MEASUREMENT OF RADIOACTIVITY IN WATER AND SEDIMENTS OF RIVER YOBE, NORTH EASTERN NIGERIA.

BY

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M.Sc/Scien/07845/2008-09

DEPARTMENT OF PHYSICS

AHMADU BELLO UNIVERSITY ZARIA, NIGERIA

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DEPARTMENT OF PHYSICS

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MAY, 2013

DECLARATION

I, HABU TELA ABBA hereby declare that this thesis titled **"Measurement of Radioactivity in water and sediments of River Yobe, North- Eastern Nigeria"** is my own work and has not been submitted in any other form for another degree or diploma to any other university or institution. Information derived from published or unpublished work of other workers have been fully acknowledged.

....

Tela Abba, Habu **Date**
M.Sc/Scien/07845/2008-09

CERTIFICATION

This thesis titled "**MEASUREMENT OF RADIOACTIVITY IN WATER AND SEDIMENTS OF RIVER YOBE, NORTH- EASTERN NIGERIA**" by Habu Tela Abba **(**M.Sc/Scien/07845/2008-09) meets the regulation governing the award of the degree of Master of Science (Radiation Biophysics) of Ahmadu Bello University Zaria, Nigeria and is approved for its contribution to knowledge and literacy presentation.

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DEDICATION

This work is dedicated to my parents, family and well wishers.

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Praise is to our creator, Lord of the worlds, the Eternal Guardian of the heavens and earths, Disposer of all created beings. Who through His blessings upon me, I was able to successfully complete this work.

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ABSTRACT

Radioactivity measurement was carried out in water and sediments of river Yobe. Sediment samples collected from areas of high fishing, farming, domestic/livestock and control area along the river were analyzed using gamma-ray spectrometric technique. The average absorbed dose rate of the samples was 50.00nGyh^{-1}, 64.10nGyh^{-1}, 46.79nGyh^{-1} and 40.12nGyh^{-1} for fishing, farming, domestic/livestock and control zone respectively. Mean dose rate equivalent, external and internal indices were also computed. The water samples were analyzed for gross alpha and beta activity with an average values of 0.153± 0.06, 0.638± 0.06, 0.207± 0.04 and 0.207± 0.07 BqL^{-1} for gross alpha and 0.245± 0.02, 0.679± 0.05, 0.393± 0.03 and 0.293± 0.05 BqL^{-1} for gross beta for the zones respectively. The overall results showed that activity concentrations of all zones are within the typical world average values of 0.5Bq/L and 1Bq/L for alpha and beta respectively, although some extreme values are obtained in the farming zone. Therefore the river, have no significance radiological health burden on the environment and the populace.

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CHAPTER ONE

INTRODUCTION

1.1 General introduction

The exposure of human beings to ionizing radiation from natural sources is a continuing and inescapable feature of life on earth. There are two main contributors to radiation exposures: Natural (high energy cosmic ray particles incident on the earth's atmosphere, radioactive nuclides that originated in the earth's crust and ore present everywhere in the environment) and artificial (man-made) sources. Both external and internal exposures to humans arise from these sources (UNSCEAR, 1993). Exposure to excess level of background ionizing radiation can cause somatic and genetic effects that tend to damage critical and/or radiosensitive organs of the body, and can even lead to death (Ajayi and Ajayi, 1999).

Recently, other artificial sources of exposure have appeared due to such human activities as nuclear power plants, nuclear weapons testing, production and use of radioactive sources. In addition, human activities such as mining, milling and processing of uranium ores, mineral sands, manufacture of fertilizers and burning of fossil fuels have raised naturally occurring radioactive material concentrations in the environment (Pujol and Sanchez-Cabeza, 2000).

Radioactive material can reach surface waters in different ways from each of the process or activities that produce technologically enhanced radioactive material.

Water quality is an important parameter of environmental studies. Radioactivity present in surface waters is mainly due to the presence of radioactive elements in the earth's crust. The earth's crust contains small amounts of Uranium, thorium, and radium as well as radioactive isotope of potassium. The average of ^{238}U in the earth's crust has been estimated to be 2.7 mg kg^{-} and average of ^{232}Th content of the earth's about 9.6 mg kg^{-1} (Lide, 1994) Uranuim in phosphate

rock deposits throughout the world range from 300 to 400 mg kg^{-1}(Guienond, 1978). Surface water and especially ground water play an important role in the migration and distribution of these radionuclides in the earth's crust.

River water can be contaminated by surface runoff of rainwater transporting leached radionuclides from cities, mine waste, agricultural areas, and so on (O'Brien, R.S., and Coper, M.B., 1998). Natural waters contain both α and β emitters in widely varying concentrations which are responsible for a generally small fraction of the total dose received from natural and artificial radioactivity (UNCEAR, 1993). For practical purposes, the recommended guideline (WHO, 2004) activity concentrations are 0.5 Bq/l for gross α and 1 Bq/l for gross β. This contamination may also pose a potential health hazard and therefore the need to investigate it is of paramount importance.

1.2 The study area

1.2.1 Location of the study area

The River Yobe, from which yobe state derived its name, is the biggest river in the state it is located between latitude 10^0 N and 130^0 N and longitude 9.45^0 E and 12.30^0 E of prime meridian, in the northern part of the state. It has a few tributaries, which include river Hadeja and Jama're. One of the most important tributaries is River Alkalam, where the famous yearly Bade fishing and cultural festival takes place.

The area of study which is at Gashua town covers a distance of about 10Km along the river coast. Along the river course, there are no large cities, no-nuclear enterprises such as radiochemical and phosphate industries and coal-fired power plants. The farmers' who live in this area generally rear animals, raise crops and some vegetables. Therefore, agrochemical such

as fertilizers, pesticides, herbicides and refuse dump by the riverside are the main contaminant of the river.

1.2.2 Geology

The geology of the study area is consistent with the general geological setting of Yobe state which principally comprises crystalline and sedimentary rocks, underlain by basement complex rocks. The crystalline rocks are represented by older granites found in pockets part of the study area. Another crystalline rock formation is also located in the area. The older granite is Precambrian in origin consisting of metamorphic structures of gneiss and amphibolites. The granitic rocks are of Jurassic period, deposited between 195 and 135 million years before the present. The sedimentary rocks that are found in most parts of the area were uncomfortably deposited on the basement crystalline rocks. In the southern fringe of the area, the sedimentary deposits are made up of the cretaceous Bima, Pindiga, Fika and Gombe formations. The Karekare formation is also found in this part of the area. However, in the greater part of the area, sedimentary formations were uncomfortably overlaid by a large expanse of Quaternary Chad formation that stretched into Jigawa and Borno States (YSPS, 2010).

The Biu basalts found in the southern end of Yobe state are believed to have been extruded during the Tertiary/Quaternary periods as lava flows. However, the influence of climatic fluctuations is reflected in the superficial deposits overlaying most of the area. This, for instance, has led to the deposition of series of longitudinal and traverse dunes in the study area (YSPS, 2010).

1.2.3 Climate

The climate of the study area is not different from the general climate of Yobe State, which is hot and dry for most periods, of the year. The mean temperature for most parts in the state is about 37°C. The highest temperature (about 42°C) is normally experienced in April, while minimum temperatures (about 30°C) are usually recorded in December. (lloeje, 1977). The State exhibits a remarkably high annual range of mean monthly temperatures.

Gashua which is the study area shows a mean maximum temperature of 30.8°C in August, 39.8°C in April and mean minimum temperatures of 12.1°C in January and 29.1°C in June. Rainfall lasts for about 120 days in the area of study.

There is a marked dry season of between eight to nine months and a wet season of only three to four months in the state. Rainfall is highly irregular in space and time, which makes farming difficult since small differences in the amount and timing of rain received at a site may determine the success or failure of critical stages in vegetation development and hence crop production. The development of agriculture here, therefore, effectively depends on irrigation farming for which River Yobe play a vital role.

1.2.4 Vegetation

Gashua and environs are in the typical Sahel savannah vegetation zone. Vegetal cover is sparse as the grass grows in individual tufts leaving bare surfaces in between. The grasses in the Sahel are short and tussock, 0.5m to 1.0m high. They are interspersed and sand dunes are the most common types there. The acacia is a thorny, narrow leafed tree, fairly short and sometimes umbrella shaped.

1.3 The Research Problem

The River Yobe is the biggest river in the state. It flows eastwards in wet seasons and drains into Lake Chad. It has a few tributaries, these include river Hadeja and Jama're. One of the most important is being River Alkalam, which is greatly used for irrigation, fishing, household activities and source of drinking water for human and livestock.

However, investigation by (Waziri *et al*., 2010) revealed that high use of agrochemicals such as fertilizers, pesticides and herbicides by farmers on the farmland by the river side, dumping of refuse and domestic wastes near the river bank as well as domestic sewage into the river are main sources of contaminants in the river. Some of these chemicals contain radioactive materials. As rain falls, its washes these chemicals into the river. For example, the fertilizers contain potassium phosphate, which has a radioactive compound ^{40}K, a beta (β) and gamma ray (γ) emitter. These may result in high concentration of radioactivity in the river (Spalding and Sackette, 1972).

High concentration of these radioactive substances in the river may endanger the health of human, animals and plants and also may affect the suitability of crops and water for human consumption (Thornton, 1983). The organs mostly affected by radiations from these sources include kidney, gonad, skin, liver, lungs and circulatory system. Signs usually associated with chronic effect of these radiations which include skin cancer, tumor, genetic effects, kidney failure and vascular disease has been reported (Dukar *et al*., 2005). In particular, kidney related diseases have been reported in large group in the area (Waziri *et al*., 2009).

1.4 Aim and objectives

The aim of this study is to measure the radioactivity levels of river Yobe, compare the results with acceptable levels and ascertain the possible radiological effects on the populace, livestock and the environment.

The Objectives of the study are to:

i. Determine the concentration of the radionuclides ^{238}U, ^{232}Th and ^{40}K in the sediment samples.
ii. Evaluate the gross alpha and gross beta radioactivity in the water of the river.
iii. Estimate the radiation dose due the activities in the samples so as to assess the radiological impact on the populace and the environment.
iv. Establish a baseline data for the area.

1.5 Justification

Dissolved radionuclide in surface water may pose public health threat when the surface water is used for domestic supply and agricultural (irrigation) practice. Alpha and beta radiations are high Linear Energy transfer (LET) radiations; hence they deposit their energy at short distance and cause serious damage to the organs and tissues (biological effects) whenever source emitting them is ingested along with food and water. The determination of their concentration and dose level will therefore help the health workers in tracing the history of the recent prevailing health cases of renal failure and kidney diseases (Waziri *et al*., 2009) and consequently be in better position to respond to them appropriately, this will go along way in reducing the loss of lives as a result of environmental contamination related diseases hence bursting the socio- economic activities in that geographical location.

Since there is no data in terms of radioactivity measurement in the area, the result of this investigation will be used by Yobe State government and other Stakeholders in putting good environmental protection strategic planning as well as protection of human health. This can be achieved by educating the endangered settlers and farmers in that area of environmental and most importantly radiological and toxicological risk involved by their activities. Useful information will also be provided in protecting the public against diseases especially those which could be as a result of ingestion of food contaminated with radioactive substances from agrochemicals and other wastes. My work will also establish a base line data in terms of radioactivity measurement in the area.

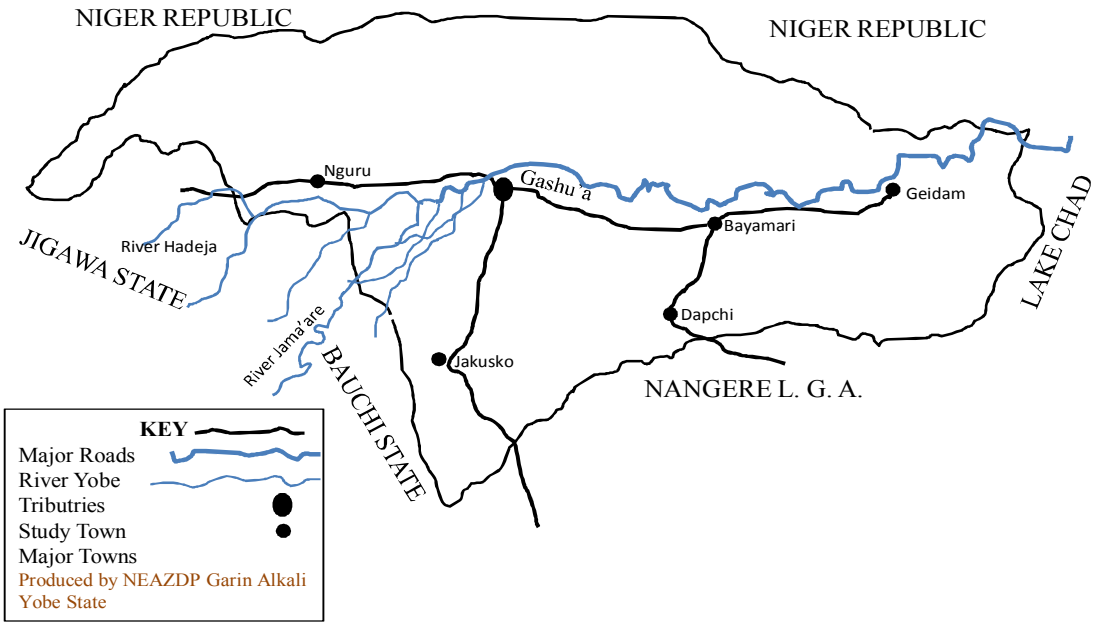


Figure: 1.1 Map of Yobe state showing study area (Adopted and modified from Waziri et.al 2010)

CHAPTER TWO

LITERATURE REVIEW

2.1 Radioactivity

Radioactivity is the term used to describe the rate of disintegration of elements. For any element there exist a certain number of neutrons to proton ratios for it to remain stable. Any deviation from this number will result in an unstable atom. Unstable atom can become stable by emitting energy in the form of radiation. Such atoms are said to be radioactive and the process is called radioactivity. Therefore, natural radioactivity is defined as the spontaneous transformation of unstable nuclei that results in the formation of new elements with the emission of particles and radiations (Cember, 1996).

