RADIOACTIVITY LEVELS AROUND THE JOS TIN MINES AND MILLS

BY

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DECLARATION

I hereby declare that this Thesis is an original work carried out by the author under the supervision of Dr. I.M. Umar, Centre for Energy Research and Training, Ahmadu Bello University, Zaria.

To the best of my knowledge no part thereof has been submitted for the award of degree or diploma. Others work is duly acknowledged and referenced.

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CERTIFICATION

This thesis entitled "Radioactivity Levels Around the Jos Tin Mines and Mills" by Rabiu Nasiru meets the regulations governing the award of the degree of Master of Science of the Ahmadu Bello University and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

I dedicate this work to my Mother and Father.

ACKNOWLEDGEMENT

First and foremost I am grateful to Allah, worthy of praise for his countless favours to me.

Adequately I can not say or mention the assistance, guidance, suggestion and correction rendered to me by the Supervisors Dr. I.M. Umar and Prof. S.B. Elegba, CERT, A.B.U. Zaria. Absolutely, I had gained much research-wise from their scholarly supervision which I didn't know before. I'm indeed grateful to them.

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ABSTRACT

Cassiterite, the most common tin bearing mineral is associated with a number of mineral impurities such as monazites, zircon, thorite and xenotime which contain radioactive U and Th that may constitute radiological hazard. The interest of this work is therefore to determine the level of radiological hazards associated with the activities of tin mining and milling. To this end, 55 samples of soil, minerals, plants and water collected around the Jos tin mines and mills were analysed for gross radioactivity using G-M tube and liquid scintillation counter in the case of water samples. The gross activity of the soils and plant range from 0.1 - 6.0 Bq/g and that of the water sample range from 0.1 - 0.3 cps. The highest activity was recorded in the monazite waste (95.9 Bq/g) and zircon (77.4 Bq/q) samples. Nine of the soils and minerals samples that were found to have appreciable activity were subsequently analysed using 3" x 3" Nal(Tl) detector coupled to a computer and the U and Th concentrations were determined. The U and Th concentrations range from 61 - 2042 ppm and 104 ppm to 2.7% respectively. The dose contribution from the U and Th were then calculated. The doses obtained were found to be within the maximum permissible dose of 5 rem/yr (50 mSv/yr) for radiation workers except in two cases where doses of 37 rem/yr (370 mSv/yr) and 79 rem/yr (790 mSv/yr) were obtained. But, all were found to be higher than the maximum permissible dose of 0.5 rem/yr (5 mSv/yr) for the general population. This makes monitoring around the tin mines and mills mandatory. However, this will only be possible when the necessary laws on radiation protection are made by the Government.

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CHAPTER ONE

GENERAL INTRODUCTION

1.1 INTRODUCTION

The Jos Plateau area is about 18,122 km² in extent and is situated in the central part of Northern Nigeria, at Latitude 9°52'N and longitude 8°54'E as shown fig 1.1. It is sited on a rugged terrain of lowlands at the edge of the highest plateau surface, (Hyde, 1986).

Four groups of rocks comprise the geology of Jos-Plateau: the basement complex, the younger granites, the older basalts and younger basalts.

Geologically the area is dominated by the younger granites a series of non-orogenic intrusive associated acid volcanics. Thus the plateau forms the focal area of Younger Granites Province and is the principal centre of tin and columbite mineralization (Macleod and Turner, 1971).

The tin deposits are distributed over an extensive area well over 25,889 km². The bulk of the output of tinstone is derived from alluvial concentration shed from the Younger Granites and particularly from the large granitic massifs of the plateau. This alluvials and detrital deposits are of varied types, owing to different conditions during different geologic times under which they were formed. Some accumulated before the elevation of the plateau in which they are found and have remained in their original area of deposition. Others have been removed and redeposited by streams forming and reforming and changing their

channels. Still yet other deposits result from the denudation of part of the ore bodies after the uplifting of the plateau. These are now found in the present river beds and flats on the river banks. Hollows or pockets filled with rich stanniferous gravels occur in the channels of rock streams. Sharp angular tinstone in quantities of economic importance occur on weathered outcrops of stanniferous quartz, pegmatite veins and other mineralized rocks.

Tinstone occurs in different mineral forms. But the major tin ore in Jos Plateau is the cassiterite (Macleod and Turner, 1971). It is generally associated with acid igneous rock, mostly granites and it is the most important ore of tin which accounts for practically all the industrial production of tin.

Frequently tinstone is associated with a number of mineral impurities which contained certain amount of Th and U. These radioactive substances are brought to the surface of the earth as a result of mining and milling activities, hence serve as a source of radiation hazard.

About two decades ago the area was reported to be of high radioactivity (Sanni 1970). An attempt was also made to estimate the concentration of Th and U in this area using Ge(li) detector by (Sanni et al, 1985 and Banwo, 1989). Similar studies were also made for tin mines and mills in Malaysia by (Hu et al, 1981, 1985 1987 and Chong et al 1985).

The present work adds up to the previous studies made by analysis of water and plants materials in addition to soils and minerals. A NaI(Tl) detector which is more efficient though poorer in resolution was used for the determination of Th and U concentrations. An attempt was

also made to estimate the dose contribution due to Th and U in this area.

1.2 CASSITERITE

Cassiterite has a chemical formula SnO_2 and is made up of 78.8% Sn. Frequently tinstone is associated with a number of minerals impurities (Betekhtin, 1979 and Mantell, 1970) among these are:

1.2.1 ZIRCON

Zircon has a chemical formula $ZrSiO_4$ and is made up of 67.1% ZrO_2; (Zr 49.5%), SiO_2 32.9%. Zircon always has a slight admixture of Fe_2O_3 (up to 0.35%) and more), often CaO (0.05 to 4%) and sometimes Al_2O_3. It always contain hafnium oxide (HfO), sometime up to 4% and may contain Y_2O_3 and rare earths, chiefly Ce_2O_3 (hagatalite) sometime up to 16% with P_2O_5 content of 4 to 5% (amagutilite), certain varieties may contain Nb and Ta (neagile), ThO_2 up to 7% and even 12% (hogtueitile) and also U_3O_8, up to 1.5% or more. Occasionally zircon contains negligible Sn and Be (except in alvite, the content of BeO + Al_2O_3 may reach 15%).

Generally, zircon occurs as small, rare disseminated crystals in magmatic intrusive rocks; nepheline synenites, granites, diogranitic pegmatities. In Jos Plateau it occurs as an accessory mineral in the biotite and riebeckite granites, recovered as a by product of tin and columbite mining containing about 3% thoria.

1.2.2. THORITE

Thorite has a chemical formula $ThSiO_4$. It contains about 10 to 16% Th at times with a higher water content. Also contains rare earths, CaO up to 13% of Fe_2O_3 etc.

It is usually formed in the latest stages of crystallization of certain acidic and alkaline magnetic rocks. In Jos Plateau, it occurs in a similar fashion as zircon.

1.2.3 MONAZITE

Monazite has a chemical formula (Ce, La, Th and Ca) [PO_4, SiO_4, SO_4]. The content of oxides of rare earth (chiefly Ce and La) may be as high as 50 to 68% and an isomorphous admixture of Y_2O_3 (up to 5%). P_2O_5 content in monazite may be as high as 22 to 31.5%. Often it contains an isomorphous admixture of ThO_2 (5 to 10%, sometimes as high as 28%) in some instances ZrO_2 (up to 7%) with SiO_2 (up to 6%) and sometimes CaO accompanied by SO_3. MgO, MnO, PbO, Fe_2O_3, Al_2O_3 and H_2O may also be present, but usually in insignificant amounts.

Monazite usually occurs in pegmatites, sometimes in granites and gneissens in paragenesis with feldspars, zirconium ($ZrSiO_4$), in some cases with magnetite, ilmenite and other minerals. In Jos Plateau, it is found to occur in biotite granite in small amount with a widespread alluvial distribution and contains between 6 to 7% thoria.

1.2.4 XENOTIME

Xenotime has a chemical formula YPO_4. Having Y_2O_4 (63%). Commonly it contains small amounts of rare earth (Eu and Le) sometimes ThO_2, UO_2 (up to 5%), ZrO_2 (up to 3%), SnO_2, SiO_2 (up to 9%) etc..

Xenotime occurs in granites and pegmatites as small disseminated crystals often in association with zircon, with which it may develop oriented intergrowth with apatite, orthite, monazite and others. In Jos Plateau, it occurs in biotite granite but appears to be restricted to the columbite rich granites of Jos-Bukuru complex.

1.3 TIN MINING ACTIVITIES

Tin mining and smelting in Jos Plateau, Nigeria started many centuries before European occupation. But major exploitation of the tinfields started after the discovery of the rich alluvial deposits of Jos Plateau in the beginning of the present century (Catvert, 1977).

Many centuries back, mining in Jos-Plateau was done by primitive hand method through tribute labour. But after European occupation, mining by large scale, highly mechanized operations was introduced. To date these two methods are going hand in hand. At present, the mining is done in small scale largely by contractors, since most of the machines used in highly mechanized operations are no more functional. In fact the exploitation of the tinfield is highly relaxed from what it was in the beginning of this century.

The mining method in adoption in Jos Plateau is the open-pit (gravel pump) method. This method requires a delivery of the entire overburden and the stanniferous earth to the sump in the pit flow.

Working faces are thus continuous from the floor to the surface and assume a roughly circular shape around the sump as a centre. The method usually involves hand work to break the materials from the bank, ground sluices to carry the materials to a sumps, pumps to elevate the material and washing troughs for concentrations. Impounding dams are built around the tailings, the water running, backs into the pit and through ground sluices along the base of the working face.

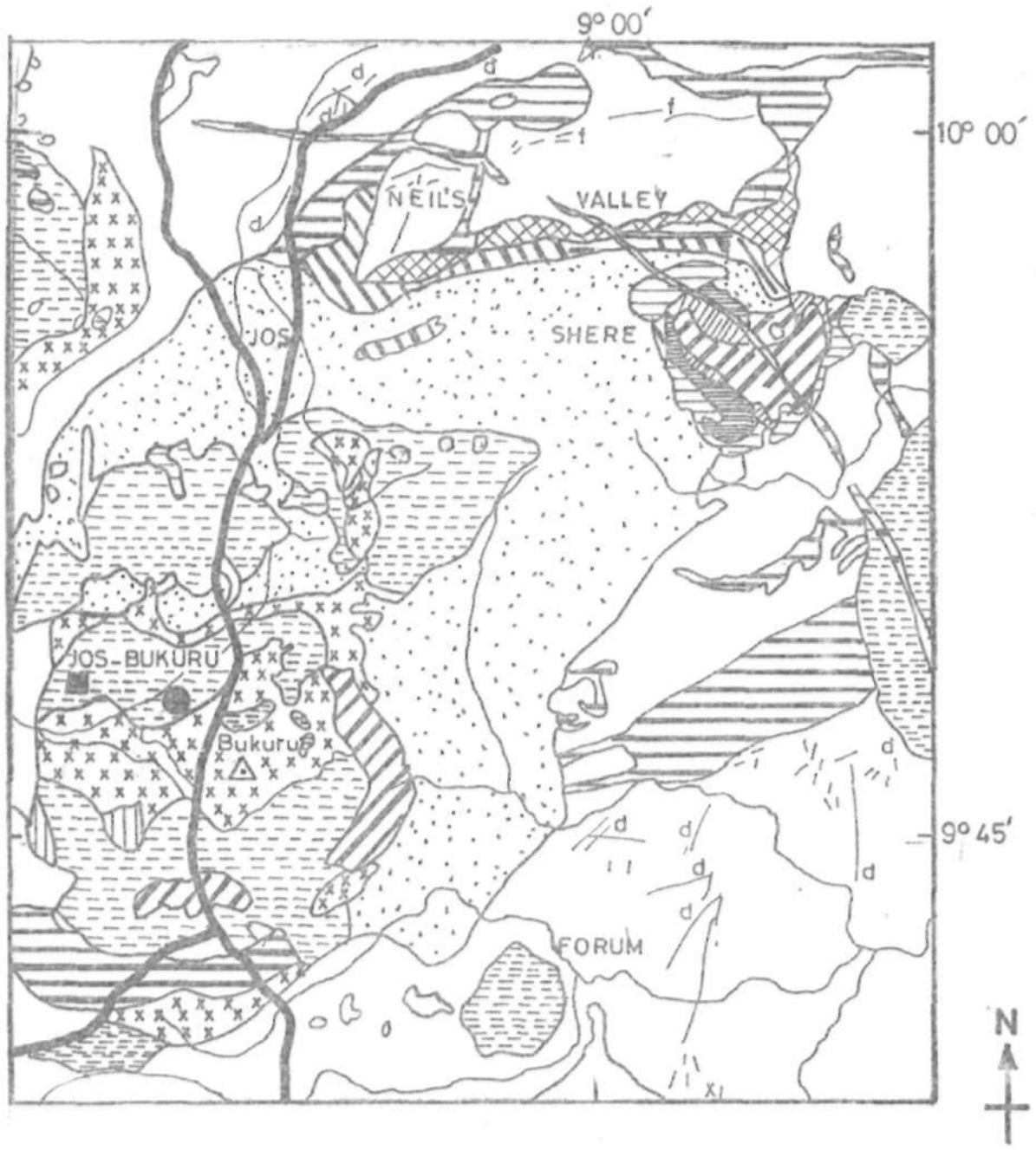
1.4 ENVIRONMENTAL IMPACTS OF MINING

The fact that tinstone (cassiterite) is associated with allied mineral impurities such as zircon, monazite and thorite which contained U and Th indicates the radiological hazard of tin mining and milling. As a result of these activities, the environment may become contaminated through which plants, animals and man may be affected. People working around this area can affected by:

i. Airborne radioactivity, as a result of inhalation of radon and its daughter and long-lived alpha emitter present in mine atmosphere in the form of dust. So also is the presence of concentration of Th in mine dust and its long-lived daughter products in the working atmosphere in addition to gaseous daughter, thoron.

