U)
(ii)	210.830	Pb-212(Th)
(iii)	265.150	Pb-214(U)
(iv)	318.704	Pb-214(U)
(v)	547.275	Tl-208(Th)

(vii)	854.836	Tl-208(Th)
(viii)	1035.771	Th
(ix)	1327.414	K-40
KINTSa (i)	264.524	U(Pb-214)
(ii)	213.361	U(Pb-214)
(iii)	318.873	U(Pb-214)
(iv)	550.176	Th(Tl-208)
(vi)	857.303	Th(Tl-208)
(vii)	1022.677	Th
(viii)	1306.515	K-40
(ix)	1586.021	K-40
KINTSb (i)	263.750	U(Pb-214)
(ii)	316.054	U(Pb-214)
(iii)	549.880	Th(Tl-208)
(v)	859.309	Th(Tl-208)
(vi)	1019.901	Th
(vii)	1317.176	K-40
(viii)	1608.994	Th(Bi-214)
BANSa (i)	210.766	Th(Pb-212)
(ii)	263.119	U(Pb-214)
(iii)	317.276	U(Pb-214)
(iv)	548.945	Th(Tl-208)
(v)	856.037	Th(Tl-208)
(vi)	1021.918	Th
(vii)	1317.553	K-40
(viii)	1597.216	Th(Bi-214)
BANSb (i)	208.885	Th(Pb-212)
(ii)	260.140	U(Pb-214)
(iii)	313.762	U(Pb-214)
(iv)	543.423	Th(Tl-208)
(v)	854.819	Th(Tl-208)
(vi)	1016.487	Th
(vii)	1316	K-40
(viii)	1583.196	Th(Tl-208)
KISSa (i)	206.972	Th (Pb-212)
(ii)	312.831	U (Pb-214)
(iii)	539.304	Th(Tl-208)
(iv)	841.834	Th(Tl-208)
(v)	1310.944	K-40
KISSb (i)	219.214	U (Pb-214)
(ii)	274.098	U (Pb-214)
(iii)	330.707	U (Pb-214)
(iv)	581.350	Th (Tl-208)
(v)	1417.711	K-40
NAMSa (i)	209.699	Th (Pb-212)
(ii)	263.269	U (Pb-214)
(iii)	316.259	U (Pb-214)
(iv)	544.249	Th (Tl-208)
(v)	847.830	Th (Tl-208)

(vi)	1285.788	U (Bi-214)
(vii)	1580.273	K-40
LUZSa (i)	204.148	Th (Pb-212)
(ii)	258.746	U (Pb-214)
(iii)	330.140	U (Pb-214)
(iv)	549.523	Th(Pb-212)
(v)	317.301	K-40
NAMSb (i)	208.148	Th (Pb-212)
(ii)	310.920	U (Pb-214)
(iii)	542.754	Th (Tl-208)
(iv)	849.922	Th (Tl-208)
(v)	1305.900	K-40
(vi)	1580.423	K-40
LUZSb (i)	208.524	Th (Pb-212)
(ii)	312.369	U (Pb-214)
(iii)	540.369	Th (Tl-208)
(iv)	845.353	Th (Tl-208)
(v)	1304.785	K-40
(vi)	1579.565	K-40