Some of the emitted particles are alpha particles, beta particles ($\beta^- or \beta^+$) and gamma radiations (γ); whose emission only accompanies alpha or beta particle emission (Cember, 1996). The exact mode of radioactive transformation depends on two factors.

(i) The type of instability i.e. neutron to proton ratio.

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

The radioactive decay is expressed in the unit of Becquerel (Bq). Where 1Bq = 1 disintegration per second. The radionuclides decay at a characteristic rate that remains constant regardless of external influences, such as temperature or pressure. The time that it takes for half the original radionuclides to disintegrate or decay is called half–life. This differs for each radioelement, ranging from fractions of a second to billions of years. For example, the half- life of Iodine 131 is eight days, but for uranium 238, which is present in varying amounts all over the world, is 4.5

billion years. Potassium-40, the main source of radioactivity in our bodies, has a half-life of 1.42 billion years (Garba, et. al,. 2008).

2.2 Environmental Radioactivity

Radioactivity is the property of some atoms to spontaneously give off known radiations and energy. The atoms that make up the radioactive materials are the source of radiation. Ionizing radiation can be found in everything in nature in trace amounts including people but in high enough concentrations, it can cause chemical and/or physical changes in human tissue. While it is true that radiation can cause biological damage, it is important to keep the risks in perspective. We cannot eliminate radiation from our environment, but we can reduce our risks by controlling exposure. Regardless of what we do on a typical day, go to school, work, or at home, in each case we are being exposed to radiation. Whether we know it or not we are being exposed to radioactivity everyday of our life.

Nuclear radiation is all around us in the environment. Low-level radiation is found in the oceans and waterways, the rocks and soils, the plant materials and in the atmosphere surrounding the planet. The radiation we are exposed to can be said to come from two sources that which occur naturally and that which is due to the activities of man (Artificial sources) (Garba, et . al,. 2008).

2.2.1 Natural Radioactivity

Radioactivity occurs naturally from primordial radionuclides in the earth's crust and from nuclear reactions in the stars. These are called terrestrial radiations and cosmic radiations respectively.

2.2.1.1 Terrestrial Radiation

Terrestrial radiation emanates from the primordial sources found in rocks and soils which consist of ^{238}U, ^{232}Th, ^{226}Ra, and ^{40}K (Peter, 1989). They exist in the three naturally occurring radioactive decay series, which undergo transition at very slow rate because of their long half-lives and produce several decay products (progeny).These progeny include ^{226}Ra, ^{210}Po, ^{210}Pb, and ^{222}Rn. The radon gas gets into the atmosphere through emanation and diffusion via soil capillaries and as inert gas, it has greater residence time in the atmosphere and higher probability of human irradiation (Ibeanu, 1999). The daughter products of ^{222}Rn such as ^{210}Po and ^{210}Pb being solid attached themselves to the atmospheric aerosols thereby contaminating the air inhaled by man. The primordial radionuclides are present in rocks, soil and building construction materials. Mining and processing of radioactive ores contribute significantly to the enhancement of terrestrial radiation fields in the environment (Ibeanu, 1999). These rocks and soils are constantly encountered by flowing rivers, streams and groundwater and consequently they contaminate the water sources.

The food we eat typically contains about 10Bq/kg of ^{40}K, our body incorporates them into tissues and bone irradiating the body continually and hence our body is naturally radioactive, which refers to NORM internal to human body. The activity in the body of a reference man of 70kg is about 4,000Bq, mainly due to presence of ^{40}K and ^{14}C (Alison, 1968). This delivers a dose of about $7\mu Sv$ per year to the skeleton (Eisebud, and Paschoa, 1989).

2.2.1.2 Cosmic radiations

Cosmic radiations emanate from the sun and interstellar space; and constitute primarily of 87% proton, 11% alpha particle, 1% heavy ion and 1% electron (NCRP, 1985). Cosmic rays permeate

all of space with high energy, approaching the earth at nearly speed of light. Secondary radiations are produced by the cosmic radiations as a result of interactions with the earth's upper atmosphere of which 80% are neutrons and 20% electrons (Martins, et al,. 1986) and these secondary cosmic radiations are the ones that get to the earth's surface. Annual dose rate from these radiations depend largely on the altitude and slightly on the latitude. Table 2.1 below gives the dependency of cosmic radiation dose rate on altitude in some countries.

Table 2.1: Dependency of cosmic radiation dose rate on altitude in some countries.

S/NO.	Altitude(m)	Dose rate (mSv/y)	Examples
1.	Sea level	0.31	Los Angeles
2.	1,525	0.55	Denver
3.	3,050	1.37	Leadville; Cole
4.	9,140	19.00	Normal Jetliner
5.	15,240	87.57	Concorde
6.	24,340	127.00	Spy plane

Source: (Adopted from Gollnick, 1988)

The latitude effects arise from the fact that the charged particles of cosmic rays on descending towards the earth's surface are deflected by the earth's magnetic field, away from the equator and toward the poles, thus the dose rate increases with increasing latitude (Martins, 1986). Another form of radionuclides is formed in the atmosphere by the interaction of cosmic rays and the suspended particles in the atmosphere known as Cosmogenic radionuclides. Cosmogenic radionuclides include ^{3}H, ^{7}Be, ^{14}C and ^{22}Na with their annual dose rate as 0.01mSv, 0.03μmSv, 12μSv and 0.15μSv respectively (Turner, 1995). Carbon-14 is produced by the reaction ^{14}N (n, p) ^{14}C. It diffuses into the lower atmosphere, oxidized to carbon dioxide (CO_2) and becomes incorporated in plants, animals, or seep into the water (Cember, 1996)

2.2.2 Artificial Radioactivity

Artificial (man-made) radioactivity results from a number of human's activities leading to designing and building of many types of apparatus that produce radiation and/or radioactive materials. The activities include the use of x-rays for medical diagnostic and therapeutic purposes, medicine, research, industry and agriculture; the generation of electricity through nuclear power plant. All these activities introduce radioactivity to the environment.

Production and the use of fertilizers for agricultural practice is a major source of artificial radioactivity to the soil, as part of fertilizer constituents is radionuclides. Spalding and Sackette (1972) observed the leaching of uranium phosphate fertilizers as in a North American river. Clergy and Forley (1958) measured the mean activity concentration of 1464Bq/kg, which is a factor of about 58 times the mean activity, concentration worldwide in a normal environment.

Fertilizers of phosphate are to have more concentration of radium followed by potassium and then thorium. The PK and NPK fertilizers have higher concentration of potassium and radium (Ibeanu, 1999). When these fertilizers are applied to soil, they add radioactivity to that of uranium and other decay series present in the soil (Eisenbud and Pachoa, 1989).

Seventy percent of the surface is covered by water. Radioactive substances from fertilizers, terrestrial and cosmic radiation return to water through dry out, rainout, or washed out directly into the surface waters. However, an important portion of the active substances pass through the hydrosphere and is leached out from the soil arrives in rivers, lakes and seas (Szabo, 1993).

Fig. 2.1 gives the sources of public exposure (in %) per annum in United State of America.

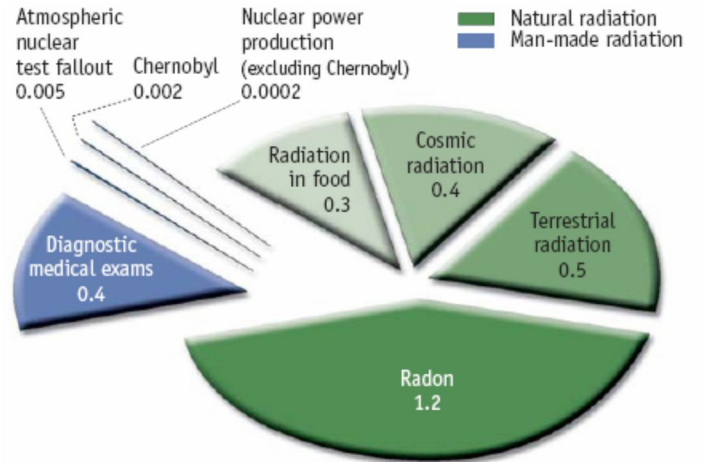


Fig. 2.10 (adopted from UNSCEAR, 2000)

2.3 Radioactive Decay Law

The radioactive decay law states that the activity of radioactive sample decreases exponentially with time. The decay is statistical in nature and it is very difficult or rather impossible to predict when any particular atom will disintegrate. The result of this random behavior of a particular radioactive sample is expressed mathematically as (leo, 1987).

2.1

Where the number of nuclei present initially, the number of nuclei presents at time t, and is the radioactive decay constant. If a nucleus has more than one mode of decay, then λ is the sum of separate constants for each mode.

2.3.1 Fluctuation in Radioactive decay

The number of decays undergone by a radioactive source in a period of time which is short compared to the half-life of the source, the activity of the source may be considered as constant.

If repeated measurements of the number of decays n in time interval Δt are now taken, fluctuations will be observed from measurement to measurement. This is due to statistical nature of the decay process and that the exact number of decay at any given time can never be predicted, but only the probability for such an even (Leo,1987).

From the radioactive decay law, the probability of observing n counts in a period Δt is given by Poisson distribution as;

$$p(n, \Delta t) = \frac{m^n}{n!} exp^{-m} \quad 2.2$$

Where m is the average number of count in the period Δt. The standard deviation of the distribution is then given by

$$\sigma = \sqrt{m} \quad 2.3$$

2.4 Half life ($T_{1/2}$)

Different radionuclides are transformed at different rates, and each radionuclide has its own characteristic transformation rate.

The time required for any given radionuclide to decrease to one-half its original quantity is called half-life ($T_{1/2}$) of the radionuclide (Cember, 1996). The half-life of a radionuclide is a measure of the speed with which it undergoes radioactive transformation. From equation (2.1), at half-life $N = {}^{N_0}/_2$ and t=$T_{1/2,}$ so that equation transform to:

$$\frac{N_0}{2} = N_0 e^{-\lambda T_{1/2}} \quad 2.4$$

Solving the equation, gives

$$T_{1/2} = \frac{ln2}{\lambda} = \frac{0.693}{\lambda} \quad 2.5$$

2.5 Source Activity

The activity of any radionuclide is the number of atoms transformed per unit time of that particular radionuclide. The activity of radionuclide increases as the number of atoms in sample increases; and decreases exponentially with time. It is given by

$$A_t = A_0 e^{-\lambda t} \quad 2.6$$

Where A_0 is the activity at time t=0 and A_t is the activity at time, t.

2.6 Specific Activity

Specific activity (A_{sp}) is used to quantify the activity of a radionuclide in a given mass or volume of the radioactive material. Thus, it relates the activity and mass of the radioactive material; which is the activity per unit mass of the radioactive material (Cember, 1996).It is expressed as

$$A_{sp} = \frac{Act}{A} = \frac{\lambda N_A}{A} \quad 2.7$$

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

2.7 Radioactivity in water

Radionuclides found in water are the members of the three naturally occurring radioactive decay series- uranium, thorium and actinium series. Other radionuclides of terrestrial origin can also find themselves in water. The specific elements of concern are radium, radon, uranium and few

other isotopes. Radium and uranium are known to be alpha emitters when ingested into the body pose a variety of health problems (Cohen and Rebers, 1987). Radon for instance has similar chemical properties with calcium thus it collects in bone tissues. Inducement of bone cancer appears to be the greatest health threat posed by ingestion of Radium (National Research council, 1988). The toxicity of Uranium is also in two folds: as a heavy metal, it may cause kidney damage and as a radionuclide it may induce some cancer (National Research council, 1988).Polonium, ^{210}Po, as a member of the decay series has also been detected in the water of east-central Florida (Baratta, 1990). Geological formation of an area, to some extent, is therefore the determinant of the radionuclide in water. Other sources such as industrial wastes and the use of radioactive substances in soil especially phosphates fertilizers.