ii. External radiation: as a result of beta and gamma radiation emitted from the ore bodies.

iii. Surface contamination; as a result of dust deposited on surfaces in the mines and mills. This can contribute to airborne activity and also a source of external radiation due to daughter product activities. Contamination hazard may also result from direct ingestion from contaminated water or food grown around the area concerned.



L E G E N D

- Albite-riebeckite-granite
- Riebeckite- aegranite
- Riebeckite-biotite-granite, riebeckite-biotite-granite-porphyry
- Biotite-microgranite
- Biotite-granite-(Group III, Rayfield-Gona type)
- Biotite-granite-(Group II, Ngell type)
- Dolerite dyke
- ML 11929
- Mill
- Biotite-granite (Group I, Jos type)
- Hornblende-, pyroxene-fayalite-granite
- Granite-porphyry, hornblende-biotite-granite
- Quartz-porphyry, quartz-fayalite-porphyry
- Early rhyolite, tuff and agglomerate
- Basement Complex
- Felsite or acid porphyry dyke
- ML 4552 MJ

FIG·M: THE GEOLOGICAL MAP OF JOS PLATEAU SHOWING AREAS WHERE SAMPLES ARE COLLECTED

CHAPTER TWO

RADIOACTIVITY

2.1 INTRODUCTION

An atomic nucleus can undergo a variety of processes resulting in the emission of radiation of some form. This processes occur due to either natural radioactive decay or nuclear reactions, (Cork, 1950 and Leo, 1987).

2.2 RADIOACTIVE DECAY

In a radioactive transformation , the nucleus spontaneously disintegrates to different species of nuclei or to a lower energy state of the same nucleus with emission of radiations. This disintegration obeys a statistical law of chance such that the number of atoms disintegrating per second (dN/dt) is directly proportional to the number of atoms, N, present at that instant. Hence:

$$\frac{dN}{dt} \propto -N \quad \text{or} \quad \frac{dN}{dt} = -\hat{e}N \qquad \ldots.2.01$$

where ê is the decay constant. It is different for different radionuclide.

Now suppose N_o is the number of radioactive atoms present at t = 0 and N is the number at the end of a time `t', we have by integration

$$N = N_o e^{-\hat{e}t} \qquad .....2.02$$

Therefore when $N = N_o/2$, $t = T_{\frac{1}{2}}$ (half-life) are substituted in equation 2.02, we get:

$$T_{\frac{1}{2}} = 0.693/\hat{e} \qquad ....2.03$$

The activity of the source is given by equation 2.01.

2.3 UNITS OF RADIATION

The developments of well defined units of radioactivity and energy deposition by ionizing radiation in matter was essential for the establishment of clear standards for the use of radionuclides. In this efforts the international Commission of radiological units and measurement (ICRU) defined four original units (Cember, 1983), viz;

The Roentgen which is defined as 2.58 x 10^4C/kg in dry air at standard temperature and pressure to be used only as measure of exposure.

The rad, defined as the deposition of 100 ergs/g to the volume of interest to be used as a measure of dose. This was later replaced by the S.I. unit Gray (1 Gy = 1J/kg = 100 rad).

The rem defined as the absorbed dose times quality factor and distribution factor as a measure of dose equivalent. This was replaced by S.I. unit Sievert (1 Sv = 1J/kg = 100 rem).

The Curie (Ci) defined as the amount of radionuclide that has an activity equal to 3.7 x 10^{10} disintegration per second as a measure of

activity. Later replaced by S.I. units Becquerel (1Bq = 1 dis/sec = 2.7 x 10^{-11} Ci).

2.4 TYPES OF NUCLEAR RADIATIONS

There are three distinct primary types of radiation emitted as a result of radioactive decay.

2.4.1 The Alpha Particle

They are positively charged particles and are identical with doubly ionized helium atoms (He^{++}). Thus, they have a mass of 4 amu and a charge of +2e. They strongly ionize the medium through which they travel and their rate of energy loss being rapid. They come to rest in short distance, therefore they could be stopped by a thin sheet of paper. They can also be slightly deflected by magnetic field.

Alpha rays are emitted by nuclei as a result of alpha decay. Mostly, heavy nuclei (Z > 82) undergo natural alpha decay. Usually alpha decay is accompanied by beta and/or gamma decay. In alpha decay parent nucleus transforms into a daughter nucleus and an alpha particle. Such a nuclear transformation can be described by an equation.

$$ {}^{A}_{Z}X \longrightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}\alpha \qquad ....2.04 $$

Example:

$$ {}^{238}_{92}U \longrightarrow {}^{234}_{90}Th + {}^{4}_{2}\alpha \qquad ....2.05 $$

2.4.2 THE BETA PARTICLE

They are corpuscular in nature and their name collectively stands for positrons or electrons. Thus, they have either negative or positive electrical charge and a mass 'm_o' (rest mass of electron). They are ejected from the active matter with a wide range of velocity and energy. They are on average far more penetrating than alpha rays. The average velocity of beta particle is in general about ten times greater than that of the alpha particle.

Energy spectrum of beta rays is continuous in nature in contrast to line spectrum of alpha rays. During beta decay a neutron/proton transforms into a proton/neutron with the emission of electron/positron and an anti neutrino/neutrino. For example, when the nucleus has too many neutrons for stability beta electron (ç⁻-decay) is emitted and when the nucleus has too many protons for stability beta positron (ç⁺-decay) is emitted as shown in equation 2.06 and 2.07.

$$^{12}_{6}C \longrightarrow {}^{12}_{7}N + ç^{-} + \bar{i} \qquad ....2.06$$

$$^{12}_{7}N \longrightarrow {}^{12}_{6}C + ç^{+} + i \qquad ....2.07.$$

where i is the neutral particle called neutrino.

There is yet another mode of beta decay called electron capture. In this process the nucleus captures one of the orbital atomic electrons (usually the K-shell electron) through the following transformations.

$$^{40}_{19}K + {}^{0}_{-1}e \longrightarrow {}^{40}_{18}Ar + \grave{i}\ (1.46MeV) \qquad ....2.08$$

Thus in electron capture (EC) the only particle that is emitted is the mono-energetic neutrino. Gamma-rays or characteristics X-rays are also emitted.

Neutrino absorption: é + p -------> n + ç⁺

2.4.3 The Gamma Rays

Gamma rays electromagnetic radiations of very small (10^{-10} to 10^{-12} m) wavelength. They are emitted by the nucleus when it makes a transition from a higher excited state to a lower excited state. In radioactive decay, daughter nucleus is usually left in an excited state as a result of the alpha and beta decay of parent nucleus. Subsequently the daughter nucleus de-excites from these higher levels by emitting gamma rays. Thus, gamma rays usually follow alpha or beta decay.

Since gamma rays result from the transition between excited nuclear states, they are monoenergetic in nature. An example of gamma decay following beta decay is as shown in fig. 2.1.

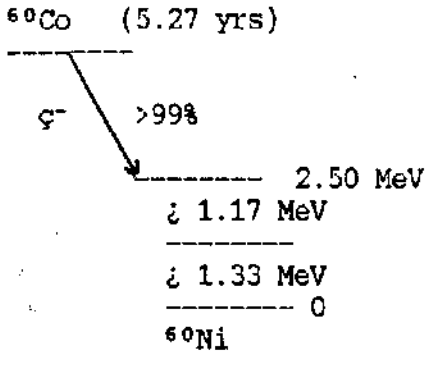


Fig.2.1 Decay Scheme of ^{60}CO.

2.5 NATURAL RADIATION SOURCES

Ionizing radiations originates either from our natural environment or from artificial sources. In both cases, the primary radiation consists of massive charged particles or of massless neutral quanta, that is photons or neutrinos.

If we observe radiation from our environment, two main origins are in evidence, one is the cosmic and solar radiations which comes from space and impinges on the outer part of the earth's atmosphere. It consists mainly of protons, light nuclei and electrons. By interacting with the terrestrial atmosphere, it produces secondary particles, including short lived σ mesons and muons.

The other natural sources of radiation as discovered by Becquerel in Uranium ores, is natural alpha, beta and gamma radioactivity. Alpha decay is a common phenomenon amongst heavy nuclei.

Natural radioactivity is of crucial importance for the interior energy balance of the earth. Many of such natural radio-activity series are known. Among these are the Uranium and the Thorium series (Table 2.1 and 2.2). Others are the actinium and neptunium series, and ^{40}K (Table 2.3).

The measurement of ionizing radiation and radionuclides in mans environment are required for the assessment of the exposure to both natural and man made radiation sources. Measurements aid in the determination of changes in the concentrations of certain radionuclides and identification of long-term trends due to the nuclear fuel cycle, to man's use of radioactive materials, and to man's extensive modification of the earth surface. Experimental studies of natural radionuclides in

the environment contribute to our knowledge of geological processes and atmospheric phenomena. A number of studies have been made on environmental radioactivity, among which are those of; (NCRP, 1985; IAEA, 1989; Gustafson, 1964; Lin, 1987 and Myasoedov *et al.*, 1989).

TABLE 2.1 ^{238}U DECAY SERIES

Isotope	Half-life	Principal radiation	Gammas per disintegration	Principal gamma-ray energy(MeV)
^{238}U	4.51×10^{9}yrs	α		
^{234}Th	24.1days	β	0.08	
^{234}Pa	1.18min	β	-	
^{234}U	2.48×10^{5}yrs	α	-	
^{230}Th	8×10^{4}yrs	α	-	
^{220}Ra	1.6×10^{3}yrs	α	0.04	
^{222}Rn	3.82days	α	-	
^{218}Po	3.05min	α	-	
^{214}Pb	26.8min	β,γ	0.6	0.29,0.35
^{214}Bi	19.8 min	β,γ	1.3	0.61,1.12,1.76
^{214}Po	1.6×10^{-4}S	α	-	
^{210}Pb	21.3 yrs	β	0.04	
^{210}Bi	5.01days	β	-	
^{210}Po	138.4 days	α	-	
^{206}Pb	stable	-	-	

Source : Adopted from IAEA 1979

TABLE 2.2 THORIUM DECAY SERIES

Isotope	Half-life	Principal radiation	Gammas per disintegration	Principal gamma-ray energy(MeV)
^{232}Th	$1.39x10^{10}$yrs	∝	-	
¿				
^{228}Ra	5.75yrs	ç	-	
¿				
^{228}Ac	6.13hrs	ç,é	0.68	0.91,0.96
¿				
^{228}Th	1.91yrs	∝	0.02	
¿				
^{224}Ra	3.64days	∝	0.04	
¿				
^{220}Rn	55.3s	∝	-	
¿				
^{216}Po	0.15s	∝	-	
¿				
^{212}Pb	10.64hrs	ç,é	0.52	0.24
¿				
^{212}Bi	60.6min	ç,é	0.12	0.73
¿				
^{212}Po	$3x10^{-7}$s	∝	-	
¿				
^{208}Tl	3.1 min	ç,é	2.3	0.51,0.58,2.62
¿				
^{208}Pb	stable	-	-	

Source : Adopted from IAEA 1979

TABLE 2.3 ^{40}K DECAY SERIES

Isotope	Half-life	Principal radiation	Gammas per disin-tegration	Principal gamma-ray energy(MeV)
^{40}K	$1.3x10^{9}$yrs	ç,é	0.11	1.4608
¿				
(89%)^{40}Ca+ç	stable			
(11%)^{40}Ar+ç	stable			

Source : Adopted from IAEA 1979

CHAPTER THREE

INTERACTIONS OF RADIATION WITH MATTER

3.1 INTRODUCTION

Radiation interacts with matter and loses energy through a variety of ways. This interactions depend on the type of radiation, namely; charge particulate or uncharge particulate radiation (Leo, 1987 and Singru, 1972).

