RADIOLOGICAL HAZARD LEVELS DUE TO GAMMA EMMITING RADIONUCLIDES IN NATURAL WATER BODIES IN SELECTED SUB-COUNTIES OF MUBENDE DISTRICT

BY

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DECLARATION

I, Candia John do hereby declare that this Dissertation is my original work and has not been presented to any institution for an academic award.

Signed .....

Date ..... 15/01/2015 .....

APPROVAL

This Dissertationwas developed and carried out under our close supervision and has been passed by the Board of Examiners and Senate for the award of the Degree of Master of Science in Physics of Kyambogo University.

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DEDICATION

To my wife Grace Candia and son Samuel Mungufeni.

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I am heavily indebted to my supervisors, Mr. Richard Oriada and Assoc. Prof. Eric Mucunguzi for guiding and directing me throughout this Dissertation. Most of all, the two supervisors had thorough and critical reading of the Dissertation. Equally, I heartily thank Dr. Edward Jurua who worked hard for the success of the Study. It was entirely the efforts of these dedicated resource persons that made this Dissertation derive the sense and meaning it carries.

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ABSTRACT

This study was carried out to investigate the health hazard levels due to gamma rays emitted by radionuclides in natural water bodies in selected sub-counties in Mubende District. Owing to the interaction between underground water wells with the mineral rich geological components of the landscape; and the link that the minerals have with gamma emitting radionuclides, the population of Mubende is exposed to unknown levels of ionizing radiation. In the study, a representative of 60 natural water samples from the sub-counties of Bukuya, Kasambya, Kassanda and Kitumbi were analyzed for radiological hazard levels using a NaI (Tl) gamma-ray detector. Specific activities due to ^{226}Ra, ^{232}Th, ^{238}U, and ^{40}K were obtained and then used to calculate the absorbed dose rates, annual effective dose equivalents and the radiological health hazard indices. To ensure quality control, the samples were collected from the sites in rinsed empty mineral water bottles which were sealed and labeled. They were transported in paper boxes whose background radiation emissions were measured with an identifier.

The mean Specific Activities in Bq/kg due to ^{226}Ra, ^{232}Th, ^{238}U and ^{40}K obtained from the laboratory investigations were 103.10 ± 2.59, 80.69 ± 1.33, 24.94 ± 0.42 and 16.02 ± 1.32, respectively. The mean absorbed dose rate was 97.45 $nGyh^{-1}$ which was higher than the published reference value of 55 $nGyh^{-1}$. The mean Annual Effective Dose Equivalent was 0.30 mSv $year^{-1}$, above the reference level of 0.12 mSv $year^{-1}$. The calculated radium equivalent was 219.50 $Bqkg^{-1}$, below the reference level of 370 $Bqkg^{-1}$. The mean external hazard index was 0.60 while the mean internal hazard index was 0.88.

Though the Specific Activities, the mean absorbed dose rate and the annual effective dose equivalent were higher than reference values, the radiological hazard indices indicate that consuming these waters did not pose a significant threat to the health of the population but precautions should be taken against high radiation water sources. The study recommended that background radiation emissions in these sites of water collection be done by Uganda Atomic Energy Council (AEC) in collaboration with Uganda National Bureau of Standards (UNBS) and National water and sewerage cooperation (NWSC). In addition, it also recommended for periodic monitoring of the radioactivity levels due to the gamma emitting radionuclides in the natural and drinking waters of the district. Finally, the study recommended that a research be carried out on radiation hazard levels posed by water bodies this study did not look at in Mubende district.

CHAPTER ONE: INTRODUCTION

1.1 Background of the Study

Uganda lies within the African plate, a continental crust that contains Archaean cratons dating at least 2700 million years ago. The geology of Uganda, blessed with a wide variety of mineral deposits, is grouped into five major tectono-thermal domains. These domains are the Archaean basement which has existed for over 2500 million years, Palaeoproterozoic Fold Belts that have existed for between 2500 and 1600 million years, Mesoproterozoic rocks that have been in existence for the last 1600 to 900 million years, Neoproterozoic rocks that have lasted for between 900 and 570 Million years and Cenozoic rocks that have lasted for at least 66 Million years. Each domain is associated with specific mineral deposits (Harold, 2010; Mining Journal, 2012). The domains vary from one place to another and in some places, two or more domains may be found. Accordingly, the mineral distribution is a function of the geological composition of the region. Some of the minerals are linked with gamma emitting radioisotopes. For example, in a survey headed by the Consortium of the Geological Survey of Switzerland (GTK) from 2008 to 2012, possible uranium deposits are being reported in areas North of Kampala, parts of West Nile, Iganga, Aboke and Mubende district (IBI Corporation, 2008; Baguma, 2010). This same survey also found potassium rich soils in North Western parts of the Country, Central region that includes Mubende. The survey further indicates gold deposits cited in Karamoja, Hoima, Buwju, Kaliro, Aboke, West Nile and Mubende district (Harold, 2010).

In Mubende district, two of the five domains are significant and these are the Palaeoproterozoic Fold Belts and the Cenozoic rocks. The former comprises argillaceous rocks together with quartzites and are characterized by underwater volcanic activity within the deposits. The rocks in this belt are metamorphosed to amphibolite facies. This system is closely associated with presence of gold, copper, cobalt, nickel, lead, columbite-tantalite and tungsten. (Harold, 2010).

Gold is being mined in the district by the informal sector from quartz stringers within schists and saprolite. The latter constitutes the Neogene Carbonatite Complexes which are the feeders of eroded remnants of volcanoes hosting limestone, apatite, pyrochlore, vermiculite, iron, titanium, vanadium, zircon, baddeleyite, uranium, thorium and traces of copper. The gold bearing green

stone belt with the mafic volcanic rocks, sediments and the granitoid intrusions in the district make it a potential mineral region that is closely linked with radioisotopes such as uranium and thorium and their progeny (Mining Journal, 2012). Mubende district is the fifth in the ranking of the fifteen priority mining targets in Uganda and the first priority target area for uranium and thorium (Baguma, 2012). These minerals may interact with the natural water resources making them hazardous to human health of the population in the region (Nguyen *et al.*, 2009). Mubende is the fifth most populated District in Uganda (UBOS, 2014) and the most populated uranium rich district in the country.

Mubende District has open natural water bodies covering 154.3 km^2 (2.5%) of the 6.196 km^2 total area. It also has wetlands that occupy 758.1 km^2 (12.2%) of the total area. The District is enclosed with Lake Wamala on the eastern side and its main rivers are Kisojo, Kattabalanga, Nkusi, Mpongo and Nabakazi. The water sources of the District comprise precipitation, ground water, run off, evapo-transpiration and surface waters on major lakes and rivers (Ministry of water and Environment, 2010). There are also valley dams, which help store water for domestic use and watering animals during the dry season (Mubende Report, 2004).

The District has its ground water supplies which are harvested in form of inflows of gravity, boreholes, wells and springs. The water resources provide water for domestic use and consumption, recreation, fishing and transport and provision of habitat to some species of the fauna and aquatics. Off-stream uses for municipality, industries and irrigation are relatively limited although there are large areas with the potential for irrigation development, storage, recreation, fishing, transport and ecological functions. On domestic use, a large part of the district both rural and urban relies on water sources such as boreholes, springs, valley dams and wells (Table 1.1, Annex four) (Mubnde Report, 2004). If the mineral component of Mubende has the gamma ray emitters, then there is a high possibility that these water sources could be contaminated.

The relief of Mubende District is in the range of 1066-1548 m above sea level, with varied landscape features. The District has at least five geomorphologic features that have designed its landscape. Low land surfaces cover the greatest proportion of the district. Zones of tors and

inselbergs are found in the western part at Nabingora and Semuto, stretching northwestwards to the area between Kokwa and Kasozi. Upland surfaces are evident at the Northern border East of Kasozi, Bulotogo, Bukuya and Kitumbi sub-counties. Areas of in-fill are associated with the rivers such as Nabakazi, Kisojo, Katabalanga, Kasambya, Kitenga and Kiganda sub-counties and also around Lake Wamala and Northeast of Kasambya. Deposits and platforms of extended Lake Victoria are found at the fringes of Lake Wamala, in Myanzi and Kiganda sub-counties. This relief suggests that surface and ground waters of Mubende flow from one point to another based on the gravitational potential difference, thus one source of contaminated water could possibly contaminate another (Mubende report, 2004).

With about 84% of the 688,819 people engaged in peasant farming, Mubende is largely an agricultural district (UBOS, 2014). Given its mineral potential, some residents have opted for mining but on small scale artisanal level. Gold mines found in the District include Lujinji A, Lujinji B, Kisiita, Kamalenge and Kitabona all in Kitumbi sub-county. There are other artisanal gold mines in Kassanda, Bukuya and Kasambya sub-counties (Paterson *et al.*, 2009; Oil Uganda, 2004). The gold miners use rudimentary tools such as forked hoes, spades, jerry cans and basins to get gold out of the ground. This may result in the exposure of the persons involved in the mining and farming around these gold mines to high levels of ionizing radiation. The radionuclides may contaminate their water bodies, crops and meat from their animals that are grazed on these lands.

The environmental contamination of the upper atmosphere naturally and due to human activities is yet another big source of radiological water pollution. This is due to the interaction of the rains with the atmosphere before arrival onto the land and the natural water bodies (Canadian Ministry of Health, 2010).

Underground water wells and springs run across rocks and minerals which contain natural radionuclides. The radionuclides in the rocks easily and naturally leach into water and then get incorporated metabolically into plants (Canadian Ministry of Health, 2010, 2007; Guogang *et al.*, 2007). The concentration levels of the radionuclides in water vary considerably from one place to another depending on geographical locations (NEMA, 2014; Anguma, 1999; UNSCEAR, 2000; Ajayi *et al.*, 2009).

Heavy radioisotopes are very unstable in water and decay to attain stability (Friedlander, 1981; Ikem *et al.*, 2002). When water with high activity concentrations of the radioisotopes is taken for a good fraction of one's life time, it becomes a notable health detriment (Elena *et al.*, 2002). Levels of ionizing radiation exposure through consumption of water are not static and for Mubende District have not yet been measured despite the recent survey reports on the availability of uranium mineral. Based on the rich geological map of Uganda in general and Mubende district in particular with the minerals that are known to associate closely with naturally occurring radioisotopes, there is a compelling demand to study and measure the specific activity levels due to gamma emitting radionuclides in the water bodies in Mubende District. This will help to assess the associated health hazard levels.

Anguma (1999) determined the activity level of caesium in Lake Victoria and Lake Kyoga and that of naturally occurring radionuclides in their biota. The study found no caesium in the lakes and found that all the fish species contained measurable levels of the radionuclides. Water hyacinth was found to retain significant amounts of Potassium while Thorium and Uranium were measurable. However, the study did not explicitly investigate the specific activity levels of the radionuclides in the natural water bodies in the Country and the associated hazard levels.

1.2 Statement of the Problem of the Study

Natural water bodies in many parts of Uganda have the likely hood of containing high radioactivity levels due to their interaction with the rocks and minerals that compose the landscape. Some of the minerals such as uranium and thorium and their progeny have links with the gamma emitting radionuclides. There is thus the chance of high radiation levels in the waters and this is a potential exposure path to man. This follows the fact that naturally occurring radionuclides are unstable and decay by emission of radioactive particles and high energy gamma rays to attain stability. The radioactivity levels in a given source of water vary from time to time. Water is a basic human demand and vital for drinking, construction work, cooking, bathing, washing and absorbed by plants. The cumulative impact of consuming water from sources that may contain considerably high activity levels of naturally occurring radio nuclides for a relatively long time becomes a significant health hazard. Despite this background, there is

inadequate research done so far to assess the ionizing radiation hazard levels due to naturally occurring radio nuclides that emit gamma rays in the natural water sources in Uganda.

1.3 Purpose of the Study

The aim of the study is to investigate the hazard levels due to gamma rays emitted by radionuclides in natural water bodies in selected sub-counties in Mubende District.

1.4 Objectives of the Study

The objectives of this study were to:-

(i) Investigate the radionuclides in natural water bodies in Mubende district.

(ii) Calculate the specific activities of radionuclides found in the water bodies.

(iii) Compute the Annual Committed Effective Dose and Specific Dose Rates due to gamma emitting radionuclides in water.

(iv) Examine the associated health hazard due to the radionuclide contaminated water based on the radiological indices.

1.5 Significance of the Study

(i) The specific activity levels of the study (^{226}Ra, ^{232}Th, ^{238}U and ^{40}K : 103.10 ± 2.59, 80.69 ± 1.33, 24.94 ± 0.42 and 16.02 ± 1.32, respectively.) can be used as a baseline by Uganda National Bureau of Standards (UNBS), National water and sewerage cooperation (NWSC) and the Uganda Atomic Energy Council (AEC).

(ii) The absorbed dose rate and the annual effective dose equivalent (97.45 $nGyh^{-1}$ and 0.30 $mSv\ year^{-1}$, respectively) found in this study can encourage the UNBS, NWSC and AEC to monitor ionizing radiation levels in water sources in the rest of the country.

(iii)The radiological health hazard indices (Ra_{eq}, H_{ex}, H_{in}, and $I_{\gamma r}$ in $Bqkg^{-1}$ were 219.5, 0.60, 0.88 and 1.51, respectively) can be used by Directorate of Water Development (DWD) in the Ministry of Water and Environment with other relevant authorities to guide residents on ionizing radiation levels direct locations for establishment of new water points.

(iv) Above results can be used to advise the people on the safety or the health hazards of the water they use and advise on control measures to avoid radiological contamination by human activities.

(v) The recommendations of this study source areas for further research.

(vi)Other researchers can use the study findings in (i) to (iii) above as reference and a frame for comparison.

1.6 Scope of the Study

The study was carried out on samples of water collected from selected sub-counties of Mubende District namely; Bukuya, Kasambya, Kassanda and Kitumbi sub-counties. Waters from Wells, Boreholes, Valley dams, and Springs were sampled.

Figure 1.1: The map of Mubende District (Google maps, 2015)

The water samples were analyzed in order to determine the specific activity levels due to gamma emitting radionuclides. Absorbed dose rates and the annual effective dose equivalents were computed. The health risk assessment was based on the radiological indices: - external hazard index, internal hazard index, radium equivalent and representative hazard index.

CHAPTER TWO: REVIEW OF RELATED LITERATURE

2.1. Introduction

This chapter focuses on the theory of ionizing radiation, human exposure to ionizing radiation, review of aspects of radioactivity, gamma ray interaction with matter. The discussion on the measurement of ionizing radiation then follows. The effect of ionizing radiation on human health, ionizing radiation dose and the assessment of the health hazards follow. Finally, some related studies previously conducted on natural radioactivity in water are briefly discussed.

2.2. Sources of ionizing radiation

Ionizing radiation is emitted from a variety of natural and artificial sources. Nuclear radiation, naturally can come from building materials, water, and radioactive substances in the earth's crust (UNSEAR, 1988). Other natural sources include cosmic rays, radon gas, ^{226}Ra, ^{232}Th,^{238}U, and ^{40}K (Canadian Ministry of Health, 2010). Natural ionizing radiation can either be of Cosmogenic or Terrestrial origin. About 70% of the cosmogenic ionizing radiations are produced by the stratosphere, 30% by troposphere (UNSCEAR, 1988). Stratosphere is the region of the upper atmosphere between 15,000 to 50,000 m above sea level. In this region, temperature increases with increase in altitude due to absorption of solar energy by ozone. Tropopause extends from 10, 000 to 15, 000 m above sea level. The region from the surface of the earth to the tropopause is the troposphere where temperature reduces with increase in altitude. Radiations of terrestrial origin are a result of radioactivity due to the rock and the mineral components of the earth (Lilley, 2001).

Man has discovered many useful applications of ionizing radiation that at the same time act as an exposure route. Human activities such as mining, quarrying, electric energy production, medical practices and military operations release significant doses of ionizing radiation into the environment (Turner, 1995). Sources of ionizing radiation that result due to human activities and they add to the natural ionizing radiation levels in the environment and these include nuclear reactors, nuclear weapons, nuclear accidents, nuclear medicine, radiation therapy, consumer products, diagnostic X–rays and industrial applications (Marilyn *et al.*, 2007).

2.3. Human Exposure to Nuclear Radiation

Human beings are constantly exposed to ionizing radiation present in the environment. Ionizing radiation from natural sources is the largest contributor to the collective radiation dose to the world Population (Vanmarcke, 2000). These exposures are both external (affected from outside) and internal (by inhalation, ingestion through drinking water and food). When inhaled or ingested, naturally occurring radio nuclides contribute significantly to the individual's radiation dose (WHO, 2008; IAEA, 2010).

Uganda is naturally blessed with a wide resource base that includes rivers, lakes, springs, oil and water wells, wetlands, mountains, minerals and adequate forest cover. Accordingly, specific activity levels of naturally occurring radionuclides in her waters vary greatly (Anguma, 1999, NEMA, 2014). Mubende District has targeted Uranium mining deposits (Mining Journal, 2012) that have the possibility to contaminate the borehole waters, valley dams and the other sources of drinking water. Water forms a large proportion of the human body fluids and thus there is a likelyhood of accumulation of these radionuclides in the body (WHO, 2008; Martnez, 1989).

Natural radioactive chains from ^{238}U, ^{235}U and ^{232}Th produce a group of radionuclides with a wide range of half-lives (Ray, 2013). Those with short half-lives decay and release significant energies inside or on the body. When impinged on matter, ionizing radiation deposits energy which may be sufficient to overcome the nuclear binding energy of the atom. This can result in the liberation of an electron from the influence of the nucleus of an atom, breaking it into positive and negative ions. Interaction of ionizing radiation with matter results in either direct or indirect ionization (Canadian Ministry of Health, 2010; Guogang, 2007; Knoll *et al.*, 2000).

X-rays, gamma rays, neutrons, electrons, protons, alpha particles and beta particles deposit energy in matter through direct interaction with the orbital electrons (Rutherford, 1911). The energy that they deposit in this case is sufficient to remove the orbital electrons from the attacked atom. These particles constitute directly ionizing radiation (IAEA, 2004).

Man is mainly exposed to ionizing radiation in drinking water by the gamma emitting radionuclides ^{226}Ra, ^{238}U, ^{232}Th and ^{40}K (UNSCEAR, 2000, Kocher, 2001). The need to know the concentration levels of these radionuclides in drinking water is on the increase daily (Yussuf *et al.*, 2012; Guogang, 2009).

Ionizing radiation from the earth due to geological compositions and geothermal processes constitute over15% of the external exposure. Cosmic rays yield into ionizing radiation as they interact with the atmosphere contributing up to 13% of the net external exposure. Food and water contribute 8% of the ionizing radiation exposure. Artificial sources add over 1% of the total external exposure. The figure below (Figure 2.1) gives the sources and distributions of average radiation exposure for the world population (WHO, 2008). The global average annual human exposure to ionizing radiation from natural sources is 2.4 mSv/year (UNSCEAR, 2000; WHO, 2008). In this particular study, focus is on the ingested radionuclides ^{226}Ra, ^{232}Th ^{238}U and ^{40}K due to radiological contamination of the natural water bodies.

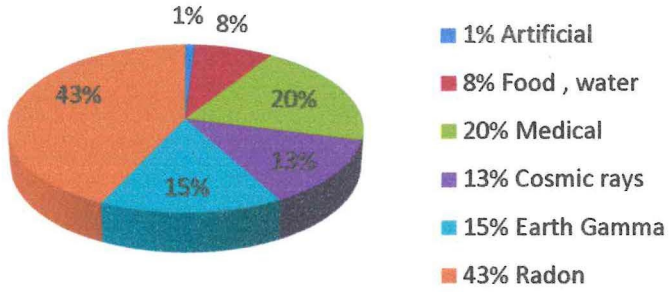

Figure 2.1: Distribution of world population average radiation exposure (WHO, 2008)

2.4. Stability of Radioisotopes

All heavy elements with atomic number, Z exceeding 82 are radioactive with exception of $^{209}_{83}Bi$ owing to its stability. The heavy elements are unstable and spontaneously disintegrate into one or several daughter nuclides by emission of alpha (α) particles, beta (β) particles and gamma (γ) rays. These form a series of radionuclides that terminate with a stable daughter (Mule, 1947; Mayer, 1906). All naturally occurring heavy radionuclides belong to one of the three series. The Uranium series which begins with ^{238}U and ends with ^{208}Pb (Figure 2.2). The Thorium series which begis with ^{232}Th and ends with ^{208}Pb (Figure 2.3). The Actinum series which starts with ^{235}U and ends with ^{207}Pb (Figure 2.4) (Martin *et al.*, 2013).