Table 2.2: Mean concentration of gross alpha and beta radioactivity in waters from a number of river in the world

S/N	River	Gross α (Bq/l)	Gross β (Bq/l)
1	Severn	0.220	0.410
2	Ebro	0.095	0.213
3	Kankakee	0.078	0.168
4	Sao Rafael	0.020	0.197
5	Fırtına (Turkey)	0.033	0.070

(Kucumeroglu, et al,. 2010)

Some physical and chemical parameters such as volume, depth, chemical composition, and its state (flowing or stagnant) of the water influence the radioactivity of the surface water. In the case of stagnant water like lakes, the depth is very important. Radioactivity concentration in lakes is usually higher than the activity in flowing waters, because a significant part of the radioactive substances brought by the river accumulates in the lakes. To provide the approximate idea of the radioactivity of the water, gross alpha and beta activity is usually measured. The gross

activity does not indicate which nuclide is responsible for the radioactivity measured, which is not a specific-nuclide activity. The result obtained gives only the degree of possible contamination hence cannot be used for direct dose calculation. Gross counting cannot be applied to water containing tritium as it evaporates while heating and the remnant may not contain tritium (Szabo, 1993). The natural radioactivity in water is shown in table 2.2

Table 2.3: Natural radioactivity of water

Type of water	**U-conc. ($\mu g/l$)**	**Activity (mBq/l)**			
		^{226}Ra	^{222}Rn	^{210}Pb	^{210}Po
Rain water	0.3-50	4.6± 0.3	37-3920		
Tape water		5.1± 0.3			
Drinking water		3.7-37			
		26-1850			
Surface fresh water					
Lakes in Finland				0.9-16.7	0.3-8.5
Baltic Sea				0.3-6.8	0.1-8.5
Pacific ocean				0.7-4.8	0.9

(Onoja, 2004)

2.7.1 Maximum acceptable values (MAV) of radioactivity in water

All life on earth is exposed to radiation from natural sources including cosmic radiation; external radiation from natural radionuclides present in soil, rocks and building materials; and internal radiation due to potassium-40 and inhaled radionuclides, particularly radon decay products. Natural radiation exposure varies regionally as the compositions of soils and rocks change, and increases with altitude as comic radiation intensity increases. Radon is a radioactive gas, which emanates from ground and can concentrate in buildings. Use of water can increase the indoor radon concentration, if radon is present in the water supply.

The risk associated with the presence of radionuclides in water is an increase in cancer rate. This prompt for the need to set limits for radiological determinants, so that the radiation exposure resulting from the presence of radionuclides in water represents only a small part of the radiation exposure from natural sources. The maximum permissible contaminant level of radioactivity in water as set by the National Interim regulation of the USEPA, (Milvy and Cothern, 1990) is as follows:

Total alpha concentration: 500 Bqm^{-3}, excluding Rn-222

Total beta concentration: 1,000 Bqm^{-3}, excluding K-40

Radon-222 concentration: 100,000Bqm^{-3}.

In the radiological context, the MAV is intended to indicate a level above which the radioactive content of the water should be investigated further and an assessment of all relevant radiological issues undertaken. The MAV is thus more of a guideline than necessarily an absolute maximum. It is also intended to be clear however, that at levels below the MAV, there is no need for further assessment.

2.8 Alpha activity in the natural radioactivity series

Three isotopes of uranium are known to occur naturally. They are U-234, U-235, and U-238. The relative abundances of U-234, U-235, and U-238 are 0.005%, 0.7110%, 99.283, respectively. Although the abundance of U-234 is much less than the abundance of U-238 on a gravimetric basis, U-234 is in secular equilibrium with U-238, so that when all of the media containing these isotopes is taken into account, the activity of U-234 must equal the activity of U-238.

The alpha activity A of a particular uranium isotope is just

$$A = \lambda N \tag{2.8}$$

Where λ the decay is constant of the uranium isotope and N is the number of atoms of the uranium isotope. And

$$N = m\frac{N_0}{w}, \tag{2.9}$$

Where m is the mass of the uranium isotope, N_0 is Avogadro's number, and w is the atomic weight of the uranium isotope.

If m is the mass of the isotope, m_T is the total uranium mass, and f is the fractional abundance of the uranium isotope, then

$$A = \frac{\lambda}{w}N_0 m = \frac{\lambda}{w}fN_0 m_T \tag{2.10}$$

The total uranium activity A_T is just the sum of three such terms, one from each uranium isotope.

$$A_T = (\frac{\lambda_{U234}}{w_{U234}}f_{U234} + \frac{\lambda_{U235}}{w_{U235}}f_{U235} + \frac{\lambda_{U238}}{w_{U238}}f_{U238})N_0 m_T \tag{2.11}$$

2.9 Interactions of Radiations with Matter

Radiation interacting with matter can be either scattered or absorbed. The mechanisms of the absorption of radiation are of interest because:

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

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

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

a. Ionization: The process resulting in the removal of an electron from an atom, leaving the atom with a net positive charge.
b. Excitation: Addition of energy to an atomic system, transferring it from the ground state to an excited state.

Radiation can be classified into two groups:

i. Particulate radiation (charged particles) such as alpha, beta particles and proton: or Uncharged radiation such as neutron.
ii. Electromagnetic radiation such as X or gamma rays.

2.9.1 Interaction of Charged Particles

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

1. The positively charged atom.
2. The negatively charged electron.

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

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

$$\text{Specific Ionization} = \frac{No\ of\ ion\ pairs\ formed}{cm\ of\ path}$$

The specific ionization is dependent on the velocity of the charged particle (and therefore its energy), and the density of the absorbing material (the number of atoms available for ionization).

2.9.1.1 Alpha Particles

An alpha particle is a helium nucleus stripped of its orbital electrons. It is emitted from a radioactive atom with a velocity of about 1/20 that of the speed of light and with energies ranging from 4 to 9 MeV. Alpha particles cause ionizations in matter when they are deflected by the positive charge of a nucleus and pull the orbital electrons (attracted by the alpha's positive charge) along with them. Alpha particles also cause excitation along their path by pulling inner orbital electrons to outer orbits. No ion pair is formed, but energy is lost from the alpha particle and added to the atom. The added energy is then given off by the atom as fluorescent radiation or low energy X-Rays when the electrons drop back down to the inner orbital vacancies.

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

Since the alpha particle has a very limited range in matter, it presents no external radiation hazard to man. Many alpha particles cannot penetrate the protective layer of skin. However, once

inside the body, surrounded by living tissue, damage will be to the local area in which the alpha emitter is deposited. Thus, alpha emitters are an internal hazard and intake to the body must be prevented.

2.9.1.2 Beta Particles

Beta particles are emitted from the nucleus of a radioactive atom with a wide range of energies up to some maximum value. When a beta is emitted that is below the maximum value, the neutrino carries away the rest of the energy.

Beta particles, like alpha particles, lose their energy by ionization and excitation, but because of their small mass (1/7300 of an alpha) and lower charge (1/2 of that of an alpha) the interactions take place at less frequent intervals. Therefore, the beta particles do not produce as many ion pairs per centimeter of path as alpha particles, and thus, have a greater range in matter. The beta particle's range in matter depends on the energy and the composition of the material.

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

Beta particles require energy of greater than 70 keV to penetrate the protective layer of the skin, and thus, are somewhat of an external hazard. The beta can also constitute an internal hazard. A beta particle has a greater range in tissue compared to an alpha particle due to its low specific ionization. The beta particle gives up less energy per unit volume of tissue and, therefore, is not as effective in causing damage as an alpha particle.

2.9.2 Interaction of X-Rays and Gamma-Rays

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

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

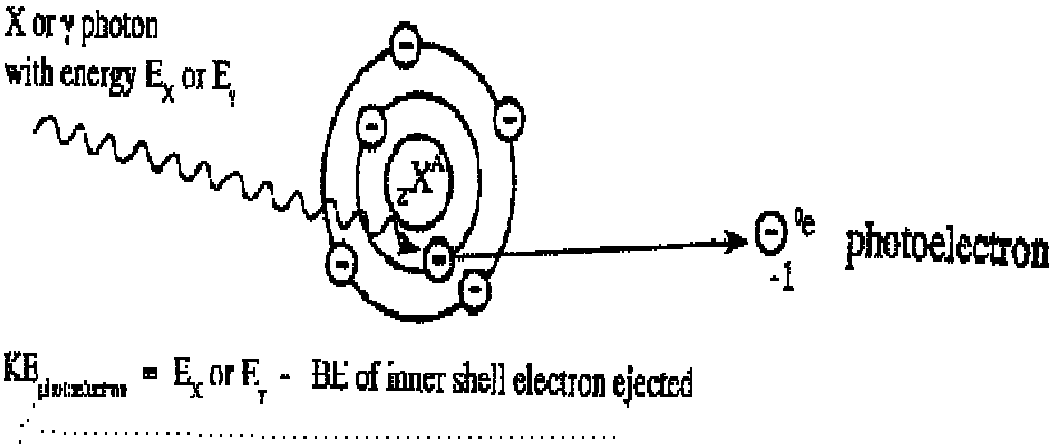
a. The Photoelectric Effect
b. The Compton Effect
c. Pair Production

The high speed electrons resulting from these interactions then cause ionization of the medium.

2.9.2.1 The Photoelectric Effect

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

Fig. 2.2: Photon interaction in photoelectric effect



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

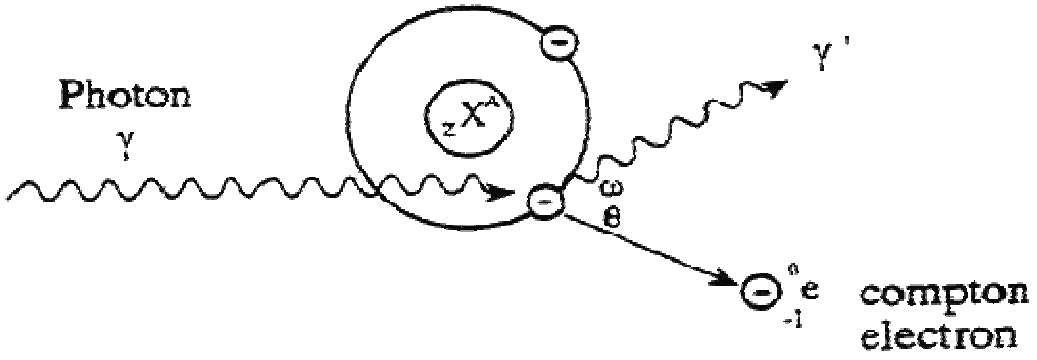
If the X or ϒ-ray photon does not have sufficient energy to knock the inner shell electron loose, the reaction will not occur.

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

2.9.2.2 The Compton Effect

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

Fig. 2.3: Photon interaction in Compton Effect.



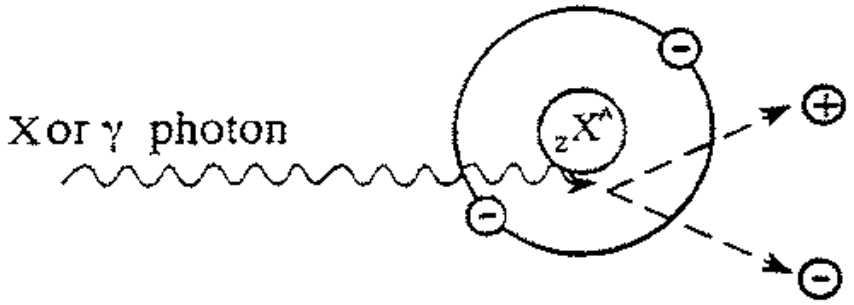
The primary γ-loses part of its energy to the Compton electron which gets scattered at an angle from the original direction of the incident γ, while the Compton scattered γ (γ^1) is scattered at an angle. In this process, the scattered photon and Compton electron share the energy of the incident γ.

The KE carried off by the Compton electron may be deposited locally (i.e., absorbed immediately by the surroundings). However, the energy carried off by the Compton scattered photon is not deposited locally. Therefore, this scattered photon can significantly contribute to the dose outside a shielding apparatus.