3.2 CHARGED PARTICULATE RADIATION

3.2.1 Electrons

There are three important processes by which electron loses energy during their passage through matter.

1. Inelastic Collision of Electrons:

In this kind of collisions, incident electron transfers part of its energy to a bound atomic electron (in the matter) taking it to an excited state (excitation) or an unbound state (ionization). The mean energy loss due to inelastic collision is given by the following formula for electron energies $E<m_oc^2$ (Singru, 1970).

$$-\frac{dE}{dx} = \frac{4\pi e^4 nz}{m_o v^2} \ln \frac{1.16\, m_o v^2}{2I} \qquad \ldots.3.01$$

Where n is the number of atoms per unit volume, Z is the atomic number of the absorber, e, m_o are charge and rest mass of the electron, respectively. I is the mean excitation energy of the atomic electrons.

ii. Elastic Collisions of Electrons:

The incident electron can have an elastic collision with a nucleus resulting in a deflection of the electron without any radiative loss or excitation of nucleus. The cross-section for this process is of the order of $(e^2/m_o v^2)$, (where v is the velocity of incident electron) and it increases with Z^2.

For practical purposes, the total energy loss per unit length of the electrons is the sum of ionization and radiative loss i.e

$$(dE/dx)_{total} = (dE/dx)_{ion} + (dE/dx)_{rad} \qquad .... 3.02$$

The ration of specific energy losses is given approximately by (Singru, 1970).

$$\frac{(dE/dx)_r}{(dE/dx)_i} \simeq \frac{EZ}{700} \qquad .....3.03$$

Where E, Z are electron energy in mev and atomic number of the absorber, respectively. Eq. 3.04 has therefore shown that radiative losses are always a small fraction of the energy losses due to ionization and excitation and are significant only in absorber materials of high atomic number.

iii. *Bremstrahlung*

Incident electron passing through a field of a nucleus experiences a deflection with a resultant emission of radiation. This process is known as bremstrahlung. This leads to a lose of kinetic energy of the incident electron. This can be considered as a radiative type of inelastic collision between the electron and an atomic nucleus. The rate of energy lose by this interaction is proportional to z^2, where z is the atomic number of the target atom. The rate of such radiative loss is given by (Singru, 1970)

$$(dE/dx)_r \propto Z^2 n/A \, [E+M_o c^2] \qquad \ldots\ldots 3.04$$

where E, A and n are the energy of the electron, the mass number of the absorber and atomic density respectively.

3.2.2 POSITRONS

The interaction of positron with matter is almost identical with that of electron but for some minor differences. However, there is a very important way in which positron can annihilate with the electron in matter. This annihilation can either be a free annihilation with an electron or via the formation of a (e^+, e^-) hydrogen like atom called positronium. The positron annihilation leads to two photons if electron - positron spin is antiparallel and to three photons if the spin orientation is parallel.

3.2.3 Heavy Charged Particles

Heavy charged particles (protons and alpha) lose their energy mostly by ionizing the atoms of the material they pass through. During its passage the heavy charge particles gives up its kinetic energy (as a result of Coulombic interaction between their positive charge and a negative charge of the orbital electrons of the absorber atom) to the atoms of the absorber. The electron of the absorber atom will either get excited to a higher level or leave the atom depending on the energy gained by it. At any given time the particle is interacting with many electrons, so the net effect is to continuously decrease its velocity until the particle stops.

The linear stopping power S(E) defined as the amount of energy loss over unit length of path of the particle. For charged particles in a given absorber S(E) is given by (Singru, 1970)

$$-\frac{dE}{dx} = \frac{4\pi(ze^2)^2 Zn}{m_o v^2}\left[\ln\frac{2m_o v^2}{I} - \ln(1-\varsigma^2) - \varsigma^2\right] \quad \ldots\ldots 3.05$$

where n, Z, I, E, ze and V are the number of atoms per unit volume of the absorber, atomic number of the absorber, average minimum excitation energy of the atom, kinetic energy, charge and velocity of the ionizing particle respectively.

3.3 UNCHARGED PARTICULATE RADIATION

3.3.1 *Electromagnetic Radiation*

Although a large number of possible interaction mechanisms are known for gamma rays in matter, only three major types play an important role in radiation measurements; photoelectric effect, Compton scattering and pair production.

3.3.1.1 Photoelectric Effect

In this process, an incoming gamma ray photon striking an absorber atom ejects one of the orbital electrons of the atom. During this process the gamma ray disappears, its entire energy being given up. The kinetic energy (K_e) of the emitted photoelectron is given by:

$$K_e = h\nu - E_B \qquad \ldots\ldots 3.06$$

where $h\nu$ is the energy of the incident photon and E_B is the binding energy of the emitted electron. The photoelectron could be emitted from the K-shell, L-shell, and others, of the atom. This process will take place only of $h\nu > E_B$.

3.3.1.2 Compton Effect

In this process the incident photon interacts with a free electron and is scattered with a loss of energy. Compton scattering also includes scattering of photons by electrons bound to an atom because in comparison to the energy of the photon, the electron binding energy is quite small. Thus an incident photon of energy $h\nu$ can be considered to

collide with a free electron of rest mass m_0. The photon is scattered through an angle à with an energy hì' (<hì) while the electron recoils with a kinetic energy K_e at an angle Ø, as illustrated in Fig. 3.1.

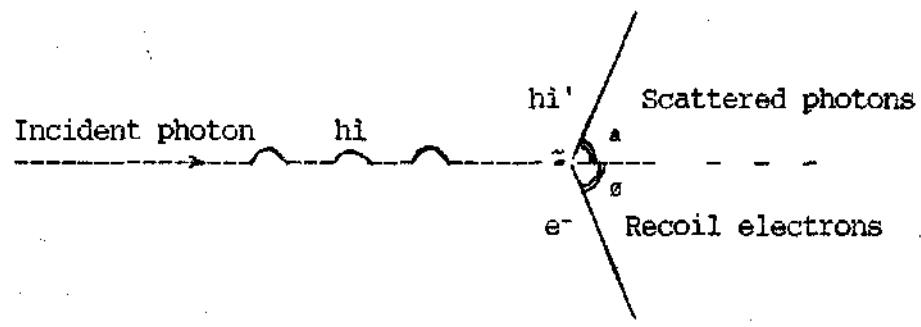


Fig 3.1 Kinematics of Compton effect.

3.3.1.3 Pair Production

When a gamma ray photon having energy greater than 1.02 MeV (twice the rest mass of energy of an electron) strikes a material of high atomic number, the photon is completely absorbed and a pair of electron and positron is produced. This process is known as pair production and the threshold energy of the photon is 1.02 MeV. Therefore this process is predominantly confined to high energy gamma rays.

3.4 EFFECTS OF RADIATION

Radiation has physical, biological and chemical effects. It can darken photographic films, enhance certain chemical reactions, and change physical properties of material.

The effects we are most interested in here are biological. Those are the ones for which we are attempting to describe and evaluate safeguards.

Radiation in large doses has been shown to kill, to induce cancer, to cause certain blood disorders, and to induce cataracts in the eye. It can cause skin burns, sterility, abnormal pregnancies, and malformed offsprings. On the other hand, it is used by physician to treat cancer and skin diseases, it often affects cures.

Even in relatively small doses, there is statistical evidence that radiation can cause certain damage to genetic materials. It is suspected of shortening man's life span and increasing his likelihood of suffering from certain illness like Leukemia, (Blastz, 1964).

The important question, which may never be answered, is this: since people have always been exposed to substantial amounts of radiation from nature, to how much additional radiation can they be exposed without an unreasonable risk to themselves or to their progenies? As in the case of many occupational or environmental hazards, this will probably have to be answered in terms of the benefits which accompany the risks.

CHAPTER FOUR

NUCLEAR RADIATION DETECTORS

4.1 INTRODUCTION

A number of nuclear radiation detectors are available now. Each has its own advantages and disadvantages. Three different types of detector systems used in this work are briefly discussed, (Knoll, 1979; Kleinknecht, 1987 and Tsoulfanidis, 1983).

4.2 GEIGER MÜLLER (G-M) TUBE

A G-M tube consists of a cylindrical cathode made of copper or other suitable material and a coaxial wire (anode) usually made of tungsten. The space between the electrodes is filled with simple monoatomic or diatomic gases such as air, hydrogen or noble gases such as argon, neon, helium or a mixture of gases, and the whole system is often enclosed in a glass envelope.

A G-M tube functions as follows: when a single ionising radiation enters the G-M tube, a few electrons and ions are produced in the gas. These electrons and ions are multiplied enormously when the breakdown potential at the anode is greater than the breakdown potential of the gas. The electrons are attracted by and move towards the anode and the positive ions move toward the cathode. Thus a discharge is obtained. The current flowing in the high resistance within the GM tube produces a p.d. which is amplified and passed to a counter. The counter registers the passage of an ionising particle (or radiation) passing through the tube. The discharge (avalanche) if allowed will upset the recording of

other ionising particles following fast on the first one recorded. It is therefore quenched by adding a polyatomic gas (like ethyl alcohol vapours) to argon gas or by using suitable electronic circuit.

A good G-M tube has a plateau of about 200 volts width and a slope of about one percent per 100 volts. Beyond the plateau, the curve leads to continuous discharge as illustrated in fig. 4.1

The main limitation of G-M tube is its dead time. This limits its use to lower counting rates only. However, because G-M tubes can detect even small activities, it is extensively used for detecting X-rays, gamma rays, electrons and beta particles.

4.3 SCINTILLATION DETECTORS

There are several substances, certain organic and inorganic materials, which emit light flashes or scintillations when charged particles, X-rays or gamma rays pass through them. These substances are called scintillators. In a scintillation detector (Fig. 4.2) these light flashes are allowed to fall on the photocathode of a photo-multiplier tube and a pulse is extracted out to signal the passage of nuclear radiation. The height of this output pulse is proportional to the energy dissipated by the ionizing radiation in the scintillator. Thus a scintillation detector can be used not only for counting but for energy analysis as well. The operation of scintillation detector is a step by step process, viz; the absorption process, the scintillation and the conversion of light to electrical pulse process.

4.3.1 THALLIUM ACTIVATED SODIUM IODIDE (NaI(Tl) SCINTILLATION DETECTOR.

The NaI(Tl) crystal is usually about 1 mm thick and is covered with a thin window usually made of 0.001" aluminium or 0.002" beryllium. The NaI(Tl) crystal is covered on all sides by a layer of reflecting material like MgO or Al_2O_3 powder. A glass window is provided at one end so that light produced by the scintillator can pass on the photo-cathode. It is usually in the form of right circular cylinders, their dimensions being determined by the needs of the particular measurement. A typical mounting of NaI(Tl) crystal in an aluminium can is shown in Fig. 4.3.

NaI(Tl) crystal is used as a gamma ray spectrometer in nuclear radiation measurement. It has remained as the most popular scintillation material for this application. This extra-ordinary success stems from its extremely good light yield, excellent linearity and high atomic number of its iodine constituent which assures that photoelectric absorption will be a relatively important process. Moreover this material has the highest intrinsic detection efficiency when compared with other gamma ray spectrometers (e.g Ge(Li)). Its response to electrons (and gamma rays) is close to linear over most significant energy range.

4.3.2 LIQUID SCINTILLATION COUNTER (LSC)

A Liquid Scintillation Counter consists of a scintillation material which is optically coupled to a photomultiplier either directly or via a light guide. As radiation passes through the scintillator, it

excites the atoms and molecules making up the scintillator causing light to be emitted. This light is transmitted to the photomultiplier tube where it is converted into a weak current of photoelectrons which is then further amplified by an electron multiplier system. The resulting current is then analysed by an electronic system. Basic elements of a scintillation counter are as sketched in Fig. 4.4

Liquid scintillation media is used to avoid some of the difficulties that may arise when measuring low energy beta particles or alphas using conventional methods. The approach, sometimes called internal source liquid scintillation counting, involves dissolving the sample to be counted directly in liquid scintillator. Under these conditions, problems relating to sample self-absorption, attenuation of particles by detector windows and beta scattering from the defector are completely avoided.