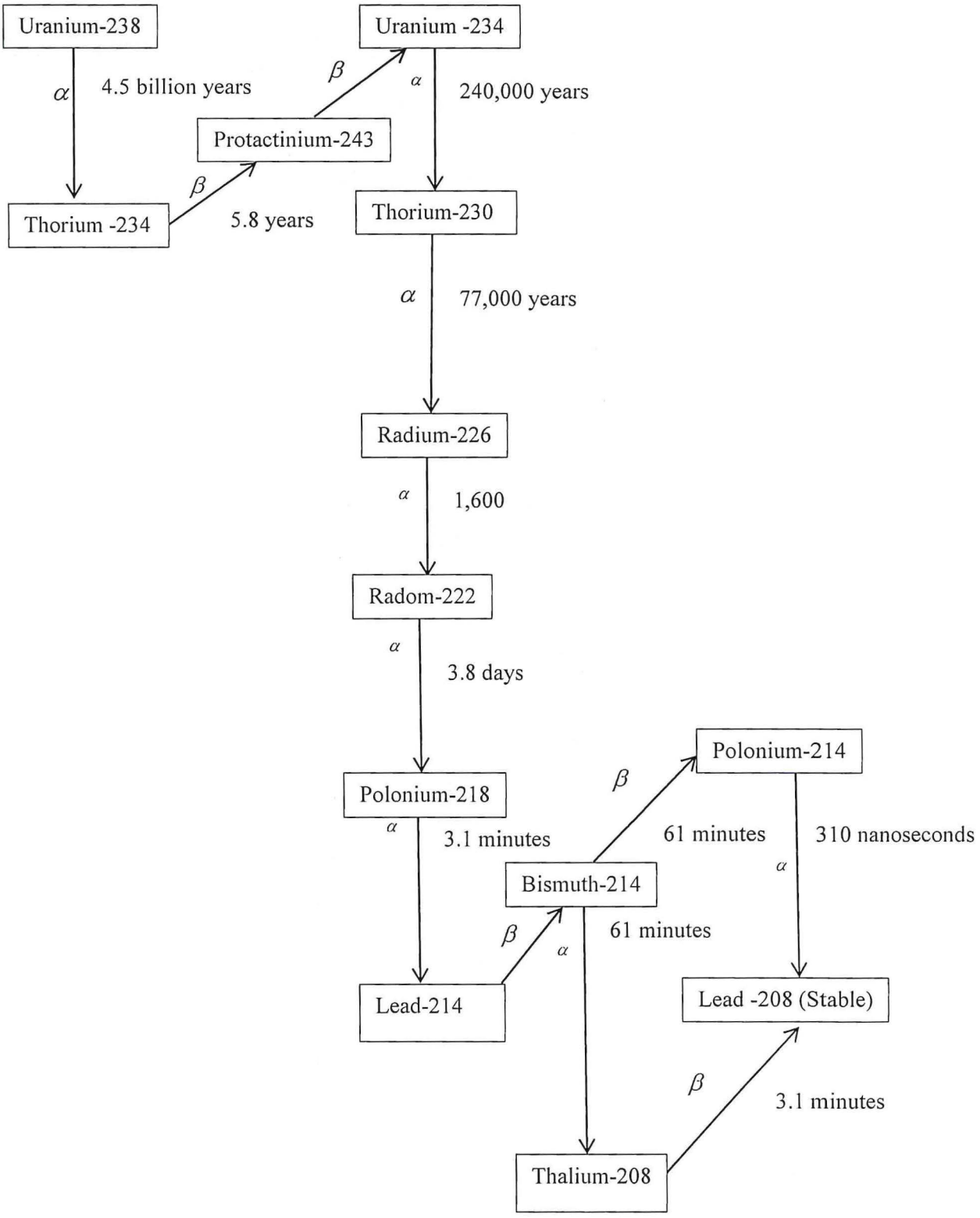

Figure 2.2: Natural decay series of Uranium-238 (Mattetnik, 1995)

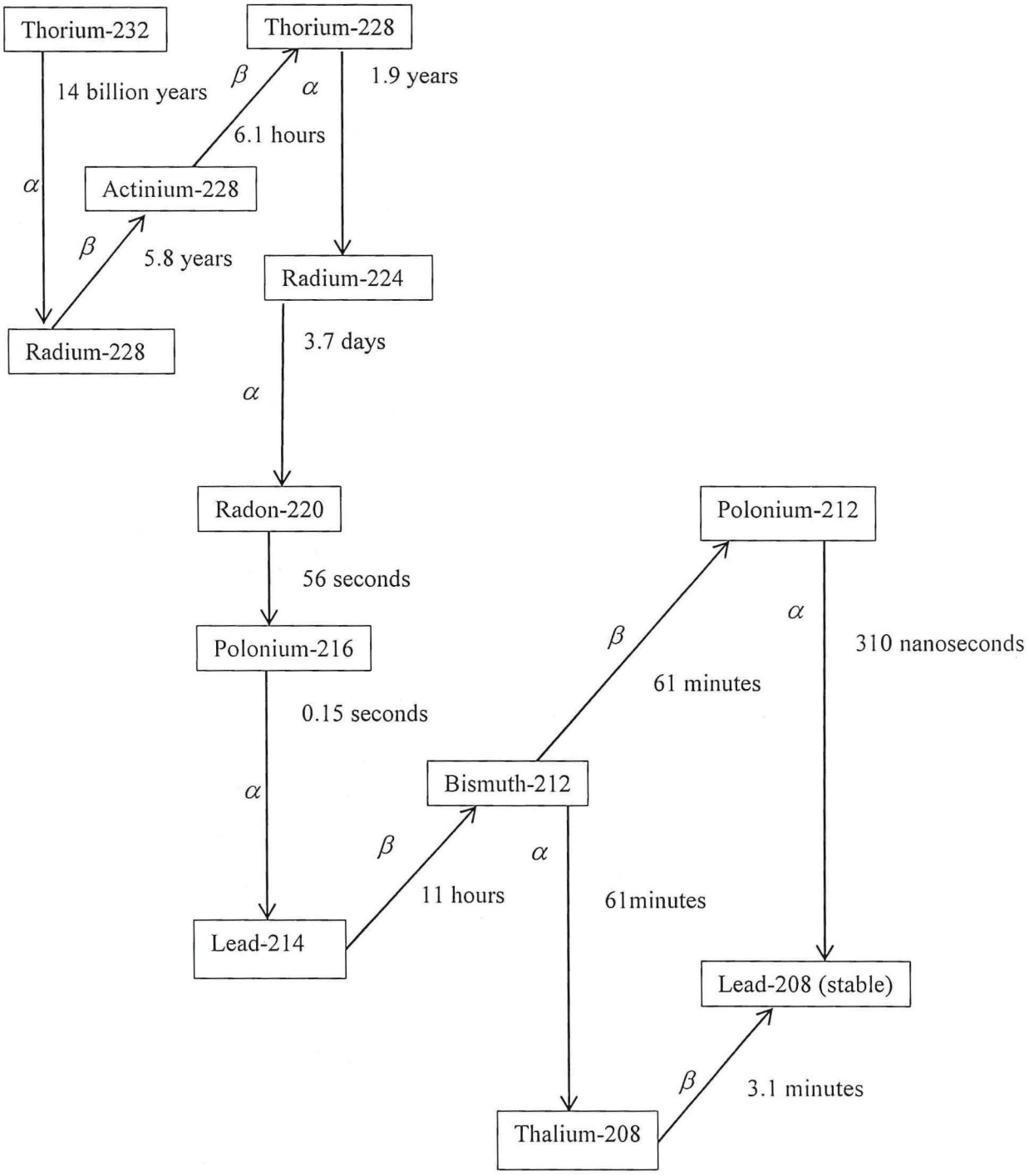

Figure 2.3: Natural decay series of Thorium-232 (Mattetnik, 1995)

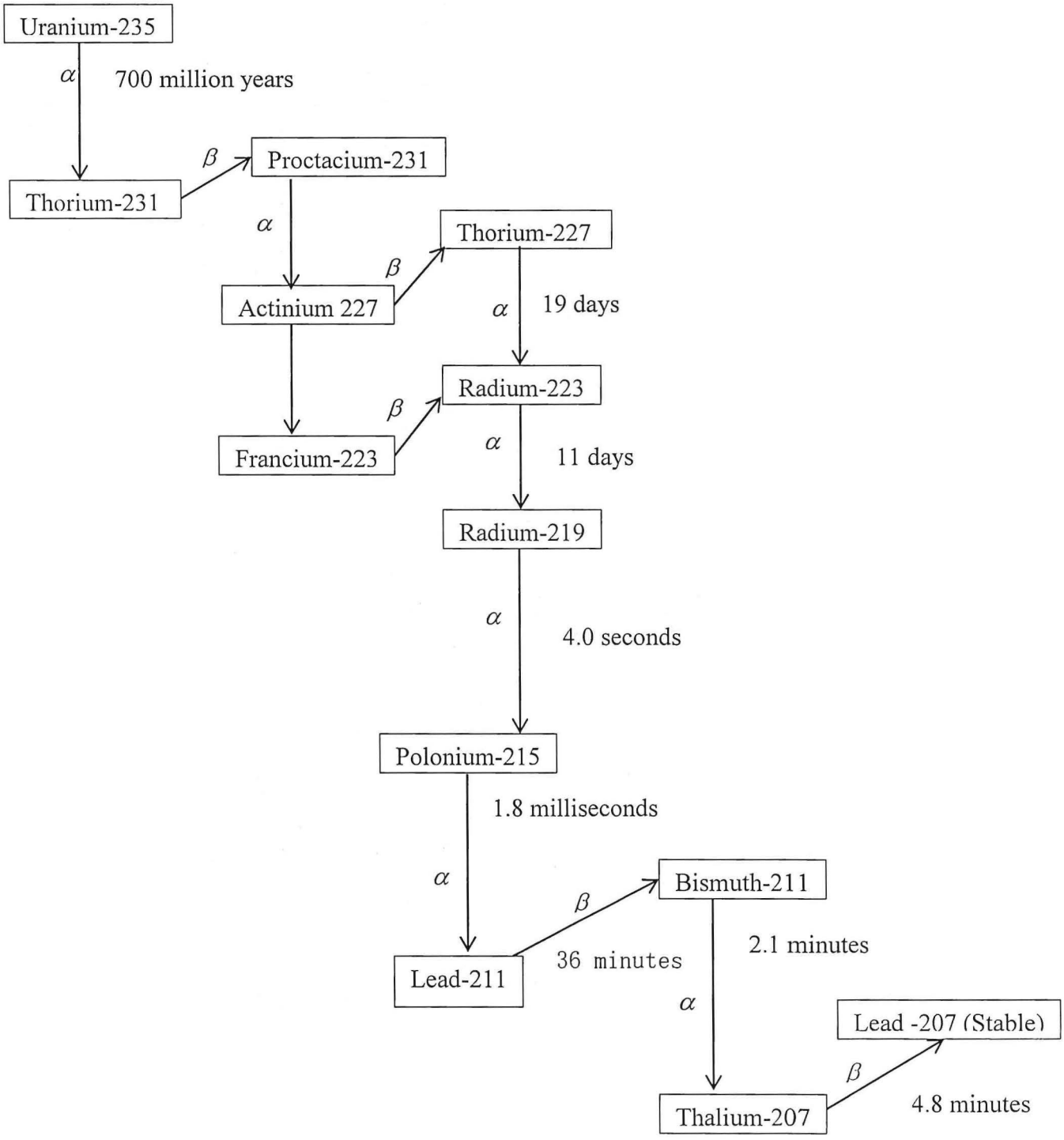

Figure 2.4: Natural decay series of Uranium 235 (Mattetnik, 1995)

The activity level of a radionuclide defines its ability to harm living body cells and gives the rate of decay or transformation of the radioactive nuclide. Activity of a pure radionuclide decreases exponentially with time (Krane *et al.,* 1988). This is expressed in the decay law which relates the decrease of the number of radioactive nuclei present at time *t,* (denoted as N_t,) the number, *dN*, decaying in a time interval, *dt* is proportional to *N*. Accordingly, $N_{(t)}$, N_o, t *and* λ, are related by the equation

$$N_{(t)} = N_o e^{-\lambda t}, \tag{2.1}$$

where N_o represents the original number of nuclei present at $t = 0$. Equation 2.1 describes the exponential radioactive decay law. The number of atoms in a sample is proportional to the activity of the sample. This can be expressed as

$$\frac{A}{A_0} = e^{-\lambda t} \tag{2.2}$$

A_0 is the activity of the sample at $t = 0$. In all decay types, total energy, momentum, charge and atomic number are all conserved (Podgorsak, 2007; Martin *et al.*, 2013).

Some radioactive elements take fractions of a second to decay to half their initial active mass while others take several years to arrive at that (Martin *et al*, 2012). The time it takes a radioactive nuclide to decay to half its active mass is the half-life for that radionuclide. The average or mean life time, τ of a radionuclide is the average of all the individual half-lives that atoms in a sample of a radionuclide experience. τ is the reciprocal of the decay constant (Martin *et al*, 2012). τ, λ and T are related by the equation

$$\tau = \frac{1}{\lambda} = \frac{\mathrm{T}}{0.693} \tag{2.3}$$

Radioactive decay may result into emission of energetic particles and rays. The decay products are the alpha and beta particles and gamma rays.

Heavy radioactive elements decay with alpha emission and energy is released due to mass loss. The energy released in an alpha decay is shared by the alpha particle and the recoiled daughter nuclide. This results into a discrete alpha spectrum (NTEC, 2009).

Alpha particles are radiations of low penetrating power in matter. They have a short range in air due to frequent collisions with gas molecules, causing intensive ionization of air particles. From the same source, alpha particles are emitted at the same speed. In matter the speed of an alpha particle reduces drastically with time (NTEC, 2009). Thus when they are stopped by matter, e.g. outer dead layer of human skin, they deposit insignificant quantities of energy (NTEC, 2009) making them less harmful.

Before emission by the parent nuclide, the alpha particle is confined in a potential well created by the daughter nucleus (NTEC, 2009). Once the alpha particle penetrates the potential well, it is repelled by the daughter nuclide and escapes (NTEC, 2009). The energy released during the decay process is quantified by a Q value and alpha decay is only possible when $Q > 0$. Alpha decay is exothermic and the decay energy is released as a positive Q_α value to enable it tunnel through the barrier and escape (NTEC, 2009).

Beta particles are much lighter than α- particles and have less ionizing potential but greater penetrating ability in matter. This is because the beta particles are lighter than air particles therefore undergoing fewer collisions with gas molecules compared to alpha particles. Beta decay occurs through β^- decay, β^+ decay and electron capture. In beta decay, a nucleus spontaneously emits an electron or a negatively charged beta particle ($^{0}_{-1}\beta$) and an antineutrino($^{0}_{0}\bar{\upsilon}$). Both the neutrino and the antineutrino have no charge. Beta decay occurs when the daughter nuclide is energetically more stable than the parent. For example, The transformation of $^{60}_{27}$Co into $^{60}_{28}$Ni with a half-life of 5.26 years (Podgorsak, 2007) is expressed by the equation

$$^{60}_{27}\text{Co} \rightarrow {}^{60}_{28}\text{Ni} + {}^{0}_{-1}\beta + {}^{0}_{0}\bar{\upsilon} \qquad (2.4)$$

Positron decay occurs when the ratio of protons to neutrons is higher than for the most stable isobar of the particular proton rich nuclei.

In positron decay, a proton is transformed into a neutron, a positron and a neutrino. For example ${}^{22}_{11}Na$ disintegrates by emission of a positively charged electron (positron) and a neutrino. This is illustrated in the decay equation

$$ {}^{22}_{11}Na \rightarrow {}^{22}_{10}Na + {}^{0}_{1}\beta^{+} + {}^{0}_{0}\upsilon \qquad (2.5) $$

There are other process such as internal conversion, orbital electron capture and positron decay associated with radioactive decay. For example, when ${}^{226}_{88}Ra$ transforms into ${}^{222}_{86}Rn$, it releases an alpha particle and energy according to the equation

$$ {}^{226}_{88}Ra \rightarrow {}^{222}_{86}Rn, + {}^{4}_{2}He + Q_{\alpha} \quad \text{(UNSCEAR, 2000)} \qquad (2.6) $$

This transformation has a half-life of 1600 years (Podgorsak, 2007). The daughter nuclide, the positron and the nutrino share energy resulting from positron decay continuously (Hsue et al., 1966). Positron decay only occurs when the mass of the parent atom, M is greater than the mass of the daughter, m by at least $2mC^2 = 1.022M$.

Gamma ray photons are quantum electromagnetic energies of range 0.1 to 10 MeV (Krane, 1998). Transitions resulting into gamma emission leave the mass number (A) and atomic number (Z) unchanged and are isomeric. In gamma decay, an excited parent nuclide attains its ground state through emission of one or several gamma photons (Podgorsak, 2007). In most alpha and beta decays, the daughter de-excitation is instantaneous and gamma rays are produced by the parent nuclide. When the daughter nucleus de-excites with a time delay, its (daughter) excited state is referred to as metastable and the process of de-excitation is referred to as isometric transformation (Podgorsak, 2007). The parent and the daughter nuclei in this case become isomers. Gamma rays are attenuated by matter after travelling hundreds of metres (Maryline *et al.*, 2000). The energy released by a radioisotope is characteristic of the particular radionuclide

present. Gamma spectroscopic techniques are therefore necessary for the determination of the intensities of the respective photons at various energies. The technique helps to establish nuclide distribution in the sample.

Internal conversion of energy resulting from instability of a radioisotope takes place when excess energy in an unexcited nuclide does not lead to a photo emission but rather ejection of orbital electrons from K or L shell. Energy supplied to the bound orbital electron must exceed its binding energy to effect internal conversion (Martin *et al,* 2012). The nuclear de-excitation energy is transferred to the orbital electrons. The electron is emitted from the atom with a kinetic energy which is equal to the difference between the de-excitation energy and the electron binding energy. The resulting shell vacancy is filled with a higher energy level orbital electron. The transition energy is emitted in form of characteristic photons or Auger electrons. For example, ^{137}Cs transforms into ^{137}Ba with a half-life of 30 years according to the equation

$$^{137}_{55}Cs \rightarrow {}^{137}_{56}Ba + e^{-} + \nu \quad \text{(Martin } et\ al\text{, 2012)} \tag{2.7}$$

Orbital electron capture results from a transformation in which an atomic electron orbiting close to the nucleus (usually from the K- shell) is captured and a neutrino of a fixed energy is released (NTEC, 2009). Characteristic x-rays of the daughter are always emitted since electron capture leaves an inner atomic shell vacant. A detailed summary of radioactive decay is shown in Table 2.1. No particle is emitted during the electron capture process, thus energy escape is undetected. For example $^{208}_{83}$Bi transforms into $^{208}_{82}$Pb according to the equation

$$^{208}_{83}Bi + e^{-} \rightarrow {}^{208}_{82}Pb + \upsilon, \tag{2.8}$$

where υ is a neutrino of a fixed energy.

Table 2.1: Summary of Radioactive decay (NTEC, 2009)

Process	Symbol	Changes in Atomic number	Changes in Mass number	Changes in Neutron number
$\alpha-$ emission	${}^{4}_{2}He \ or \ \alpha$	-2	-4	-2
$\beta-$ emission	${}^{0}_{-1}e \ or \ \beta^{-}$	$+1$	0	-1
$\gamma-$ emission	γ	0	0	0
Positron decay	β^{+}	-1	0	$+1$
Electron capture	E.C	-1	0	$+1$

The specific activity of a radionuclide in sample can be determined by dividing the activity by the sample mass. For a pure radioactive nuclide, the specific activity is a function of its decay constant or half-life and its atomic weight, M, which is the number of atoms per gram of the nuclide (Martin *et al.*, 2013). The specific activities (*S.A*) of all the naturally occurring radionuclides can be calculated using the equation

$$S.A = \frac{N}{tmC} \quad \text{(Matteknik, 1995)} \tag{2.9}$$

where C is the correction coefficient for the detector, m is the mass of the sample, N is the number of photons under the region of interest and t the time taken to run the sample in the detector. The error, σ, associated with the determination of the specific activity can be obtained using the expression

$$\sigma = \frac{\sqrt{N}}{tmC} \quad \text{(Mattetnik, 1995)} \tag{2.10}$$

The correction coefficient, C of the NaI (Tl) detector is calculated using the equation

$$C = \varepsilon\eta, \quad \text{(Mattetnik, 1995)} \tag{2.11}$$

where ε is detector efficiency and η branching ratio of the radionuclides. Measurements in this study were carried out by the use of NaI(Tl) detector. The correction coefficients for NaI(Tl) detector are as in Table 2.2

Table 2.2: Correction coefficients for NaI(Tl) Detector (Matteknik, 1995)

Energy In keV	**Decay series**	**Coefficient** $\times 10^{-2}$
84	Th (Th – 228)	2.86
185	U (Ra – 226)	4.3×10^{-1}
205-238	Th (Pb - 212)	6.08
242	U (Pb - 214)	4.04
295	U (Pb - 214)	2.37
309-352	U (Pb - 214)	3.0
538-580	Th(Tl - 208)	1.01
610	U (Bi - 214)	2.1
780	Eu - 152	2.96
860.56	Th (Tl - 208)	1.254×10^{-3}
1170	Co - 60	2.0
1460	K - 40	2.34×10^{-1}

Serial activity, which describes the activity of a sample in which one radionuclide produces one or more radioactive offspring(s) in a chain, is an activity where species one decays only to species two and species two decays only to species three and so on (Martin *et al*, 2012).

Time to reach radioactive equilibrium depends on the half-lives of the parent nuclide, T_1 and that of the daughter nuclide, T_2. There are two distinguished cases of radioactive equilibrium: secular equilibrium, transient equilibrium and a case where there is no equilibrium (Martin *et al*, 2012).

If a radioactive sample is closed for a significantly longer period than the half-life of the daughter nuclide ($T_1 >> T_2$, where T_1 and T_2 are the half-lives of the long lived parent and the relatively short lived daughter nuclide respectively), the system approaches secular equilibrium. The parent nuclide undergoes a very slow rate of decay without any appreciable change in its activity during many half-lives of its decay products. Daughters grow-in and then decay (Butt, 1972; Friedlander *et al*., 1981). Consider the total activity, A which is expressed as

$$A = A_1 + A_2, \tag{2.12}$$

where A_1 and A_2 are the activities of a long lived parent nuclide and a relatively short lived daughter respectively. At any time when a long lived parent decays into a relatively short lived daughter, the daughter in turn decays into a stable nuclide.

Consider intervals of time which are short compared to T_1 such that the activity A_1 of the parent is treated as constant. Considering the activity A_2 of the daughter nuclide, the following relationship holds

$$A_2 = A_1\left(1 - e^{-\lambda_2 t}\right) + A_{20}e^{-\lambda_2 t}. \quad \text{(Butt, 1972)} \tag{2.13}$$

Practically when one starts with a pure sample of the parent nuclide at $T = 0$ and $A_{20} = 0$, Where A_{20} denotes the activity of the daughter nuclide at time $t = 0$ seconds, the activity A_2 then builds up after about 7 daughter half-lives. In this case, $e^{-\lambda_2 t} << 1$ and Equation 2.13 reduces to

$$A_1 = A_2 \tag{2.14}$$

This condition is called secular equilibrium($T_1 >> T_2$). (Martin *et al*, 2012).

Transient equilibrium occurs when the half-life of the daughter nuclide is of the same order but smaller than that of the parent. For example ${}^{140}_{1}Ba(T_1 = 12.75 \text{ days})$ in transient equilibrium with ${}^{140}_{1}La$ ($T_2 = 1.68$ days). Transient equilibrium is reached when $N_{20} = 0$ and $T_1 \geq T_2$. N_2 and hence $A_2 = \lambda_2 N_2$ initially builds up steadily (Martin *et al*, 2012).

If the half-life of the parent nuclide is shorter than that of daughter nuclide ($T_1 < T_2$), no equilibrium arises. The daughter activity grows to a maximum and then decays with its own characteristic, e.g. ${}^{146}Ce$ ($T_1 = 13.5$ minutes) and ${}^{146}\text{Pr}$ ($T_2 = 24.2$ minutes) (Fenyves *et al.*, 1969).

2.5. Gamma Ray Interaction with Matter.

There are three basic ways in which gamma rays interact with matter. These are photoelectric effect, Compton scattering and pair production. In a NaI(Tl) detector, photoelectric effect predominates at low energy levels of gamma rays (Burcham *et al.*, 1995).