APPENDIX B
TABLES OF SPECIFIC ACTIVITIES OF THE RADIO-NUCLIDES OBTAINED IN THE SAMPLES

Table 5: Radio-nuclides present in Yam samples

Sample (Peak number)	Mean energy/keV	FWHM /keV	Rate	Mass/kg	Nuclide present	Specific activity/$\times 10^5$ Bq/kg
BANYa (i)	211.081	58.77	0.22	0.138	Pb-212(Th)	0.00158
(ii)	262.991	20.266	0.16	0.138	Pb-214(U)	0.00049
(iii)	319.668	29.196	0.28	0.138	Pb-214(U)	0.00068
(iv)	555.159	44.882	0.27	0.138	Bi-214(U)	0.00093
(v)	1324.054	58.771	0.22	0.138	K-40	0.00784
BANYb (i)	546.806	55.758	0.13	0.216	Tl-208(Th)	0.00059
(ii)	1322.054	70.464	0.42	0.216	K-40	8.30959
KINTYa (i)	217.785	48.017	0.07	0.369	Th(Pb-212)	0.00003
(ii)	329.649	34.325	0.05	0.369	U(Pb-214)	0.00005
(iii)	549.594	43.955	0.09	0.369	Th(Tl-208)	0.00024
(v)	1308.702	62.941	0.39	0.369	K-40	4.51671
KINTYb(i)	213.379	44.017	0.09	0.220	Th(Pb-212)	0.00007
(ii)	558.580	43.313	0.06	0.220	U(Bi-214)	0.00013
(iii)	1005.711	95.308	0.06	0.220	U(Bi-214)	0.00013
(iv)	1321.331	60.053	0.25	0.220	K-40	4.85625
LUZYb(i)	168.521	21.136	0.09	0.308	U(Pb-214)	0.00028
(ii)	216.057	11.880	0.03	0.308	Th(Pb-212)	0.00002
(iii)	297.640	31.605	0.06	0.308	U(Pb-214)	0.00006
(iv)	1311.316	54.548	0.21	0.308	K-40	2.91375
LUBYa (i)	163.704	36.879	0.13	0.271	U(Pb-214)	0.00046
(ii)	213.381	27.321	0.09	0.271	U(Pb-214)	0.00032
(iii)	299.423	34.073	0.14	0.271	U(Pb-214)	0.00017
(iv)	441.740	22.189	0.04	0.271	Th(Tl-208)	0.00015
(v)	529.747	44.399	0.04	0.271	Th(Tl-208)	0.00015

(vi)	1311.456	58.516	0.37	0.271	K-40	5.83467
LUBYb (i)	191.933	24.575	0.08	0.279	U(Th-227)	
(ii)	303.142	32.711	0.08	0.279	U(Pb-214)	0.00010
(iii)	428.274	40.917	0.05	0.279	Th(Tl-208)	0.00018
(iv)	762.904	55.735	0.05	0.279	Th(Tl-208)	0.00018
(v)	928.045	64.652	0.05	0.279	Th(Tl-208)	0.00018
(vi)	1314.736	55.655	0.03	0.279	K-40	0.45952
NAMYa (i)	206.938	12.688	0.02	0.238	Th(Pb-212)	0.00001
(ii)	218.192	29.324	0.05	0.238	U(Pb-214)	0.00020
(iii)	317.131	32.891	0.04	0.238	U(Pb-214)	0.00006
(iv)	569.194	26.089	0.03	0.238	Th(Tl-208)	0.00012
(iv)	1334.924	60.195	0.22	0.238	K-40	3.95030
NAMYb (i)	202.849	17.581	0.04	0.235	Th(Pb-212)	0.00003
(ii)	303.945	19.542	0.03	0.235	U(Pb-214)	0.00004
(iii)	544.730	43.360	0.03	0.235	Th(Tl-208)	0.00013
(iv)	1311.642	63.270	0.28	0.235	K-40	5.09183
LUZYa (i)	199.894	35.722	0.12	0.310	Th(Pb-212)	0.00006
(ii)	307.702	32.041	0.10	0.310	U(Pb-214)	0.00011
(iii)	548.384	50.938	0.08	0.310	Th(Tl-208)	0.00026
(iv)	852.113	54.259	0.06	0.310	Th(Tl-208)	0.00019
(v)	1312.204	64.498	0.33	0.310	K-40	4.54921
KISYa (i)	204.155	14.234	0.05	0.348	Th(Pb-212)	0.00002
(ii)	303.577	17.916	0.03	0.348	U(Pb-214)	0.00003
(iii)	551.834	37.020	0.03	0.348	Th(Tl-208)	0.00009
(iv)	860.742	27.276	0.03	0.348	Th(Tl-208)	0.00009
(v)	1304.425	61.181	0.35	0.348	K-40	4.29806
KISYb (i)	207.297	13.059	0.09	0.482	Th(Pb-212)	0.00003
(ii)	258.140	22.525	0.04	0.482	U(Pb-214)	0.00004
(iii)	330.260	18.857	0.04	0.482	U(Pb-214)	0.00003
(iv)	533.159	27.532	0.03	0.482	Th(Tl-208)	0.00006
(v)	815.192	56.478	0.07	0.482	Th(Tl-208)	0.00014
(iv)	1296.387	55.644	0.36	0.482	K-40	3.19183