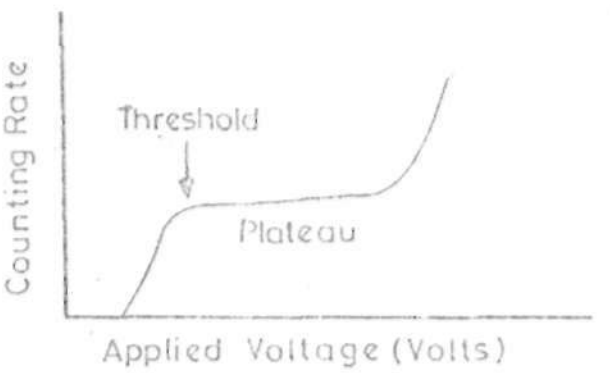
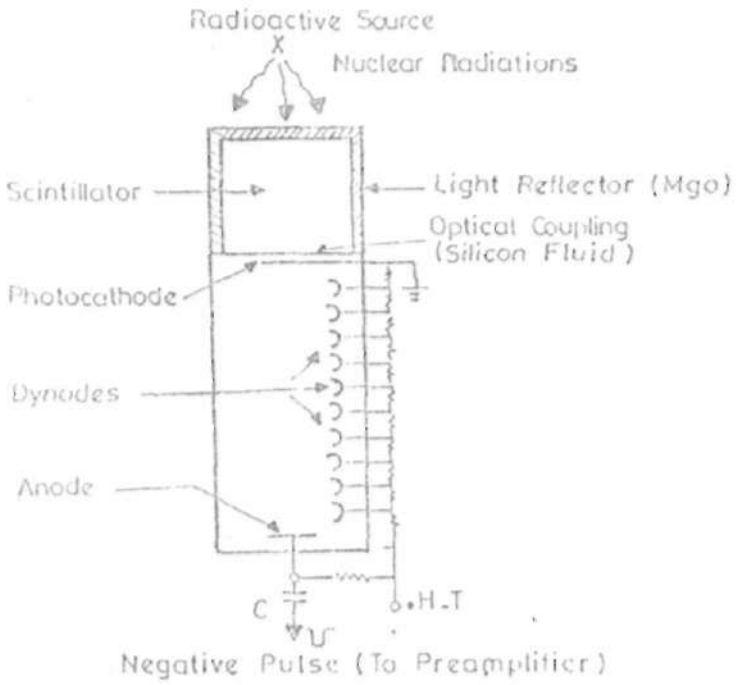


Fig-4.1: Typical plot of counting rate versus the applied voltage for a G.M. counter.



Fig·4·2 : Schematic construction of a scintillation detector.

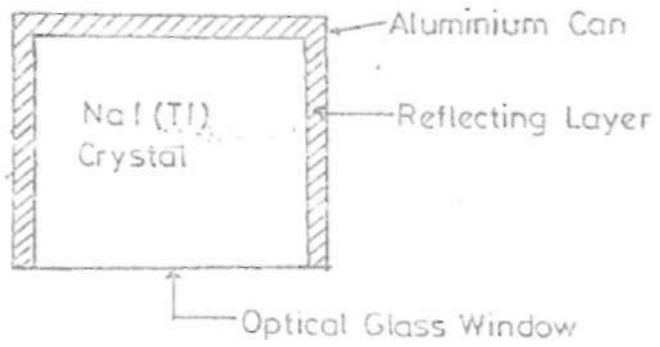


Fig 4.3 Typical mounting of NaI (Tl) crystal in an aluminium can

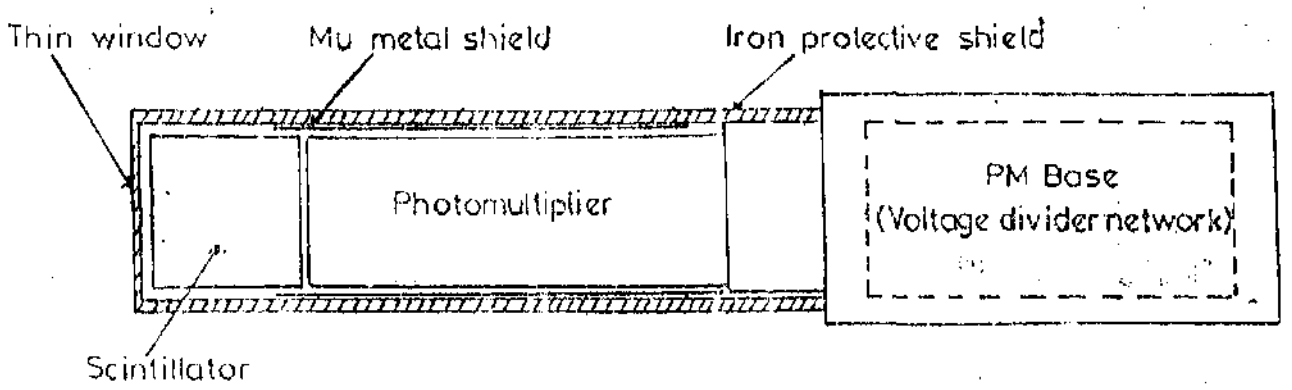


Fig.4.4.Simple schematic diagram of a scintillation counter

CHAPTER FIVE

MATERIALS AND METHOD

5.1 SAMPLE COLLECTION

Samples of soils, plants and water were collected from three areas. viz; Ladi Valley (ML11929), Majohota (ML4552MJ) and Karina mills as shown in Fig 1.1. Ladi valley and Majohota are located at Barkin Ladi whereas Karina mills is located at Bukuru both in Jos Plateau.

5.1.1 Soil Samples

Soil samples were collected at depths ranging between 0 - 10 cm in the paddock, its surrounding and also around the mill. Also collected from these areas are tailings (sampled within the radius of 100 - 200 m from the centre of the paddocks). Monazite and other waste dumped within the surrounding of Karina mill, as well as graded tin and zircon samples were received from the mill courtesy of Consolidated Tin Mines Bukuru, Jos.

5.1.2 Plant Samples

The samples were collected in such a way that they did not include the root of the plant and each particular type of plant is sampled separately. The samples were collected within the paddock and its surrounding and also around the mill.

5.1.3 Water Samples

The samples were collected from the tailing streams, paddock and surrounding streams (in ML11929 and ML4552MJ). Samples were also collected from water processing plants, reservoirs and surface water in Karina mills.

5.2 SAMPLE PREPARATION

The following methods were used for sample preparation prior to measurement. The soils, tailings and plants samples were air dried for about seven days. The soils and tailings were each separately grounded to fine powder using Rock Crusher made by Siebtechnik.

The plant samples were ashed in a muffle furnace at 250 - 400°C.

5.3 SAMPLE COUNTING USING G-M TUBE

A `PANAX' GM tube set up was used for gross activity measurement. The set up includes a Mullard M203 GM tube in a lead shield and a PANAX scalar.

Initially the operating voltage was obtained as 600 V by measuring at different high voltages. The background contribution was determined. The efficiency of the GM tube was then determined using KCl salt. The materials were accurately weighed and each then placed in an aluminium planchet of 3.0 cm diameter and placed into the GM window for counting. Each sample was counted for 3000 secs and for at least three times. Ashed plant samples were also counted in a similar manner.

5.4 GAMMA MEASUREMENT USING 3" X 3" NaI(Tl) DETECTOR

Samples with high gross activity were selected for detailed gamma studies. The samples were accurately weighed in a plastic container and properly sealed. they were allowed to attain equilibrium for 30 days before counting. A 3" x 3" NaI(Tl) detector made by Canberra was used. It was housed in a lead shield made by Canberra and connected to a PC which has a NaI(Tl) ACCUSPEC 2086K Card for gamma spectrometry. After initial calibration using gamma standards supplied by DAMRI, Cedex, France each sample was counted for about 2 hrs and the gamma spectra printed. Uranium and Thorium standard supplied by IAEA were also measured and used for producing callibration curves which were later used to determine the concentration of Th and U in the samples.

5.5 LIQUID SCINTILLATION COUNTING

The water samples were measured using a series 1000 TRICARB Scintillation Counter made by PACKARD. The counter is a 3 channel automatic microprocessor controlled. The counter was first self normalized and the efficiency checked using C-14, H-3 standards supplied by PACKARD. The background was then checked using the background standard supplied by PACKARD and a scintillator blank used in this work. 1 ml of the water samples was mixed with 14 ml of a general purpose xylene based scintillator (NE 260) supplied by Nuclear Enterprise, UK, for counting. Each sample was counted for 1 hr. In addition samples of distilled water from the laboratory was also counted.

CHAPTER SIX

RESULTS AND DISCUSSION

6.1 CALIBRATIONS

For any measurement to be meaningful, the instrument used must be properly calibrated. For the GM tube the first thing always is to determine the proper operating voltage. This was done by counting a Cs-137 standard and varying the high voltage. An operating voltage of 600 V was obtained and used throughout this work.

The efficiency of the GM tube was determined using KCl and was found to be 54.5% (see Appendix). The efficiency value was used in the conversion of cpspg to Bq/g as shown in Tables 6a and 6b.

For the NaI(Tl) detector the high voltage was set at 1000 V and the amplifier gain properly adjusted. Apart from the daily energy calibration, the efficiency of the system was determined using standard point source as shown in Figs 6.1 and 6.2. The intrinsic efficiency was obtained from the absolute efficiency using the geometric factor of 2π since the source is directly on the detector surface. The efficiency values obtained are comparable to those normally expected for a 3" x 3" NaI(Tl) detector which are in the range of 0. - 30% (Knoll 1979). The FWHM obtained was plotted against energy as shown in Fig 6.3. The slope was found to be about half as expected.

The efficiency of the liquid scintillation counter was checked before use by measuring tritium and carbon - 14 standards. Efficiency

values of 58% and 96% were measured for tritium and carbon-14, respectively.

6.2 GROSS ACTIVITY OF SOILS AND PLANTS

The gross activity of the soils, plants and other minerals measured using the GM tube are shown in Tables 6a and 6b. The activity of the soils ranges from 0.1 - 2.5 Bq/g. Few of the samples were found to be within the background range. The highest activity was found in the monazite waste (95.9 Bq/g) and the zircon (77.4 Bq/g) samples. For the plant samples the gross activity ranges from 0.3 - 6 Bq/g. Some of the samples were within the background range. Generally, plants within the processing mill were found to have higher activity. The plants samples have higher or comparable activity to the soil samples. This may be due to dust contamination from the monazite wastes or the plants take up uranium or thorium or both. If the activity in the plant is as result of accumulation due to uptake than the plant specie *Tridax procumbers* has the highest uptake with the highest activity followed by Cynodon dactylon.

6.3 GROSS ACTIVITY OF WATER SAMPLES

The activity of the water samples were found to be higher than the background as shown in Table 6c. The samples were also found to have higher activity than distiled water. The ML4552 samples were found to have higher activity followed by those at the Karina mill and then the ML11929MJ samples.

The level of radioactivity in the water samples may have been higher if not because of the fact that zircon and monazite are refractory minerals which are very difficult to leach.

6.4 DETERMINATION OF URANIUM AND THORIUM CONCENTRATIONS.

For the measurement of U and Th concentrations, the low energy gamma peaks were mostly used because of their higher efficiency and abundance (Bloxam, 1962 and Culbert, 1981. In our case relatively high energy peaks were also used since low energy gamma rays have high mass attenuation coefficient than high energy ones, it can be concluded that self absorption is negligible.

The calibration spectra of Th and U were examined and three energy peaks were chosen that exhibited dissimilar shapes in each spectrum when compared with the other two. However the spectra selected were not without errors due to overlapping of other daughter peaks as a result of poor resolution of NaI(Tl) detector.

For U the Bi-214 peaks at 295.2, 352.0 and 1764.7 keV were used and for Th and Bi-212 peaks at 238.6, 583.1 and 911.0 keV were used. The Bi-212 peak at 2640 keV was not used because it was not within our initial settings (IAEA, 1979).