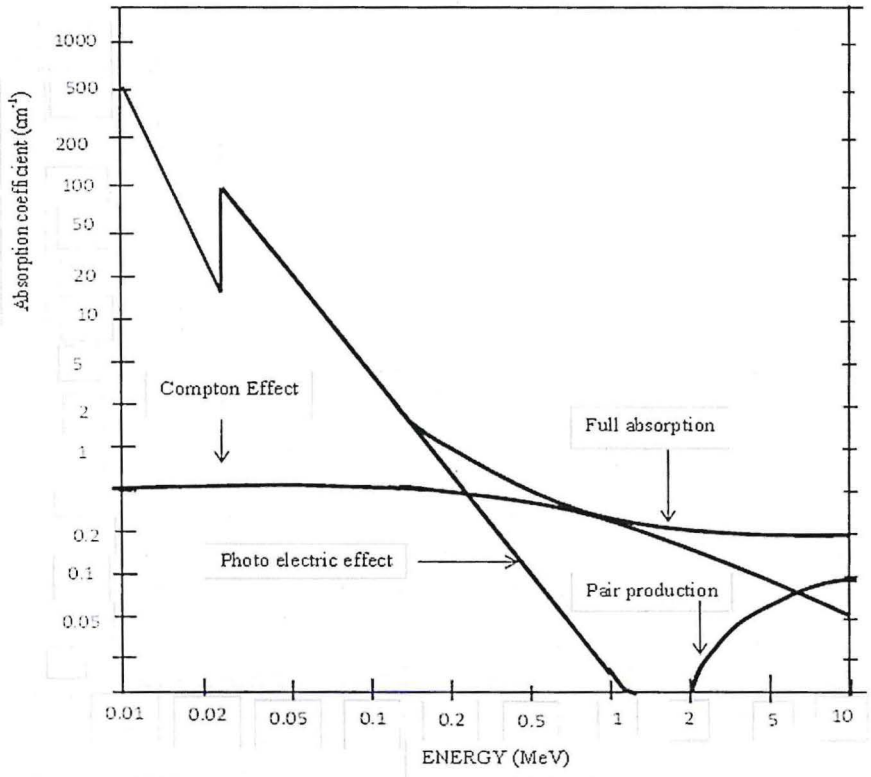

Figure 2.5: Gamma ray absorption characteristics of NaI (Tl) scintillator (Hamamatsu, 2007)

Pair production increases at high energy levels. Compton Effect is dominant at intermediary energy levels. Figure 2.5 illustrates the three ways of gamma ray interaction with matter.

When a photon of energy $h\upsilon$ (where h is Plank's constant and υ the frequency) interacts with a tightly bound electron, the photon disappears. Consequently an orbital electron is emitted with kinetic energy, E_K given by

$$E_K = h\upsilon - E_B, \tag{2.15}$$

where E_B is the binding energy of the orbital electron. The ejected orbital electron is called photo electron. When the photon energy, $h\upsilon$ exceeds the K- shell binding energy, $E_{B(K)}$ of the absorber

atom, the photo electric effect is most likely to occur with a K-shell electron other than higher shell electrons.

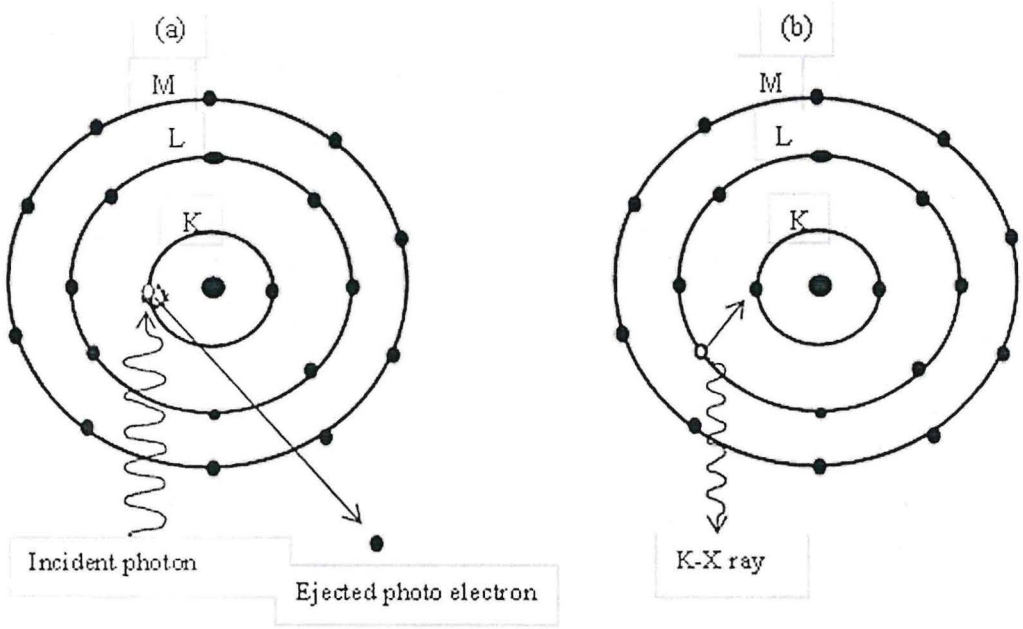

Figure 2.6: Photo electric absorption process (Martin et al., 2012)

When photon with energy, hv interacts with a loosely held electron, part of the incident photon energy is transferred to the free orbital electron, which is emitted from the atom as Compton (recoil) electron. The photon is scattered through a scattering angle, θ and its energy is lower than the incident photon energy hv. Angle, ϕ is the angle between the incident photon and the direction of recoil electron (Martin *et al*, 2012).

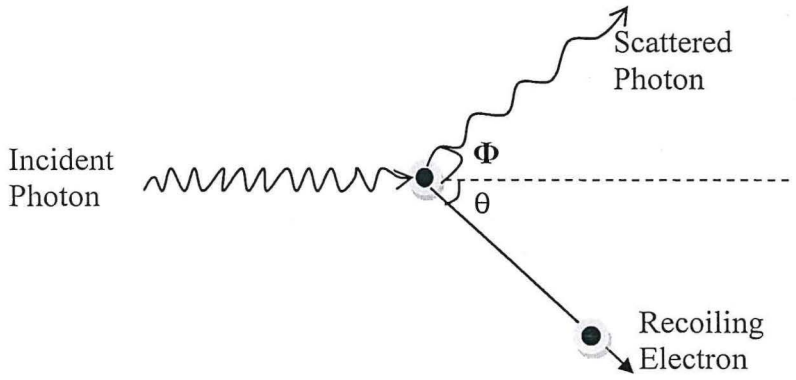

Figure 27: Kinematics of Compton Scattering (Martine *et al.*, 2012)

A gamma ray (photon) that is incident on an atom with threshold energy of 1.022 MeV can produce an electron-proton pair by providing a strong electromagnetic influence proximate to the nucleus (Nelson *et al.*, 2014). The Nucleus receives a very small amount of energy to recoil for momentum conservation. If the photon energy exceeds the threshold value of 1.022 MeV, the excess energy is shared by the positron and the electron as kinetic energy. The positron combines with the electron in annihilation process after losing its kinetic energy (Figure 2.8) (Evans, 1955).

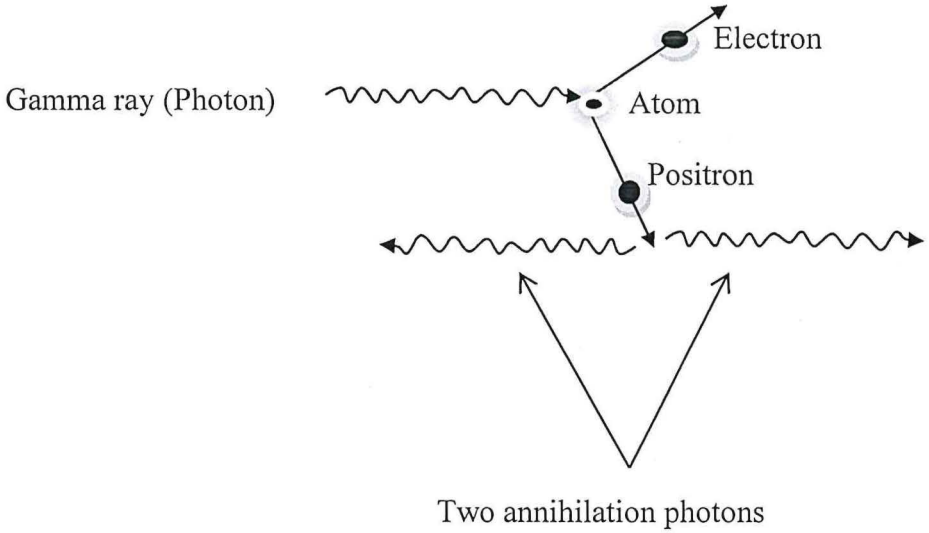

Figure 2.8: Pair production and pair annihilation (Martin *et al.*, 2012)

This releases a gamma ray with energy 0.511MeV (Podgorsak, 2007). The combined kinetic energy, E_K, of the electron-positron pair is given by the equation

$$E_K = h\upsilon - 2m_eC^2 \tag{2.16}$$

The energy in Equation 2.16 is produced in the nuclear coulomb field. Threshold energy for pair production, E_o is

$$E_o = 2mC^2\left(1 + \frac{M_eC^2}{M_AC^2}\right) = 2M_eC^2 \tag{2.17}$$

Where M_e is electron mass, M_A is mass of the nucleus and $M_eC^2 = 0.511$ MeV.

2.5. Measurement of ionizing radiation

Two broad categories of radiation detecting equipment majorly used are the real time detectors (which respond instantly to the radiation) and time integrating detectors (in which information about the radiation is accumulated and read at a later time). A radiation detector is typically characteristic of its size, material and state of aggregation of the sensitive volume in relation to its stopping power to radiation; its thickness and material of window (if any) through which the radiation must pass before emitting the sensitive volume (Martine *et al.*, 2012). In this study, a scintillation detector was used and it is briefly discussed in the following subsection.

There are three different types of scintillation detectors. These are the inorganic, the organic and the Gaseous scintillation detectors. The inorganic scintillators work on the principle of impurity activators. An alkali iodide is incorporated into the system with a small impurity component. Examples include NaI (Tl), CaI(Na), LiI(Eu), and CaF_2(Eu). The element in brackets in each case is the impurity. Though in a little concentration, the impurity is responsible for the luminescence of the crystal detector. Figure 2.9 shows a block diagram of a scintillation detector (Matteknik, 1995).

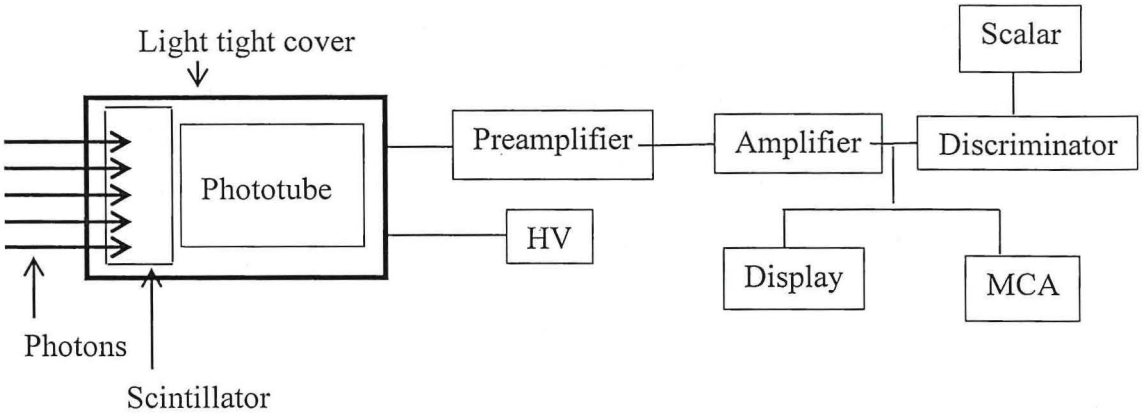

Figure 2.9: Block diagram of a Scintillation Detector (Matteknik, 1995)

The NaI detector and its photo multiplier tube are mounted on a box (with a built-in high voltage module). The detector is surrounded by a silver containing lead shot for shielding the detector from background radiation. The hermetic seal protects the hygroscopic NaI from moisture absorption and external radiological influence (Figure 210).

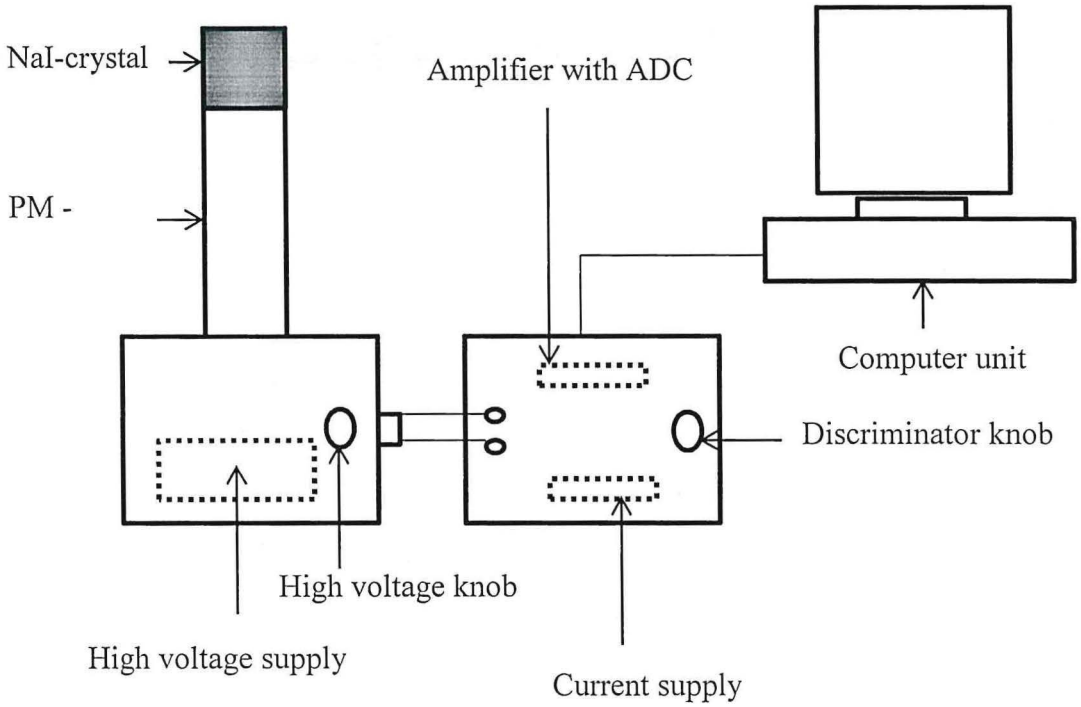

Figure 2.10: Schematic illustration of the detector and its accessories (Matteknik, 1995)

On analyzing each peak of a stored spectrum (after stripping off the background radiation), the NaI(Tl) detector gives readings of the Centroid, Standard deviation (S.D), FWHM, Sum (total number of radionuclides detected), Rate and Photo peaks (Matteknik, 1995).

The sensitive part of the detector is a scintillator which consists of a cylindrical a metallic crystal. Incoming gamma quanta deposit all or part of their energy to the electrons in the crystal due to collisions by Compton Effect or Photoelectric Effect. The resulting fast electrons collide with the atoms of the crystal, which are excited and subsequently deexcited by emitting photons with a wave length in the region of visible light. The photons reach the photocathode of the Photomultiplier (PM) tube where they cause electron emission through Photoelectric Effect. The number of the emitted electrons is proportional to the energy of the gamma radiation. The electrons are accelerated in the PM tube towards a structure of metal plates (dynodes). At the first dynode, the electrons emit more electrons (Figure 2.11).

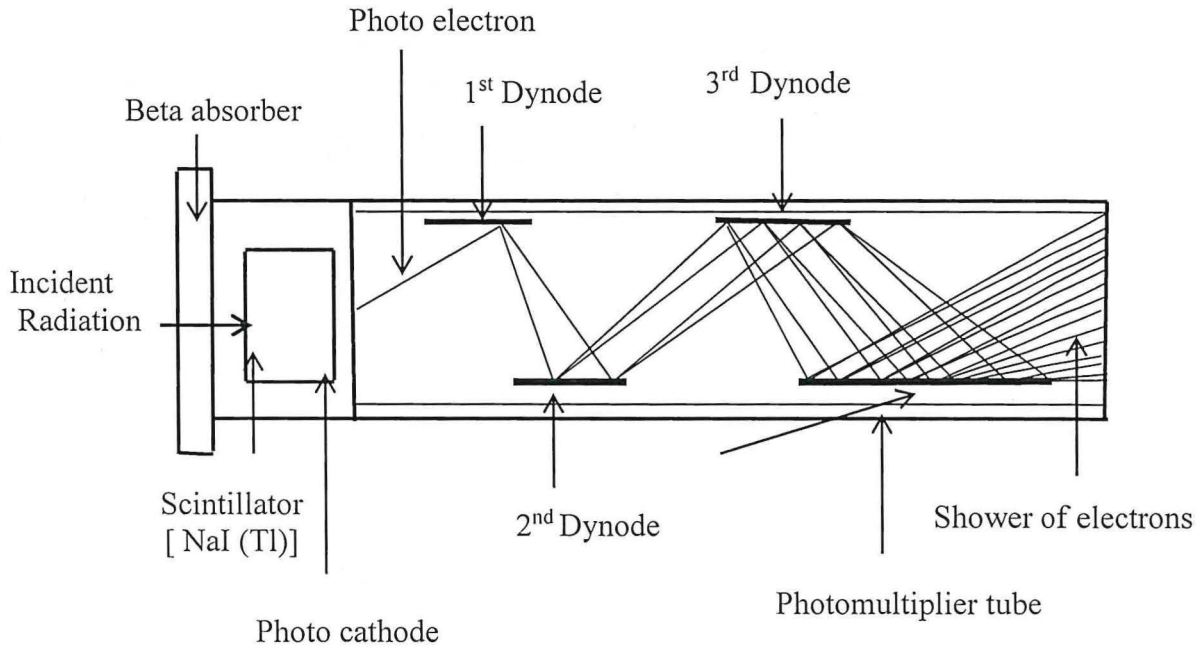

Figure 2.11: Schematic representation of detector (Matteknik, 1996)

The shower of electrons is amplified at each of the ten dynodes. The resulting amplified electron shower generates an electric pulse whose amplitude is a function of the quantity of light energy collected on the photo cathode and thus directly proportional to the energy deposited by the incident gamma radiation. By measuring the amplitude, the energy of the incident gamma quantum can be determined (Matteknik, 1996).

The preamplifier which is always normally positioned and very close to the photomultiplier tube sustains the low signal levels which could attenuate before arrival at the amplifier. The preamplifier provides optimal coupling between the detector and the rest of the counting components of the unit. Noise degrades the energy resolution of the system unit. There are three basic types of preamplifiers, categorized based on their response to some particular measurable quantities. These are charge sensitive, current sensitive and voltage sensitive preamplifiers. Most commonly used in spectroscopy and the only one in use in semiconductor detectors is the charge sensitive preamplifier

The amplifier is the component of the detector where the signal is amplified, increasing signal amplitude by at least 1000 times. Most amplifiers produce signal output not less than a few millivolts but not exceeding 10 V, regardless of the input and the amplification. See Figure 2.12 for a typical pulse – type detector signal. For spectrometric measurements where good energy resolution is the most important parameter, pulse shaping should increase the signal – noise ratio.

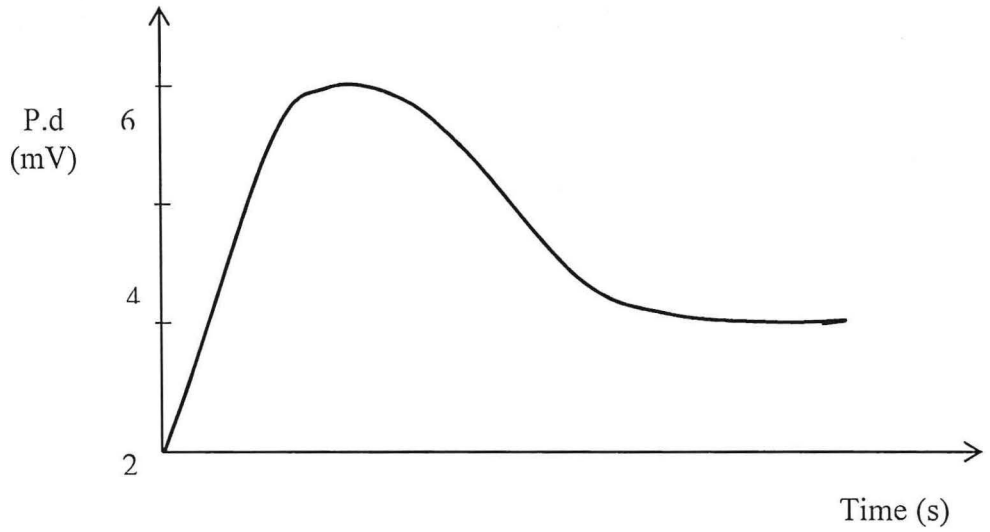

Figure 2.12: A typical pulse – type detector signal (Podgorsak, 2007)

The high voltage power supply (HVPS) provides a positive or negative voltage that is necessary for detector operation. Most detectors need positive high voltage (PHV). PHV output does not fluctuate much with changes in HVPS owing to its construction design.

When successive photons arrive and display separate pulses, the scintillator resolves these two pulses to give a continuous pulse. The minimum time taken for this resolution is the dead time. The sum of the decay time of the scintillator (which is 0.23μs for NaI), time for electron multiplication in the photo multiplier tube (in the order of 20 to 30 ns) and signal amplification time (of the order 1μs) constitutes the dead time. The sum of the trio is within the range 1 to 5μs

The aggregates constitute the latent image. The latent image is converted into metallic silver which appear to the eye as darkening of the film. The degree of darkening increases with increase in the incident ionizing radiation absorbed. An optical densitometer can then be used to measure light transmitted through the film. This enables films to be intensively used to detect and measure ionizing radiation (Martin *et al*, 2012).

The spectrum must be energy calibrated in order to determine the energy of the detected gamma radiation. For the NaI(Tl) detector, the amplitude of the signal from the PM tube is proportional to the energy of the detected gamma radiation. To determine the linear calibration function, two photo peaks whose energies are situated at the beginning and the end of the energy interval of interest are required. After the calibration, the amplification must be maintained exactly the same in the unknown spectrum such as in the calibration spectrum.

The energy region of the acquired spectrum containing the peaks of ^{226}Ra ^{232}Th, ^{238}U and ^{40}K defines the region of interest (ROI) of the spectrum. The background spectrum obtained by running an empty beaker for the same time as the samples is stripped off from the acquired spectrum to give the net spectrum due to radionuclides present in a sample.

2.6. Ionizing radiation Dose

Intake of ionizing radiation through exposure to a radiation pathway is quantified by computing the radiation dose. The absorbed dose rate and the annual effective dose equivalent of ionizing

radiation can be computed using the appropriate criteria. A brief discussion on radiation dose follows.

Radiological clinical effects of ionizing radiation are directly related to the Absorbed Dose Rate, D since the severity depends on dose level. The measured activity concentrations are converted into doses by applying conversion factors 0.462, 0.604 and 0.0417 for Uranium, Thorium and Potassium respectively. This is illustrated by the equation

$$D = 0.462A_{Ra} + 0.604A_{Th} + 0.0417A_K, \quad \text{(UNSCEAR, 2000)} \tag{2.18}$$

where D is the dose rate in $nGyh^{-1}$, A_{Ra}, A_{Th} and A_K are the activity concentrations (in $Bqkg^{-1}$) of ^{226}Ra, ^{232}Th and ^{40}K in the sample respectively. For one to be safe from the impact of the absorbed dose rate, the level must be below 55 $nGyh^{-1}$ (UNSCEAR, 2000).