Table 6: Specific Activities of radio-nuclides in Yam

Sample	Mass(kg)	Specific Activity (Bq/kg)		
		U	Th	K-40 $\times 10^5$
BANY a	0.138	68	158	0.00784
BANYb	0.216	00	59	8.30950
NAMYa	0.238	06	12	3.95030
NAMYb	0.235	04	13	5.09183
LUBYa	0.271	17	15	5.83467
LUBYb	0.279	10	18	0.45952
KINTYa	0.369	05	12	4.51671
KINTYb	0.220	13	07	5.85625
LUZYb	0.308	06	02	2.91375
LUZYa	0.310	11	17	4.54921
KISYa	0.348	03	09	4.29806
KISYb	0.482	03	06	3.19183

The average values for the specific activity in each of the areas were presented in chapter 4.

Table 7: Radio-nuclides found in Sugarcane samples

Sample(Peak number)	Mean energy/kev	FWHM/keV	Rate	Mass(kg)	Radionuclide	Specific Activity / $\times 10^5\ Bqkg^{-1}$
BANSGa(i)	1324.813	39.214	0.04	0.519	K-40	0.32936
BANSGb(i)	None					
LUBSGa (i)	161.546	10.548	0.04	0.360	U(Pb-214)	0.00011
(ii)	221.546	14.351	0.02	0.360	Th(Pb-212)	0.00001
(iv)	344.905	17.955	0.02	0.360	U(Pb-214)	0.00002
(v)	423.751	22.918	0.02	0.360	Th(Tl-208)	0.00005
(vi)	1301.882	13.380	0.04	0.360	K-40	0.47483
LUBSGb (i)	170.319	21.011	0.02	0.378	U(Pb-214)	0.00005
(ii)	209.176	17.527	0.03	0.378	Th(Pb-212)	0.00001
(iii)	300.249	10.311	0.02	0.378	U(Pb-214)	0.00002
(iv)	529.269	14.439	0.02	0.378	Th(Tl-208)	0.00005
(V)	1301.012	28.652	0.03	0.378	K-40	0.33917
KINTSGb(i)	1315.051	35.269	0.03	0.476	K-40	0.26934
KINTSGa(i)	1298.534	29.982	0.02	0.375	K-40	0.22792

KISSGa (i)	161.403	8.084	0.04	0.382	U(Pb-214)	0.00010
(ii)	198.331	28.811	0.06	0.382	Th(Pb-212)	0.00003
(iii)	248.750	28.493	0.05	0.382	Th(Tl-208)	0.00013
(iv)	530.544	23.331	0.02	0.382	Th(Tl-208)	0.00052
(v)	992.370	11.743	0.01	0.382	U(Bi-214)	0.00001
(vi)	1306.558	48.457	0.04	0.382	K-40	0.44749
KISSGb (i)	200.645	18.303	0.03	0.503	Th(Pb-212)	0.00001
(ii)	302.320	17.787	0.02	0.503	U(Pb-214)	0.00001
(iii)	1381.014	34.925	0.04	0.503	K-40	0.33984
LUZSGa (i)	227.254	34.492	0.03	0.505	Th(Pb-212)	0.00001
(ii)	335.044	10.652	0.02	0.505	U(Pb-214)	0.00001
(iii)	1306.362	42.940	0.04	0.505	K-40	0.33850
LUZSGb (i)	194.779	19.235	0.03	0.466	Th(Pb-212)	0.00001
(ii)	232.323	20.369	0.02	0.466	Th(Pb-212)	0.00001
(iii)	350.115	10.798	0.01	0.466	U(Pb-214)	0.00001
(iv)	1307.913	50.983	0.06	0.466	K-40	0.55024
NAMSGa(i)	280.809	50.496	0.05	0.430	U(Pb-214)	0.00005
(ii)	432.477	28.270	0.03	0.430	Th(Tl-208)	0.00007
(iii)	1311.661	42.387	0.03	0.430	K-40	0.29815
NAMSGb(i)	357.512	39.352	0.03	0.484	U(Pb-214)	0.00002
(ii)	450.389	25.931	0.02	0.484	Th(Tl-208)	0.00004
(iii)	1298.493	37.182	0.03	0.484	K-40	0.26489

The specific activities below were obtained from the above tables by considering the most prominent peak of all those that are obtained for a particular radio-nuclide.