Although initially three energy peaks were considered for the determination of U and Th concentrations but only two peaks were finally used due to much interference observed in peak 295.2KeV and 583.1KeV for U and Th, respectively.

U and Th standards were used for the calculation of the concentrations. Three U standards were obtained from the IAEA which originated from Spain. Although their state of equilibrium is not

known, they may be adequate for the type of study here. The Th standards were also obtained from IAEA and originated from Turkey.

In each case three U and Th standards were measured and the calibration curves plotted for the respective peaks as shown Figs 6.4 - 6.9. The slopes calculated from the curves are (0.429, 3.116, 1.568) cpspg/eU% and (0.876, 0.711, and 2.391) cpspg/eTh%, respectively. The curves in Fig 6.4, 6.5 and 6.7, 6.9 were used to calculate the concentrations of U and Th in the samples at the respective peaks by dividing the cpspg in each peak by the respective slopes at that peak. The correlation coefficient obtained between cpspg and concentration for three of the samples were 0.63, 0.81 and 0.78 for Th and 0.56, 0.61 and 0.94 for U. As a result of this fairly good correlation between the results of the selected peaks, the average concentration of each sample is taken to represent the concentration of Th or U in the sample as shown in Table 6f.

Looking at the values it could be seen that the Th concentrations vary from 104ppm - 2.7% with sample 6ML11929 having the least value of 104 ppm and the monazite waste having the highest value of 2.7%. This values compare favourably to those of similar studies (Sanni *et al*; 1985; Banwo, 1989; Hu, et al; 1981 and IAEA, 1976) except that in the studies of Sanni, et al (1985) a very high value of 40% Th was obtained in one of his samples. Although such a high value is not impossible as values of 40% Th have been recorded in mines and mills of the Malagasy Republic (IAEA, 1976), but such a high value has not been obtained in this study.

The U concentrations range from 61 - 2042ppm, where sample 6ML4552 has the least value of 61 ppm and the Zircon sample has the highest of

2042 ppm. The U concentrations also agree with the findings of Sanni, et al (1985) and Banwo, (1989).

From the Th and U concentrations and the Th/U ratio it may be said that the major source of the radioactivity is Th and the radioactive mineral is mainly monazite.

6.5 RADIOLOGICAL HAZARDS.

With this fairly high concentrations of Th and U, the mines and mills workers and indeed the general public may run into the risk of radiation exposure. This could be due to external radiation exposure, inhalation of dust and ingestion. The general public may also come in contact with the radioactivity from the dust particulates that could be blown to a long distance, the likely use of the mine tailings as building materials, drinking of water contaminated due to mining and milling activities and eating food grown on tailing and other waste dumps.

At the mines external exposure may be minimal because of the open pit mining technique but inhalation and ingestion may not be ruled out because of the dusty environment. External exposure at the mill site maybe a problem because of the nearby dump sites and monazite and other radioactive minerals store. Inhalation and ingestion may be a serious problem at the mills because of the dust produced during the milling process.

An attempt has been made to estimate the dose contribution of a large source with the concentration of U and Th obtained in this work as shown in Table 6f. The conversion factors used are 6.2 uR/h /10ppmeU

and 3.1 uR/h 10 ppmeTh as given by (IAEA, 1979). Looking at the values in Table 6f all are within the maximum permissible dose of 5 rem/yr (50 mSv/yr) for radiation workers except in the case of monazite waste and zircon where they have been found to be much higher than the maximum permissible dose. This may suggest that it is possible to exceed the maximum permissible dose at the mills where the monazite waste dumps and radioactive mineral stores may be located. However, the values obtained in this work are within the values given by IAEA (1976) and ICRP (1977) for a monazite processing plant where doses of 0.1mR/h - 8mR/h are common and 18-35mR/h in the case of monazite product stores. With this level of exposures all personnel in the plant received less than 3 rem/1yr (30 mSv/yr) and about 70% received less than 1 rem/yr (10 mSv/yr). Therefore there is a need for proper monitoring at the mines and mills. This will only be possible when laws on nuclear radiation are made by the government.

Another observation from the results in Table 6f is that all the samples gave a dose value higher than the maximum permissible dose of 0.5 rem/yr (5 mSv/yr) for the general public (NCRP, 1985). This may suggest that in areas where the levels of U and Th concentration are high, then such areas may not be suitable for habitation.

6.6 CONCLUSION

It was found that the gross activity of soil, plant and water samples ranges from about 0.1 - 2.5 Bq/g, 0.3 - 6.0 Bq/g and 0.1 - 0.3 cps respectively. Similarly, Th and U concentration recorded ranges from about 104 ppm to 2.7% and 61 - 2042 ppm respectively. The doses arising

from such high Th and U concentration are clearly higher than the Maximum Permissible Dose (MPD) of 0.5 rem/yr (5mSv/yr) for the general public in all the samples, but all are within the MPD for workers of 5 rem/yr (50mSv/yr) except in the case of monazite waste and zircon sample. In (all our) findings in this study, Zircon and monazite waste samples have shown the highest activities (about 77 Bq/g and 96 Bq/g) and highest doses (about 37 rems/yr (370mSv/yr) and 79 rem/yr (790mSv/yr)), respectively.

From the above results, we can conclude that:

i) The Jos tin mines and mills are contaminated with radioactive minerals and general public living around the area may be at risk of being exposed to radiation higher than permitted.

ii) The highest activity recorded for monazites indicates that it may be the principal radioactive mineral in the granites from the tin mined in the Jos Plateau.

iii) The activity of the plant and water samples is an evidence for the possible uptake and leaching out of the constituent parts of the radioactive minerals present in the Jos Plateau area, thus compounding the radiological hazards due to ingestion.

iv) The high activity in plant samples compared to soils samples may be due to the radioactive dust in the mills, uptake and accumulation of U and Th from the soils.

6.7 SUGGESTIONS

Monitoring at the mines and mills should be routinely carried out. The likely use of mine tailings and other wastes from the mills as building materials and for other uses should be discouraged. Further studies of the tin mines and mills using different techniques and samples should be carried out.

TABLE 6a: Gross Activity of Soil Samples

Sample	Mass(grams)	Net count rate(CPS)	Specific Activity (Bq/g)
1ML4552	0.6731	*	*
2ML4552	0.7615	*	*
3ML4552	0.9236	*	*
4ML4552	1.3667	1.1517	1.5462
5ML4552	1.3710	0.5087	0.6808
6ML4552	1.4747	0.6080	0.7565
7ML4552	0.7122	*	*
8ML4552	0.6483	*	*
9ML4552	0.6472	1.9818	2.2076
10ML4552	0.8293	*	*
11ML4552	0.7951	*	*
12ML4552	0.7034	0.1954	0.5097
13ML4552	0.5910	*	*
14ML4552	1.0040	0.0957	0.1749
15ML4552	1.1462	1.1263	1.8031
16ML4552	0.8934	0.0492	0.1011
17ML4552	0.9730	*	*
18ML4552	0.4255	*	*
1ML11929	1.6164	2.2336	2.5355
2ML11929	0.8133	*	*
3ML11929	0.8295	0.1343	0.2971
4ML11929	0.7855	0.0567	0.1324
5ML11929	0.4761	0.1473	0.5677
6ML11929	2.0419	1.0628	0.9550
Zircon	1.5760	66.5040	77.4270
Monazite waste	1.8604	97.2638	95.9287
Iron waste	1.8451	1.6102	1.6013
Tin	2.0819	0.8565	0.7549

* - Same as background.

TABLE 6b: Gross Activity of Plant Samples

Sample Location	Type of Specie(Family) and site grown	Mass (g)	Net Count rate (cps)	Specific Activity (Bq/g)
Karina Mill	*Psidium guajava* (Myrtaceae) behind the processing mill	0.3278	0.1818	1.0176
Karina Mill	*Tridax procumbers* (Compositae) behind the processing mill	0.3091	0.9800	5.8174
Karina Mill	*Andropogon gayanusi* (Gramineae) on mill waste	0.4133	0.2012	0.8932
Karina Mill	*Persea americana* (Lauraceae) behind the processing mill	0.3611	0.0635	0.3227
Karina Mill	*Magnifera indica* (Anacardiaceae) behind the processing mill	0.5228	*	*
Karina Mill	*Saccharum officinarum* (Gramineae) behind the processing mill	0.3001	0.3445	2.1063
Karina Mill	*Cynodon dactylon* (Gramineae) within an underground well (borehole) behind the processing mill	0.3990	0.6882	3.1648
Karina Mill	*Cynodon dactylon* (Gramineae) on mill waste (Fe)	0.1630	0.1207	1.3587
ML11929MJ	*Pennisetum pedicellatum.* Within the paddock	0.3040	*	*
ML4552	*Cynodon dactylon* (Gramineae). Within the paddock.	0.3040	*	*
ML4552	*Setaria congiseta* (Gramineae). Around the paddock.	0.2480	*	*
ML4552	*Cyperus* Sp (Cyperaceae). Around the paddock.	0.3670	*	*

Table 6c Gross Counts of Water Samples after Background Subtraction

Sample	Location	Net Count(CPS)
1ML11929MJ	Surrounding stream	0.091
2ML11929MJ	Paddock	0.113
3ML11929MJ	Tailings	0.093
4Karina Mill	Bore hole	0.173
5Karina Mill	Overhead Tank	0.123
6ML4552	Surrounding stream	0.161
7ML4552	Surrounding stream	0.149
8ML4552	Tailings	0.195
9ML4552	Paddock	0.230
10ML4552	Paddock	0.231
11ML4552	Tailings	0.180
12ML4552	Surrounding stream	0.150
13ML4552	Paddock	0.253
14ML4552	Paddock	0.211
15 Distiled H_2O	Laboratory	0.065

TABLE 6d: Concentration of Th From Peaks of Selected Dominant Gamma Rays Emitted By Daughter Isotopes of Th-232.

		Energy Peak = 238.6 keV			Energy Peak = 911.1 keV		
Sample	Mass (g)	Count-rate (cps)	cpspg*	Concentration (ppm)	Count-rate (cps)	cpspg*	Concentration (ppm)
9ML4552	26.920	3.39 3.27	0.1237	517	1.07 1.36	0.0451	515
4ML4552	29.358	1.01 1.09	0.0358	150	0.34 0.49	0.0141	161
6ML4552	98.806	2.20 2.02	0.0214	90	0.84 1.49	0.0118	135
15ML4552	114.825	9.07 9.23	0.0814	340	4.03 4.18	0.0358	409
1ML11929	147.296	7.20 6.84	0.0477	200	2.63 3.74	0.0216	183
6ML11929	84.963	1.99 1.81	0.0219	92	0.93 0.81	0.0102	116
Monazite waste	132.631	763.20 777.10	5.8067	24286	364.08 359.45	2.7276	31137
Zircon	153.940	357.05 357.08	2.3195	9701	141.78 149.14	0.9449	10787
Iron waste	111.172	10.13 9.18	0.0868	363	3.82 3.78	0.0342	390

*Count per second per gram (cpspg)

TABLE 6e: Concentration of U from Peaks of Selected Dominant Gamma Rays Emitted by Daughter Isotopes of U-238.

		Energy Peak = 352.0 keV			Energy Peak = 1764.7 keV		
Sample	Mass (g)	Count-rate (cps)	cpspg*	Concentration (ppm)	Count-rate (cps)	cpsg*	Concentration (ppm)
9ML4552	26.920	1.41 1.26	0.0496	159	0.15 -	0.0056	131
4ML4552	29.358	0.71 0.81	0.0259	83	- 0.11	0.0038	89
6ML4552	98.806	1.78 1.67	0.0175	56	0.33 0.22	0.0028	65
15ML4552	114.825	3.38 4.19	0.0351	113	- 0.47	0.0041	96
1ML11929	147.296	5.52 5.00	0.0357	115	0.59 0.60	0.0040	93
6ML11929	84.963	2.52 2.44	0.0292	94	0.33 -	0.0039	91
Monazite waste	132.631	219.79 237.80	1.7251	5536	7.86 7.99	0.0595	1387
Zircon	153.940	162.33 163.90	1.0596	3401	13.04 13.93	0.0876	2042
Iron waste	111.172	2.48 2.32	0.02159	69	- 0.29	0.0026	61

*Count per second per gram (cpspg)

Table 6f: Estimated Exposure Rate and Dose Rate from Estimated Concentrations of Thorium/Uranium in the Samples.