The annual effective dose equivalent, H (in mSv/y) is computed by use of the dose criterion

$$H\left(\frac{mSv}{y}\right) = \frac{A_{Ra}}{740} + \frac{A_{Th}}{520} + \frac{A_K}{9620} \qquad \text{(UNSCEAR, 2000)} \tag{2.19}$$

For the samples not to pose a significant carcinogenic threat to the population, the annual effective dose equivalent should not exceed 0.12 mSv $year^{-1}$ (UNSCEAR, 2000; ICRP, 1996)

2.7. Effect of ionizing radiation on human body

Molecules within the living cells of human body get damaged when they absorb energy deposited by ionizing radiation (Elena *et al.*, 2001). The damage can either destroy or cause malfunction of the cells through mutation. This can lead to multiplication of cells inducing cancerous cell formation. For a considerably long time, ingested radionuclides accumulate in some specified parts of the body. ^{238}U accumulates in the human lung and the proximal tubules of the kidneys, ^{232}Th accumulate in the lungs, liver and skeletal tissues while ^{40}K accumulates in the muscles (Canadian Ministry of Health, 2010). These affect reproductive health of the individual, the kidney, causing damage to the proximal tubule. Cumulative deposits of these radionuclides in the specified organs weaken the human immune system, cause oxidative damage and cellular dysfunction including several diseases such as cancer induction, immune disorders, chronic illnesses and increases mortality rate (Tawalbeh *et al.*, 2012; Nadeiko *et al.*, 2008).

Direct effects of ionizing radiation are produced by initial action of the radiation itself. For example, a strand break in DNA can be caused by ionization in the molecule itself. Indirect effects are caused by the later chemical action of the radicals and other radiation products. For example, a strand break that results when an OH radical attacks a DNA sugar at a later time. Depending on the dose, kind of radiation and the observed end point, the biological effects of radiation can differ widely. Some occur relatively rapidly, e.g., in about 10^{-3}s, radicals produced by charged particle tracks in a biological system have all reacted (Podgorsak, 2007). Cell division can be effected in a matter of minutes. Other effects may appear after years, e.g. Damages such as lung fibrosis may take several months to develop, Cataract and cancer occur years after exposure to radiation.

Genetic effects are first seen in the next or subsequent generations of an exposed individual. Experiments confirmed that a large dose of radiation delivered accurately into human body generally has more dangerous drastic effect compared to the same dose delivered over an extended period of time (Podgorsak, 2007). Biological effects of ionizing radiation on human body cells can generally be divided into two and are briefly discussed as follows.

When human body cells are exposed to low dose of ionizing radiation, they suffer a stochastic effect however small the radiation. There is no threshold dose value for effect to occur. Occurrence and severity of the effect are not predictable in an individual (Partridge, 2013). Severity of the effect is not dose related (ICRP 2011).There exists an increased probability of effect with increase in dose (ICRP, 1991; Martin *et al*, 2012; Partridge, 2013). If a large population is exposed to a significant dose of ionizing radiation, an accumulated incidence of cancer can be expected for example. This suggests a statistical manner of occurrence. Stochastic effect of ionizing radiation can become evident eventually after exposure. Stochastic effects of ionizing radiation include radiation carcinogenesis, hereditary effects, DNA misrepair, chromosome damage, cancer induction, late tissue reactions eg. cataract, circulatory diseases (ICRP, 2011; Partridge, 2013).

Delayed reaction to stochastic effect of ionizing radiation is expressed by a risk factor known as probability coefficient. The factors can be assigned to different conditions (leukemia) or grouped together to include overall category solid cancer of all types (Canadian Ministry of Health, 2010).

Deterministic effect of ionizing radiation is associated with high dose incident in a short time interval. (Partridge, 2013). There exists a threshold dose value below which ionizing radiation is deterministically ineffective to cause any problem to the body cells. Above the threshold exposure limit, the severity of the response of body cells to radiation increases with increase in dose (Martin *et al.*, 2013; Partridge, 2013). Different tissues and individuals have different threshold dose values for deterministic effects (Partridge, 2013). Deterministic effect shows a clear causal relationship between dose and effect in a given individual. In case of a radiation accident, the doses may be significantly appreciable and the victim is prone to deterministic effects and they appear quite soon after exposure. These effects include skin reddening, cataract formation, sterility and fetal death (Martin *et al.*, 2013).

2.8. Assessment of radiation health hazard level

The level of health hazard associated with the exposure to ionizing radiation through the various pathways is assessed by use of radium equivalent activity and the hazard indices. There are three health hazard indices that comprise external hazard index, internal hazard index and representative level index (UNSCEAR, 2000). The value of each index must be less than one in order to be safe from exposure (UNSCEAR, 2000). The discussion of the indices follows.

The radium equivalent activity, Ra_{eq}(in $Bqkg^{-1}$) is widely used to evaluate the radiological hazards caused by ^{226}Ra, ^{232}Th and ^{40}K. It is assumed that 370 $Bqkg^{-1}$ of ^{226}Ra, 529 $Bqkg^{-1}$ of ^{232}Th and 4810 $Bqkg^{-1}$ of ^{40}K produce the same gamma ray dose rate (UNSCEAR, 2000). The Ra_{eq} is defined as

$$Ra_{eq}(Bq\ Kg^{-1}) = A_{Ra} + 1.43A_{Th} + 0.0077A_{K} \text{ (UNSCEAR, 1982)} \qquad (2.20)$$

The Ra_{eq} should not exceed 370 $Bqkg^{-1}$ for the water to be safe for drinking (UNCSEAR, 2000). The value of the radium equivalent must not exceed 370 $Bqkg^{-1}$ for one to have insignificant radiation exposure hazard due to use of a sample in question (UNSCEAR, 2000).

The external gamma ray hazard index, H_{ex} is given by the equation

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad \text{(UNSCEAR, 2000)} \qquad (2.21)$$

The internal hazard index, H_{in} gives internal exposure to casnogenic radon and its short lived progeny (Ramasamu *et al.*, 2011; Quindos *et al.*, 1987; Cottens, 1990) and is given by the equation

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad \text{(UNSCEAR, 2000; ICRP, 1991)} \tag{2.22}$$

In order to evaluate whether a given sample under investigation meets the limits of dose criteria, the representative level index, $I_{\gamma r}$ is used. It estimates the level of gamma radiation hazard associated with the naturally occurring radionuclides in the sample investigated. $I_{\gamma r}$ is defined as

$$I_{\gamma r} = \frac{A_{Ra}}{150} + \frac{A_{Th}}{100} + \frac{A_K}{1500} \quad \text{(ICRP, 1990; IJST, 2013)} \tag{2.23}$$

The experimental specific activities, associated doses and gamma ray indices found in this study were compared with the theoretical reference levels published by WHO, UNSCEAR and ICRP and the findings of other studies. These were used to evaluate the risk level associated with the water samples as discussed in Chapter Five.

Owing to the unstable nature of radioisotopes and their exposure pathways that are closely associated with man's way of life and feeding, ionizing radiation has attracted a lot of attention of scholars and researchers. This study has included some related previous studies on the activity levels due to gamma emitting radionuclides in water and their health hazard implications. The selected studies on ionizing radiation in water briefly follow.

Elham *et al.* (2014) conducted a study on drinking water from 472 private wells selected randomly from across Finland. The study looked at the activity concentrations and the radiation exposure from drinking water of people living outside the public water supply in Finland. It reported that the specific activity levels due to ^{232}Th ranged between 0.2 and 28215 mBq/l while for ^{40}K ranged from detectable value to a maximum of 10332 mBq/l. Radium equivalent activity below the defined limit of 370 Bq/Kg. The calculated external hazard indices were found to be less than unity thus no significant radiological threat to the population.

Omeje *et al.* (2013) evaluated the suitability of different sites as locations for obtaining underground water for consumption by analyzing activity concentrations of ^{238}U, ^{232}Th and ^{40}K

from rock samples in Gosa and Lubge, Abuja, North central Nigeria. Gamma-ray spectrometry was carried out using a high-purity germanium detector coupled to a computer-based high-resolution multichannel analyzer. The mean activity concentrations for ^{238}U, ^{232}Th and ^{40}K were 23 Bq/kg, 55 Bq/kg and 744 Bq/kg, respectively. The study recommended all the sites sampled suitable for underground water consumption.

Najat, *et al.* (2013) determined the activity levels due to ^{238}U, ^{232}Th and ^{40}K in 20 water samples from Nduluma River in Likuyu village in Tanzania by low level gamma spectrometry. Results revealed the specific activity levels to be 1.85 Bq/l, 2.35 Bq/l and 10.40 Bq/l, respectively. The study found the average activity concentration values higher than world averages published by UNSCEAR (2000).

A study of the radiological quality of ^{238}U, ^{232}Th and ^{40}K in some samples of drinking and mineral water from Johor Bahru in Malaysia was carried out and the activity concentration levels (in Bq/kg) determined by direct gamma ray spectroscopy using high purity germanium detector. The study reported specific activities of 1.48 ± 0.12, 9.59 ± 0.83 and 39.67 ± 1.69 ppm for ^{238}U, ^{232}Th and ^{40}K, respectively. The mean calculated doses were 00015 ±0.0001, 0.0122 ±0.0011 and 5.53 ±0.23 nSv per year, respectively. These values showed much lower levels than the published UNSCEAR (2000) world average of 0.12 mSv per year, and WHO and ICRP reference limits of 0.1 mSv per year (Yussuf, *et al.*, 2012).

Natural radioactivity of water in the industrial District of the Federal Capital Territory of Abuja, Nigeria was measured and the activity concentration levels due to ^{40}K and ^{238}Th obtained were reported (in Bq/kg) as 54 and 34, respectively. These values are below tolerable levels (Umar, *et al.*, 2012).

In another study, samples of drinking water in the Western province of the Kingdom of Saudi Arabia, were analyzed for the activity concentrations of ^{40}K and ^{238}U were found to be 6.5 Bq/l and 1.2 Bq/l respectively while for ^{232}Th was not detected in the water samples analyzed. The study reported most of the samples found to give higher estimated annual doses than the 0.1 mSv $year^{-1}$ allowed by the WHO for all the radionuclides in drinking water (Afaf, 2011).

CHAPTER THREE: METHODOLOGY OF THE STUDY

3.1. Introduction

This chapter dealt with the design this study used, variables involved, sampling and sampling techniques, measurement of activity levels, how the collected data was presented, analyzed and treated.

3.2. Research Design and the Variables

Water samples were collected from the identified sources and analyzed of the level of activity of naturally occurring radionuclides that emit gamma rays for exploration. The activity levels were explained and described based on geology of their original landscape. Findings were related to the studies carried earlier on the same aspect elsewhere and then compared with world reference levels. Therefore this study adopted an exploratory, descriptive and relational design.

The study had both independent and dependent variables. The independent variables comprised the type of source of water and its location in a given sub-county. Another independent variable was the sub-county of origin and this comprised Bukuya, Kasambya, Kassanda and Kitumbi sub-counties. The dependent variables of the study were the centroid of the peak of each spectrum analysed (in $Bqkg^{-1}$), Rate of photon interaction with the detector, Sum between the markers (N) Gamma emitting radionuclides, Standard Deviation (SD), Full Width at Half Maximum (FWHM), Specific Activity (SA) in $Bqkg^{-1}$, Absorbed Dose Rate (D) in nGh^{-1}, Annual Effective Dose Equivalent (H) in mSv/year and the Radiological indices (H_{in}, H_{ex}, $I_{\gamma r}$ and Ra_{eq}).

3.3. Sampling and sampling Techniques

The study samples were selected from Mubende District from four of the 19 sub-counties. The four sub-counties were selected based on the GTK geological findings on them, the ongoing small scale mining activities there and most of all, the population of the people living in each of them.

A total of sixty samples were collected from the four sub-counties using one litre plastic bottles. These comprised waters from Boreholes, Springs, Wells and Valley dams. Therefore, the

sampling and the sampling technique for sub-counties and types of source of water was purposive. Where there were many alternative sources at a point, simple random sampling technique was used.

From each water point selected, two litres of water were collected. Each plastic bottle used was rinsed thoroughly with the sample water before filling it. This was aimed at removing traces of contaminants retained within the bottle. The bottle was then labeled detailing the location of the collection point, time and date of collection. Table 3.1 indicates number of each type of water source sampled. Zero in the table means absence of this source of water. The selection criterion was based on the Mubende District stock record of water sources and the population of people using each water source. The samples were transported directly to the laboratory in hard empty paper boxes whose background emissions were determined using an identifier.

Table 3.1: Sample selection matrix (in litres) per Sub County

Sub-county	Borehole	Spring	Well	Valley dam	Total
Bukuya	5	3	4	0	12
Kasambya	8	0	3	5	16
Kassanda	6	3	4	3	16
Kitumbi	7	4	5	0	16
Total	**26**	**10**	**16**	**08**	**60**

3.4. Sample preparation

The masses of the samples were weighed using a triple beam balance allowing an error limit of $\pm 0.5g$. The samples were then sealed in 500ml marinelli beakers and kept at room temperature for a minimum of thirty days. This was to enable the ^{232}Th and ^{238}U to attain secular equilibrium with their respective progenies. In so doing, each sample was handled to avoid mixing and cross contamination with others. Since a good number of marinelli beakers were in place, the beakers were not shared.

3.5. Measurement of Natural Radioactivity in Water.

The specific activities of gamma emitting radionuclides in water were measured using a Thallium activated Sodium iodide scintillator, (NaI(Tl)), GDM20. The system made use of an IBM compatible computer. The detector operated using a cylindrical thallium activated scintillator of NaI crystal of height 12.0 cm and diameter 8.0 cm. An error limit of ± 0.5 cm was allowed in these measurements. To reduce the gamma-ray background, a cylindrical lead (100 mm thick) with a fixed bottom and movable cover envelopes the detector. The lead shield contains an inner concentric cylinder of copper (0.3 mm thick) in order to absorb X-rays generated in the lead. The detector was connected to a computer with a multi-channel analyzer (MCA) card (Accuspec) and autoDAS version 3.16. Equation 2.10 was used on each spectrum analyzed to take care of the level of accuracy of the Thalium scintillation detector.

Before the detector was used for the nuclear radiation measurement in the samples, it was calibrated.

System energy axis was calibrated using a solution of ^{152}Eu to cover the energy range from 0.344 to 1.41 MeV. The ^{152}Eu was selected for use because it was what many studies used and the only available calibration solution at hand. These two energies, 0.344 and 1.41 MeV are at the beginning and end of the range of the gamma photon energy. The radionuclides present in the counted samples were identified from their individual photo peaks as illustrated in Table 3.3. The activity of ^{226}Ra during the equilibrium was assumed to be the same as that of the parent ^{238}U (Jabbar *et al.*, 2009).

The solution of ^{152}Eu was used to determine the efficiency of the detector at different gamma energies. This solution emits gamma quanta per second of energy 0.244 MeV. The activity of the solution was measured for the live time, t, and the area of the corresponding photo peak, A was determined to Y pulses. The efficiency of the detector at that energy was then computed using the equation

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

When the gamma radiation hits the crystal, it creates a weak light. The light is collected and converted into electrical pulses by a photo multiplier tube (PM). The pulses amplify and then get converted to digital information by an A/D converter. The information is then processed by the computer. The computer presents the results on its monitor in form of a frequency diagram of the energy distribution of the detected gamma quanta (spectrum). Figure 3.2 shows a simplified block diagram of the detector.

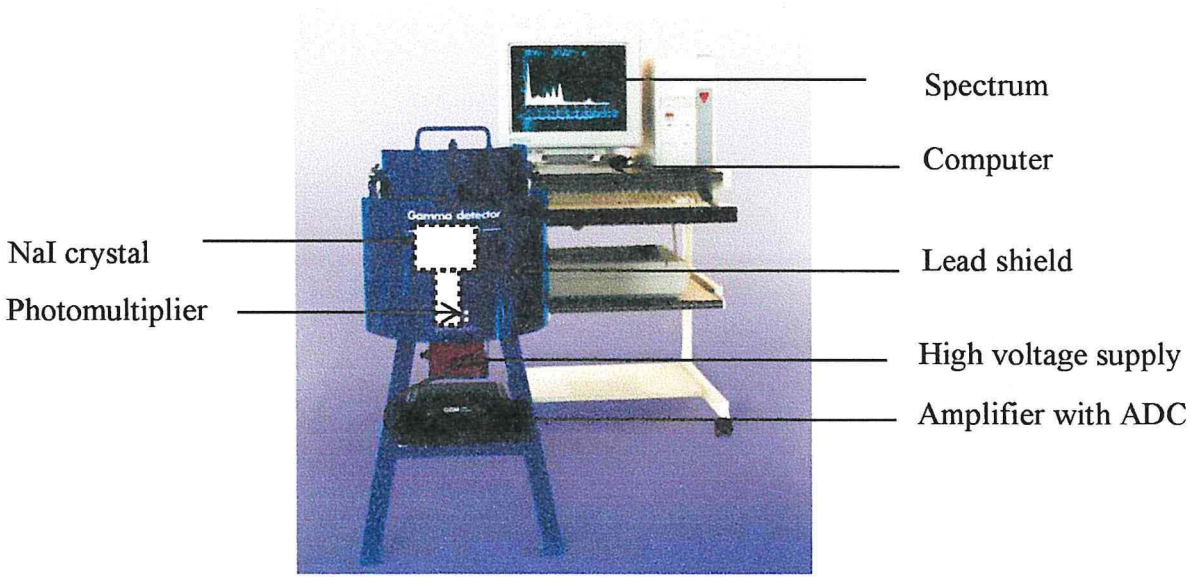

Figure 3.1: GDM20 gamma detector (Matteknik, 1995).

In this study, all the 60 samples of water analyzed by the gamma ray NaI (Tl) detector were labeled. Samples BKBH1 and BKBH2 for example were water samples collected from boreholes one and two in Bukuya sub-county. The coding followed this same technique for all the remaining water samples. Before sample BKBH1 was put into the detector, its mass was determined using a triple beam balance and recorded. It was then run in the detector for a live time of 6000 seconds. The spectrum obtained was stored with file name BKBH1. This procedure was repeated for the remaining samples.

The background radiation distribution in the environment due to different sources in the room and the components of the detector was measured by running an empty sealed Marinelli beaker for (6000 s). This time frame was sufficient for the interaction of the NaI (Tl) detector with the

beaker and the samples (Lemeriga, 1998; Anguma,1999). The spectrum obtained was stored as background.

In the same way, the sample spectrum for KTBH6, borehole water from Kitumbi sub-county Headquarters, was obtained and stored. The background spectrum was stripped off from its spectrum. The resultant spectrum was the net spectrum due to the gamma ray emitting radionuclides present in the sample (Figure 3.2).

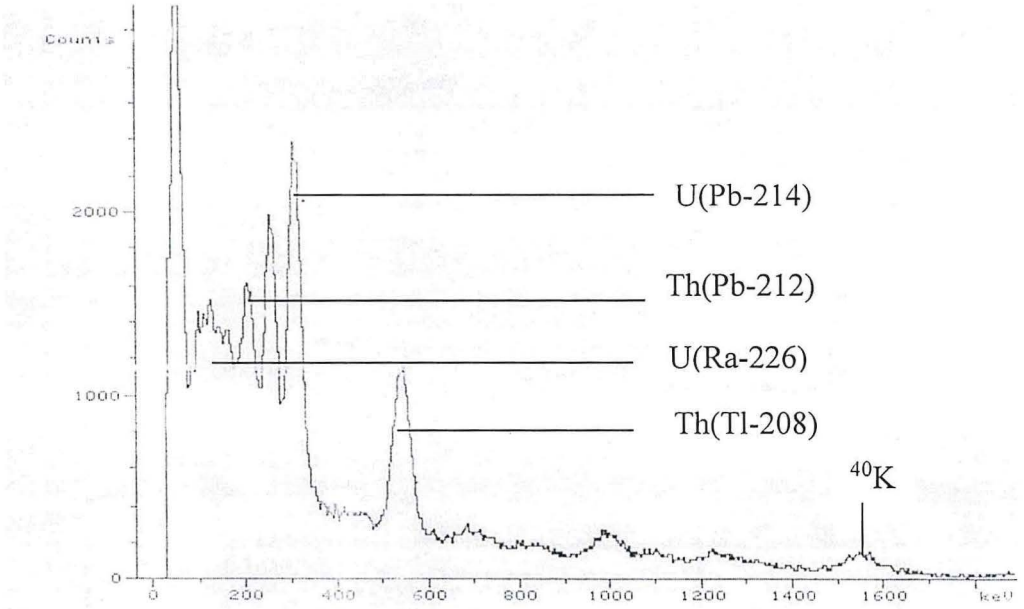

Figure 3.2: The spectrum for Borehole water collected from Kitumbi sub-county.

The spectrum in Figure 3.2 was then analyzed to obtain the Centroid (C), Standard Deviation (SD), Full Width at Half Maximum (FWHM), sum between the markers (N) and the rate. The first peak from the origin of the spectrum axes, which is associated with X-rays emitted by the components of the instrument, was ignored.

Table 3.2: Gamma ray detector readings for Sample KTBH6

Mass: 0.496 ± 0.0005 kg								**Live time: 6210 s**	
S/n Pk	**Radioisotope**	**Coefficient (C)**	**Centroid (keV)**	**SD (keV)**	**FWHM (keV)**	**Sum (N)**	**Rate**	**S.A ($Bqkg^{-1}$)**	**Error ($Bqkg^{-1}$)**
1	U(Ra-226)	0.00430	206.727	9.634	22.639	2113	0.35	11.2829	0.2455
2	U(Pb-214)	0.06080	256.226	8.709	20.466	3814	0.63	30.6497	0.4963
3	U(Pb-214)	0.02370	310.143	11.346	26.664	8249	1.37	113.0003	1.2442
4	Th(Tl-208)	0.01010	542.052	20.418	47.981	6863	1.14	220.6070	2.6629
5	K-40	0.00234	1416.042	23.017	54.090	321	0.05	44.5365	2.4858

Based on the centroid and using Table 2.2, the radioisotopes responsible for the rest of the peaks were identified. The data was then used to calculate the specific activities of the radioisotopes (Table 3.2). This procedure was repeated for all the remaining water samples and the results entered in Table 4.13 (in appendix one).

The specific activities in Table 4.13 were then used to generate the specific activity of each radionuclide and results entered in Tables 4.10 to 4.17 (Annex two). The results were further displayed in bar graphs (See Annex two, Figures 4.10 to 4.16). Using Microsoft office excel model 2010, the mean Specific Activities were then calculated per type of water sample (Tables 4.1 to 4.5) and per sub-county (Table 4.6). These were further displayed in bar graphs (Figure 4.1 to Figure 4.5) and Figure 4.6, respectively. All the bar graphs were prepared using MATLAB 7.5.0 (R2007b).

The specific activities in Table 4.13 were further used to compute the absorbed dose rate, the annual effective dose equivalent and the radiological hazard indices. The results obtained were displayed in Tables and illustrated in bar graphs (Mean doses: Table 4.8 to Table 4.13 and then Doses: Table 4.18 to Table 4.21, Annex Two; Figure 4.15 to Figure 4.18). Find the Detailed Presentation of the data Chapter four.