2.9.2.3 Pair Production

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

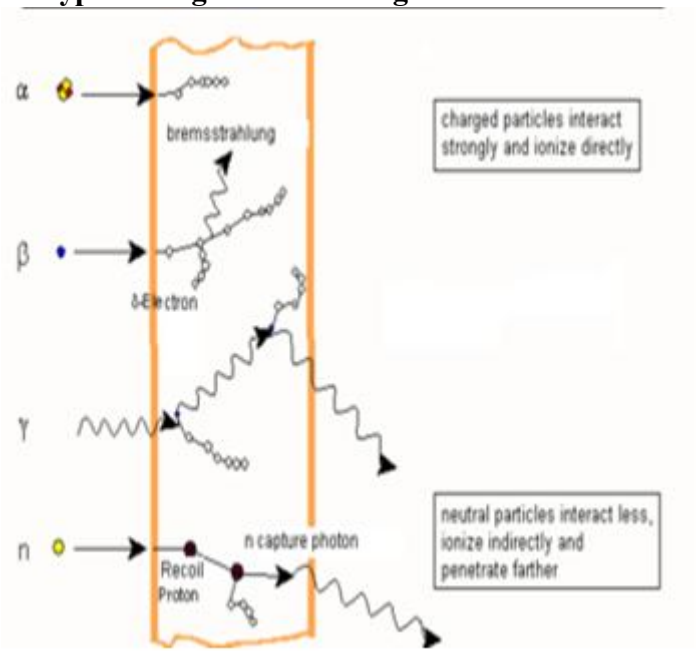
Fig. 2.4: Photon interaction in pair production



Since both particles are created from energy supplied by the incident photon, the process is energetically possible only if $E\gamma$ or E_X is greater than 1.02 MeV.

When the positron slows down (i.e., loses its KE), it will annihilate itself by combining with an electron. This produces two photons with energy of 0.51 MeV each. This "annihilation radiation" represents the energy equivalent of the rest mass of two electrons which is converted to pure energy according to the principles of Einstein's theories, in particular, $E = mc^2$; where E = energy of two 0.51 MeV photons, m = the rest mass of two electrons (1/1840 amu), c = the velocity of light (3×10^8 m/sec).

Fig. 2.5: below is a typical diagram indicating how radiations interact with matter.



Ionization process leaves the atom with net positive charged ions and an electron. Hence, Ionizing radiation has the ability to affect the chemical state of a material and so cause changes which are biologically important, like in the case of incident radiation directly attacking the DNA of the water molecule in which ionizes water molecules and electrons are released. The ionized water molecules can react further forming highly reactive molecules such as hydrogen peroxide, or radicals such as hydroperoxyl. Depending on the received dose, this mechanism may cause damage to living tissue. If the dose is sufficient, the effect may be seen immediately, in the form of radiation poisoning. However, lower dose may cause cancer in long term or it can lower the ability of the body to respond to infections by reducing or interfering with the immune system. Therefore ionization is the process by which a particle of energy interacts and knockout electrons from molecules like water, DNA and proteins leaving it with net positive ions.

2.10 Radiation Dose

A dose here is the quantity of radiation energy received or deposited per unit of mass. A low dose can be classified according its health impact or in comparison to natural background radiation. Background radiation comes from such sources as cosmic ray, radon, radium, and other radioactive material in the earth and has not been shown to have adverse effect. This dose of radiation is considered to be low. For the Low Dose Radiation Research programme , allow dose of acute low-LET(Linear energy transfer) radiation such as x-rays, gamma rays or beta particles is defined as being less than 10 rem or 1Sv (ICRP, 1991).This level of exposure(of less than10 rem) has been at or 4J below the limit of detection for most biological changes observed in the past research.

2.11 Radiation Biological Effect

The interaction between radiation and the body which is 70% water result in the production of highly reactive free radicals (compound of an element with unpaired electron) such as hydrogen peroxide, which are strongly toxic to biological cells and are stable within the cell. These radicals may be removed by the action of some specific enzymes (BEIR, 1980). When a radioactive particle enters the body, it reacts with water which is more than 70% of the total components making the cell. The most important reactions are:

Water is ionized, $H_2O \rightarrow H_2O^+ + e^-$

Positive dissociate immediately, $H_2O^+ \rightarrow H^+ + OH$

Electron is picked up by a neutral H_2O molecule. $H_2o + e^- \rightarrow H_2o^-$

H_2o^- dissociates immediately $H_2O^- \rightarrow H + OH^-$

The free radicals H and OH may combine with like radicals or react with other molecules in solution. The products of the reactions are H^+ and OH^-, H and OH (Alan and Samuel, 1992).

For other particle of high activity, the free OH radicals are formed close enough to enable them combine with free H radicals. This lead to the production of hydrogen peroxide, while the free H^- radicals combine to form gaseous hydrogen

$$OH + OH \rightarrow H_2O_2$$

The hydrogen peroxide is a powerful oxidizing agent and can affect molecule or cells that did not suffer radiation damage directly. If the irradiated water contains dissolved oxygen, the free hydrogen radical may combine with oxygen to form the hydroperoxyl radical (Cember, 1992).

H+$O_2 \rightarrow HO_2$ (non reactive).

Therefore, radiation is seen to produce biological effects by the production of free radicals and hydrogen peroxide in the water of the body fluids. Hydrogen peroxide is strongly to biological molecules and is stable within the cell. It may be removed by a number of enzymes in the cell that are there to specifically protect against this material. There is always a chance that a radioactive particle will score a direct hit on a DNA, but the odds of these are much smaller than the indirect damage due to hydrogen peroxide. Massive radiation damage to a cell usually results in the cell death. It is actually better than a situation in which the cell is damage to the point where the cell's defenses are over whelmed. Here it is possible for the hydrogen peroxide or other fragments to actually damage the cellular mechanism, enzymes, and the like, or damage the DNA itself. If the genes on the DNA responsible for turning off cell division are damage, the cell continues to reproduce without control. This is cancer.

In comparing the damage of various types of radiation, we have to bear in mind which kind of radiation deposit the most energy or do most damage in a small volume of cells. In this regard, the most dangerous is the alpha radiation followed by beta and lastly gamma. The most common effect of radiation is mutation and cancer induction. Radiation can cause damage to DNA, and massive damage alters a gene or set of genes so that the resulting organism reveals the effects of the damage. Fertilized eggs, which have significant damage, simply do not develop. They are sloughed off and aborted spontaneously. In fact, some estimates suggest that almost half of the fertilized cells are lost in this natural process (Cember, 1992). The action of radiation on the cell is classified as either Direct or Indirect as shown in figure 2.3 below:

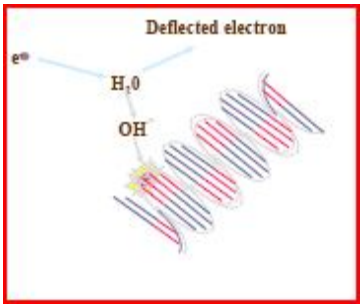


Fig. 2.6(a) Indirect attack

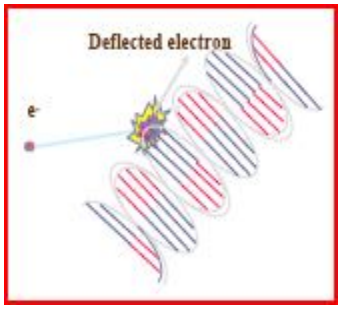


Fig. 2.6(b) direct attack

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

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

2.12 Radiation Health Effect:

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

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

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

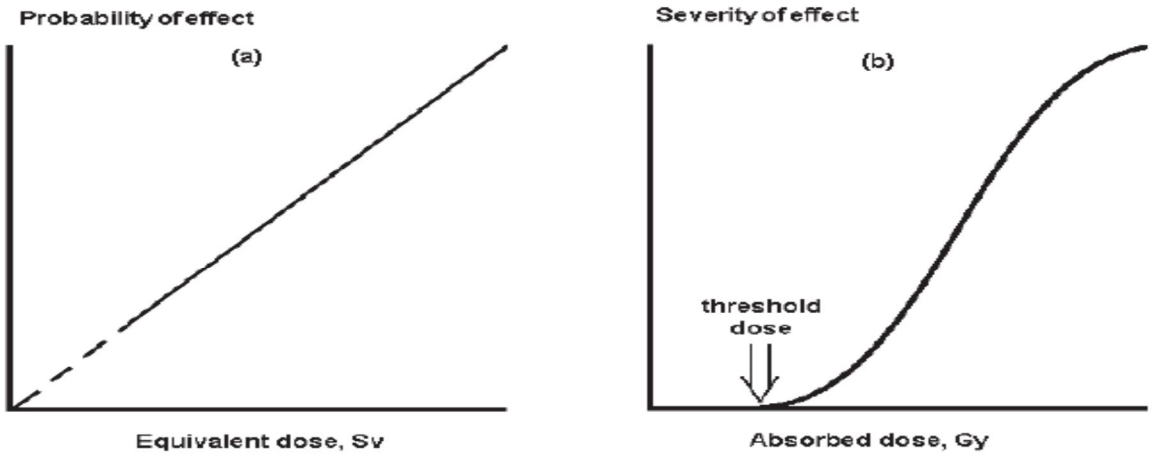


Fig. 2.7 *(IAEA, 2004)*

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

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

Radiation effects are broadly divided into two categories:

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

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

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

The two figures below give common examples of deterministic effect of radiation.



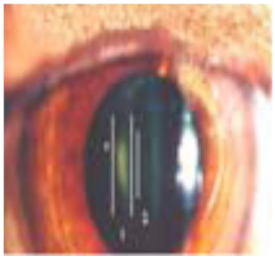


Fig. 2.8a (burn) fig. 2.8b (carrtaract)

Fig. 2.8: Biological effect of ioninig radiation (Adopted from IAEA, 2000)

2.13 Radiation Potential Effects.

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

(a) Acute dose

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

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

(b) Chronic dose

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

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

2.14 Possible Effects of Radiation on Cells:

(a) Cells are undamaged by the dose

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

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

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

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

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

(d) Cells die as a result of the damage

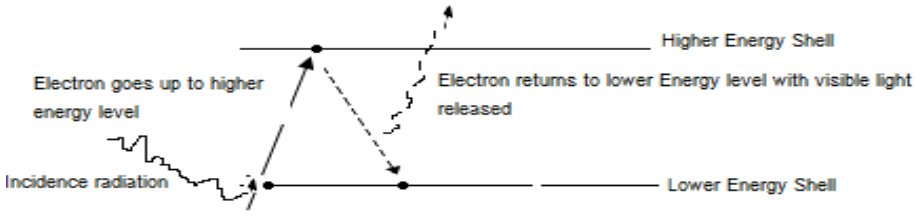
If a cell is extensively damaged by radiation, or damaged in such a way that reproduction is affected, the cell may die. Radiation damage to cells may depend on how sensitive the cells are to radiation.

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

2.15 Scintillation detectors

Historically, scintillation detectors remain one of the available techniques used for detecting radiations. In the early years of nuclear physics, Rutherford and his team used to detect α particles using microscope to view scintillation from Zinc sulphate. The modern scintillation detectors followed from the production of materials that are transparent to their own fluorescent light (phosphor) and the development of photomultiplier tube (PMT) as an extremely sensitive detector of this light. The scintillation detectors rely on the fact that these materials (phosphor) will emit visible light when electrons change energy levels. As a result of interaction of radiation with matter, ionizing radiation can give electrons sufficient energy to move into a higher energy shell. In phosphors, these electrons do not remain in the higher energy level for very long, instead, they fall back to their original level and, as they do so, they emit photons of visible light.

Basic scintillation process is given in figure 2.9 below.



These photons are directed at the photomultiplier tube's photocathode which emits electrons by photoelectric effect. These electrons are electrostatically accelerated and focused by an electrical potential so that they strike the first dynode of the tube. The impact of a single electron on the dynode releases a number of secondary electrons which are in turn accelerated to second dynode. Each subsequent dynode impact releases further electrons, and so there is a current amplifying effect at dynode stage. Each stage is at higher potential than previous to provide the accelerating field. The resultant output signal at the anode is in the form of a measurable pulse for each photon detected at the photocathode, and is passed to the processing electronics. The pulse carries information about the energy of the original incident radiation on the scintillator. Thus both intensity and energy of the radiation can be measured. Fig. 2.10 shows a schematic scintillation (phosphor detector) counter assembly of the experimental set-up.

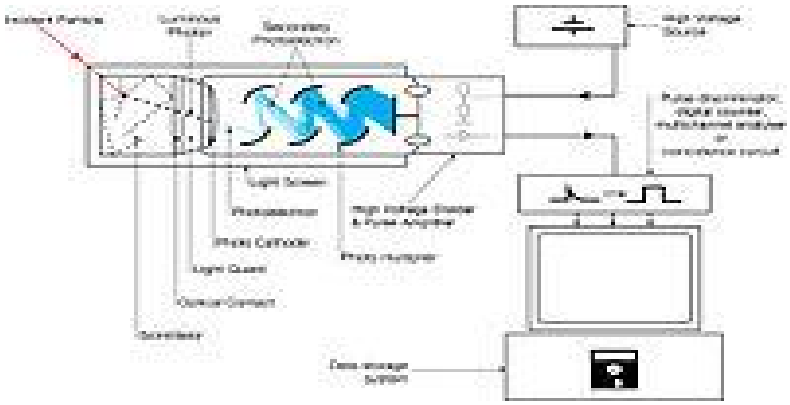


Fig.2.10: A simplified scintillation (phosphor detector) counter Experimental set-up.