Table 8: Specific Activities of radio-nuclides in Sugarcane

Sample	Mass(kg)	Specific Activity (Bq/kg)		
		U-238	Th-232	K-40 ($x10^5$)
NAMSGa	0.430	05	07	0.29815
NAMSGb	0.484	02	04	0.26489
LUZSGa	0.505	01	01	0.33850
LUZSGb	0.466	01	01	0.55024
BANSGa	0.519	00	00	0.39936
BANSGb	0.520	00	00	0.00000
KISSGa	0.382	01	52	0.44749
KISSGb	0.503	01	01	0.33984
KINTSGa	0.375	00	00	0.22792
KINTSGb	0.476	00	00	0.26934
LUBSGa	0.360	02	01	0.47483
LUBSGb	0.378	02	05	0.33917

The mean specific activities for sugarcane were obtained for each of the area and it is represented in Table 4.7 .

Table 9: Radio-nuclides found in Water samples

Sample (Peak number)	Mean energy /keV	FWHM /keV	Activity	Mass /kg	Nuclide present	Specific Activity / $\times 10^5$ (Bq/kg)
BANWa (i)	132.061	39.993	0.48	0.517		
(ii)	211.584	21.086	0.37	0.517	Th(Pb-212)	0.00012
(iii)	261.970	20.049	0.59	0.517	U(Pb-214)	0.00048
(iv)	317.225	26.623	1.20	0.517	U(Pb-214)	0.00077
(v)	552.369	50.246	1.18	0.517	U(Bi-214)	0.00109
(vii)	1016.234	53.683	0.23	0.517	Th	
(viii)	1267.051	55.177	0.13	0.517	U(Bi-214)	0.00011
(ix)	1579.519	65.121	0.16	0.517	K-40	1.32255
BANWb (i)	129.319	38.809	0.50	0.474		
(ii)	210.226	21.198	0.32	0.474	Th(Pb-212)	0.00011
(iii)	262.972	20.794	0.65	0.474	U(Pb-214)	0.00058
(iv)	319.111	26.341	1.27	0.474	U(Pb-214)	0.00089
(v)	557.264	48.587	1.21	0.474	Th(Tl-208)	0.00252
(vii)	846.107	70.805	0.16	0.474	Th(Tl-208)	0.00033
(viii)	1027.62	54.022	0.21	0.474	Th	
(ix)	1274.975	71.973	0.18	0.474	U(Bi-214)	0.00018
(x)	1595.352	124.915	0.34	0.474	K-40	3.06538
KINTWa(i)	199.426	35.318	0.05	0.405	Th(Pb-212)	0.00002
(ii)	258.687	13.649	0.02	0.405	U(Pb-214)	0.00002

(iii)	308.206	25.946	0.03	0.405	U(Pb-214)	0.00002
KISWa (i)	213.430	21.729	0.15	0.429	U(Pb-214)	0.00034
(ii)	316.975	25.297	0.50	0.429	U(Pb-214)	0.00039
(iii)	551.908	42.237	0.44	0.429	Th(Tl-208)	0.00100
(iv)	1578.283	67.796	0.09	0.429	K-40	0.89654
KISWb (i)	219.681	21.697	0.10	0.438	Th(Pb-212	0.00004
(ii)	279.284	21.707	0.15	0.438	U(Pb-214)	0.00014
(iii)	337.409	26.954	0.28	0.438	U(Pb-214)	0.00021
(iv)	578.745	42.664	0.33	0.438	Th(Tl-208)	0.00074
(v)	1375.481	63.324	0.03	0.438	K-40	2.92706
(vi)	1699.267	60.511	0.04	0.438	U(Bi-214)	0.00001
LUBWa (i)	212.613	26.288	0.13	0.347	Th(Pb-212)	0.00006
(ii)	255.156	22.341	0.16	0.347	U(Pb-214)	0.00019
(iii)	313.602	26.578	0.30	0.347	U(Pb-214)	0.00029
(iv)	551.219	35.723	0.27	0.347	Th(Tl-208)	0.00077
(v)	1263.785	48.447	0.02	0.347	U(Bi-212)	0.00003
(vi)	1569.705	35.104	0.03	0.347	K-40	0.00040
NAMWa (i)	210.565	15.721	0.15	0.423	Th(Pb-212)	0.00006
(ii)	263.366	23.915	0.44	0.423	U(Pb-214)	0.00044
(iii)	319.063	25.375	0.78	0.423	U(Pb-214)	0.00062
(iv)	555.416	47.078	0.75	0.423	U(Bi-214)	0.00084
(v)	856.936	63.308	0.07	0.423	Th(Tl-208)	0.00016
(vi)	1585.744	97.631	0.17	0.423	K-40	1.71748
LUBWb (i)	221.731	32.134	0.06	0.395	Th(Pb-212)	0.00003
(ii)	260.487	20.372	0.10	0.395	U(Pb-214)	0.00011
(iii)	310.036	20.215	0.11	0.395	U(Pb-214)	0.00009
(iv)	549.272	40.931	0.20	0.395	Th(Tl-208)	0.00801
(v)	1267.266	37.356	0.02	0.395	U(Bi-214)	0.00002
NAMWb (i)	0.000	0.000	0.00	0.000	-	-
LUZWa (i)	210.712	24.677	0.11	0.417	Th(Pb-212	0.00004
(ii)	263.987	26.295	0.20	0.417	U(Pb-214)	0.00020
(iii)	316.881	26.618	0.35	0.417	U(Pb-214)	0.00028
(iv)	555.531	46.256	0.31	0.417	U(Bi-214)	0.00035
(v)	1599.340	57.466	0.13	0.417	K-40	1.33227
LUZWb (i)	210.829	25.965	0.13	0.498	Th(Pb-212	0.00004
(ii)	260.968	27.897	0.20	0.498	U(Pb-214)	0.00017
(iii)	315.621	27.958	0.31	0.498	U(Pb-214)	0.00021
(iv)	553.592	47.761	0.31	0.498	Th(Tl-208)	0.00061
(v)	1266.363	78.086	0.05	0.498	U(Bi-214)	0.00005
(vi)	1587.256	80.615	0.05	0.498	K-40	0.42907