CHAPTER FOUR: RESULTS OF THE STUDY

4.1. Introduction

The Mean Specific Activities and the radiological parameters were presented sub-county by sub-county, and then by type of source of sample. The presentations follow.

4.2. Mean Specific Activities

The mean specific activities and the associated statistical parameters (SP) were as presented in the following subsections.

4.2.1. Mean Specific Activities in Bukuya sub-county

Table 4.1: Specific activities by type of source for Bukuya sub-county

ID	SPECIFIC ACTIVITIES ($Bqkg^{-1}$)			
	^{226}Ra	^{232}Th	^{238}U	^{40}K
BH	164.26 ± 3.43	209.66 ± 2.40	58.40 ± 0.68	32.03 ± 1.93
PS	100.57 ± 2.73	78.24 ± 1.34	27.36 ± 0.48	10.60 ± 1.16
SW	41.85 ± 1.45	25.64 ± 0.67	6.93 ± 0.18	6.09 ± 0.82
Mean	93.03 ± 0.42	50.85 ± 0.48	12.63 ± 0.11	8.30 ± 0.36
Std Dev	35.21 ± 0.42	50.85 ± 0.48	12.63 ± 0.11	8.30 ± 0.36
Std Err	10.16 ± 0.12	14.68 ± 0.14	3.64 ± 0.03	2.40 ± 0.10

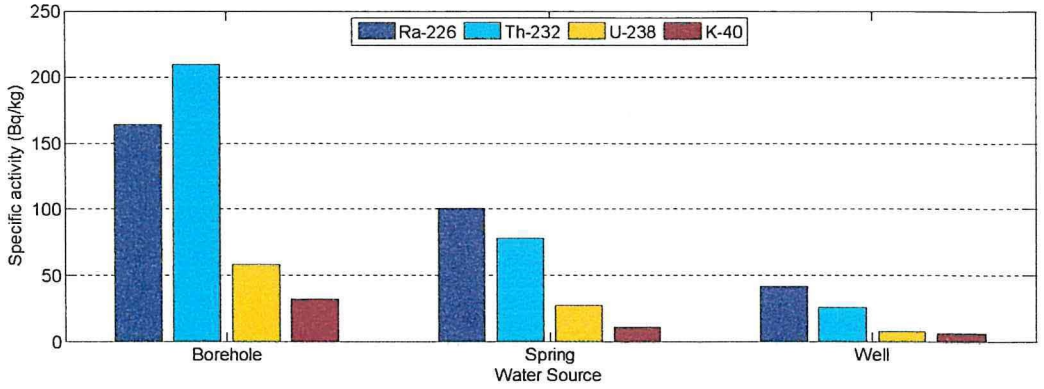

Figure 4.1 Specific activities by type of source of sample for Bukuya sub-county

The highest specific activity in Bukuya sub-county water samples were found in boreholes for all the radionuclides. In boreholes, thorium was found to give the highest activity concentration than all the radionuclides. Ra-226 was more abundant in the rest of the water sources than the other three radionuclides. Shallow wells gave the least activity concentrations compared to the rest of the water samples.

4.2.2. Mean Specific Activities in Kassanda sub-county

Table 4.2: Mean Specific Activities per type of sample of Kassanda sub-county

ID	SPECIFIC ACTIVITIES (Bq kg^{-1})			
	^{226}Ra	^{232}Th	^{238}U	^{40}K
BH	148.04 ± 3.24	158.57 ± 2.14	45.49 ± 0.63	23.46 ± 1.76
PS	62.61 ± 2.11	25.24 ± 0.81	13.68 ± 0.34	7.48 ± 1.00
SW	40.63 ± 1.59	19.01 ± 0.67	15.30 ± 0.32	17.42 ± 1.36
VD	90.15 ± 2.54	8.00 ± 0.47	6.64 ± 0.24	6.04 ± 0.89
Mean	85.36 ± 2.37	52.71 ± 1.02	20.28 ± 0.38	13.60 ± 1.25
Std Dev	46.44 ± 0.70	70.94 ± 0.76	17.22 ± 0.17	8.29 ± 0.39
Std Err	11.61 ± 0.17	17.73 ± 0.19	4.31 ± 0.04	2.07 ± 0.10

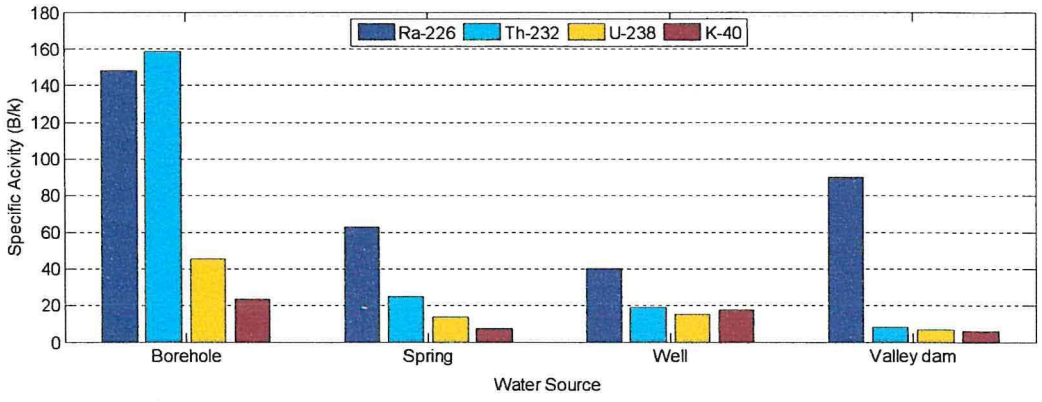

Figure 4.2: Mean Specific activities for Kassanda sub-county by type of source of sample

Bore holes in Kassanda sub-county gave the highest specific activities compared to the rest of the types of samples. In these boreholes, the highest peak was registered by Th-232 as Ra-226

gave the highest readings in the rest of the sources of water on the other hand. Protected wells and valley dams gave very low specific activities in all the radionuclides detected.

4.2.3. Mean specific activities in Kasambya sub-county

Table 4.3: Specific Activities per type of water sample of Kasambya sub-county

ID	SPECIFIC ACTIVITIES (Bq kg^{-1})			
	^{226}Ra	^{232}Th	^{238}U	^{40}K
BH	8.19 ± 0.19	96.11 ± 1.52	24.29 ± 0.43	23.11 ± 1.55
SW	5.31 ± 0.16	50.26 ± 1.14	16.46 ± 0.39	6.15 ± 0.90
VD	7.66 ± 0.20	66.31 ± 1.40	24.36 ± 0.50	16.34 ± 1.41
Mean	7.05 ± 0.18	70.89 ± 1.35	21.70 ± 0.44	15.20 ± 1.29
Std Dev	1.53 ± 0.02	23.27 ± 0.19	4.54 ± 0.06	8.54 ± 0.34
Std Err	0.38 ± 0.01	5.82 ± 0.05	1.14 ± 0.01	2.13 ± 0.09

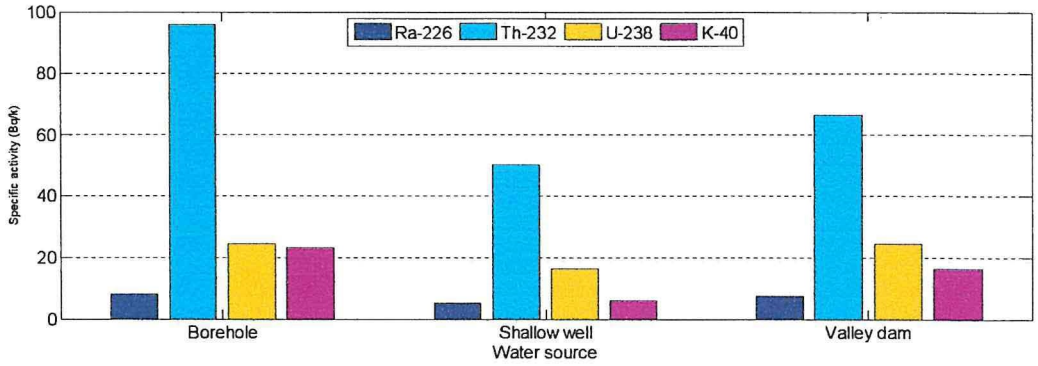

Figure 4.3: Specific activities by type of sample of Kasambya sub-county

Kasambya sub-county water samples gave high Thorium specific activities. Bore holes gave higher specific activities for all the radionuclides followed by valley dams. Protected wells gave lower readings. Thorium registered the highest specific activity in all the water samples compared to the rest of the radionuclide.

4.2.4. Mean specific activities in Kitumbi sub-county

Table 4.4: Mean specific activities by type of water sample in Kitumbi sub-county

ID	MEAN SPECIFIC ACTIVITIES (Bq kg^{-1})			
	^{226}Ra	^{232}Th	^{238}U	^{40}K
BH	161.70 ± 3.20	122.95 ± 1.69	40.80 ± 0.55	22.72 ± 1.63
PS	70.46 ± 2.20	47.48 ± 1.14	12.74 ± 0.31	10.28 ± 1.11
SW	57.47 ± 2.03	19.09 ± 0.72	9.59 ± 0.28	5.53 ± 0.83
Mean	96.54 ± 2.48	63.17 ± 1.18	21.04 ± 0.38	12.84 ± 1.19
Std Dev	56.80 ± 0.63	53.68 ± 0.49	17.18 ± 0.15	8.88 ± 0.41
Std Err	14.20 ± 0.16	13.42 ± 0.12	4.30 ± 0.04	2.22 ± 0.10

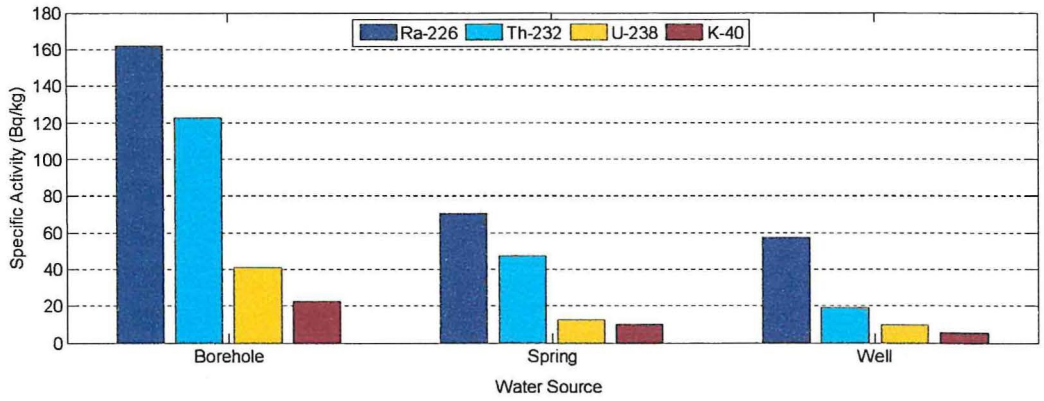

Figure 4.4: Specific activities by type of sample of Kitumbi sub-county

Boreholes in Kitumbi sub-county gave higher radioactivity due to all the radionuclides identified compared to the rest of water sources.Ra-226 was more plenty in all the water sources than the other radionuclides.Th-232 gave the least radiation activity in all the types of water sources sampled in the sub-county.

4.2.5. Overall Mean Specific Activity for all the sub-counties

The mean specific activities for all the sub-counties per source of water sample were as shown in Table 4.6

Table 4.5: Mean specific activities per type of water sample for all the sub-counties

ID	SPECIFIC ACTIVITIES (Bq kg^{-1})			
	^{226}Ra	^{232}Th	^{238}U	^{40}K
BH	144.92 ± 3.07	139.58 ± 1.88	39.39 ± 0.54	24.80 ± 1.69
PS	77.14 ± 2.33	50.04 ± 1.10	17.41 ± 0.37	9.54 ± 1.09
SW	67.12 ± 2.10	23.75 ± 0.73	9.74 ± 0.27	6.07 ± 0.87
VD	82.92 ± 2.35	48.57 ± 1.12	19.72 ± 0.40	16.75 ± 1.39
Mean	93.03 ± 2.46	65.49 ± 1.21	21.57 ± 0.40	14.29 ± 1.26
Std Dev	35.21 ± 0.42	50.85 ± 0.48	12.63 ± 0.11	8.30 ± 0.36
Std Err	4.55 ± 0.05	6.56 ± 0.06	1.63 ± 0.01	1.07 ± 0.05

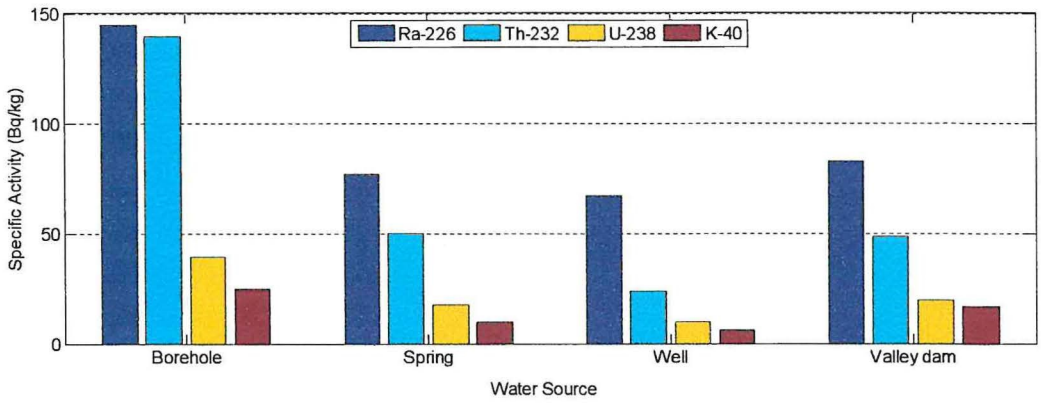

Figure 4.5: Mean Specific Activities of types of source of sample

Ra-226 gave the highest reading in all the water sources analyzed. The specific activities of Thorium were higher in Bore holes than the other radionuclides while the least thorium specific activity was found in wells. Generally, wells gave higher specific activities than springs and Valley dams.

4.3. Overall Mean specific activity per sub-county for all the water samples

The overall mean specific activities per sub-county were as illustrated in Table 4.6

Table 4.6: Mean Specific Activities per sub-county

Sub County	ACTIVITY CONCENTARATIONS (Bq kg^{-1})			
	^{226}Ra	^{232}Th	^{238}U	^{40}K
Bukuya	107.53 ± 2.60	115.46 ± 1.56	33.48 ± 0.46	18.03 ± 1.37
Kassambya	105.51 ± 2.63	74.94 ± 1.38	20.51 ± 0.40	17.27 ± 1.37
Kassanda	97.41 ± 2.54	69.76 ± 1.20	24.15 ± 0.42	14.97 ± 1.32
Kitumbi	106.32 ± 2.58	71.63 ± 1.25	24.03 ± 0.40	14.24 ± 1.25
Mean	104.19 ± 2.59	82.95 ± 1.35	25.54 ± 0.42	16.13 ± 1.33
Std Dev	4.60 ± 0.04	21.78 ± 0.16	5.55 ± 0.03	1.81 ± 0.06
Std Err	0.59 ± 0.00	2.81 ± 0.02	0.72 ± 0.00	0.23 ± 0.01

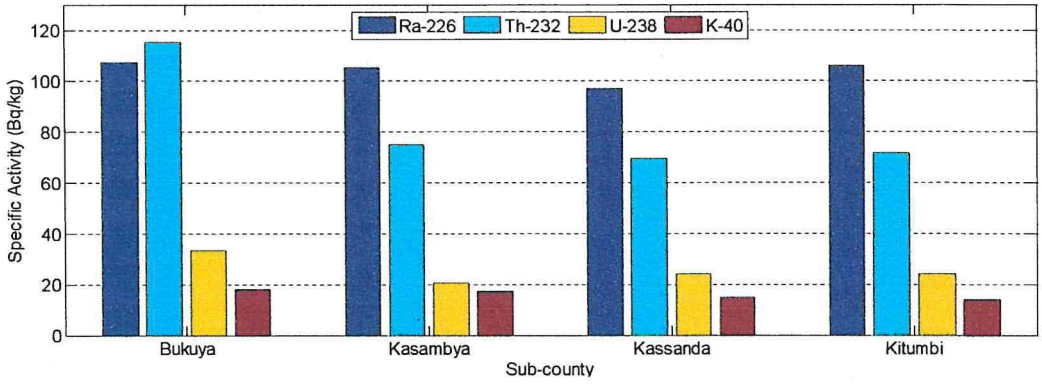

Figure 4.6: Mean specific activities for all the sub-counties

The mean specific activities are higher in water samples from Bukuya sub-county than the rest of the samples for all the radionuclides detected. Radium was higher than Thorium in the three sub-counties other than Bukuya, where Thorium is at the lead in specific activity. The lowest levels of Radium and Thorium were in Kassanda while for Uranium was found in Kasambya as that for Potasium was found in Kitumbi.

These results revealed that in three of the four sub-counties, Ra-226 had higher specific activities than the rest of the radionuclides in all the types of water sources unlike Bukuya sub-county where Th-232 was highest. Uranium gave the second least specific activity concentration level

after K-40. The Borehole waters were found to have higher specific activity levels than the other water types in all the four sub-counties.

It was observed that all the water samples in Kasambya sub-county had radiological indices below unity. However, BKH3, BKH7 and BKH8 had relatively high radiological indices. The Radium equivalent levels were all greater than 370 $Bqkg^{-1}$ (Table 4.15, Annex Two).

4.4. Dose calculation and Radiological indices

The risk assessment associated with the use of the water was estimated using the Absorbed Dose Rate (**D**) in $nGyh^{-1}$ computed using Equation 2.18; the Annual Effective Dose Equivalent (**H**) in $mSvyr^{-1}$ calculated using Equation 2.19; the radium equivalent ($\mathbf{Ra_{eq}}$) calculated using Equation 2.20; external and internal indices, $\mathbf{H_{ex}}$ and $\mathbf{H_{in}}$ calculated using Equations 2.21 and 2.22 respectively; the representative index, $I_{\gamma r}$ calculated using Equation 2.23 (Appendix Two, Table 4.19 to Table 4.22). The mean values of the doses and indices were computed by type of water sample per sub-county using MATLAB 7.5.0 (R2007b) and the results entered tabulated (Table 4.8 to Table 4.11). The overall mean dose and radiological index for each criterion per type of source of water was also computed using the same software and results tabulated (Table 4.12).

4.4.1. Mean dose and radiological index per type of water source per sub-county

The mean absorbed dose rate, the annual effective dose equivalent, the radium equivalent, the external health hazard indices, the internal health hazard indices and the representative health hazard indices computed from the specific activities were as in table 4.7

Table 4.7: Mean Doses and radiological indices - Bukuya

Sample ID	D (nG/h)	H (mSv/y)	Ra_{eq} (Bq/kg)	H_{ex} (Bq/kg)	H_{in} (Bq/kg)	$I_{\gamma r}$ (Bq/kg)
BH	203.86	0.63	464.31	1.26	1.70	3.21
PS	94.16	0.29	212.53	0.58	0.85	1.46
SW	35.08	0.11	78.56	0.21	0.33	0.54
MEAN	0.34	251.80	0.68	0.96	1.74	111.03
STD DEV	0.26	195.85	0.53	0.69	1.36	85.65
STD ERR	0.08	56.54	0.15	0.20	0.39	24.72

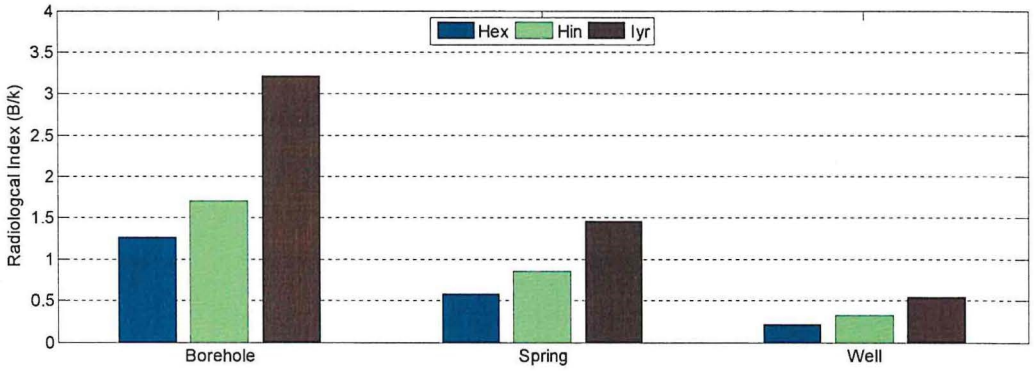

Figure 4.7: Radiological indices for Bukuya Sub-county

Boreholes gave higher dozes and radiological indices than springs and wells in Bukuya sub-county. It is observed that the representative index stayed above unity throughout the samples with highest in the boreholes and the least in the wells. Both internal and external health hazard indices calculated for the samples were higher than unity in boreholes unlike in the rest of the samples collected from the sub-county. Springs gave the least readings in all the indices and dozes as compared to the springs and the boreholes sampled from the sub-county.

Table 4.8: Mean Doses and radiological indices - Kasambya

Sample ID	D (nG/h)	H (mSv/y)	Ra_{eq} (Bq/kg)	H_{ex} (Bq/kg)	H_{in} (Bq/kg)	$I_{\gamma r}$ (Bq/kg)
BH	112.52	0.34	253.42	0.69	1.00	1.75
SW	64.11	0.19	143.54	0.39	0.61	0.98
VD	90.76	0.28	203.24	0.55	0.84	1.40
MEAN	0.27	200.07	0.54	0.82	1.38	89.13
STD DEV	0.08	55.01	0.15	0.20	0.39	24.25
STD ERR	0.02	13.75	0.04	0.05	0.10	6.06

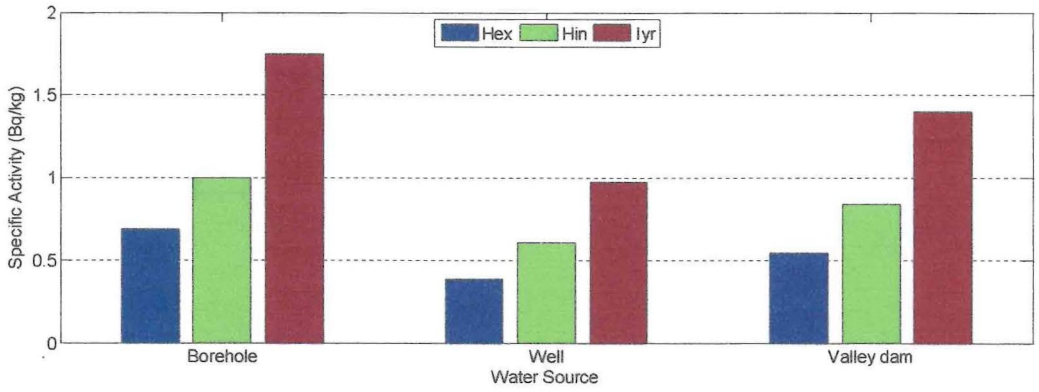

Figure 4.8: Radiological indices for Kasambya Sub-county

Representative indices for all the water sources sampled and analyzed from Kasambya sub-county were above the world reference level of unity though all the doses satisfied the required limit for safety. All the calculated doze and health hazard values were highest in boreholes and least in well waters. The external hazard indices were lower than the rest of the radioisotopes in the water samples analyzed.