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

2.16 Gamma Spectrometric measurement

A popular method for the detection of gamma rays involves the use of crystal scintillators. When used as gamma ray detector, the scintillator does not directly detect the gamma rays. Instead the gamma rays produce charged particles in the scintillator crystals that interact with the crystal and emit photons. These photons (of lower energy) are subsequently collected by photomultiplier tubes (PMTs). When gamma rays pass trough matter, they can undergo three basic processes which are; Compton scattering, photo- electric, or pair production. Each of these processes can create high-energy electrons or anti-electrons (positrons), which interact in the scintillator as charged particles. By adding up the energy collected in the surrounding photomultiplier tube, we can determine the energy of the gamma ray detected (IAEA, 1990).

In gamma spectrometry, the characteristic photon energy is measured and used to quantify the different radionuclides in the sample. The count rate in distinct energy windows for the gamma of a particular radionuclide is recorded. In a gamma spectrometer, the characteristic photon energy is measured to quantify radionuclides of interest. This is done by recording the net count in distinct energy windows specific for gamma radiation energy of a particular radionuclide. Some systems use 3 more energy windows depending on the nature of the analysis.

2.17 Secular Equilibrium

Secular equilibrium is phenomenon observed when a radioactive parent isotope decays via one or more daughter isotopes to a stable product, and is only observed if the parent has a longer (very much greater) half-life than any of its intermediate daughters.

Under these conditions a series of radioactive equilibrium are set up so that the rate of decay of the parent isotope equals that of each of the daughters, which there equals the rate of formation of the stable product. The decay chain is then said to be in a state of secular equilibrium (Potts, 1987). In other words, if the half-life of the parent is at least 10 times greater than that of the daughter and if there is essentially no change in the activity of the parent during the experimental observation, then the condition of secular equilibrium is attained (Ehmann and Vance, 1991). In this situation, the activity from daughter of an initially pure parent will grow in or increase until it is exactly equal to that of the parent. Hence, when secular equilibrium has been achieved, the daughter will decay at exactly the same rate as the parent (Kathren, 1985).

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

$$N_1\lambda_1 = N_2\lambda_2 = \cdots .. N_n\lambda_n \quad 2.12$$

is satisfied. In this equation, $N_1, N_2 \ldots .. N_n$ are the number of atoms of the nuclide 1, 2, …….n and $\lambda_1, \lambda_2, \ldots \ldots \ldots \lambda_n$ are respective decay constants (Potts, 1987). When U and Th are deposited, each daughter will attain equilibrium with its parent ^{238}U or ^{232}Th in a time dependent on its half-life. The nuclides with short half-lives will reach equilibrium first, so that by the time the longest lived daughter reaches equilibrium, the whole series must have reached equilibrium as well. Therefore, the time required for the whole series to reach equilibrium is determined by the equilibrium time of the daughter with the longest half-life (Dewu, 1993).

2.18 Alpha/ beta Counter

Alpha/ beta counter is one of the solid state radiation detectors that operates based on scintillation process. It uses a scintillation crystal (phosphor) to detect radiation and produce pulse. As radiations interact with the scintillation crystal, energy is transferred to bound electrons of the crystal's atoms. If the energy transferred is greater than the ionization energy, the electron enters the conduction band and is free from the binding forces of the parent atom. In phosphors, these electrons do not remain in the higher energy level for very long, instead, they fall back to their original level and, as they do so, they emit photons of visible light.

2.19 Review of Previous Works

Some works have been done in the field of radioactivity in water from different parts of the world including Nigeria in the past. Some of these works include:

Arkian et al, (2006) measured the gross alpha and beta radioactivity in the surface air of Tehran Nuclear Research Centre in Iran. The gross alpha and beta activity concentration was found to range from 71.04-121.20 and 174.91-305.46 respectively. Similar work was done by Dogru et al,

in the ground water of Van Lake in Turkey for which activity concentration was found to range from 630-782 and 21-816 Bqm^{-3} respectively. Mahesh (2001) in his study to determine the concentration of ^{222}Rn in ground waters of coastal Karnataka and Kaiga of South Western Coast of India. His result revealed that the concentration of ^{222}Rn in open well water to range from (0.14 to 25.4 BqL^{-1}) with a mean value of (3.75BqL^{-1}) and that of borehole water in the range of (0.22 to 197 BqL^{-1}).Gross alpha and beta activities in water samples of Firtina River in the eastern black sea region of Turkey has been measured by Kucukomeroglu et al., (2009). The overall result showed that the gross beta activities were higher than the corresponding gross alpha activities. The result show that these activity concentration did not exceed the recommended levels by WHO and ITS. El-Daly T.A., and Hussaini A.S., (2008).Studied the concentration of radionuclides ^{238}U, ^{232}Th and ^{40}K in soil and sediment samples from North Western desert of Egypt using gamma spectroscopy. The measurement results indicate that the region has background radioactivity levels within natural limits. Cothern and Lappenbush (1990) measured uranium in ground and surface water in the USA and reported that many of the community drinking water supplies exceeded a uranium concentration of 370 and 185 Bq L^{-1} limits by USAEPA and WHO respectively. Surveyed of lake Ontario by Bawaja *et al*. (1987) reported that uranium and ^{226}Ra levels were in an average of $0.7x10^{-6}$ and 1.2 m Bq L^{-1}, respectively while in Lake Michigan, Nelson and Metta (1983) measured the levels of ^{232}Th and obtained an average value of $28x10^{-6}$ Bq L^{-1}. Research by Ramasamy et al., (2009) to determine the distribution of radionuclides ^{238}U, ^{232}Th and ^{40}K in beach sediment samples along north east coast of Tamilnadu, India using a NaI(TI) gamma ray spectrometric technique. The mean activity concentrations of measured radionuclides were compared with other literature values.

Avwiri, (2003) uses the gamma ray spectrometry to study the radionuclide concentration levels in soil and water samples around Eagle, atlas and Rock cement companies in Port Harcout. The average absorbed dose rates of the soil samples were found to be (49.27nGyh^{-1}, 45.2 nGyh^{-1} and 42.3 nGyh^{-1}), for Eagle, Atlas and Rock cement respectively. While the water values were (22.16 nGyh^{-1}, 20.75 nGyh^{-1} and 19.37 nGyh^{-1}) for the respective companies. Mean dose rate equivalent of 0.18 mSvy^{-1}, and 0.39mSvy^{-1} were obtained for the water and soil samples. Natural radionuclides level have also studied in surface soils in Ijen-Ekiti (Ajayi, et al 1995), in soil and water around cement company in Ewekoro by Jibiri, et al (1991) and in rocks in Ekiti by Ajayi, et al (1991) in all these studies a non- significant level of radioactivity was observed. In their study of gross alpha and beta activity in Okpare- Creek Delta state Nigeria, Avwiri and Agbalagba (2007) show that the average alpha activities in the farming, residential/commercial and industrial zones are 1.003± 0.097, 4.261± 0.109 and 10.296± 0.489 Bq/L respectively. The average beta activities in the three zones are 0.129± 0.100, 0.523± 0.003 and 0.793± 0.0110 Bq/L, respectively. The overall result showed that the alpha and beta activities in the three zones are far below the practical screening level for both alpha and beta. Ekpo and Inyang (2000) determine radioactivity, physical and chemical parameters of underground and surface water in Qua Iboa River Estuary. Odogu (2001) in his studies to determine the concentration of trace elements in commercial water supplies and heavy metals in fadama water, soil and vegetation, his result could not give the actual concentration of alpha and beta radiations in water. Avwiri *et al*. (2005) surveyed the radionuclide concentration of soil, sediments and water in Aba River, Nigeria and reported that the results obtained for the observed radionuclide isotopes were below international standard and concluded that the river has no radiological burden on the populace.

Tajudeen (2006) measured the gross alpha and beta activity concentration in well water from Gwammaja in Kano State of Nigeria. The results indicated very low alpha and beta activity concentrations with a range of 2.06-11.48 Bqm^{-3} for alpha and 2.00-17.75 for beta.

Onoja, (2004) surveyed gross alpha and beta radioactivity in well water from Zaria area of Kaduna state Nigeria. The result indicated the range of alpha activity in well water to be between 0.58 to 43.19 Bqm^{-3} with geometric mean of 6.35± 0.45 Bqm^{-3} and that of beta activity to be between 3.58 to 622 Bqm^{-3} with a geometric mean of 75.34± 1.53 Bqm^{-3} the values were below the practical screening level of radioactivity in drinking water of 500 Bqm^{-3} for alpha and 1000 Bqm^{-3} for beta as recommended by CEC, FAO and WHO. Juliet (2006) also measured the gross alpha and beta radioactivity in River Kaduna and reported a mean value of 0.117±0.002 and 0.439±0.006 Bq L^{-1} for alpha and beta activity, respectively. The overall results in this research work showed that both alpha and beta activities are below the WHO practical screening level of radioactivity in drinking water. (Gide, 2008) reported that activity concentration for both alpha and beta in groundwater from Katsina Metropolis ranges between 80± 5 Bqm^{-3} to 2300± 41 $Bqm^{-3}$and 120± 8 Bqm^{-3} to 4970± 78 Bqm^{-3} respectively, this indicates elevated areas of activities when compared with values of ICRP (1991).

CHAPTER THREE

MATERIALS AND METHOD

3.1 Materials and software

(a) Sampling materials: 15 Plastic containers- (2 litres), Disposable hypodermic syringe (20ml) dilute nitric acid, Thermometer, Indelible pen and masking tape, Polyethene bags for sediment samples and Ickmang grab device.

(b) TDS experiment materials: Cellulose membrane filtration (0.45μm pore size), Filtration apparatus, Mechanical suction pump, Analytical balance (0.1 mg), Measuring cylinder, beakers and evaporating dish.

(c) Sample preparation materials: Hot plate for evaporation, vinyl Acetate, ethanol for even spread of the sample in the planchette, sources for alpha and beta standards, deionized water, planchette (0.3m in diameter, 0.002 thickness), candle wax and Vaseline.

(d) Analytical systems

Gamma ray spectrometry system

Alpha/beta detecting system

3.2 Water Samplings

To measure radioactivity in river Yobe, a total of fifteen (15) water samples were collected in a period of low water level during dry season using GPS (Global Positioning System) to record the exact position of the sampling sites. Four (4) samples each were collected in an area where

farming, fishing and domestic/livestock activities is very high along the course of the river while three samples were collected from control area.

Samples were collected in 2 litre polyethene bottles with tight covers which were carefully washed in a laboratory and rinsed three times with the sample water to be sure that sample collected are representative of the bulk. These samples were collected at the bank of the river an area where there is less dilution of the washout from the surrounding environment. The samples at the time of collection were acidified with few drops of dilute nitric acid to pH 2 (15mL per litre) to preserve the water from biological growth and chemical action with the surface of the container and transferred to laboratory.

3.2.1 Total Dissolved Solids (TDS) calculation

Certain amount of (100ml) V_A of each sample was filtered with suction pump using cellulose membrane (0.45μm pore size). The filtrate was transferred to porcelain evaporating dish of mass M_d in grams and evaporated to dryness on a hot plate. The mass of evaporating dish and dried residue M_c was obtained. Total dissolved solids (TDS) for each sample was calculated in mg/l using the formula (ISO 9697, 1992).

$$\text{TDS} = \frac{M_c - M_d}{V_A} \times 10^6 \qquad 3.1$$

The value of the TDS for each sample was used to calculate the volume of sample V_p which when evaporated will give a mass of residue corresponding to 0.1A mg where A in the area of planchette which is as follows:

$$V_p = \frac{0.1A}{TDS} \times 10^6 \qquad 3.2$$

Sample efficiency for each sample was calculated as:

$$sample\ efficiency = \frac{M_T}{0.1A} \times 100\% \quad 3.3$$

Where M_T is the mass of residue in the planchette got from sample preparation and 0.1A (mg) is the expected mass of the residue in the planchette.

3.2.2 Sample Preparation

In the laboratory, the calculated sample volume for each was measured in a beaker slowly evaporated using hot plate at a temperature range of $50℃ - 60℃$ till required residues were obtained. Few drops of vinyl Acetate were added to the sample during evaporation to act as a binder to prevent precipitation of source of the radionuclides in the sample. Difference of mass of empty planchette and that of planchette and residues was recorded as mass of residue to be counted. Drops of ethanol were used to provide uniform spread of residue on the planchette. The residues were allowed to dry and then covered with Mylar film, stored for a period of at least 28 days to attain secular equilibrium after which is ready for counting.

The gross activities of alpha and beta were estimated using low background (gas free) desktop alpha/ beta detector (Model: MPC 2000-DP, SERIAL NO: 01872140) single channel analyzer (Protean Instrument Corporation) at Health physics division, Center For Energy Research and Training Zaria.