Sample	Th conc. (ppm)	Exposure Rate (uR/hr)	Dose Rate (mrem/yr)	U conc. (ppm)	Exposure Rate (uR/hr)	Dose Rate (mrem/yr)	Total Dose (rem/yr) **(mSv/yr)**
9ML4552	516±1	159.96	1332.47	145±14	89.90	748.87	2.081 **20.81**
4ML4552	156±6	48.36	402.84	86±3	53.32	444.16	0.847 **8.47**
6ML4552	113±23	35.03	291.80	61±5	37.82	315.04	0.607 **6.07**
15ML4552	375±36	116.25	968.36	105±9	65.10	542.28	1.511 **15.11**
1ML11929	192±9	59.52	495.80	104±11	64.48	357.12	1.033 **10.33**
6ML11929	104±12	32.24	268.56	93±2	57.66	480.31	0.749 **7.49**
Monazite waste	27712±3426	8590.72	71560.70	1387	859.94	7163.30	78.724 **787.24**
Zircon	10244±543	3175.64	26453.08	2042	1266.04	10546.11	36.990 **369.99**
Iron waste	377±14	116.87	973.53	65±4	40.30	335.70	1.309 **13.09**

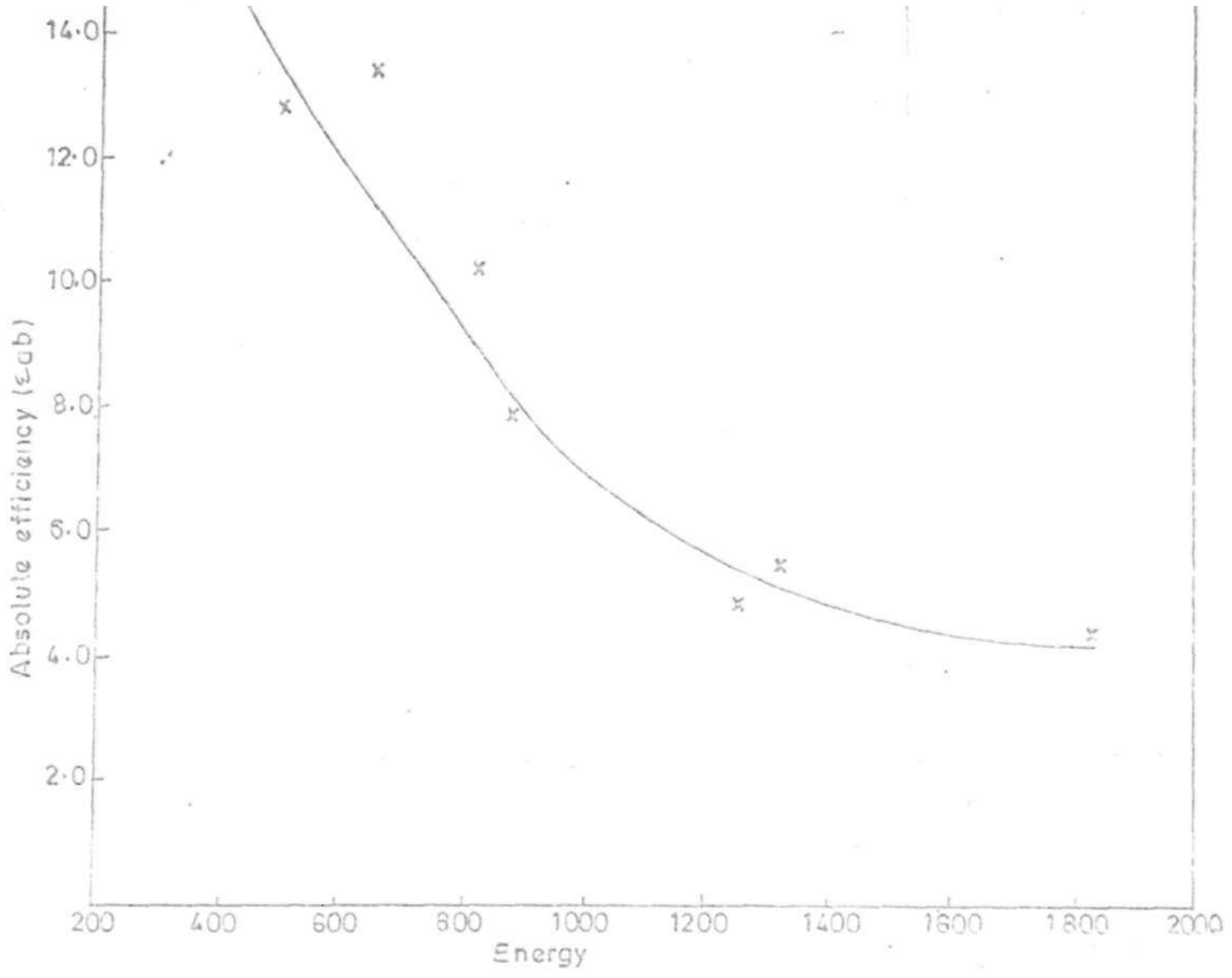


Fig.6.1: Absolute efficiency as a function of gamma ray energy