Table 4.9: Mean Doses and radiological indices - Kassanda

Sample ID	D (nG/h)	H (mSv/y)	Ra_{eq} (Bq/kg)	H_{ex} (Bq/kg)	H_{in} (Bq/kg)	$I_{\gamma r}$ (Bq/kg)
BH	165.15	0.51	374.97	1.02	1.42	2.59
PS	44.49	0.13	98.77	0.27	0.44	0.67
VD	30.98	0.09	67.95	0.19	0.30	0.47
SW	46.74	0.14	101.64	0.28	0.52	0.69
MEAN	71.84	0.22	160.83	0.44	0.67	1.11
STD DEV	62.59	0.20	143.57	0.39	0.51	0.99
STD ERR	15.65	0.05	35.89	0.10	0.13	0.25

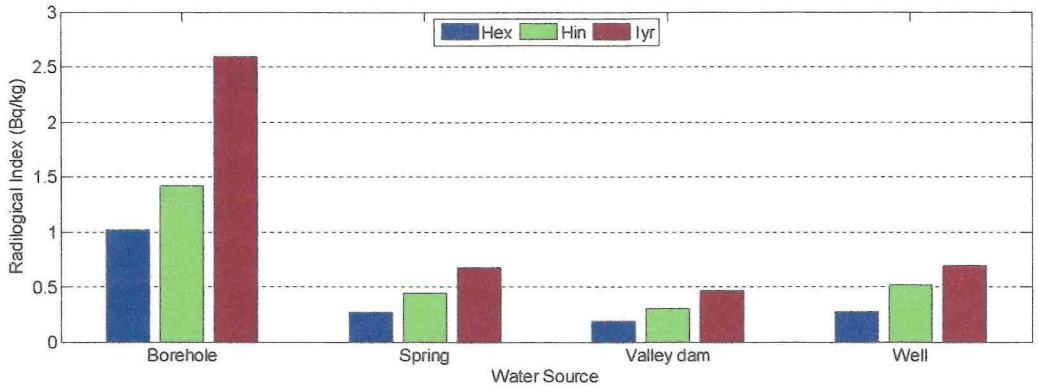

Figure 4.9: Radiological indices for Kassanda Sub-county

The borehole waters sampled from Kassanda sub-county gave much higher dose values and radiological hazard indices than the springs, valley dams and the wells. Borehole waters, in addition, gave a representative index above unity and generally, the representative indices were higher than those for external and internal hazard indices. Valley dams gave the least radiological health hazard indices and dozes compared to the rest of the water samples.

Table 4.10: Mean Doses and radiological indices - Kitumbi

Sample ID	D (nG/h)	H (mSv/y)	Ra_{eq} (Bq/kg)	H_{ex} (Bq/kg)	H_{in} (Bq/kg)	$I_{\gamma r}$ (Bq/kg)
BH	149.91	0.46	337.68	0.92	1.35	2.32
PS	61.66	0.19	138.44	0.38	0.57	0.95
SW	38.31	0.12	84.82	0.23	0.39	0.58
MEAN	83.29	0.26	186.98	0.51	0.77	1.28
STD DEV	58.86	0.18	133.24	0.36	0.51	0.92
STD ERR	14.72	0.04	33.31	0.09	0.13	0.23

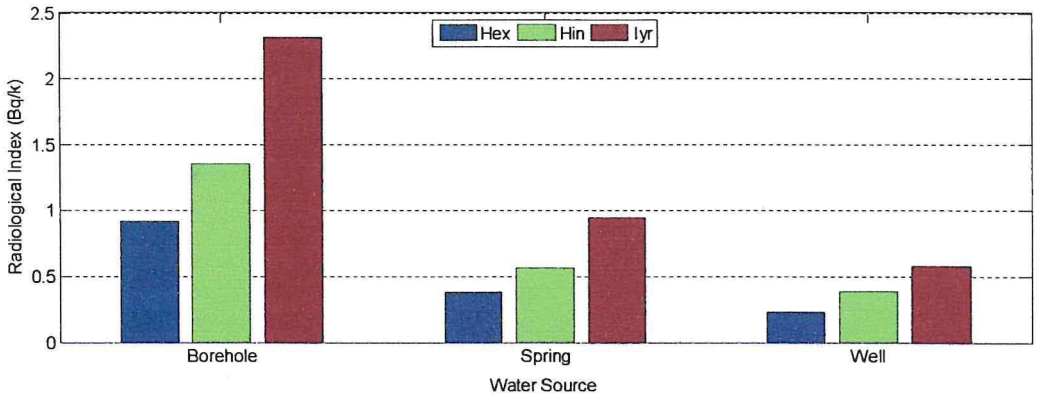

Figure 4.10: Radiological indices for Kitumbi Sub-county

Higher dozes and health hazard indices were obtained from waters of boreholes of Kitumbi sub-county than springs and wells. Representative indices were higher than other indices and exceeded unity in boreholes. For all the water samples in this sub-county, internal health hazard indices exceeded the external health hazard indices and were above unity in the boreholes.

Table 4.11: Mean Doses and radiological indices by type of source

Sample ID	D (nG/h)	H (mSv/y)	Ra_{eq} (Bq/kg)	H_{ex} (Bq/kg)	H_{in} (Bq/kg)	$I_{\gamma r}$ (Bq/kg)
BH	152.30	0.47	344.71	0.94	1.33	2.38
PS	66.26	0.20	148.77	0.40	0.61	1.02
SW	45.60	0.14	101.12	0.27	0.46	0.69
VD	68.34	0.21	152.50	0.42	0.64	1.05
MEAN	83.13	0.26	186.78	0.51	0.76	1.29
STD DEV	47.25	0.15	107.86	0.30	0.39	0.75
STD ERR	6.10	0.02	13.92	0.04	0.05	0.10

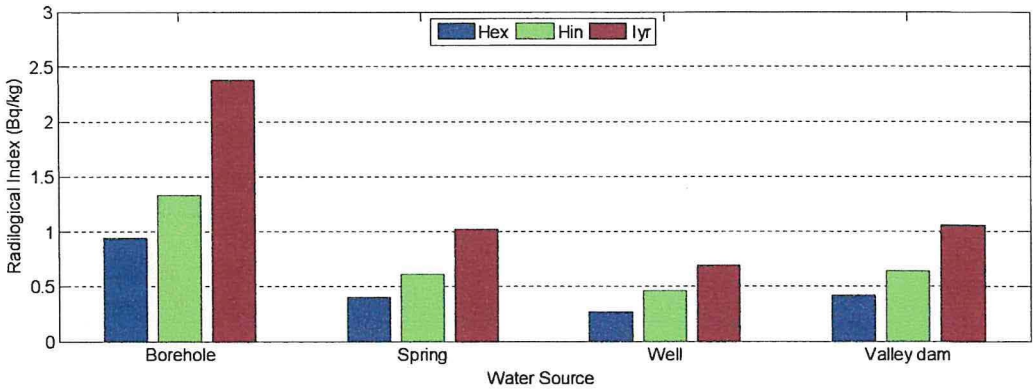

Figure 4.11: Mean radiological index by type of water sample

Majority of the water samples gave radiological indices below unity. BKH2 and BKH5 gave readings above the recommended level. This may due to the location of the bore holes which is rocky and hilly. They are possibly deeper than those in swampy areas that have a raised water table. The waters of the borehole might be interacting with underground minerals and rocks that have high radioactivity.

4.4.2. Mean Dose and Radiological indices per sub-county

Table 4.12: Mean Doses and Radiological indices per sub-county

Sub-county	D (nG/h)	H (mSv/y)	Ra_{eq} (Bq/kg)	H_{ex} (Bq/kg)	H_{in} (Bq/kg)	$I_{\gamma r}$ (Bq/kg)
Bukuya	120.17	0.37	272.78	0.74	1.03	1.88
Kasambya	94.73	0.29	212.81	0.58	0.86	1.46
Kassanda	87.76	0.27	197.28	0.54	0.80	1.36
Kitumbi	92.97	0.28	208.85	0.57	0.85	1.43
Mean	98.91	0.30	222.93	0.61	0.89	1.53
Std Dev	14.48	0.05	33.88	0.09	0.10	0.24
Std Err	3.62	0.01	8.47	0.02	0.03	0.06

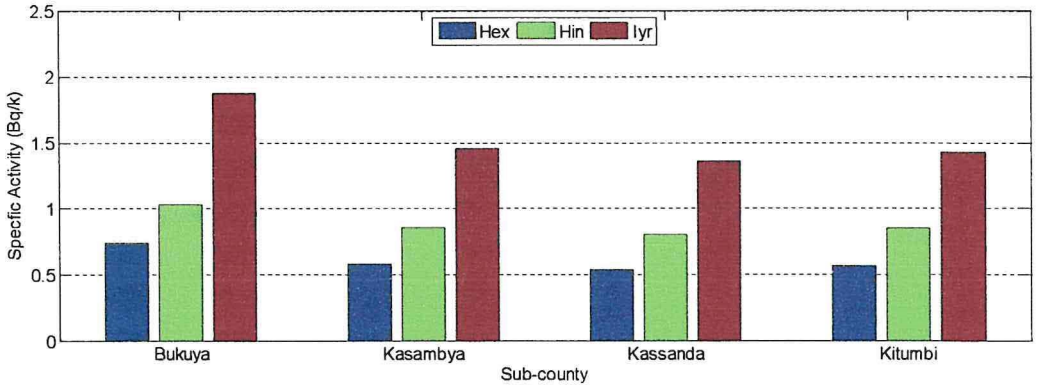

Figure 4.12: Mean radiological indices per sub-county

Bukuya sub-county water samples gave higher internal and external radiological indices than the other three sub-counties. However, the readings are all below the thresh hold value of unity. Kasambya had the waters of the highest representative index and Kassanda the least.

CHAPTER FIVE: DISCUSSION, CONCLUSION AND RECOMENDATONS

5.1. Discussion

The discussion focused on the levels of the specific activities in the drinking water samples, their associated doses and radiological indices. These are discussed into details in the following sub sections.

5.1.1 Specific activities

The specific activity levels varied depending on the type of source, sub-county of collection and the particular location in the sub-county from which it was collected. These variations may be attributed to the difference in the geological composition of the earth's crust in the case of the borehole water and valley dam, the rate of leaching and uptake by vegetation for wells and springs in the site of sample collection.

The specific activities due to ^{226}Ra were highest in every water sample in all the four sub counties, ranging between 97.41±2.54 and 107.53 ±2.60 $Bqkg^{-1}$. This high specific activity agrees with the findings of the study by Ehsanpour *et al* (2014) on the Radiological quality of ^{226}Ra, ^{232}Th and ^{40}K water samples collected from the Central desert in Iran though the geological components of the two regions might not be alike. The high ^{232}Th specific activity may be a function of the nature of the geological structure of the region.

The specific activities due to ^{232}Th were lower than those due to ^{226}Ra but higher than for ^{238}U and ^{40}K in every water sample in all the four sub counties. The mean specific activities by sub-county due to ^{232}Th ranged from 69.76±1.20 to 115.46 ±1.56 $Bqkg^{-1}$. This also conquers with the findings of the study by Ehsanpour and relates to the geology of the region.

Specific activities due to ^{238}U were higher compared to ^{40}K for every water sample in all the sub-counties in the range of 24.15 ± 0.46 to 33.48 ± 0.46 $Bqkg^{-1}$. This is in conformity with the study by Afaf *et al.* (2011) in Western province of Saudi Arabia where the high ^{238}U specific activity may be associated with content of the source rocks, sediments or soils in the geological make of the area. In addition, this may be due to ^{238}U leaching into the natural water bodies. This might also be due to the proximity of the natural water source to uranium source. The specific activity may also get elevated due to the degree of hydraulic isolation of the water by fresher surfaces or ground waters. Oxidation state of the water may also lead to rise in the specific

activity of ^{238}U. High concentration of suitable complexing agents can increase the solubility of ^{238}U in water hence leading to high specific activities.

The specific activities due to ^{40}K measured lowest compared to the other three radionuclides investigated, ranging from 14.24 ± 1.25 to 18.03 ± 1.37 $Bqkg^{-1}$. Low specific activity of ^{40}K may be associated with the fact that it leaches down the earth and is rapidly trapped in the soil and absorbed by the plants (Omeje *et al.*, 2013).

These gave mean values of 104.±2.59, 80.69 ±1.33, 24.94 ± 0.42 and 16.02 ± 0.33 $Bqkg^{-1}$ due to ^{226}Ra, ^{232}Th, ^{238}U and ^{40}K, respectively. The high mean specific activity due to ^{226}Ra may be due to it being sparingly soluble in natural water (Ritcey, 1990) and thus slow to leach away.

The mean specific activities of this study were higher than 1.48 ± 0.12, 9.59 ± 0.83 and 39.67 ± 1.69 $Bqkg^{-1}$ due to ^{238}U, ^{232}Th and ^{40}K respectively reported by Yusuf *et al* (2012) in drinking water samples in Malayisia. In this study, the mean specific activities obtained are higher than those reported by Afaf (2011) in drinking water samples in Saudi Arabia whose mean values were 6.5 and 1.2 $Bqkg^{-1}$ due to ^{40}K and ^{238}U respectively and that reported by Najat *et a*l (2013) in drinking water in Tanzania of 1.85, 2.35 and 10.40 $Bqkg^{-1}$ due to ^{238}U, ^{232}Th and ^{40}K. High specific activities found in this study may be associated with the Palaeoproterozoic granite (the extensive Mubende-Singo Batholiths) that has close links with the uranium deposits (Paterson *et al.*, 2009).

The mean specific activities due to ^{226}Ra in this study were all below guidance level of 10 $Bqkg^{-1}$ for drinking water (WHO, 2004; WHO, 2008). This implied that the radioactivity in human body due to drinking and using the waters over relatively small periods of time may not be a significant health hazard.

5.1.2 Absorbed Dose Rate and Annual Effective Dose Equivalent

Bukuya had the highest mean absorbed dose rate (120.17 $nGyh^{-1}$) with Kassanda sub-county giving the least (87.76 $nGyh^{-1}$). The mean estimated absorbed dose was dose rate was 97.45 n Gyh^{-1} which is higher than the reference level of 55 $nGyh^{-1}$ for all sources of drinking water (Abdi *et al.*, 2009).

The mean annual effective dose equivalent in this study was highest in Bukaya sub-county (0.37 mSv $year^{-1}$) and lowest in Kassanda sub-county (0.27 mSv $year^{-1}$). The overall mean annual effective dose for all the four sub-counties was estimated to be 0.30 mSv $year^{-1}$ which is slightly higher than twice the world average value of 0.12 mSv $year^{-1}$ (**UNSCEAR**, 2000; the **WHO**, 2004) reference limit of 0.1 mSv $year^{-1}$ but lower than the **UNSCEAR** (2000), **ICRP** (2000) and **NHMRC** (1995) recommended level 1 mSv $year^{-1}$ for all sources of drinking water (Ajayi and Andesida, 2009).

5.1.3 The radiological hazard indices

The mean radium equivalents found in this study ranged from 197.28 to 272.78 $Bqkg^{-1}$ giving mean value of 219.50 $Bqkg^{-1}$. This value is lower than the published acceptable maximum value of 370 $Bqkg^{-1}$ (**UNSCEAR**, 2000). The mean External Hazard indices were generally low in all the four sub-counties, giving an overall mean value of 0.60 which was much lower than the world reference level of 1. The Mean Internal Hazard index was found to be 0.88 which was lower than unity but generally high. The mean Representative Index was 1.51 which was higher than the maximum value of unity by half.

5.2. Conclusion

The radium equivalent (219.50 $Bqkg^{-1}$), the external hazard index (0.60 $Bqkg^{-1}$), the internal hazard index (0.88 $Bqkg^{-1}$) obtained in this study are all below the world referenced levels published by UNSCEAR (2000). Therefore, these findings indicate that there is no potential radiation hazard associated with drinking of the water from all the analysed sources of water in Mubende District. The high radium equivalent (1.51 $Bqkg^{-1}$) calls for precautionary measures more especially in areas with elevated radiological health hazard levels.

5.3. Recommendations

The study came up with the following recommendations:-

(i). There is need to determine the background radiation emissions in these sites of water collection by Uganda Atomic Energy Council (AEC) in collaboration with Uganda National Bureau of Standards (UNBS) and National water and sewerage cooperation (NWSC).

(ii). It also requires AEC, UNBS and NWSC to have a periodic monitoring of the radioactivity levels due to the gamma emitting radionuclides in the natural and drinking waters of the district.

(iii). A research be carried out on radiation health hazard levels posed by water bodies this study did not look at in Mubende Dstrict.

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Geology of Uganda and First priority Uranium targets

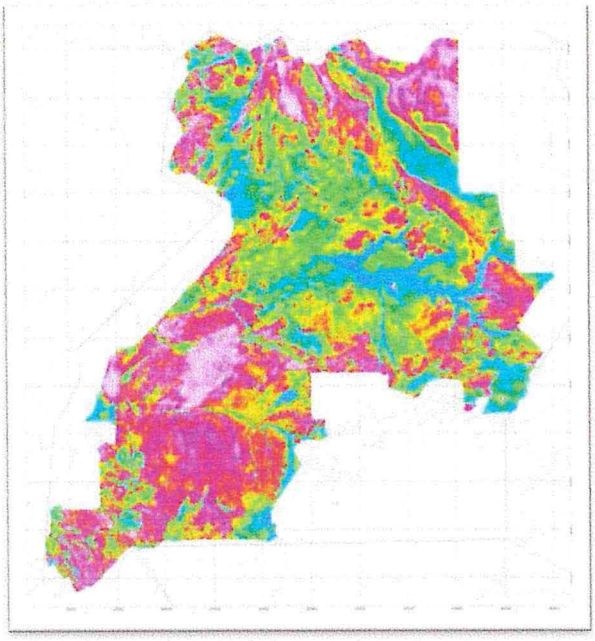

Fig. 1.1 Geology and uranium prospects

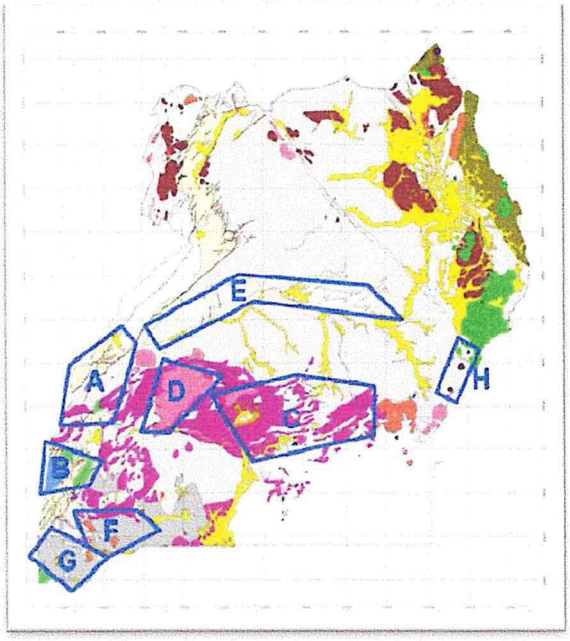

Fig 1.2 Uranium concentrations (ppm)

According to data interpretation by Paterson, Grant & Watson Limited, there are 80 uranium targets in Uganda based on the geology of the country (Figure 1.1). First priority areas comprise are codded A, B,C, D, E, F ,G and H in Figure 1.2 and these are keyed in Table 1.1

Table 1.1: First priority Uranium targets in Uganda (Paterson *et al.*, 2010)

ID	Description
A	The belt from Lake Edwards to Lake Albert where the rock type is basically volcanic
B	The region south of Lake George that is of volcanic components and sedimentary rocks
C	Mubende granite
D	The region between Lake Edwards and lake Albert which is purely volcanic
E	The Bunyoro-Kyoga series
F	Southern Mbarara Karagwe-Ankolean overlying sediments
G	SW Kabale area Karagwe-Ankolean overlying sediments
H	Carbonatites of eastern Uganda

ANNEX TWO: Main water bodies and wetlands of Mubende district

Table 1.1: The major water bodies and wet lands of Mubende District.

Drainage System	Major Wetlands
L. Wamala	Nabisisi, Bimbye, Nabira, wabirombe, Binaja Zigoti/Kayanja, Nabagjgere, Nakatongoli, wabiluko, Myanzi, Kabasuma
Mayanja Kato	Kababolalu, nakusiga, mugoja, kabowe, Namukoma, Nsokwa, kiragwe, katonga, katungulu and matte
Kitumbi	Nabisunsa, Namasa, Kyawamala, katungulu, Kamulenge, Katabalimbe, Nabutiti, Lugolima, Kalangalo
Nkusi	Kwetuna
Kuzizi	Wesikira, Ntolo, Namukya, Namiko, Kanyegera and kaija
Katonga	Kakoko, Namukekemya, Nabijjoka and Kisojjo
Nabakazi	Kattabalanga, mpologoma, lwamagembe, kakindu, kabala, Kakwale, Bwola, kiiye and Kabolokota.

ANNEX THREE: Experimental Primary Data obtained from the water samples.