Table 10: Specific activities of Radio-nuclides in water

Sample	Mass(kg)	Specific Activity (Bq/kg)		
		U-238	Th-232	K-40 ($x10^5$)
BANWa	0.517	93	12	1.32255
BANWb	0.474	74	99	3.06568
NAMWa	0.423	63	11	1.71748
KISWa	0.429	37	100	0.89654
KISWb	0.438	18	39	2.92706
KINTWa	0.405	02	02	0.00000
LUBWa	0.347	24	42	0.00040
LUBWb	0.395	10	402	0.00000
LUZWa	0.417	32	04	1.33227
LUZWb	0.498	21	33	0.42907

Table 11: Radio-nuclides found in Soil Samples

Sample (Peak number)	Mean energy /keV	FWHM /keV	Rate	Mass /kg	Nuclide present	Specific Activity(Bq/kg)
LUBSa (i)	114.286	28.044	0.84	0.422		
(ii)	206.978	34.740	7.59	0.422	Th(Pb-212)	0.00296
(iii)	262.210	18.426	0.38	0.422	U(Pb-214)	0.00038
(iv)	315.203	27.847	2.21	0.422	U(Pb-212)	0.00175
(v)	545.918	48.334	2.75	0.422	Th(Tl-208)	0.00644
(vii)	859.123	79.392	2.30	0.422	Th(Tl-208)	0.00539
(viii)	1027.069	56.427	0.38	0.422	Th	
(ix)	1325.203	64.954	0.30	0.422	K-40	3.03804
(x)	1472.397	69.100	0.16	0.422	K-40	1.62029
(xi)	1604.225	56.796	0.15	0.422	Bi-214(U)	0.00017
LUBSb (i)	165.073	6.680	0.09	0.464	Pb-214(U)	0.00019
(ii)	210.830	21.388	1.34	0.464	Pb-212(Th)	0.00048
(iii)	265.150	22.616	0.16	0.464	Pb-214(U)	0.00015
(iv)	318.704	31.881	0.50	0.464	Pb-214(U)	0.00040
(v)	547.275	46.751	0.67	0.464	Tl-208(Th)	0.00143
(vii)	854.836	73.942	0.47	0.464	Tl-208(Th)	0.00100
(viii)	1035.771	54.395	0.13	0.464	Th	
(ix)	1327.414	67.651	0.20	0.464	K-40	1.84203
KINTSa (i)	264.524	21.417	0.44	0.328	U(Pb-214)	0.00057
(ii)	213.361	19.169	1.94	0.328	U(Pb-214)	0.00567
(iii)	318.873	27.966	1.27	0.328	U(Pb-214)	0.00129
(iv)	550.176	47.997	1.30	0.328	Th(Tl-208)	0.00392
(vi)	857.303	68.281	0.51	0.328	Th(Tl-208)	0.00154
(vii)	1022.677	61.108	0.21	0.328	Th	