3.3 Sediment Samplings.

Bottom sediment were collected from the 15 different locations from the areas mentioned above in a period of low water levels during the dry season from the middle of the water bodies so that undisturbed sediments could be taken (Kabir,et al., 2008).Using Ickmang grab device (Bureau

technique Wintgen (BEW) Eupen/Belgium). Each about 300g wet weight placed in polyethene bag, labeled and transferred to the laboratory.

3.3.1 Sample Pretreatment: In the laboratory, samples were transferred to stainless steel buckets and dried in an oven at 100-105^{0}C for 3 days (Kabir,et al., 2008). Each of the sediment samples were crushed to fine powder with the use of a pulverizer homogenized and sieved to pass through meshes (1mm mesh). The process was followed by packaging into plastic containers selected based on the space allocation of the detector vessel. A 3-stage sealing system was made for each of the packaging to prevent radon -222 escapes; smearing of the inner rims of each container lid with Vaseline wax, filling the lid assembly gap with candle wax to block the gaps between lid and container, and finally the lid-container was tightly sealed with a masking adhesive tape. The so prepared samples were then stored for a period of about 35 days for attainment of secular equilibrium.



Fig. 3.1 prepared sediment samples

3.4 Instrumentation

The instruments used for gamma spectroscopy was NaI(Tl) which consists of a 7.62cm by 7.62cm Na(Tl) detector optically coupled to a photomultiplier tube (PMT).The stated set-up is then incorporated with NIM Bin consisting of preamplifier, amplifier and MCA system. Fig. 3.2 shows a simplified NaI(Tl) detector Assembly of the Experimental set-up.

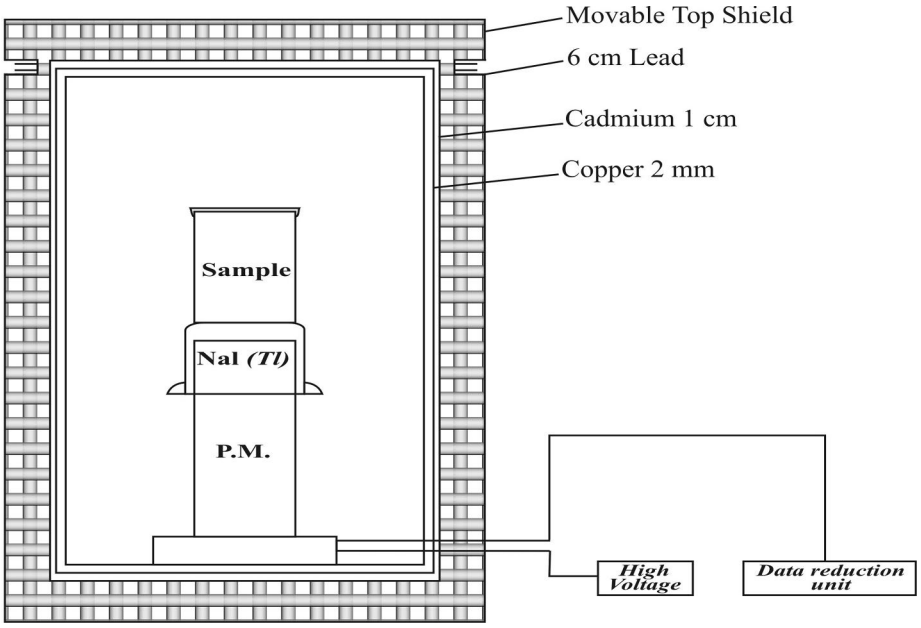


Figure 3.2 A simplified NaI(Tl) detector Assembly of the Experimental set-up.

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

In this particular work, differential spectrometry is employed in three channels. The ^{40}k channel which is determined from the 1460keV energy peak, the ^{238}U channel of 1764keV energy peak and the ^{232}Th channel having energy peak of 2614keV.

Table 3.1 Spectral Energy windows used in analysis using NaI (Tl) gamma spectroscopy system

Element analyzed	Isotope Used	Ray Energy(KeV)	Energy windows(KeV)
Th	^{208}Tl	2614.5	2460-2820
U	^{214}Bi	1764.0	1620-1820
K	^{40}K	1460.0	1380-1550

3.5 Activity concentration

The activity concentrations in the samples were obtained using the equation 3.4 (Obed, *et al*., 2005; Jibiri *et al.,*, 2007):

$$C(Bqkg^{-1}) = kC_n \qquad 3.4$$

where $k = \frac{1}{\varepsilon P_\gamma M_s}$, C is the activity concentration of the radionuclide in the sample given in Bqkg^{-1}, C_n is the count rate under the corresponding peak, ε is the detector efficiency at the specific γ-ray energy, P_γ is the absolute transition probability of the specific γ-ray, and M_s is the mass of the sample (*kg)*. The below detection limit (BDL) of a measuring system describes its operating capability without the influence of the samples. The BDL given in Bqkg^{-1} which is required to estimate the minimum detectable activity in samples was obtained using equation (3.5), (Jibiri *et al.,* 2007):

$$DL(Bqkg^{-1}) = 4.65\ \frac{\sqrt{C_b}}{t_b}k \qquad 3.5$$

where C_b is the net background count in the corresponding peak, $t_b$is the background counting time (s) and k is the factor that converts counts per second (cps) to activity concentration (Bqkg^{-1}) as given in equation (3.4)

All the obtained raw data were converted to convectional units using conversion factors of 8.632×10^{-4}, 8.768×10^{-4} and 6.431×10^{-4} for ^{40}K, ^{226}Ra and ^{232}Th respectively to determine their activity concentrations. With the counting time of 29,000 seconds for each sample, the environmental γ-ray background of the laboratory site was determined using an empty container under identical measured conditions. This then gave the below detectable limit (BDL) limits to be 14.54 $Bqkg^{-1}$ for ^{40}K, 3.84 $Bqkg^{-1}$ for ^{226}Ra and 9.08 $Bqkg^{-1}$ ^{232}Th respectively. This was subtracted from the measured γ-ray spectrum of each sample.

3.6 Calibration Factors (CF)

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

$$\left.\begin{aligned} CF\ ^{40}K &= \frac{cps(40_k)}{ppm(40_K)} \quad \text{or} \quad \frac{cps(40_k)}{Bq(40_K)/kg} \\ CF\ ^{226}Ra &= \frac{cps(226_{Ra})}{ppm(226_{Ra})} \quad \text{or} \quad \frac{cps(226_{Ra})}{Bq(226_{Ra})/kg} \\ CF\ ^{232}Th &= \frac{cps(232_{Th})}{ppm(232_{Th})} \quad \text{or} \quad \frac{cps(232_{Th})}{Bq(232_{Th})/kg} \end{aligned}\right\} \qquad 3.6$$

(Ibeanu ,1999).

Based on the above, the obtained calibration factors for this work were entered into table 3.4 and subsequently the activities at calibration were used to arrive at current activities of the radioisotopes.

The calibration factors (CF), were obtained from the experimental works of Ibeanu (1999) on the same instrument and same set of radionuclides. The resulting table from the stated work on the calibration factor is as below;

Table 3.2 Energy calibration for Quantitative spectra analysis

Isotope	**Calibration Factor**			**Detection Limit**	
	$X10^{-3}$cps/ppm	$X\ 10^{-4}$cps/Bqkg^{-1}	Conversion Factor (Bqkg^{-1}/ppm)	ppm	Bq/kg
^{40}k	0.026	6.431	0.032	454.54	14.54
^{226}Ra	10.500	8.632	12.200	0.32	3.84
^{232}Th	3.612	8.768	4.120	2.27	9.08

Source: (Ibeanu, 1999)

3.7.1 Calculation of absorbed dose rate from measured activity concentrations for sediments

Radiation emitted by a radioactive substance is absorbed by any material it encounters. (UNSCEAR, 2000) has given the dose conversion factors for converting the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K into dose (nGyh^{-1} per Bqkg^{-1}) as 0.427, 0.662 and 0.043, respectively. Using these factors, the total absorbed dose rate in air is calculated as given in the Equation (3.7) (UNSCEAR, 2000).

$$D = (0.427C_{Ra}+0.662C_{Th} + 0.043C_K)\ nGyh^{-1}, \qquad 3.7$$

Where C_{Ra}, C_{Th} and C_K are the activity concentrations (Bqkg^{-1}) of radium, thorium and potassium, respectively in the samples.

3.7.2 Calculation of annual effective dose from sediment

The estimation of the annual effective dose rates, depended on conversion coefficient from absorbed dose to effective dose, 0.7 SvGy^{-1} and outdoor occupancy factor of 0.2 as proposed by (UNSCEAR, 2000). The effective dose rate in units of mSvy^{-1} was calculated by the following formula in equation (3.8)

Effective dose rate ($mSvy^{-1}$) = D ($nGyh^{-1}$) x 8760h x 0.2 x 0.7$SvGy^{-1}$ x 10^{-6} 3.8

3.7.3 External hazard index (Hex)

Radiation exposure due to ^{226}Ra, ^{232}Th and ^{40}K may be external. This hazard, defined in terms of external hazard index or outdoor radiation hazard index and denoted by H_{ex}, can be calculated using the equation (3.9) (Beretka and Mathew, 1985):

$$H_{ex} = \frac{C_{Ra}}{370} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \quad 3.9$$

where C_{Ra}, C_{Th} and C_K are the activity concentrations ($Bqkg^{-1}$) of radium, thorium and potassium, respectively as obtained in the analyzed samples. The value of this index should be less than 1 mSvy^{-1} in order for the radiation hazard to be considered acceptable to the public.

3.7.4 Internal hazard index (H_{in})

The internal hazard index (H_{in}) gives the internal exposure to carcinogenic radon and is given by equation (3.10), (Beretka and Mathew, 1985):

$$H_{in} = \frac{C_{Ra}}{185} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \quad 3.10$$

The value of this index should be less than 1 $mSvy^{-1}$ in order for the radiation hazard to have negligible hazardous effects to the respiratory organs of the public (Beretka and Mathew, 1985):

3.8 Protean MPC-2000 Dual Phosphor (DP) Counter

The protean MPC 2000- DP is a convenient and versatile “benchtop” alpha/beta radiation sample counter equipped with a dual phosphor scintillator type detector that supports gasless operation and easy portability. The dual phosphor detector gets its name from the use of ZnS(Ag) that is

adhered to a thin disk plastic scintillation. The detector is supplied with an alminium window. The assembly is coupled to a photomultiplier tube and encased in a light tight enclosure. The dual phosphor detector provide excellent alpha-beta efficiency, albeit not at the same performance level of the gas flow detectors, only voltage is required to count a sample. Figure 3.5 shows MPC-2000-DP detector used and the prepared samples at Center For Energy Research and Training Zaria.



Fig. 3.3a (MPC-2000 Desktop Alpha/Beta Counter)

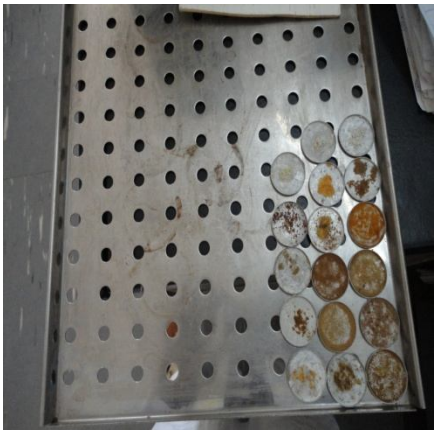


Fig. 3.3b (prepared samples in a planchette)

3.9 Data presentation

3.9.1 Alpha - Activity

The alpha activity was expressed as activity concentration C in Becquerel per litre (Bq/l), using the formula (ISO 9696: 1992 E) as follows:

$$C = \frac{R_n \times a_s \times m \times 1.02}{R_b - R_0 \times 1000 \times V} \qquad 3.11$$

Where

R_n is the count rate per second corrected for background counts.

Thus, $$R_n = R_b - R_0$$

R_b is the observed sample count rate in count per second.

R_0 is the background planchet count rate in counts per second.

a_s is the specific activity of the alpha standard

is the volume of the sample evaporated in litre.

Mass in mg of the residue from volume and 1.02 is included to correct for 20ml of nitric acid added per litre as a stabilizer.

3.9.2 Beta –Activity: The gross beta activity was expressed as activity Concentration C in (Bq/l) using the equation (ISO 9697: 1992E) as:

$$C = \frac{R_n \times a_s \times 14.4 \times m \times 1.02}{R_b - R_0 \times 1000 \times V} \qquad 3.12$$

Where: —— represent the specific activity of ^{40}K in KCl, all other terms have their usual meanings.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

Radioactivity measurement in water, soil and sediment in many parts of the world has been on increase in the past two decades because of hazard on the health of the populace (Belivermis et al., 2009). While the above is the case, the research into radiological measurement in water and sediment of North-Eastern Nigeria is grossly at the lowest ebb. To open focus on this area, gamma spectrometric was carried out on the sediment samples collected from the four areas (fishing, farming, domestic/livestock and control area) to determine the concentration of radium-226, thorium-232 and potassium-40 and their corresponding radiological impacts for each was also computed. The areas were named zone A (fishing), zone B (farming), zone C (domestic/livestock) and zone D as control zone.