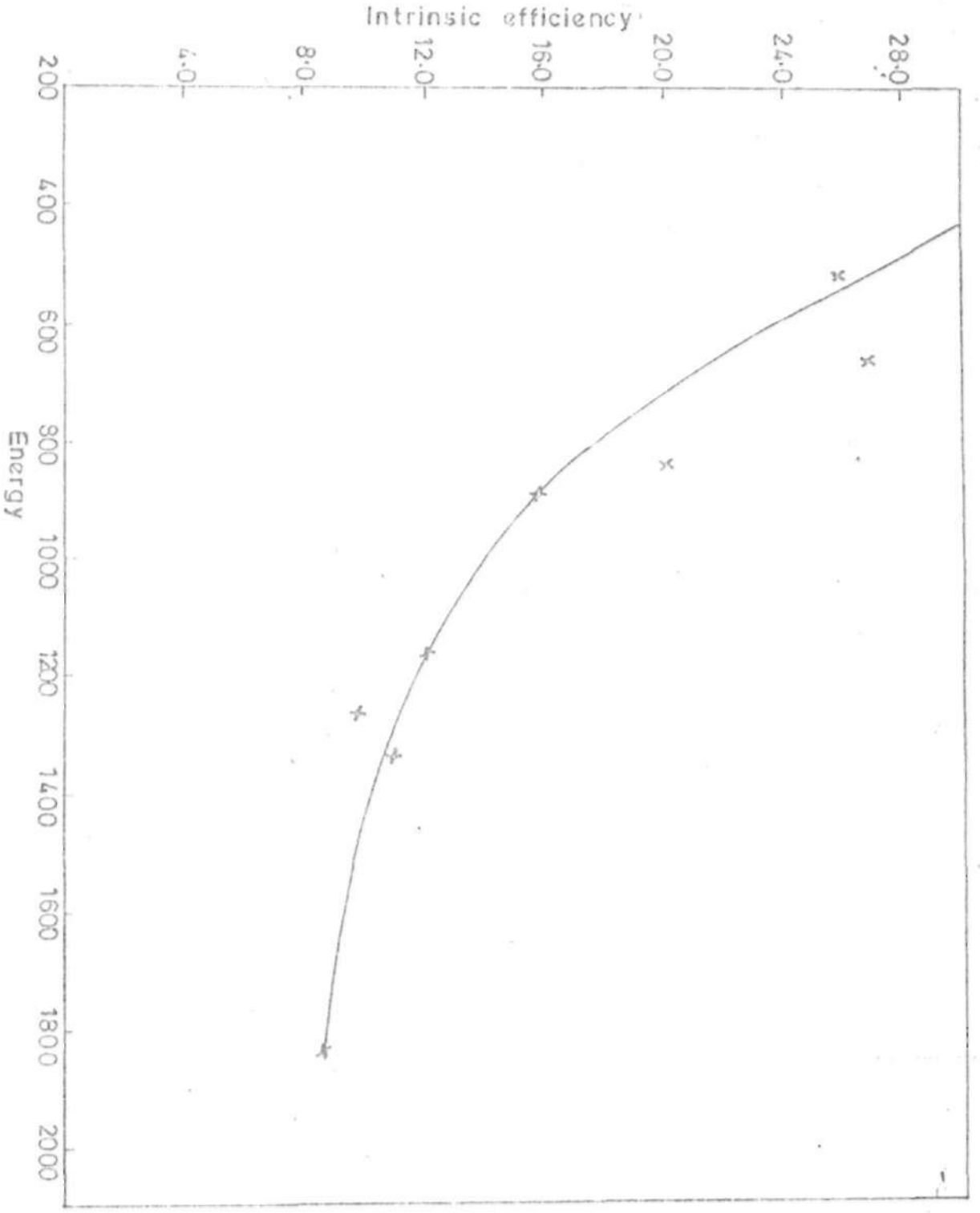


Fig 6.2: Intrinsic efficiency as a function of gamma ray energy

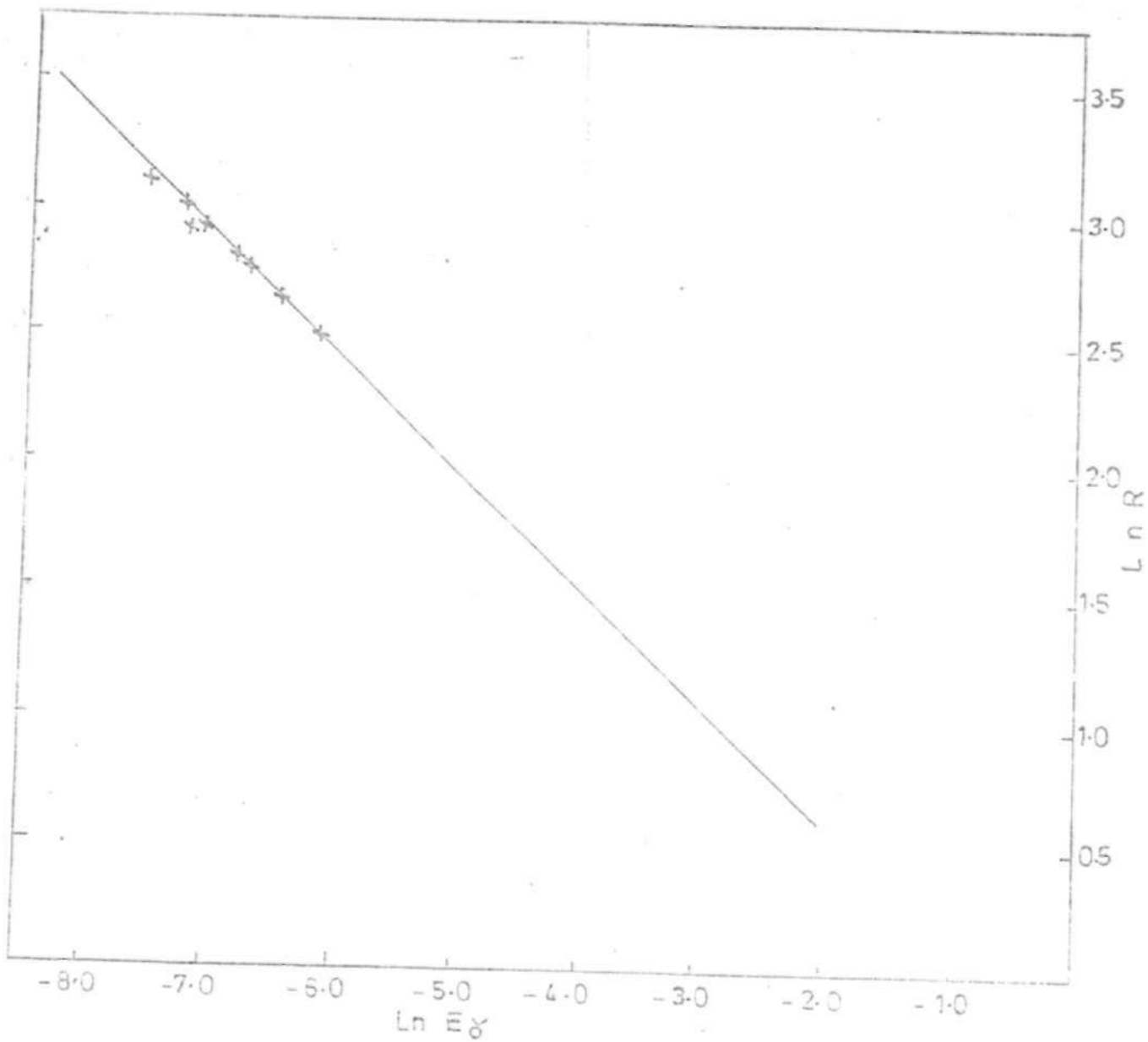


Fig.6.3:Resolution as a function of gamma ray energy

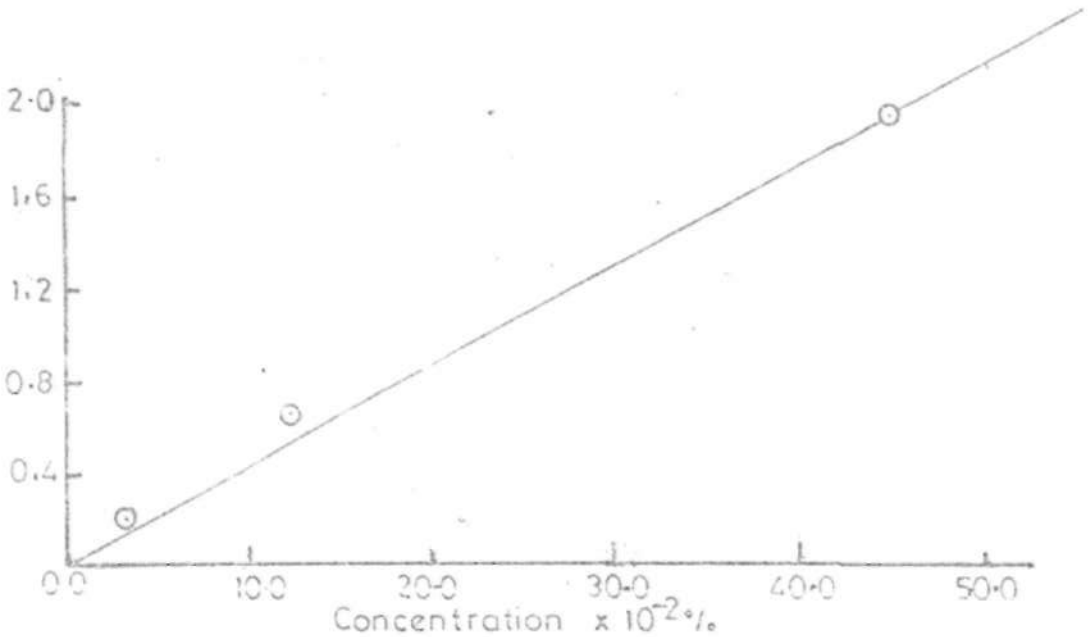


Fig.6-4:Counts per second per gram(cpspg)as a function of uranium concentration at 1764·7 KeV peak

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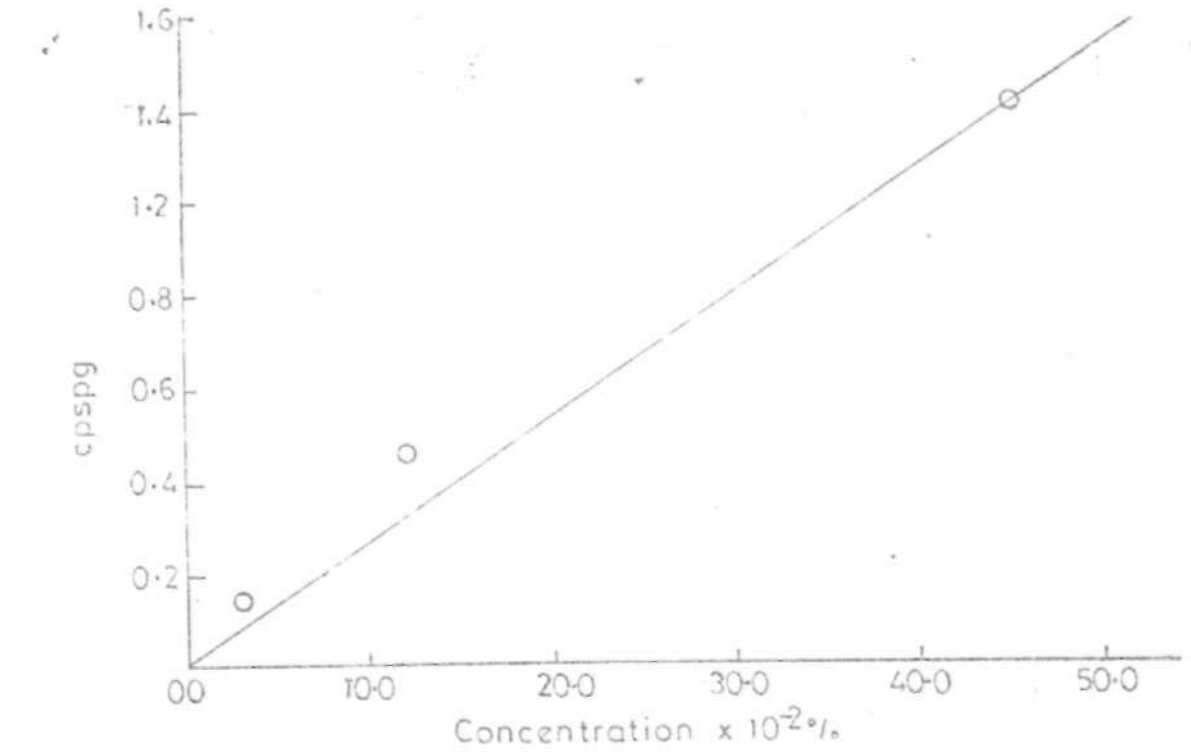


Fig-6.5: Counts per second per gram (cpspg) as a function of uranium concentration at 352 KeV peak

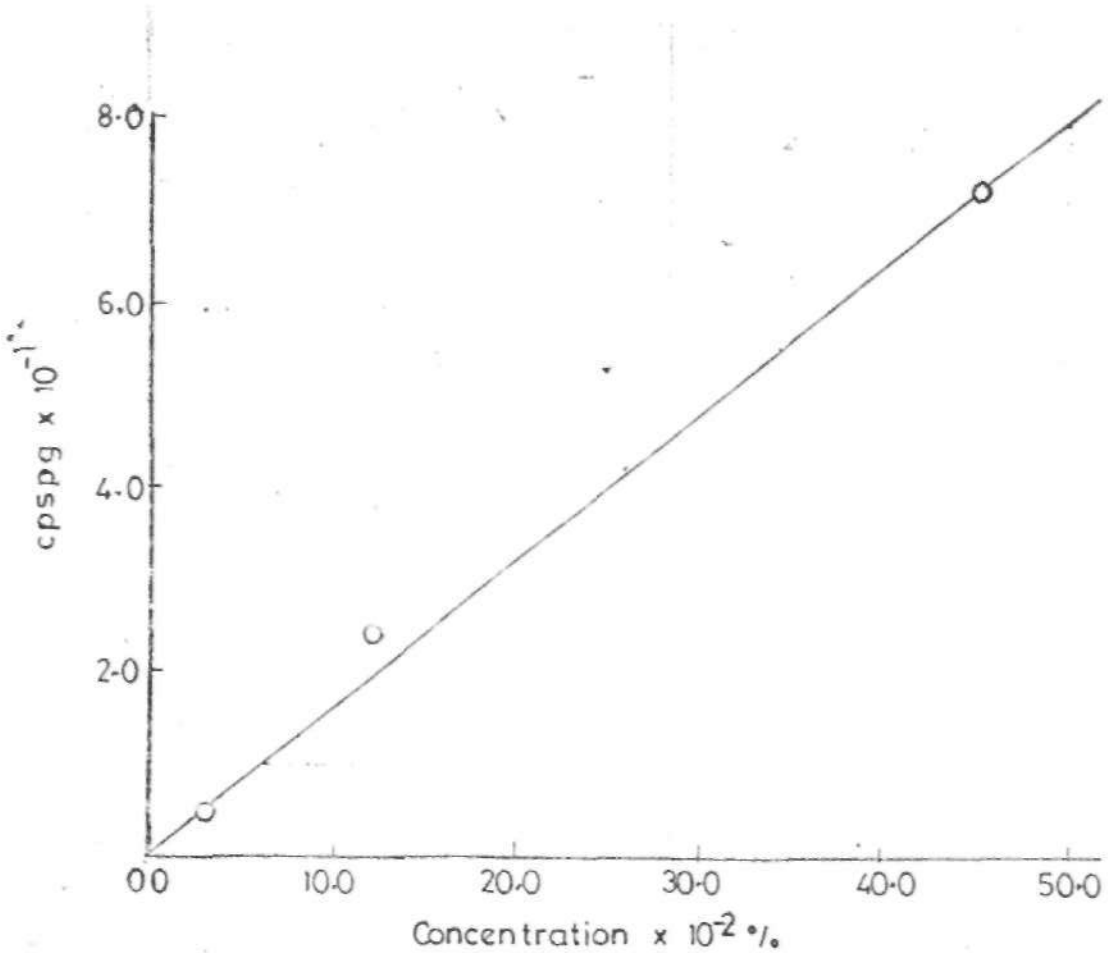


Fig.6.5: Counts per second per gram (cpspg) as a function of uranium concentration at 295·2 KeV peak

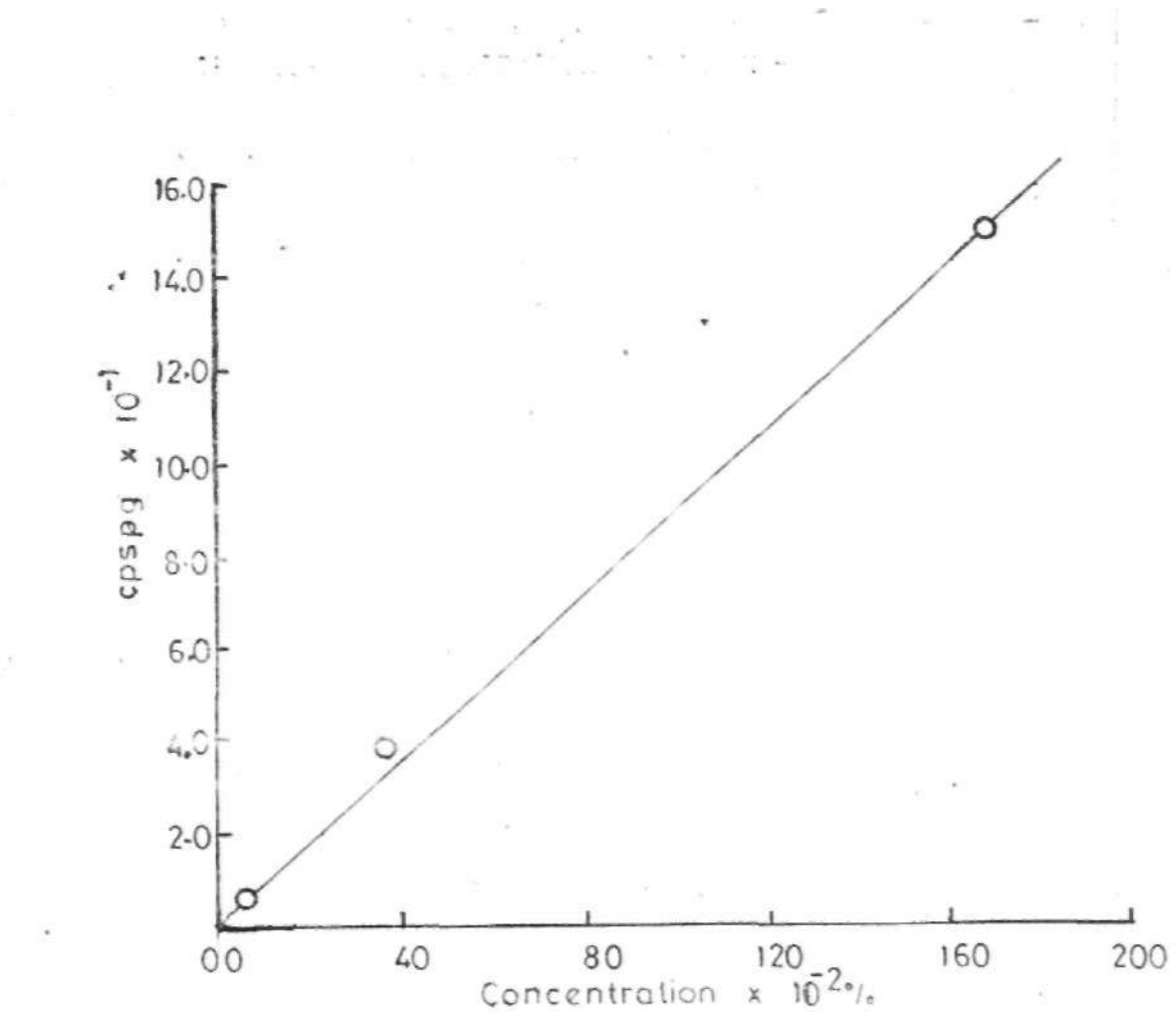


Fig.6.7 Counts per second per gram (cpspg) as a function of thorium concentration at 911.1 KeV