Table 4.13: Priamry Data from the GDM Detector

SAMPLE ID	MASS (Kg) ±5E-5	t (s)	P	C	CEN (keV)	SD (keV)	FWHM (keV)	SUM N	Rate (s^{-1})	SA (Bq Kg^{-1})	ERROR (Bq kg^{-1})
BKBH1	0.506	6184	1	0.00430	166.550	30.193	70.954	2527	0.41	187.8092	3.7361
	0.506	6184	2	0.06080	254.874	13.629	32.028	1188	0.19	6.2444	0.1812
	0.506	6184	3	0.02370	310.524	13.843	52.028	1939	0.31	26.1463	0.5938
	0.506	6184	4	0.01010	539.248	27.957	65.696	1647	0.27	52.1137	1.2841
	0.506	6184	5	0.00234	1441.682	13.595	31.949	64	0.01	8.7407	1.0926
BKBH2	0.495	6121	1	0.00430	207.535	7.855	18.459	4038	0.67	309.9348	4.8774
	0.495	6121	2	0.06080	256.822	8.644	20.361	8790	1.44	47.7153	0.5089
	0.495	6121	3	0.02370	311.703	11.172	26.254	18336	3.00	255.3458	1.8857
	0.495	6121	4	0.01010	543.057	18.274	42.944	16149	2.64	527.7117	4.1526
	0.495	6121	5	0.00234	1431.662	18.861	44.324	217	0.04	30.6067	2.0777
BKBH3	0.436	6010	1	0.00430	203.542	11.223	26.375	1639	0.27	145.4620	3.5930
	0.436	6010	2	0.06080	256.617	9.944	23.367	2955	0.49	18.5478	0.3412
	0.436	6010	3	0.02370	310.243	12.476	29.319	6234	1.04	100.3824	1.2714
	0.436	6010	4	0.01010	540.308	20.133	47.313	5293	0.88	199.9952	2.7490
	0.436	6010	5	0.00234	1425.321	10.958	25.751	177	0.03	28.8667	2.1698
BKBH4	0.485	6011	1	0.00430	153.033	13.372	31.425	341	0.06	27.2018	1.4731
	0.485	6011	2	0.06080	203.994	16.661	39.153	582	0.10	3.2835	0.1361
	0.485	6011	3	0.02370	314.064	14.399	33.838	1009	0.17	14.6034	0.4597
	0.485	6011	4	0.01010	539.387	22.038	51.790	799	0.17	27.1354	0.9600
	0.485	6011	5	0.00234	1465.694	3.789	8.901	23	0.00	3.3715	0.7030
BKBH5	0.489	6008	1	0.00430	205.716	7.962	18.711	1906	0.32	150.8744	3.4558
	0.489	6008	2	0.06080	256.326	8.719	20.489	3634	0.60	20.3443	0.3375
	0.489	6008	3	0.02370	312.569	14.394	33.825	8470	1.41	121.6456	1.3218
	0.489	6008	4	0.01010	544.300	20.056	47.133	7161	1.19	241.3312	2.8519
	0.489	6008	5	0.00234	1406.551	27.926	65.627	609	0.10	88.5855	3.5897
BKPS1	0.489	6125	1	0.00430	128.716	19.809	46.551	961	0.16	74.6174	2.4070
	0.489	6125	2	0.06080	199.760	13.766	32.350	416	0.07	2.2844	0.1120
	0.489	6125	3	0.02370	277.915	28.546	67.083	1426	0.23	20.0889	0.5320
	0.489	6125	4	0.01010	529.782	24.012	56.429	429	0.07	14.1815	0.6847
	0.489	6125	5	0.00234	1433.996	3.863	9.079	32	0.01	4.5658	0.8071

BKPS2	0.495	6121	1	0.00430	206.111	8.201	19.273	1729	0.26	132.7086	3.1915
	0.495	6121	2	0.06080	255.065	8.930	20.986	3209	0.26	17.4196	0.3075
	0.495	6121	3	0.02370	309.114	12.182	28.682	6890	1.03	95.9496	1.1559
	0.495	6121	4	0.01010	539.052	22.530	52.944	6158	0.92	201.2291	2.5643
	0.495	6121	5	0.00234	1419.046	6.806	15.993	136	0.02	19.1821	1.6448
BKPS3	0.532	6082	1	0.00430	127.446	21.878	51.412	1313	0.22	94.3709	2.6044
	0.532	6082	2	0.06080	230.528	26.546	62.384	1425	0.23	7.2436	0.1919
	0.532	6082	3	0.02370	304.230	14.786	34.747	947	0.16	12.3493	0.4013
	0.532	6082	4	0.01010	534.942	20.516	48.401	631	0.10	19.3086	0.7687
	0.532	6082	5	0.00234	1452.452	19.984	46.961	61	0.01	8.0567	1.0316
BKSW1	0.523	6072	1	0.00430	136.212	7.464	17.540	150	0.02	10.9847	0.8969
	0.523	6072	2	0.06080	278.938	24.809	58.301	288	0.05	1.4916	0.0879
	0.523	6072	3	0.02370	326.094	14.195	33.359	125	0.02	1.6608	0.1486
	0.523	6072	4	0.01010	526.869	23.476	55.168	84	0.01	2.6189	0.2857
	0.523	6072	5	0.00234	1433.058	11.399	26.787	16	0.00	2.1531	0.5383
BKSW2	0.535	6131	1	0.00430	111.650	16.000	37.600	999	0.16	70.8291	2.2409
	0.535	6131	2	0.06080	195.311	16.584	38.976	816	0.13	4.0917	0.1432
	0.535	6131	3	0.02370	280.591	27.002	63.454	14	0.23	0.1851	0.0488
	0.535	6131	4	0.01010	536.483	20.747	48.756	424	0.07	12.7985	0.6216
	0.535	6131	5	0.00234	1455.806	16.427	38.604	59	0.01	7.6869	1.0007
BKSW3	0.481	6195	1	0.00430	205.606	9.483	22.285	872	0.42	68.0553	2.3046
	0.481	6195	2	0.06080	257.917	9.904	23.274	1326	0.21	7.3190	0.2010
	0.481	6195	3	0.02370	312.681	13.057	30.684	2690	0.43	38.0906	0.7344
	0.481	6195	4	0.01010	539.968	27.190	63.896	2532	0.41	84.1310	1.6720
	0.481	6195	5	0.00234	1436.840	16.960	39.857	95	0.02	13.6245	1.3978
BKSW4	0.486	60110	1	0.00430	158.022	38.837	91.267	2201	0.44	17.5214	0.3735
	0.486	60110	2	0.06080	256.083	11.154	26.211	940	0.19	0.5292	0.0173
	0.486	60110	3	0.02370	308.930	13.885	32.630	1431	0.29	2.0668	0.0546
	0.486	60110	4	0.01010	541.176	17.529	41.192	891	0.18	3.0198	0.1012
	0.486	60110	5	0.00234	1458.013	11.607	27.277	6	0.00	0.0878	0.0358
KBBH1	0.501	6038	1	0.00430	206.446	11.205	26.449	953	0.16	73.2645	2.3733
	0.501	6038	2	0.06080	254.523	8.850	20.797	1051	0.18	5.7144	0.1763
	0.501	6038	3	0.02370	314.973	18.186	42.736	216	0.36	3.0128	0.2050
	0.501	6038	4	0.01010	555.178	35.520	83.471	2755	0.46	90.1715	1.7179
	0.501	6038	5	0.00234	1415.501	23.092	54.266	322	0.05	45.4893	2.5350

KBBH2	0.554	6007	1	0.00430	107.292	18.154	42.661	466	0.08	32.5649	1.5085
	0.554	6007	2	0.06080	201.316	15.703	36.902	266	0.04	1.3147	0.0806
	0.554	6007	3	0.02370	311.447	10.613	24.939	158	0.03	2.0033	0.1594
	0.554	6007	4	0.01010	532.339	25.548	60.037	188	0.03	5.5933	0.4079
	0.554	6007	5	0.00234	1432.914	12.651	29.729	57	0.01	7.3197	0.9695
KBBH3	0.491	6008	1	0.00430	201.457	12.961	30.457	1850	0.31	145.8451	3.3908
	0.491	6008	2	0.06080	256.044	9.006	21.165	2827	0.47	15.7620	0.2964
	0.491	6008	3	0.02370	309.840	12.044	28.044	1650	1.20	23.6007	0.5810
	0.491	6008	4	0.01010	540.999	20.130	47.306	5306	0.88	178.0879	2.4448
	0.491	6008	5	0.00234	1433.578	10.067	23.657	46	0.01	6.6639	0.9825
KBBH4	0.599	6011	1	0.00430	153.033	13.372	31.425	341	0.06	22.0248	1.1927
	0.599	6011	2	0.06080	203.994	16.661	39.153	582	0.10	2.6586	0.1102
	0.599	6011	3	0.02370	314.064	14.399	33.838	1009	0.17	11.8241	0.3722
	0.599	6011	4	0.01010	539.387	22.038	51.790	799	0.13	21.9711	0.7773
	0.599	6011	5	0.00234	1465.694	3.789	8.903	23	0.00	2.7298	0.5692
KBBH5	0.567	6008	1	0.00430	202.146	18.350	43.123	1157	0.19	78.9863	2.3221
	0.567	6008	2	0.06080	215.887	15.726	36.957	624	0.10	3.0128	0.1206
	0.567	6008	3	0.02370	288.505	28.403	66.747	2650	0.44	32.8235	0.6376
	0.567	6008	4	0.01010	537.661	24.531	57.647	856	0.14	24.8794	0.8504
	0.567	6008	5	0.00234	1400.385	22.914	53.848	527	0.09	66.1122	2.8799
KBBH6	0.513	6438	1	0.00430	206.446	11.205	26.332	934	0.16	65.7673	2.1520
	0.513	6438	2	0.06080	254.689	8.802	20.685	1057	0.18	5.2638	0.1619
	0.513	6438	3	0.02370	315.727	18.687	43.915	2183	0.36	27.8893	0.5969
	0.513	6438	4	0.01010	553.730	35.669	83.823	2711	0.45	81.2718	1.5609
	0.513	6438	5	0.00234	1428.068	11.744	27.598	113	0.02	14.6216	1.3755
KBBH7	0.512	7104	1	0.00430	132.993	21.351	50.176	3844	0.54	245.7774	3.9642
	0.512	7104	2	0.06080	239.394	24.151	56.755	5028	0.71	22.7362	0.3206
	0.512	7104	3	0.02370	307.829	12.033	28.276	7290	1.03	84.5680	0.9905
	0.512	7104	4	0.01010	540.600	20.558	48.311	7290	1.03	198.4418	2.3242
	0.512	7104	5	0.00234	1455.277	29.174	26.558	210	0.03	24.6735	1.7026
KBBH8	0.532	7104	1	0.00430	133.803	22.856	53.713	4262	0.64	262.2590	4.0172
	0.532	7104	2	0.06080	236.168	25.738	60.485	5883	0.88	25.6024	0.3338
	0.532	7104	3	0.02370	309.029	14.080	33.088	7114	1.07	79.4238	0.9417
	0.532	7104	4	0.01010	514.910	24.832	58.354	6430	0.96	168.4516	2.1007
	0.532	7104	5	0.00234	1474.625	13.369	31.418	153	0.02	17.3006	1.3987

KBSW1	0.496	6005	1	0.00430	207.204	9.779	22.980	491	0.08	38.3370	1.7301
	0.496	6005	2	0.06080	257.319	10.786	25.346	819	0.14	4.5226	0.1580
	0.496	6005	3	0.02370	310.969	16.258	38.205	1574	0.29	22.2978	0.5620
	0.496	6005	4	0.01010	536.144	23.600	55.460	1371	0.23	45.5744	1.2308
	0.496	6005	5	0.00234	1449.752	15.489	36.400	60	0.01	8.6088	1.1114
KBSW2	0.499	6082	1	0.00430	127.446	21.878	51.412	1313	0.22	100.6119	2.7766
	0.499	6082	2	0.06080	151.625	16.789	39.475	800	0.13	4.3355	0.1533
	0.499	6082	3	0.02370	260.606	40.486	95.141	2253	0.37	31.3232	0.6599
	0.499	6082	4	0.01010	532.013	22.791	53.558	700	0.12	22.8365	0.8631
	0.499	6082	5	0.00234	1452.452	19.984	46.961	61	0.01	8.5895	1.0998
KBSW3	0.548	6015	1	0.00430	190.840	16.095	37.824	1507	0.24	106.3233	2.7389
	0.548	6015	2	0.06080	254.498	8.768	20.604	1770	0.29	8.8319	0.2099
	0.548	6015	3	0.02370	309.344	15.399	36.188	3605	0.58	46.1467	0.7686
	0.548	6015	4	0.01010	536.768	23.948	56.279	3260	0.58	97.9219	1.7150
	0.548	6015	5	0.00234	1464.776	18.322	43.057	52	0.01	6.7417	0.9349
KBSW4	0.524	6071	1	0.00430	113.298	28.144	66.138	1100	0.18	80.4142	2.4246
	0.524	6071	2	0.06080	252.052	10.270	24.135	430	0.07	2.2232	0.1072
	0.524	6071	3	0.02370	302.031	13.076	30.728	519	0.09	6.8838	0.3022
	0.524	6071	4	0.01010	523.217	18.220	42.817	234	0.04	7.2829	0.4761
	0.524	6071	5	0.00234	1446.802	12.942	30.413	23	0.00	3.0897	0.6443
KBVD1	0.507	6041	1	0.00430	109.511	14.354	33.731	1411	0.23	107.1376	2.8522
	0.507	6041	2	0.06080	199.092	14.887	34.985	1202	0.20	6.4548	0.1862
	0.507	6041	3	0.02370	310.801	13.253	31.145	2642	0.44	36.3972	0.7081
	0.507	6041	4	0.01010	533.822	26.851	63.100	3551	0.59	114.7922	1.9264
	0.507	6041	5	0.00234	1432.336	15.385	36.154	133	0.02	18.5575	1.6091
KBVD2	0.504	6007	1	0.00430	109.339	13.586	31.926	1758	0.29	135.0399	3.2207
	0.504	6007	2	0.06080	256.744	7.977	18.745	1352	0.23	7.3449	0.1998
	0.504	6007	3	0.02370	311.776	12.938	30.404	2950	0.49	41.1136	0.7570
	0.504	6007	4	0.01010	539.892	21.627	50.825	3169	0.53	103.6365	1.8410
	0.504	6007	5	0.00234	1469.616	13.903	32.073	240	0.04	33.8772	2.1868
KBVD3	0.537	6009	1	0.00430	143.064	13.650	32.077	609	0.10	43.8907	1.7785
	0.537	6009	2	0.06080	226.347	32.682	76.803	1836	0.31	9.3582	0.2184
	0.537	6009	3	0.02370	306.325	12.502	29.379	983	0.16	12.8537	0.4100
	0.537	6009	4	0.01010	546.183	16.522	38.827	571	0.10	17.5202	0.7332
	0.537	6009	5	0.00234	1464.271	0.000	0.000	14	0.00	1.8541	0.4955

KBVD4	0.489	6291	1	0.00430	127.569	22.404	52.649	2024	0.32	152.9140	3.3989
	0.489	6291	2	0.06080	199.094	18.104	42.545	1592	0.25	8.5064	0.2132
	0.489	6291	3	0.02370	290.880	28.563	67.123	3539	0.56	48.5107	0.8154
	0.489	6291	4	0.01010	534.912	22.057	51.833	1711	0.27	55.0343	1.3305
	0.489	6291	5	0.00234	1449.940	27.925	65.624	109	0.02	15.1327	1.4494
KBVD5	0.495	6121	1	0.00430	117.315	12.151	28.554	1335	0.18	102.4673	2.8044
	0.495	6121	2	0.06080	178.661	23.057	54.183	1407	0.19	7.6377	0.2036
	0.495	6121	3	0.02370	291.558	28.242	66.368	3270	0.44	45.5378	0.7963
	0.495	6121	4	0.01010	538.012	21.768	51.154	1241	0.17	40.5530	1.1512
	0.495	6121	5	0.00234	1435.178	20.490	48.151	87	0.01	12.2709	1.3156
KSBH1	0.542	6015	1	0.00430	204.356	12.110	28.459	1379	0.23	98.3696	2.6490
	0.542	6015	2	0.06080	257.182	9.916	23.302	2355	0.39	11.8810	0.2448
	0.542	6015	3	0.02370	310.218	12.759	29.984	4932	0.82	63.8322	0.9089
	0.542	6015	4	0.01010	4544.861	26.557	62.408	4747	0.79	144.1660	2.0924
	0.542	6015	5	0.00234	1426.495	13.032	30.265	133	0.02	17.4342	1.5117
KSBH2	0.460	6023	1	0.00430	208.297	8.329	19.574	1810	0.30	151.9286	3.5711
	0.460	6023	2	0.06080	255.515	9.079	21.335	3688	0.61	21.8936	0.3605
	0.460	6023	3	0.02370	310.587	11.876	27.908	8493	1.41	129.3427	1.4035
	0.460	6023	4	0.01010	540.295	21.204	49.829	7711	1.28	275.5616	3.1381
	0.460	6023	5	0.00234	1441.948	16.228	38.135	206	0.03	31.7746	2.2138
KSBH3	0.512	6009	1	0.00430	201.982	16.931	39.789	1379	0.23	104.2374	2.8070
	0.512	6009	2	0.06080	256.809	10.336	24.289	1649	0.27	8.8155	0.2171
	0.512	6009	3	0.02370	312.095	13.749	32.310	3434	0.57	47.0955	0.8037
	0.512	6009	4	0.01010	541.285	23.749	55.460	2508	0.42	80.7112	1.6116
	0.512	6009	5	0.00234	1437.738	15.110	35.509	91	0.020.501	12.6402	1.3251
KSBH4	0.494	6016	1	0.00430	207.352	8.123	19.089	1903	0.32	148.9140	3.4136
	0.494	6016	2	0.06080	257.751	8.630	20.281	3245	0.54	17.9588	0.3153
	0.494	6016	3	0.02370	311.571	11.912	27.992	8062	1.34	114.4616	1.2748
	0.494	6016	4	0.01010	544.338	20.817	48.920	7176	1.19	239.0707	2.8222
	0.494	6016	5	0.00234	1433.422	16.858	39.616	295	0.05	42.4201	2.4698
KSBH5	0.498	6022	1	0.00430	110.190	13.570	31.889	1307	0.22	101.3531	2.8035
	0.498	6022	2	0.06080	187.111	28.855	67.850	1442	0.24	7.9085	0.2083
	0.498	6022	3	0.02370	312.467	15.571	36.593	1589	0.26	22.3566	0.5608
	0.498	6022	4	0.01010	541.469	22.040	51.795	933	0.15	30.8028	1.0084
	0.498	6022	5	0.00234	1433.995	14.553	34.200	116	0.02	16.5300	1.5348

KSBH6	0.534	7106	1	0.00430	132.554	23.967	56.322	4625	0.65	283.4502	4.1679
	0.534	7106	2	0.06080	239.014	24.254	56.996	5125	0.75	22.2138	0.3103
	0.534	7106	3	0.02370	307.283	10.399	24.437	7021	0.99	78.0700	0.9317
	0.534	7106	4	0.01010	540.564	19.351	45.474	6940	0.98	181.0805	2.1737
	0.534	7106	5	0.00234	1479.546	9.966	23.419	177	0.02	19.9338	1.4983
KSPS1	0.549	6025	1	0.00430	105.289	17.370	40.820	578	0.10	40.6378	1.6903
	0.549	6025	2	0.06080	169.997	27.538	64.714	627	0.10	3.1177	0.1245
	0.549	6025	3	0.02370	287.719	28.704	67.704	591	0.10	7.5389	0.3101
	0.549	6025	4	0.01010	516.390	23.190	54.497	173	0.03	5.1784	0.3937
	0.549	6025	5	0.00234	1463.656	19.594	46.045	55	0.01	7.1059	0.9582
KSPS2	0.523	6049	1	0.00430	196.420	15.629	36.927	1237	0.20	90.9318	2.5854
	0.523	6049	2	0.06080	254.814	11.119	26.131	4046	0.17	21.0347	0.3307
	0.523	6049	3	0.02370	307.133	14.378	33.788	1896	0.31	25.2874	0.5807
	0.523	6049	4	0.01010	535.913	22.763	53.493	1704	0.28	53.3289	1.2919
	0.523	6049	5	0.00234	1404.191	34.984	82.212	55	0.01	7.4295	1.0018
KSPS3	0.516	6072	1	0.00430	117.353	11.986	28.126	758	0.12	56.2625	2.0435
	0.516	6072	2	0.06080	195.800	16.620	39.058	545	0.09	2.8610	0.1225
	0.516	6072	3	0.02370	286.849	28.450	66.858	1534	0.25	20.6583	0.5275
	0.516	6072	4	0.01010	529.600	22.838	53.670	545	0.09	17.2224	0.7377
	0.516	6072	5	0.00234	1443.619	22.348	52.519	58	0.01	7.9110	1.0388
KSVD1	0.498	6009	1	0.00430	145.254	11.599	27.164	511	0.09	39.6960	1.7560
	0.498	6009	2	0.06080	225.871	32.710	76.868	1818	0.30	9.9881	0.2343
	0.498	6009	3	0.02370	314.158	32.710	76.868	1818	0.30	25.6236	0.6010
	0.498	6009	4	0.01010	356.777	25.812	60.659	715	0.12	23.6471	0.8844
	0.498	6009	5	0.00234	1447.960	14.561	34.219	32	0.01	4.5680	0.8075
KSVD2	0.546	6609	1	0.00430	196.316	14.768	34.705	1115	0.17	71.8585	2.1520
	0.546	6609	2	0.06080	252.881	8.599	20.208	7700	0.12	35.0961	0.4000
	0.546	6609	3	0.02370	305.820	14.476	34.020	1505	0.23	17.5979	0.4536
	0.546	6609	4	0.01010	537.116	22.029	51.768	1174	0.18	32.2120	0.9401
	0.546	6609	5	0.00234	1462.042	23.017	54.090	321	0.05	38.0155	2.1218
KSVD3	0.513	6193	1	0.00430	145.432	25.550	60.043	141	0.07	10.3212	0.8692
	0.513	6193	2	0.06080	270.751	34.159	80.273	341	0.06	1.7654	0.0956
	0.513	6193	3	0.02370	375.329	29.396	69.080	130	0.02	1.7265	0.1514
	0.513	6193	4	0.01010	508.433	5.823	13.685	38	0.01	1.1843	0.1921
	0.513	6193	5	0.00234	1446.435	26.799	62.979	72	0.01	9.6850	1.1414

KSSW1	0.528	6068	1	0.00430	123.015	22.325	52.463	689	0.11	50.0117	1.9053
	0.528	6068	2	0.06080	195.791	16.222	38.122	375	0.06	1.9251	0.0994
	0.528	6068	3	0.02370	282.877	26.999	63.448	958	0.16	12.6165	0.4076
	0.528	6068	4	0.01010	520.304	20.310	47.728	179	0.03	5.5316	0.4135
	0.528	6068	5	0.00234	1437.986	20.360	47.846	40	0.01	5.3354	0.8436
KSSW2	0.511	6007	1	0.00430	1361.308	36.152	84.958	1586	0.26	120.1590	3.0172
	0.511	6007	2	0.06080	263.886	23.700	55.694	857	0.14	4.5920	0.1569
	0.511	6007	3	0.02370	314.745	16.972	39.885	625	0.10	8.5912	0.3436
	0.511	6007	4	0.01010	519.742	22.154	52.063	59	0.01	1.9031	0.2478
	0.511	6007	5	0.00234	1461.916	22.154	52.063	59	0.01	8.2141	1.0694
KSSW3	0.520	6005	1	0.00430	116.942	19.983	46.960	1637	0.27	121.9169	3.0133
	0.520	6005	2	0.06080	198.221	19.263	45.269	939	0.16	4.9459	0.1614
	0.520	6005	3	0.02370	299.399	29.302	68.860	1068	0.18	14.4313	0.4416
	0.520	6005	4	0.01010	529.435	32.300	75.905	566	0.09	17.9465	0.7543
	0.520	6005	5	0.00234	1449.575	22.619	53.155	58	0.01	7.9377	1.0423
KSSW4	0.520	6168	1	0.00430	115.358	17.780	41.738	945	0.15	68.5197	2.2289
	0.520	6168	2	0.06080	284.842	23.695	55.684	532	0.09	2.7281	0.1183
	0.520	6168	3	0.02370	324.765	11.049	25.965	249	0.04	3.2757	0.2076
	0.520	6168	4	0.01010	546.765	20.668	48.570	215	0.03	6.6370	0.4526
	0.520	6168	5	0.00234	1434.794	2.727	6.409	20	0.00	2.6648	0.5959
KTBH1	0.523	6029	1	0.00430	188.891	20.037	47.087	929	0.19	68.5173	2.2480
	0.523	6029	2	0.06080	256.688	10.563	24.822	1157	0.23	6.0351	0.1774
	0.523	6029	3	0.02370	310.280	12.814	30.112	2060	0.41	27.5659	0.6073
	0.523	6029	4	0.01010	542.587	22.263	52.331	1735	0.35	54.4793	1.3079
	0.523	6029	5	0.00234	1423.872	17.560	41.265	326	0.05	44.1830	2.4471
KTBH2	0.555	6079	1	0.00430	119.833	19.970	46.929	476	0.08	32.8105	1.5039
	0.555	6079	2	0.06080	211.452	8.743	20.546	235	0.04	1.1456	0.0747
	0.555	6079	3	0.02370	311.755	7.171	16.853	187	0.03	2.3387	0.1710
	0.555	6079	4	0.01010	565.199	15.423	36.244	31	0.01	0.9097	0.1634
	0.555	6079	5	0.00234	1429.863	5.745	13.500	49	0.01	6.2066	0.8867
KTBH3	0.565	6038	1	0.00430	9.634	22.639	22.639	2113	0.35	144.0421	3.1336
	0.565	6038	2	0.06080	8.709	20.466	20.466	3814	0.63	18.3880	0.2977
	0.565	6038	3	0.02370	288.443	25.521	59.974	1863	0.31	23.0421	0.5338
	0.565	6038	4	0.01010	548.345	17.040	40.045	535	0.09	15.5271	0.6713
	0.565	6038	5	0.00234	1445.121	13.516	31.763	30	0.00	3.7581	0.6861