As a measure to ensure that the hazard assessments covers an acceptable range, gross alpha and gross beta measurement was carried out on the water samples collected to identify concentration of each radiation with a view of predicting possible hazards from ingestion of their sources..

4.2 Activity Concentration in Sediments

Radionuclides concentration for the collected sediment samples indicates the nature of human activities in the area as well as geological formation for the area studied. Table 4.1 summarizes the specific activity of ^{226}Ra, ^{232}Th, and ^{40}K in the sediments in Bq/kg.

Table 4.1 **Specific Activity of Radionuclides (Zone A)**

SAMPLE CODE	SAMPLE NUMBER	K-40 (Bq/kg)	Ra-226 (Bq/kg)	Th-232 (Bq/kg)	TOTAL	LOCATION
S-A1	1	169.517± 10.88	10.440± 0.97	44.127± 0.71	224.084± 12.56	$N12^0$51.72 $E11^0$02.13
S-A2	2	266.407± 9.33	23.407± 0.03	43.672± 1.37	333.486± 10.73	$N12^0$51.67 $E11^0$02.10
S-A3	3	196.111± 6.22	7.763± 0.11	50.855± 3.42	254.729± 9.75	$N12^0$51.56 $E11^0$02.17
S-A4	4	402.332± 9.95	16.106± 0.05	59.064± 1.25	477.502± 11.25	$N12^0$51.45 $E11^0$02.29
Mean	-	258.592± 9.10	14.429± 0.29	49.430± 1.69	322.451± 11.08	
Range	-	169.517 - 402.332	7.763 - 23.407	43.672 - 59.064	224.084 - 477.502	

KEY: - S = sediment, A = zone A, B = zone B, C = zone C

The activity ^{40}K is distinctly higher than the ^{226}Ra and ^{232}Th and it ranges between 169.517± 10.88 Bq kg^{-1} and 402.332± 9.95 Bq kg^{-1} with mean activity of 258.592± 9.10 Bq kg^{-1}. The ^{232}Th concentration ranges from 43.672 ± 1.37 Bq kg^{-1} to 59.064 ± 1.25 Bq kg^{-1} with a mean activity of 49.430± 1.69Bq kg^{-1}. The ^{226}Ra concentration ranges from 7.763 ± 0.11 Bq kg^{-1} to 23.407 ± 0.03 Bq kg^{-1} with a mean activity of 14.429± 0.29Bq kg^{-1}.

Table 4.2 **Specific Activity of Radionuclides (Zone B)**

SAMPLE CODE	SAMPLE NUMBER	K-40 (Bq/kg)	Ra-226 (Bq/kg)	Th-232 (Bq/kg)	TOTAL	LOCATION
S-B1	1	488.180± 8.08	1.506± 0.17	57.240± 1.14	546.926± 9.39	$N12^0$51.67 $E11^0$02.43
S-B2	2	447.900± 6.84	13.673± 0.04	20.068± 1.25	481.641± 8.13	$N12^0$51.68 $E11^0$02.56
S-B3	3	419.906± 9.33	4.403± 0.08	73.090± 1.60	497.400± 11.01	$N12^0$51.71 $E11^0$02.72
S-B4	4	524.883± 12.44	56.779± 0.03	65.484± 1.14	647.146± 13.61	$N12^0$51.76 $E11^0$02.84
Mean	-	470.217± 9.17	19.090± 0.08	53.971± 1.28	543.278± 10.55	
Range	-	419.906 - 524.883	1.506 - 56.779	20.068 - 73.090	481.641 - 647.146	

The activity ^{40}K is distinctly higher than the ^{226}Ra and ^{232}Th, it ranges between 419.906 ± 9.33 and 524.883 ± 12.44 Bq kg^{-1} with mean activity of 470.217± 9.17 Bq kg^{-1}. The ^{232}Th concentration ranges from 20.068 ± to 73.090 ± 1.60 Bq kg^{-1} with a mean activity of 53.971± 1.28 Bq kg^{-1}. The ^{226}Ra concentration ranges from 1.506 ± 0.17 to 56.779 ± Bq kg^{-1} with a mean activity of 19.090± 0.08Bq kg^{-1}.

Table 4.3 Specific Activity of Radionuclides (Zone C)

SAMPLE CODE	SAMPLE NUMBER	K-40 (Bq/kg)	Ra-226 (Bq/kg)	Th-232 (Bq/kg)	TOTAL	LOCATION
S-C1	1	196.112± 2.02	17.560± 0.15	23.420± 0.38	237.092± 2.55	N12^{0}50.20 E10^{0}59.43
S-C2	2	375.734± 9.33	24.565± 0.06	52.793± 0.48	453.092± 9.87	N12^{0}50.51 E10^{0}58.64
S-C3	3	207.620± 0.77	17.265± 0.03	18.175± 3.19	243.060± 3.10	N12^{0}50.48 E10^{0}58.80
S-C4	4	398.289± 10.1	4.056± 0.22	70.923± 0.57	473.268± 10.90	N12^{0}50.77 E10^{0}58.65
Mean	-	294.441± 5.56	15.861± 0.12	41.328± 1.16	351.628± 6.61	
Range	-	196.112 - 398.289	4.056 - 24.565	18.175 - 70.923	237.092 - 473.268	

The activity ^{40}K is higher than the ^{226}Ra and ^{232}Th and it ranges between 196.112± 2.02 Bq kg^{-1} to 398.289 ± 10.01 Bq kg^{-1} with mean activity of 294.441± 5.56 Bq kg^{-1}. The ^{232}Th concentration ranges from 18.175 ± 3.19 Bq kg^{-1} to 70.923 ± 0.57 Bq kg^{-1} with a mean activity of 41.328± 1.16 Bq kg^{-1}. The ^{226}Ra concentration ranges from 4.056 ± 0.22 Bq kg^{-1} to 24.565 ± 0.06 Bq kg^{-1} with a mean activity of 15.861± 0.12 Bq kg^{-1}.

Table 4.4 **Specific Activity Of Radionuclides (Zone D)**

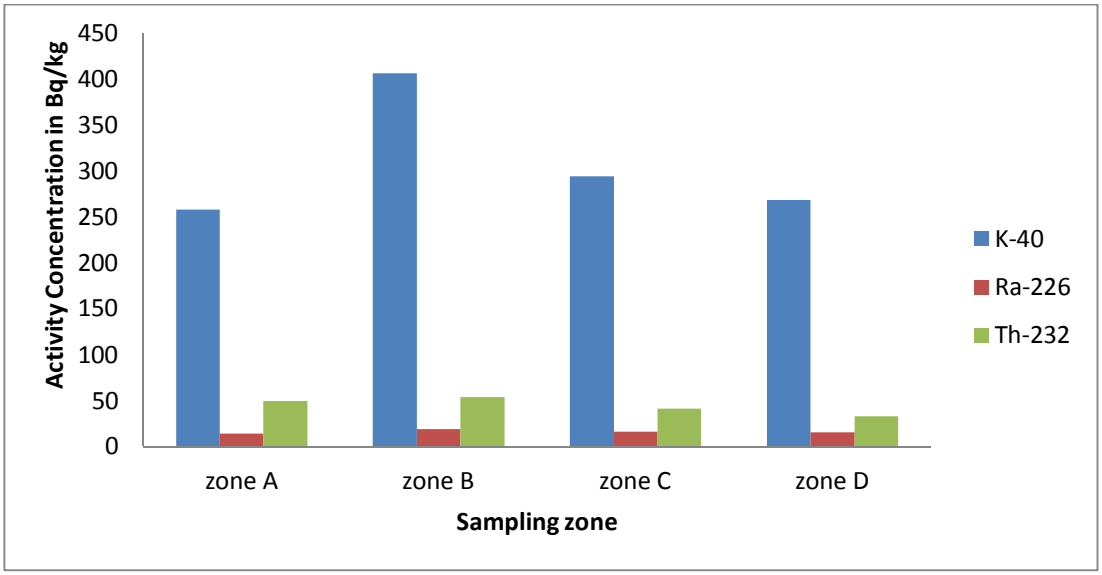
SAMPLE CODE	SAMPLE NUMBER	K-40 (Bq/kg)	Ra-226 (Bq/kg)	Th-232 (Bq/kg)	TOTAL	LOCATION
S-D1	1	264.852± 10.89	14.020± 0.02	35.803± 1.14	314.675± 12.05	$N12^{0}51.88$ $E11^{0}02.67$
S-D2	2	303.421± 9.33	16.918± 0.06	41.277± 1.82	361.616± 11.21	$N12^{0}51.85$ $E11^{0}02.66$
S-D3	3	239.035± 3.11	15.990± 0.12	22.041± 0.34	277.066± 3.57	$N12^{0}51.91$ $E11^{0}02.96$
Mean	-	269.103± 7.78	15.643± 0.07	33.040± 1.10	317.786± 8.94	
Range	-	239.035 - 303.421	14.020 - 16.918	22.041- 41.277	277.066 - 361.616	

The activity ^{40}K higher than the ^{226}Ra and ^{232}Th and it ranges between 239.035± 3.11 Bq kg^{-1} and 303.421± 9.33 Bq kg^{-1} with mean activity of 269.103± 7.78 Bq kg^{-1}. The ^{232}Th concentration ranges from 22.041 ± 0.34 Bq kg^{-1} to 41.277 ± 1.82 Bq kg^{-1} with a mean activity of 33.040± 1.10 Bq kg^{-1}. The ^{226}Ra concentration ranges from 14.020 ± 0-02 Bq kg^{-1} to 16.918 ± 0.06 Bq kg^{-1} with a mean activity of 15.643± 0.07 Bq kg^{-1}.

4.3 AVERAGE DISTRIBUTIONS OF ^{226}RA, ^{232}TH AND ^{40}K FOR THE FOUR AREAS

Fig. 4.1 presents the bar chart of the average activity concentration of ^{226}Ra, ^{232}Th and ^{40}K as obtained during the spectrometry for the four zones of sediment collected.

Fig. 4.1 Average activity concentration of ^{40}K, ^{226}Ra and ^{232}Th for the four zones



It is observed that potassium-40 is having a relatively higher concentration ranging from a mean value of 258.592± 9.10 Bq kg^{-1} to 470.217± 9.17Bq kg^{-1} in all the zones with the highest mean concentration in farming zone of 470.217± 9.17 Bq kg^{-1} followed by Thorium-232 ranging from 33.040± 1.10 Bq kg^{-1} to 53.971± 1.28 Bq kg^{-1} with highest mean concentration of 53.971± 1.28 Bq kg^{-1} also in the farming zone. Radium-226 is the one having the least concentration ranging from 14.429± 0.29 Bq kg^{-1} to 19.090± 0.08 Bq kg^{-1} with highest mean value of 19.090± 0.08 Bq kg^{-1}. For the entire zones, activity concentration of ^{40}K in zone B is higher when compared to those of ^{226}Ra and ^{232}Th respectively. The elevated concentration of potassium-40 and thorium-232 in farming zone could be attributed to the use of agrochemicals such as NPK fertilizer for agricultural practice.

4.3.1 ABSORBED DOSE RATE, ANNUAL EFFECTIVE DOSE EQUIVALENT, EXTERNAL AND INTERNAL HAZARD INDICES FOR SEDIMENT

The absorbed dose rates due to gamma rays in air at 1 m above ground surface for the activity concentration from ^{226}Ra, ^{232}Th and ^{40}K in the sediments were obtained and calculated based on guidelines provided by (UNSCEAR, 2000) using equation (3.7).

Table. 4.5 Absorbed dose and hazard index for sediment in A zone

SAMPLE NUMBER	SAMPLE CODE	Absorbed dose Rate ($nGyh^{-1}$)	Effective dose Rate ($mSvy^{-1}$)	External hazard Index (H_{ex})	Internal hazard Index (H_{in})
1	S-A1	40.95919	0.502323	0.233833	0.322603
2	S-A2	50.36115	0.617629	0.287266	0.322603
3	S-A3	45.41358	0.556952	0.258104	0.322603
4	S-A4	63.27791	0.77604	0.355221	0.322603
	Min	40.95919	0.502323	0.233833	0.262050
	Max	63.27791	0.77604	0.355221	0.322603
	Mean	50.00296	0.613236	0.283606	0.322603

Table 4.5 presents the dose rate, effective dose equivalent, external and internal hazard indexes for A zone. The absorbed dose values ranges from 40.9$nGyh^{-1}$ to 63.28$nGyh^{-1}$ with an average of 50.00$nGyh^{-1}$. The effective annual dose rate was obtained from equation (3.8), and the values ranges from 0.502$mSvy^{-1}$ to 0.776 $mSvy^{-1}$ with an average value of 0.613$mSvy^{-1}$.