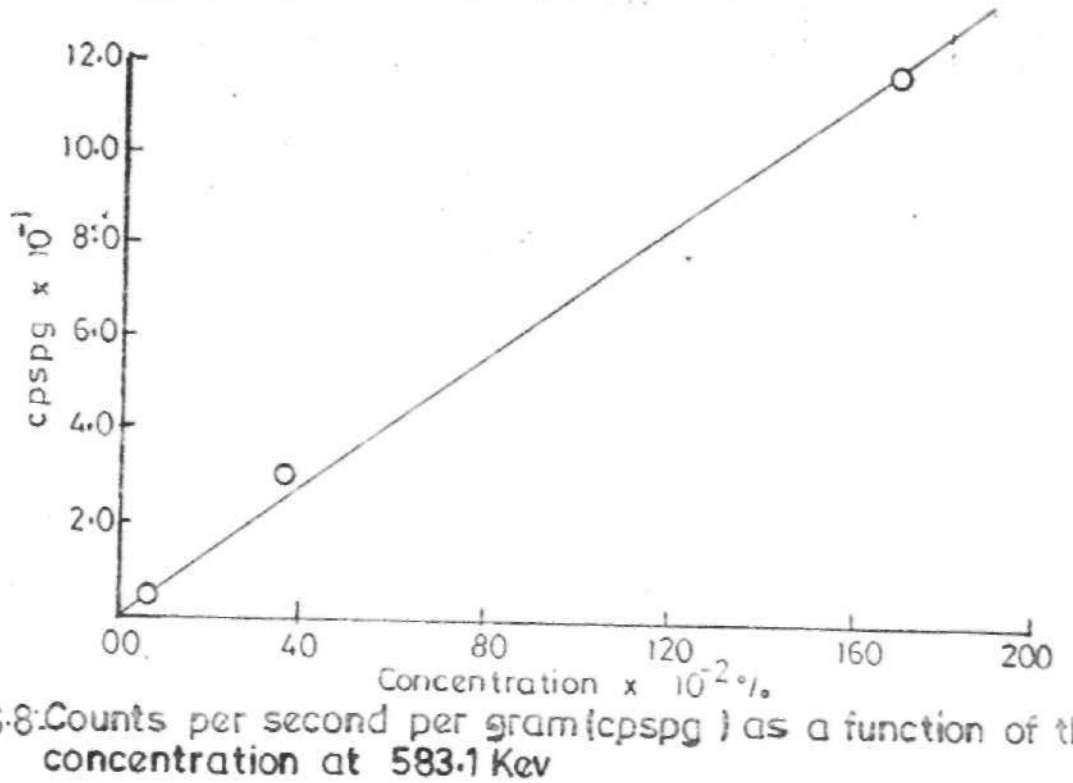


Fig.6.8: Counts per second per gram (cpspg) as a function of thorium concentration at 583.1 Kev

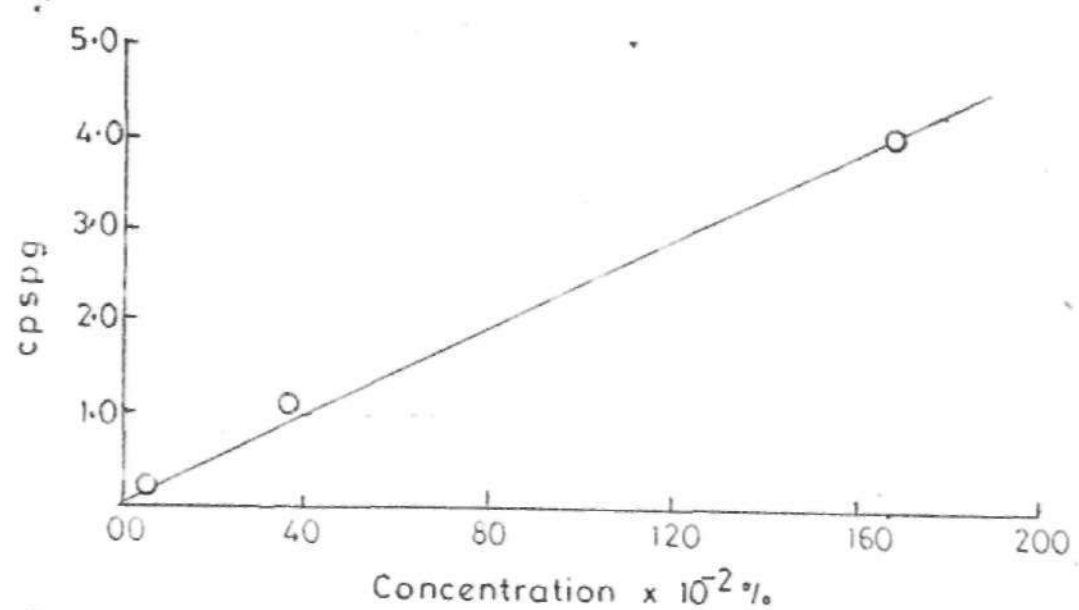


Fig.6.9: Counts per second per gram (cpspg) as a function of thorium concentration at 238 KeV

REFERENCES

Banwo, A., (1989), Comparison of Natural Background Radiation in Soils from Zaria and Jos, Nigeria; M.Sc Thesis, Physics Department, A.B.U., Zaria.

Betekhtin, A., (1979). **A Course of Mineralogy**, Moscow. Peace Publishers, Moscow.

Blastz, H, (1964). **Introduction to Radiological Health** McGraw Hill - Book Company, New York.

Bloxam, T.W., (1962)., Quantitative Determination of Uranium and Thorium in Rocks, **Journal of Scientific Instruments**, 39, 387 - 389.

Catvert, A.F. (1977) **Nigeria and its Tin Fields**, Arno Press, New York.

Cember, H., (1983); **Introduction to Health Physics**, Pergamon Press, New York.

Chong, C.S., Chong, H.Y., Fun, H.K. and Leong, L.S (1985), Gamma Radioactivity in Sn-slag Dumps; **Health Physics**, 49(5), 1008 - 1010.

Cork, M.J., (1950); **Radioactivity and Nuclear Physics**, D. Van Nostrend Company, Inc., Toronto.

Culbert, R.P. and Leighton, D.G. (1981)., Low Energy Gamma Spectrometry in the Geochemical Exploration for Uranium, **Journal of Geochemical Exploration**, 14, 49 - 68.

Gustafson, P.F. and Brav, S.S. (1964), Measurement of Gamma-emitting Radionuclides in soils and calculation of the Dose Arising. In John, A. S and Lowder W. M. (Eds), **The Natural Radiation Environment**, The University of Chicago Press, ILLinois, 499 - 512.

Hu, S.J., (1981). ^{238}U and ^{232}Th in Cassiterites samples and Amang by products, **Health Physics**, 40, 248 - 260.

Hu, S.J., (1985). Radium -226 and Th-232 concentration in Amang, **Health Physics** 49(5), 1003 - 1007.

Hu, S.J., Kandaiya, S. and Benoan, F. (1987), Gamma Activity in struverite, **Health Physics**; 52(3) 379 - 380.

Hyde, R.J., (1986), **The Jos Plateau A Field Course Handbook**, Department of Geography, A.B.U. Zaria.

International Atomic Energy Agency, (1976), Manual of Radiological Safety in Uranium and Thorium Mines and Mills, Safety Series, No.43, Vienna.

International Atomic Energy Agency, (1979), Gamma-Ray Survey in Uranium Exploration, Technical Reports Series No.186 Vienna.

International Atomic Energy Agency, (1989), Measurement of Radionuclides in Food and the Environment, A Guide book, Technical Report Series No. 295, Vienna Austria.

International Commission on Radiation Protection, (1977), Annals of the ICRP, Radiation Protection in Uranium and other Mines, ICRP Publication, Pergamon Press, Oxford.

Kleinknedit, K., (1987) Detectors for particle Radiation; Cambridge University Press, New York.

Knoll, F.G., (1979) Radiation Detection and Measurement, Cambridge University Press, New York.

Leo, R.W. (1987) Techniques for Nuclear and Particle Physics Experiment, A How-to-Approach. Springer verley, Berlin Heidelberg, New York.

Lin, Y.M., Lin, P.H., Chen, C.J. and Huang, C.C. (1987), Measurement of Terrestrial Gamma Radiation in Taiwan, Republic of China., **Health Physics**, 52(6), 805 - 811.

Macleod, W.N. and Turner, D.C. (1971), The Geology of the Jos Plateau. In: **The Geological Survey of Nigeria Vol I and** II, Federal Ministries of Mines and Power, Lagos, Nigeria.

Mantell, D.L. (1970), **Tin, its Mining, Production,** Technology **and Applications**, Hafner Publishing Company Inc. New York.

Myasoedov, B.F. and Pavlotskaya, F.I. (1989), Measurement of Radioactive Nuclides in the Environment, **Analyst**, 114, 255-263.

NCRP (1985). Environmental Radiation Measurements, **NCRP Report No.50**, NCRP, Bethesda, USA.

Sanni, A.O., (1970) Report on the Radiation Hazards in the Mines of Jos Area, Federal Radiation Protection Service Annual Report.

Sanni, A.O., James, D. and Scheweikert, E.A. (1985). Radioactivity of the By products of Tin Mining in Nigeria., **Nig. Journ. of** Science, Vol 19, (1 and 2), 115 - 120.

Sgorbati, G., (1989); Gamma Spectrometry of Natural Radionuclides; Proc. Int. Workshop on Radon Monitoring in Radioprotection,

Environmental Radioactivity and Earth Sciences, ICTP, Trieste, Italy.

Singru, R.M. (1972). Introduction to Experimental Nuclear Physics, Wiley Eastern Private Limited, New York.

Taylor, D., (1957). The Measurement of Radio-Isotopes; Methuen and Co. Ltd, New York. John Wiley and Sons, Inc.

Tsoulfanidis, N. (1983). Measurement and Detection of Radiation; Hemisphere Publishing Corporation New York.

APPENDIX

The efficiency of the GM tube was determined using KCl standard as follows:-

Initially the background counting was carried out followed by sample counting of 0.5770g of KCl and the count rates are as follows:-

Background count rate	1.90 cps
Sample count rate	7.88 cps
Net count rate	5.98 cps

Noting that the R.M.M. of KCl = 39.1g of K + 35.5g of Cl

= 74.6g

Therefore mass of K in 0.5770g of KCl

$$= \frac{39.1}{74.6} \times 0.5770g = 0.3024g$$

But 0.0117% of 0.3024g of K-39.1 is radioactive K-40. This implies that

0.0117% X 0.3024g = 3.5381×10^{-5}g.

Hence, the number of atoms in much of K-40 is

$$N = \frac{3.5381 \times 10^{-5}}{40} \times 6.023 \times 10^{23}$$

$$= 5.327494075 \times 10^{17}$$

Therefore the Activity

$$A = \hat{e}N, = \frac{0.693 \times N}{T_{1/2}}$$

where ê is the decay constant and $T_{1/2}$ is the half life of K-40 (1.37×10^{9} yrs).

This implies that $$A = \frac{0.693 \times 5.327494075 \times 10^{17}}{1.37 \times 10^{9} \times 365 \times 24 \times 3600}$$

$$= 12.33\text{dps}$$

The efficiancy of the detector is given by:-

$$E = \frac{N \times 100}{A \times B.R}$$

Where N is the observed count-rate and A is the absolute activity and B.R is the branching ratio of K-40

$$\text{Therefore } E = \frac{5.98 \times 100}{12.33 \times 0.89} = 54.5\%$$

Hence $E = (54.5 \pm 7.38)\%$

The activity of the soils and plant samples was determined using the equation:

$$A = N/E \times M$$

Where N is the net count-rate of our samples, E is the effeciency of the GM-tube and M is the weight of samples in grammes. For example 5ML4552 sample has an activity (A):

$$A = \frac{0.5087}{0.545 \times 1.3710} = 0.6808\text{Bq/g}$$