KTBH4	0.496	6031	1	0.00430	193.926	17.731	41.668	901	0.15	70.0463	2.3336
	0.496	6031	2	0.06080	253.947	9.366	22.009	1296	0.21	7.1257	0.1979
	0.496	6031	3	0.02370	306.779	13.271	31.186	2686	0.45	37.8867	0.7310
	0.496	6031	4	0.01010	537.166	21.659	50.900	2291	0.38	75.8285	1.5842
	0.496	6031	5	0.00234	1455.180	19.089	44.859	95	0.02	13.5718	1.3924
KTBH5	0.534	6043	1	0.00430	156.383	39.960	93.906	5655	0.94	407.5401	5.4194
	0.534	6043	2	0.06080	255.838	8.849	20.795	3151	0.52	16.0602	0.2861
	0.534	6043	3	0.02370	308.262	11.770	27.660	5958	0.99	77.9037	1.0093
	0.534	6043	4	0.01010	544.058	26.864	63.130	5966	0.99	183.0493	2.3699
	0.534	6043	5	0.00234	1478.307	11.436	26.874	131	0.02	17.3485	1.5157
KTBH6	0.496	6210	1	0.00430	206.727	9.634	22.639	2113	0.35	159.5357	3.4706
	0.496	6210	2	0.06080	256.226	8.709	20.466	3814	0.63	20.3659	0.3298
	0.496	6210	3	0.02370	310.143	11.346	26.664	8249	1.37	113.0003	1.2442
	0.496	6210	4	0.01010	542.052	20.418	47.981	6863	1.14	220.6070	2.6629
	0.496	6210	5	0.00234	1416.042	23.017	54.090	321	0.05	44.5365	2.4858
KTBH7	0.523	6100	1	0.00430	210.434	11.401	26.792	3421	0.56	249.3751	4.2636
	0.523	6100	2	0.06080	253.936	8.505	19.989	6131	1.01	31.6079	0.4037
	0.523	6100	3	0.02370	304.979	14.828	34.845	14272	2.34	188.7578	1.5800
	0.523	6100	4	0.01010	539.544	17.171	40.353	9996	1.64	310.2225	3.1028
	0.523	6100	5	0.00234	1422.813	9.549	22.439	220	0.04	29.4697	1.9868
KTPS1	0.541	6210	1	0.00430	198.411	15.859	37.268	1379	0.22	95.4568	2.5705
	0.541	6210	2	0.06080	254.413	8.716	20.482	1720	0.28	8.4205	0.2030
	0.541	6210	3	0.02370	308.445	12.645	29.716	3675	0.59	46.1551	0.7614
	0.541	6210	4	0.01010	536.563	24.367	57.261	3316	0.53	97.7247	1.6971
	0.541	6210	5	0.00234	1461.455	22.311	52.478	156	0.03	19.8436	1.5888
KTPS2	0.607	6007	1	0.00430	210.955	14.385	33.804	810	0.13	51.6619	1.8152
	0.607	6007	2	0.06080	288.505	28.403	66.747	265	0.44	1.1954	0.0734
	0.607	6007	3	0.02370	374.758	13.172	30.955	273	0.04	3.1591	0.1912
	0.607	6007	4	0.01010	532.917	28.668	67.371	842	0.14	22.8636	0.7879
	0.607	6007	5	0.00234	1442.447	20.728	48.710	51	0.14	5.9773	0.8370
KTPS3	0.552	6004	1	0.00430	125.172	20.374	47.879	948	0.16	66.5212	2.1605
	0.552	6004	2	0.06080	226.992	31.242	73.419	1395	0.23	6.9229	0.1854
	0.552	6004	3	0.02370	312.276	16.382	38.498	1134	0.19	14.4373	0.4287
	0.552	6004	4	0.01010	540.842	26.817	63.021	996	0.17	29.7549	0.9428
	0.552	6004	5	0.00234	1446.478	15.674	36.834	65	0.01	8.3814	1.0396

KTPS4	0.523	6044	1	0.00430	198.857	16.322	38.358	927	0.15	68.2001	2.2400
	0.523	6044	2	0.06080	256.324	10.972	25.784	826	0.14	4.2978	0.1495
	0.523	6044	3	0.02370	307.939	12.576	29.553	1299	0.21	17.3394	0.4811
	0.523	6044	4	0.01010	536.611	24.796	58.271	1264	0.21	39.5913	1.1136
	0.523	6044	5	0.00234	1445.054	13.542	31.823	51	0.01	6.8949	0.9655
KTSW1	0.534	6117	1	0.00430	127.986	18.509	43.497	983	0.16	69.9851	2.2322
	0.534	6117	2	0.06080	219.509	30.686	72.111	1234	0.20	6.2134	0.1769
	0.534	6117	3	0.02370	311.682	21.368	50.214	699	0.11	9.0292	0.3415
	0.534	6117	4	0.01010	531.764	24.536	57.659	398	0.07	12.0637	0.6047
	0.534	6117	5	0.00234	1439.807	21.364	50.206	33	0.01	4.3174	0.7516
KTSW2	0.512	6021	1	0.00430	105.704	15.359	36.095	825	0.14	62.2367	2.1668
	0.512	6021	2	0.06080	198.235	19.711	46.322	704	0.12	3.7560	0.1416
	0.512	6021	3	0.02370	289.046	27.797	65.323	1745	0.29	23.8841	0.5718
	0.512	6021	4	0.01010	534.711	24.346	57.213	724	0.12	23.2530	0.8642
	0.512	6021	5	0.00234	1428.330	13.802	32.434	49	0.01	6.7927	0.9704
KTSW3	0.499	6016	1	0.00430	112.227	11.901	27.967	886	0.15	68.6368	2.3059
	0.499	6016	2	0.06080	174.256	13.962	32.810	552	0.09	3.0243	0.1287
	0.499	6016	3	0.02370	288.443	25.521	59.974	1863	0.31	26.1852	0.6067
	0.499	6016	4	0.01010	548.345	17.040	40.045	535	0.09	17.6451	0.7629
	0.499	6016	5	0.00234	1445.121	13.516	31.763	30	0.00	4.2707	0.7797
KTSW4	0.568	6028	1	0.00430	199.874	18.266	42.924	920	0.15	62.4882	2.0602
	0.568	6028	2	0.06080	254.992	9.427	22.154	805	0.13	3.8670	0.1363
	0.568	6028	3	0.02370	306.433	10.762	25.291	1469	0.24	18.1031	0.4723
	0.568	6028	4	0.01010	536.830	21.623	50.815	1364	0.23	39.4431	1.0680
	0.568	6028	5	0.00234	1458.209	17.260	40.561	83	0.01	10.3595	1.1371
KTSW5	0.500	6013	1	0.00430	112.723	19.266	45.275	310	0.05	24.0031	1.3633
	0.500	6013	2	0.06080	192.209	19.436	45.675	202	0.03	1.1062	0.0778
	0.500	6013	3	0.02370	307.739	12.697	29.838	53	0.01	0.7446	0.1023
	0.500	6013	4	0.01010	546.039	25.292	59.435	93	0.02	3.0657	0.3179
	0.500	6013	5	0.00234	1464.271	0.000	0.000	14	0.00	1.9920	0.5324

ANNEX FOUR: Specific Activities per sub-county

Table 4.14: Specific activities in the samples from Bukuya sub-county

	ACTIVITY CONCENTARATIONS (Bq kg^{-1})			
ID	^{226}Ra	^{232}Th	^{238}U	^{40}K
BKBH1	187.81 ± 3.74	52.11 ± 1.28	16.20 ± 0.39	8.74 ± 1.09
BKBH2	309.93 ± 4.88	527.71 ± 4.15	136.38 ± 1.10	30.61 ± 2.08
BKBH3	145.46 ± 3.59	200.00 ± 2.75	59.47 ± 0.81	28.87 ± 2.17
BKBH4	27.20 ± 1.47	27.14 ± 0.96	8.94 ± 0.30	3.37 ± 0.70
BKBH5	150.87 ± 3.46	241.33 ± 2.85	71.00 ± 0.83	88.59 ± 3.59
BKPSI	74.62 ± 2.41	14.18 ± 0.68	11.19 ± 0.32	4.57 ± 0.81
BKPS2	132.71 ± 3.19	201.23 ± 2.56	61.08 ± 0.81	19.18 ± 1.64
BKPS3	94.37 ± 2.60	19.31 ± 0.77	9.80 ± 0.30	8.06 ± 1.03
BKSW1	10.98 ± 0.90	2.62 ± 0.29	1.58 ± 0.12	2.15 ± 0.54
BKSW2	70.83 ± 2.24	12.80 ± 0.62	2.14 ± 0.10	7.69 ± 1.00
BKSW3	68.06 ± 2.30	84.13 ± 1.67	22.70 ± 0.47	13.62 ± 1.40
BKSW4	17.52 ± 0.37	3.02 ± 0.10	1.30 ± 0.04	0.88 ± 0.36

Table 4.15: Activity levels of Kasambya sub-county samples

Sample ID	ACTIVITY CONCENTARATIONS (Bq kg^{-1})			
	^{226}Ra	^{232}Th	^{238}U	^{40}K
KBBH1	73.26 ± 2.37	90.17 ± 1.72	4.36 ± 0.19	45.49 ± 2.54
KBBH2	32.56 ± 1.51	5.59 ± 0.41	1.66 ± 0.12	7.32 ± 0.97
KBBH3	145.85 ± 3.39	178.09 ± 2.44	19.68 ± 0.44	6.66 ± 0.98
KBBH4	22.02 ± 1.19	21.97 ± 0.78	7.24 ± 0.24	2.73 ± 0.57
KBBH5	78.99 ± 2.32	24.88 ± 0.85	17.92 ± 0.38	66.11 ± 2.88
KBBH6	65.77 ± 2.15	81.27 ± 1.56	16.58 ± 0.38	14.62 ± 1.38
KBBH7	245.78 ± 3.96	198.44 ± 2.32	53.65 ± 0.66	24.67 ± 1.70
KBBH8	262.26 ± 4.02	168.45 ± 2.10	52.51 ± 0.64	17.30 ± 1.40
KBSW1	38.34 ± 1.73	45.57 ± 1.23	13.41 ± 0.36	8.61 ± 1.11
KBSW2	100.61 2.78	22.84 0.86	17.83 0.41	8.59 1.10
KBSW3	106.32 ± 2.74	97.92 ± 1.72	27.49 ± 0.49	6.74 ± 0.93
KBSW4	80.41 ± 2.42	7.28 ± 0.48	4.55 ± 0.20	3.09 ± 0.64
KBVD1	107.14 ± 2.85	114.79 ± 1.93	21.43 ± 0.45	18.56 ± 1.61
KBVD2	135.04 ± 3.22	103.64 ± 1.84	24.23 ± 0.48	33.88 ± 2.19
KBVD3	43.89 ± 1.78	17.52 ± 0.73	11.11 ± 0.31	1.85 ± 0.50
KBVD4	152.91 ± 3.40	55.03 ± 1.33	28.51 ± 0.51	15.13 ± 1.45
KBVD5	102.47 ± 2.80	40.55 ± 1.15	26.59 ± 0.50	12.27 ± 1.32

Table 4.16: Specific Activity levels of Kassanda sub-county samples

Sample ID	ACTIVITY CONCENTARATIONS (Bq kg^{-1})			
	^{226}Ra	^{232}Th	^{238}U	^{40}K
KSBH1	98.37 ± 2.65	144.17 ± 2.09	37.86 ± 0.58	17.43 ± 1.51
KSBH2	151.93 ± 3.57	275.56 ± 3.14	75.62 ± 0.88	31.77 ± 2.21
KSBH3	104.24 ± 2.81	80.71 ± 1.61	27.96 ± 0.51	12.64 ± 1.33
KSBH4	148.91 ± 3.41	239.07 ± 2.82	66.21 ± 0.80	42.42 ± 2.47
KSBH5	101.35 ± 2.80	30.80 ± 1.01	15.13 ± 0.38	16.53 ± 1.53
KSBH6	283.45 ± 4.17	181.08 ± 2.17	50.14 ± 0.62	19.93 ± 1.50
KSPS1	40.64 ± 1.69	5.18 ± 0.39	6.12 ± 0.25	7.11 ± 0.96
KSPS2	90.93 ± 2.59	53.33 ± 1.29	23.16 ± 0.46	7.43 ± 1.00
KSPS3	56.26 ± 2.04	17.22 ± 0.74	11.76 ± 0.33	7.91 ± 1.04
KSVD1	39.70 ± 1.76	23.65 ± 0.88	17.81 ± 0.42	4.57 ± 0.81
KSVD2	71.86 ± 2.15	32.21 ± 0.94	26.35 ± 0.43	38.02 ± 2.12
KSVD3	10.32 ± 0.87	1.18 ± 0.19	1.75 ± 0.12	9.69 ± 1.14
KSSW1	50.01 ± 1.91	5.53 ± 0.41	7.27 ± 0.25	5.34 ± 0.84
KSSW2	120.16 ± 3.02	1.90 ± 0.25	6.59 ± 0.25	8.21 ± 1.07
KSSW3	121.92 ± 3.01	17.95 ± 0.75	9.69 ± 0.30	7.94 ± 1.04
KSSW4	68.52 ± 2.23	6.64 ± 0.45	3.00 ± 0.16	2.66 ± 0.60

Table 4.17: Specific Activity in samples collected from Kitumbi sub-county.

Sample ID	ACTIVITY CONCENTARATIONS (Bq kg^{-1})			
	^{226}Ra	^{232}Th	^{238}U	^{40}K
KTBH1	68.52 ± 2.25	54.48 ± 1.31	16.80 ± 0.39	44.18 ± 2.45
KTBH2	32.81 ± 1.50	0.91 ± 0.16	1.74 ± 0.12	6.21 ± 0.89
KTBH3	144.04 ± 3.13	15.53 ± 0.67	20.72 ± 0.42	3.76 ± 0.69
KTBH4	70.05 ± 2.33	75.83 ± 1.58	22.51 ± 0.46	13.57 ± 1.39
KTBH5	407.54 ± 5.42	183.05 ± 2.37	46.98 ± 0.65	17.35 ± 1.52
KTBH6	159.54 ± 3.47	220.61 ± 2.66	66.68 ± 0.79	44.54 ± 2.49
KTBH7	249.38 ± 4.26	310.22 ± 3.10	110.18 ± 0.99	29.47 ± 1.99
KTPS1	51.66 ± 1.82	97.72 ± 1.70	23.68 ± 0.42	19.84 ± 1.59
KTPS2	95.46 ± 2.57	22.86 ± 0.79	5.79 ± 0.20	5.98 ± 0.84
KTPS3	66.52 ± 2.16	29.75 ± 0.94	10.68 ± 0.31	8.39 ± 1.04
KTPS4	68.20 ± 2.24	39.59 ± 1.11	10.82 ± 0.32	6.89 ± 0.97
KTSW1	69.99 ± 2.23	12.06 ± 0.60	7.62 ± 0.26	4.32 ± 0.75
KTSW2	62.24 ± 2.17	23.25 ± 0.86	13.82 ± 0.36	6.79 ± 0.97
KTSW3	68.64 ± 2.31	17.65 ± 0.76	14.60 ± 0.37	4.27 ± 0.78
KTSW4	62.49 ± 2.06	39.44 ± 1.07	10.99 ± 0.30	10.36 ± 1.14
KTSW5	24.00 ± 1.36	3.07 ± 0.32	0.93 ± 0.09	1.92 ± 0.53

Table 4.18: Doses and Radiological indices in Kasambya sub-county

ID	D	H	Ra_{eq}	H_{ex}	H_{in}	$I_{\gamma r}$
KBBH1	90.2087	0.2771	202.5600	0.5556	0.7536	1.4205
KBBH2	18.7286	0.0555	40.6197	0.1111	0.1991	0.2779
KBBH3	175.2234	0.5403	400.5621	1.0832	1.4773	2.7576
KBBH4	23.5598	0.0723	53.4645	0.1449	0.2045	0.3684
KBBH5	54.2757	0.1615	115.0729	0.3233	0.5368	0.8194
KBBH6	80.0824	0.2467	182.0986	0.4946	0.6723	1.2609
KBBH7	234.4369	0.7163	529.7392	1.4356	2.0998	3.6394
KBBH8	223.6299	0.6801	503.2780	1.3628	2.0716	3.4444
KBSW1	45.5976	0.1403	103.5747	0.2814	0.3850	0.7171
KBSW2	60.6341	0.1808	133.3342	0.3619	0.6338	0.9048
KBSW3	108.5473	0.3327	246.4035	0.6668	0.9542	1.6925
KBSW4	41.6791	0.1230	90.8525	0.2461	0.4634	0.6110
KBVD1	119.6059	0.3675	271.4333	0.7366	1.0262	1.8745
KBVD2	126.3976	0.3853	283.5009	0.7722	1.1371	1.9592
KBVD3	30.9370	0.0932	68.9589	0.1867	0.3053	0.4690
KBVD4	104.5180	0.3140	231.7296	0.6289	1.0422	1.5799
KBVD5	72.3456	0.2177	160.5526	0.4361	0.7130	1.0968

Table 4.19: Dose and radiological indices in Bukuya sub-county

ID	D	H	Ra_{eq}	H_{ex}	H_{in}	$I_{\gamma r}$
BKBH1	118.6090	0.3549	262.3991	0.7106	1.2182	1.7790
BKBH2	463.2040	1.4368	1064.7980	2.8815	3.7192	7.3638
BKBH3	189.2043	0.5842	431.6774	1.1713	1.5645	2.9889
BKBH4	29.0976	0.0893	66.0314	0.1790	0.2525	0.4549
BKBH5	219.1620	0.6772	496.6601	1.3580	1.7657	3.4782
BKPSI	43.2293	0.1286	94.9321	0.2574	0.4590	0.6423
BKPS2	183.6536	0.5683	420.6139	1.1396	1.4983	2.9098
BKPS3	55.5977	0.1655	122.0442	0.3313	0.5863	0.8276
BKSW1	6.7465	0.0201	14.7463	0.0402	0.0699	0.1009
BKSW2	40.7739	0.1211	89.1901	0.2424	0.4339	0.6053
BKSW3	82.8248	0.2552	188.4675	0.5116	0.6955	1.3041
BKSW4	9.9555	0.0296	21.8465	0.0592	0.1066	0.1476

Table 4.20: Doses and Radiological indices in Kassanda sub-county

ID	D	H	Ra_{eq}	H_{ex}	H_{in}	$I_{\gamma r}$
KSBH1	133.2500	0.4120	304.6612	0.8261	1.0920	2.1091
KSBH2	237.9552	0.7385	546.2264	1.4812	1.8918	3.7897
KSBH3	97.4343	0.2974	219.7517	0.5960	0.8777	1.5105
KSBH4	214.9659	0.6654	491.1117	1.3343	1.7368	3.4117
KSBH5	66.1193	0.1979	145.5284	0.3963	0.6702	0.9947
KSBH6	241.1579	0.7333	542.5488	1.4694	2.2355	3.7138
KSPS1	22.1987	0.0656	48.0976	0.1313	0.2411	0.3274
KSPS2	74.5310	0.2262	167.2493	0.4532	0.6990	1.1445
KSPS3	36.7255	0.1100	80.9515	0.2202	0.3723	0.5526
KSVD1	32.8129	0.0996	73.5465	0.1995	0.3068	0.5042
KSVD2	54.2399	0.1630	118.2144	0.3265	0.5207	0.8265
KSVD3	5.8876	0.0172	12.0893	0.0345	0.0624	0.0871
KSSW1	26.6690	0.0788	57.9630	0.1576	0.2928	0.3923
KSSW2	57.0055	0.1669	122.9437	0.3338	0.6586	0.8256
KSSW3	67.4963	0.2001	147.6415	0.4004	0.7300	0.9975
KSSW4	35.7759	0.1056	78.0311	0.2114	0.3966	0.5249

Table 4.21: Doses and Radiological indices in Kitumbi sub-county

ID	D	H	Ra eq	Hex	Hin	$I_{\gamma r}$
KTBH1	66.4029	0.2020	146.7629	0.4047	0.5899	1.0310
KTBH2	15.9667	0.0467	34.1592	0.0935	0.1822	0.2320
KTBH3	76.0825	0.2249	166.2748	0.4500	0.8393	1.1181
KTBH4	78.7278	0.2419	178.5856	0.4849	0.6742	1.2343
KTBH5	299.5687	0.9046	669.4342	1.8118	2.9133	4.5590
KTBH6	208.8093	0.6445	475.3466	1.2922	1.7234	3.2993
KTBH7	303.8146	0.9366	693.2202	1.8779	2.5519	4.7844
KTPS1	83.7210	0.2598	191.5610	0.5211	0.6607	1.3349
KTPS2	58.1599	0.1736	128.1978	0.3475	0.6055	0.8690
KTPS3	49.0545	0.1480	109.1353	0.2964	0.4762	0.7466
KTPS4	55.7091	0.1690	124.8687	0.3386	0.5229	0.8552
KTSW1	39.7996	0.1182	87.2694	0.2366	0.4258	0.5901
KTSW2	43.0814	0.1295	95.5408	0.2594	0.4276	0.6520
KTSW3	42.5459	0.1271	93.9022	0.2545	0.4400	0.6369
KTSW4	53.1252	0.1614	118.9716	0.3233	0.4922	0.8179
KTSW5	13.0213	0.0385	28.4019	0.0771	0.1420	0.1920