(viii)	1306.515	97.299	0.32	0.328	K-40	4.16927
(ix)	1586.021	56.585	0.08	0.328	K-40	1.04232
KINTSb (i)	263.750	21.002	0.37	0.378	U(Pb-214)	0.00041
(ii)	316.054	26.816	1.14	0.378	U(Pb-214)	0.00101
(iii)	549.880	51.604	1.35	0.378	Th(Tl-208)	0.00353
(v)	859.309	73.814	0.67	0.378	Th(Tl-208)	0.00175
(vi)	1019.901	56.720	0.18	0.378	Th	
(vii)	1317.176	86.818	0.27	0.378	K-40	3.05250
(viii)	1608.994	81.099	0.14	0.378	Th(Bi-214)	1.58278
BANSa (i)	210.766	22.027	2.30	0.377	Th(Pb-212)	0.00100
(ii)	263.119	23.279	0.44	0.377	U(Pb-214)	0.00049
(iii)	317.276	28.136	1.19	0.377	U(Pb-214)	0.00105
(iv)	548.945	52.457	1.44	0.377	Th(Tl-208)	0.00377
(v)	856.037	71.978	0.74	0.377	Th(Tl-208)	0.00194
(vi)	1021.918	64.173	0.25	0.377	Th	2.83389
(vii)	1317.553	79.946	0.25	0.377	K-40	2.83389
(viii)	1597.216	68.083	0.13	0.377	Th(Bi-214)	1.47362
BANSb (i)	208.885	21.133	1.57	0.389	Th(Pb-212)	0.00066
(ii)	260.140	21.370	0.24	0.389	U(Pb-214)	0.00026
(iii)	313.762	32.913	0.69	0.389	U(Pb-214)	0.00059
(iv)	543.423	50.760	0.98	0.389	Th(Tl-208)	0.00249
(v)	854.819	91.456	0.60	0.389	Th(Tl-208)	
(vi)	1016.487	52.913	0.16	0.389	Th	1.75774
(vii)	1316	62.323	0.23	0.389	K-40	2.52675
(viii)	1583.196	71.213	0.08	0.389	Th(Tl-208)	0.00020
NAMSa (i)	209.699	19.470	0.54	0.207	Th(Pb-212)	0.00043
(ii)	263.269	18.410	0.11	0.207	U(Pb-214)	0.00022
(iii)	316.259	26.220	0.37	0.207	U(Pb-214)	0.00060
(iv)	544.249	48.979	0.51	0.207	Th(Tl-208)	0.00243
(v)	847.830	76.664	0.25	0.207	Th(Tl-208)	0.00119
(vi)	1285.788	91.419	0.15	0.207	U(Bi-214)	0.00035
(vii)	1580.273	70.669	0.09	0.207	K-40	1.85804
NAMSb (i)	208.148	21.835	1.64	0.342	Th(Pb-212)	0.00079
(ii)	310.920	26.254	0.94	0.342	U(Pb-214)	0.00092
(iii)	542.754	50.260	1.14	0.342	Th(Tl-208)	0.00329
(v)	849.922	72.218	0.52	0.342	Th(Tl-208)	0.00150
(vi)	1305.900	77.974	0.38	0.342	K-40	4.74834
(ix)	1580.423	91.114	0.19	0.342	K-40	2.37417
LUZSb (i)	208.524	18.824	1.02	0.366	Th(Pb-212)	0.00046
(ii)	312.369	25.454	0.45	0.366	U(Pb-214)	0.00041
(iii)	540.284	52.058	0.79	0.366	Th(Tl-208)	0.00213
(v)	845.353	73.175	0.42	0.366	Th(Tl-208)	0.00113
(vi)	1304.785	72.040	0.20	0.366	K-40	2.33352
(vii)	1579.565	60.604	0.08	0.366	K-40	0.93410
LUZSa (i)	204.148	26.572	0.07	0.375	Th(Pb-212)	0.00003
(ii)	258.746	16.825	0.02	0.375	U(Pb-214)	0.00002
(iii)	330.140	28.471	0.03	0.375	U(Pb-214)	0.00003