The external (H_{ex}) and internal (H_{in}) hazard indices, which represent the risk associated from exposure of these radionuclides in the sediments was calculated using equation (3.9) and (3.10) respectively. Which has a (Min. of 0.23, Max. 0.35 with an overall average value of 0.28) and (Min. of 0.26, Max. of 0.32 and average of 0.32) for the external and internal hazard indices respectively.

Table 4.6 Absorbed doses and hazard index for sediment in B zone

SAMPLE NUMBER	SAMPLE CODE	Absorbed dose Rate ($nGyh^{-1}$)	Effective dose Rate ($mSvy^{-1}$)	External hazard Index (H_{ex})	Internal hazard Index (H_{in})
1	S-B1	59.52768	0.730047	0.326567	0.330637
2	S-B2	38.38309	0.47073	0.207555	0.244509
3	S-B3	68.32162	0.837896	0.381399	0.393299
4	S-B4	90.16501	1.105784	0.515414	0.668871
	Min	38.38309	0.47073	0.207555	0.244509
	Max	90.16501	1.105784	0.515414	0.668871
	Mean	64.09935	0.786114	0.357734	0.409329

Table 4.6 presents the dose rate, effective dose equivalent and external and internal hazard indexes for B zone. The absorbed dose values ranges from 38.3$nGyh^{-1}$ to 90.16 $nGyh^{-1}$ with an average of 64.09$nGyh^{-1}$. The effective annual dose rate was obtained to ranges from 0.47 $mSvy^{-1}$ to 1.10$mSvy^{-1}$ with an average value of 0.78$mSvy^{-1}$.

The external (H_{ex}) and internal (H_{in}) hazard indexes, has a (Min. of 0.207, Max. 0.515 with an overall average value of 0.357) and (Min. of 0.244, Max. of 0.668 and average of 0.409) for the external and internal hazard indices respectively.

Table 4.7 Absorbed doses and hazard index for sediment in C zone

SAMPLE NUMBER	SAMPLE CODE	Absorbed dose Rate ($nGyh^{-1}$)	Effective dose Rate ($mSvy^{-1}$)	External hazard Index (H_{ex})	Internal hazard Index (H_{in})
1	S-C1	31.43498	0.385519	0.178656	0.226115
2	S-C2	61.59478	0.755398	0.348341	0.414733
3	S-C3	28.33167	0.34746	0.16000	0.206662
4	S-C4	65.80937	0.807086	0.367601	0.378563
	Min	28.33167	0.34746	0.160000	0.206662
	Max	65.80937	0.807086	0.367601	0.414733
	Mean	46.7927	0.573866	0.263649	0.306518

Table 4.7 presents the dose rate, effective dose equivalent, and external and internal hazard indexes for C zone. The absorbed dose values ranges from 28.33$nGyh^{-1}$ to 65.80$nGyh^{-1}$ with an average of 46.79 $nGyh^{-1}$. The effective annual dose rate was obtained to ranges from 0.34 $mSvy^{-1}$ to 0.80 $mSvy^{-1}$ with an average value of 0.57$mSvy^{-1}$.

The external (H_{ex}) and internal (H_{in}) hazard indices, has a (Min. of 0.16, Max. 0.36 with an overall average value of 0.26) and (Min. of 0.20, Max. of 0.41 and average of 0.30) for the external and internal hazard indices respectively.

Table 4.8 Absorbed doses and hazard indices for sediment in D zone

SAMPLE NUMBER	SAMPLE CODE	Absorbed dose Rate ($nGyh^{-1}$)	Effective dose Rate ($mSvy^{-1}$)	External hazard Index (H_{ex})	Internal hazard Index (H_{in})
1	S-D1	41.07676	0.503765	0.23119	0.269082
2	S-D2	47.59646	0.583723	0.268176	0.313901
3	S-D3	31.69738	0.388737	0.178012	0.221228
	Min	31.69738	0.388737	0.178012	0.221228
	Max	40.12353	0.583723	0.225793	0.313901
	Mean	40.12353	0.492075	0.225793	0.26807

Table 4.8 presents the dose rate, effective dose equivalent and external and internal hazard indexes for D zone. The absorbed dose values ranges from 31.69nGyh^{-1} to 40.12nGyh^{-1} with an average of 40.12nGyh^{-1}. The effective annual dose rate was also obtained to range from 0.38mSvy^{-1} to 0.58mSvy^{-1} with an average value of 0.49mSvy^{-1}.

The external (H_{ex}) and internal (H_{in}) hazard indices, has a (Min. of 0.17, Max. 0.22 with an overall average value of 0.22) and (Min. of 0.22, Max. of 0.31 and average of 0.26) for the external and internal hazard indices respectively.

The absorbed dose rates in all the zones fall within the worldwide value range which is from 18nGyh^{-1} to 93nGyh^{-1} and the average absorbed dose rate is greater than the average worldwide population weight value from absorbed dose rate in outdoor air, 43nGyh^{-1} (UNSCEAR, 2000).

The effective annual dose rate is also less than the average annual dose limit set for radiological assessment which is 1mSvy^{-1}. The external (H_{ex}) and internal (H_{in}) hazard indices, which represent the risk associated from exposure these radionuclides in the sediments indicates that the risk associated with sediments sample is quite below the limit set by (ICRP, 2000) for radiological exposure protection to the public which is unity. However care has to be taken since it is believed that radiation at any given level pose a risk.

4.4 ALPHA AND BETA ACTIVITY CONCENTRATION IN WATER SAMPLE

Gross alpha and beta activity concentration analysis for the collected water samples is presented in table 4.9. The alpha activity concentration have an average value of 0.153± 0.06 Bq L^{-1} in the fishing zone (A), in the farming zone (B), the activity concentration have an average value of 0.638± 0.06 Bq L^{-1}, the average concentration value in zone (C) is 0.207± 0.04. In the control zone (D), the average concentration value of 0.207± 0.07 Bq L^{-1} was obtained. The beta activity

concentration have an average value of 0.245± 0.02 Bq L^{-1} in the fishing zone, in the farming zone, the activity concentration have an average value of 0.679± 0.05 Bq L^{-1}, the average concentration value in zone (C) is 0.399± 0.03 Bq L^{-1}.In control zone (D), the average concentration value of 0.293± 0.05 Bq L^{-1} was obtained.

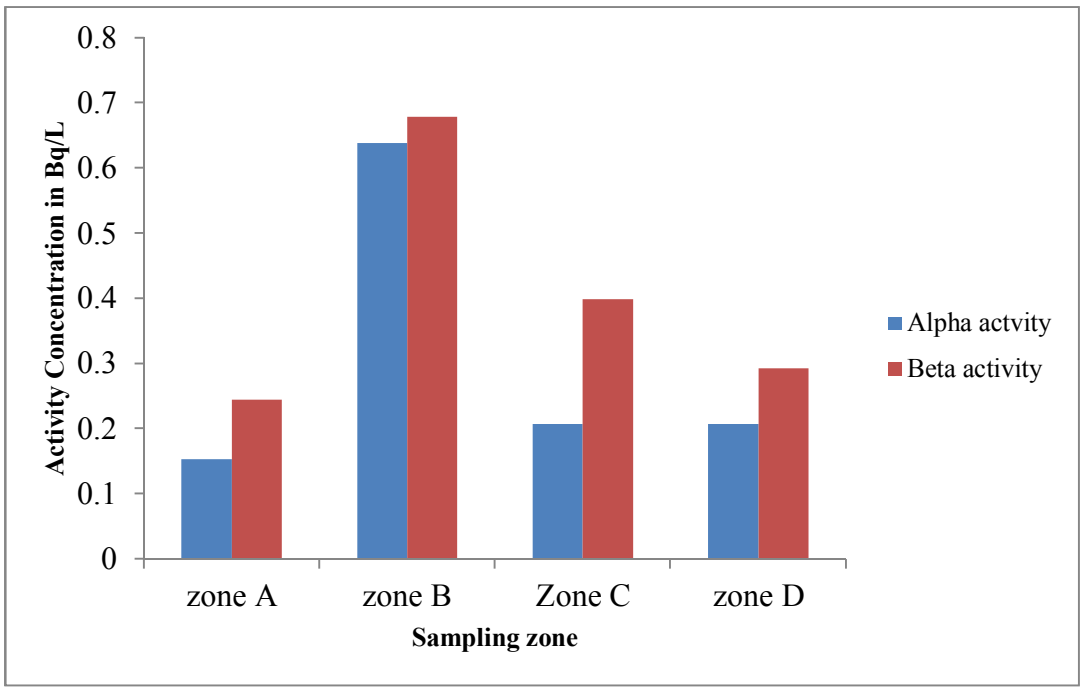
Table 4.9 Alpha and Beta Activity Concentration in Water Sample collected

S/N	SAMPL ID	Alpha Activity in Bq/L	Beta Activity in Bq/L
1	W-A1	0.207±0.03	0.240±0.04
2	W-A2	0.117±0.04	0.151±0.04
3	W-A3	0.098±0.06	BDL
4	W-A4	0.191±0.09	0.589±0.01
5	W-B1	0.55±0.02	0.062±0.04
6	W-B2	0.807±0.05	0.895±0.03
7	W-B3	0.451±0.01	0.588±0.04
8	W-B4	0.745±0.17	0.707±0.11
9	W-C1	0.395±0.02	0.606±0.04
10	W-C2	0.024±0.01	0.354±0.02
11	W-C3	0.379±0.08	0.574±0.03
12	W-C4	0.031±0.03	0.062±0.04
13	W-D1	BLD	0.254±0.03
14	W-D2	0.284±0.03	BDL
15	W-D3	0.339±0.06	0.061±0.08
Mean		0.308± 0.05	0.374± 0.05
Max		0.807± 0.05	0.895± 0.03
Min		0.024± 0.01	0.062± 0.04

It can be seen from the above table that the gross beta activity is generally higher than the corresponding gross alpha activity in all zones while alpha activity concentrations is highest in

the farming zone. It was determined that the total α and total β activity concentrations for all water samples except in three locations of the farming zone (WB1,WB2 and WB4) are lower than 0.5 Bq /L and 1 Bq/L respectively. These levels are recommended by WHO. Water from this river is used by people of that area as a source of drinking water for their livestock, farming, fishing as well as domestic activities. Hence, water taken from the river except the farming zone is suitable for drinking.

Fig 4.2: Average alpha/beta activity distribution in the zones



CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

The activity concentration value obtained for the sediments in this study were found to be within the acceptable limits. Most of the values obtained were lower than the world's average values. The ranges of the values obtained are 14.429±0.29 $Bqkg^{-1}$ to 19.090±0.08 $Bqkg^{-1}$ for ^{226}Ra, 33.040±1.10 to 53.971±1.28 $Bqkg^{-1}$ for ^{232}Th and 258.592±9.10 $Bqkg^{-1}$ to 470.217±9.17 $Bqkg^{-1}$ for ^{40}K with the sediments. The calculated average absorbed dose rate (47.782$nGyh^{-1}$) in air due to gamma ray from the studies on these sediments was found to be 11.12% greater than the world measure average 43$nGyh^{-1}$ while the average effective dose (0.585 $mSvy^{-1}$) is found to be 41.5% less than the world average value of 1$mSvy^{-1}$ (UNSCEAR, 2000). Likewise the average hazard indexes (0.27 and 0.31) obtained for both external and internal exposure respectively do not exceeded the limits of 1$mSvy^{-1}$ set by (UNCEAR, 2000). Therefore the river's sediment does not pose much or any threat to the public, though no radiation is said to be safe.

Radioactivity in the surface water of river Yobe could due to agricultural practice and other domestic activities within or by the river side. It is assumed that the gross alpha activity derived mainly from Uranium and radium and its alpha daughters which are contained in some of agrochemicals such as fertilizers, and that of gross beta was mostly due to ^{40}K, ^{226}Ra beta daughters and ^{90}Sr (Osmond and Carwart, 1992).

The enhancement of gross beta activity in the farming zone is mainly due to the increase in potassium concentration. Agricultural fertilizers products contain various trace of elements such as uranium and thorium decay series members and ^{40}K (NCRP, 1987). The use of fertilizers in

agricultural areas can increase the concentration of these natural radionuclides in the soil. Therefore, the possible sources of gross beta activity are the runoff of fertilizers from agricultural practice in this area.

5.2 RECOMMENDATIONS

i. There is need to extend this study to cover the entire river's sediment as well as to have a comprehensive radiological study of the entire water ways that activate it. This is due variations of human activities along the river's coarse and geologic formation and radiations depend mostly on it.

ii. There is need to carry out gross alpha and gross beta activity of groundwater to ascertain the possible source (s) leading to the renal failure and kidney diseases in the area.

iii. Different types of crops (such as roots and tubers, fruits, legumes, vegetables and cereals) and weeds grown in the area of study should be collected and analyzed.

iv. There is need for seasonal study of the radioactivity of the river in the mentioned zones to check whether the radioactivity is affected by seasons.

v. There needs to enforce existing public health law, to safeguard the lives of the inhabitants and aquatic lives.

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