Measurement of Natural Radioactivity Level and Radilogical Hazards in soil Sample of Bale Zone, Oromia, Ethiopia Using Gamma Spectrometry

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Declaration

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MEASUREMENT OF NATURAL RADIOACTIVITY LEVEL AND RADIOLOGICAL HAZARDS IN SOIL SAMPLE OF BALE ZONE, OROMIA, ETHIOPIA USING GAMMA SPECTROMETRY

BY

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Abstract

In this study, our objective was to measure the level of activity concentration and radiological hazards of soil samples from agricultural and virgin lands of Bale zone, Oromia, Ethiopia. The activity concentrations of naturally occurring radionuclides ^{238}U, ^{232}Th, and ^{40}K were calculated total for of twelve(12) which is six(6) from agricultural and the other six(6) from virgin soil samples randomly collected from four kebele's of Bale zone southeastern part of Ethiopia by mixing equal masses of soil from three different depths starting from 0 to 10cm,then 0 to 20cm, and 0 to 30cm. Gamma-ray spectrometer was applied using high-purity germanium (HPGe) gamma-ray detector and a PC-based MCA that uses Genie 2000 Spectroscopy Software. Additionally, in our some soil samples of two sites there is an artificial radionuclide of ^{137}Cs that fallout from any nuclear accidents can be seen when the samples analyzed by Gamma-ray spectrometry using high-purity germanium. The mean value of radioactivity concentrations of ^{238}U , ^{232}Th, and ^{40}K were found to be 21.74±0.569 with ranged from 6.565±0.206 to 41.15±0.748, 71.72±1.95 with ranged from 26.2±0.77 to 122±2.57 and 1111.5±3.39 Bq kg^{-1} with ranged from 555±8.94 to 2180 ± 3.21 Bq kg^{-1} , respectively, in agricultural soils and 18.89 ± 0.667 with ranged from 7.54 ± 0.378 to 30.25 ± 1.340, 69.93 ± 2.38 with ranged from 36.2 ± 0.96 to 121.0 ± 2.55, and 642.83 ± 4.39 Bq kg^{-1} with ranged from 413 ± 7.01 to 808 ± 1.21 Bq kg^{-1} , respectively, in virgin soils. The radioactivity concentrations in agricultural soils are higher than those in virgin soils as of phosphate fertilizers added to agricultural land soils. Out of twelve samples the activity concentrations of the artificial radionuclide ^{137}Cs was measured by HPGe only in six samples. The mean value was 1.542 ± 0.635 Bq kg^{-1} with ranged of 0.451 ± 0.507 to 2.19 ± 0.151 Bq kg^{-1}. The minimum activity concentration value of ^{137}Cs was obtained for a soil sample collected from virgin land, similarly the maximum value was measured in a soil sample collected from virgin land site, which is no health effects on the people living around the sites where soil samples were collected.

The Gamma-ray radiation of radiological hazards caused by specific radionuclides of ^{238}U, ^{232}Th, and ^{40}K was evaluated using different hazard indices. The mean values of radium equivalent activity (Ra_{eq}), absorbed dose rates (DR), annual effective dose(ADR), external hazard index(H_{ex}), and internal hazard index(H_{in}) are 209.88 ± 3.617 Bqkg^{-1} which ranged from 93.45 ± 2.110 to 296.46 ± 4.543 Bq kg^{-1}, 101.76 ± 1.873 nGy h^{-1} which ranged from 45.85 ± 1.001 to 138.73 ± 1.988

nGy h^{-1}, 0.12 ± 0.002 mSvy^{-1} with ranged from 0.06 ± 0.001 to 0.17 ± 0.002mSv y^{-1}, 0.57, ranged from 0.25 to 0.80, and 0.625, ranged from 0.29 to 0.91, respectively, were found in agricultural soils and 168.40 ± 4.402 Bqkg^{-1} with ranged from 98.92 ± 2.283 to 256.05 ± 4.147 Bqkg^{-1}, 79.28 ± 1.954 nGy h^{-1} with ranged from 46.87 ± 1.058 to 119.01 ± 1.815 nGy h^{-1}, 0.098 ± 0.002 mSv y^{-1} with ranged from 0.06 ± 0.001 to 0.15 ± 0.002 mSv y^{-1}, 0.46 with ranged from 0.27 to 0.69, and 0.51 with ranged from 0.31 to 0.75, respectively, were found in virgin soils samples. Further, the annual dose rate was calculated only for outdoor. In a comparison of the world wide average value calculated by UNSCEAR and ICRP with our results mean value for absorbed dose rates (DR),and annual effective dose(ADR) were out of the recommended mean values of 59nGy/h and 0.07mSv/y by these institutions. But, others like radium equivalent activity (Ra_{eq}), external hazard index(H_{ex}), and internal hazard index(H_{in}) mean values were within the recommended value. Finally, in all radiological hazard indices when we compare two sites(agricultural and virgin lands), the mean values of agricultural soil were greater than the mean values of virgin soil samples.

key words: Natural radionuclides, Activity concentration level, Radiological hazard and HPGe gamma-ray Spectrometry

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Introduction

1.1 Background of the study

Natural radionuclides are widely spread on the earth's environment that we leave in. Environmental natural sources of gamma radiation were formed from terrestrial and cosmic sources [8]. The naturally occurring radioactive material(NORM) was existing in soil, plants, water, and air. Based upon this natural radionuclide in soil generates a significant component of the background radiation that causes exposure to human beings. According to our country Ethiopia context the background radiation, sources of radiation, and where those sources exist are almost not known. The terrestrial component of the natural background depends on the compositions of the soils and rocks in which the natural radionuclide is contained. So, a significant contribution to the total dose from natural sources comes from terrestrial radionuclide can be like uranium-238, thorium-232, and Potassium-40 [9]. Additionally, the radionuclides are encountered in terrestrial strata (soil or rocks) or lakes and water bodies (ocean, sea, or lakes) and can be easily accumulated into the food chain. Therefore, the natural radioactivity in the soil is derived mainly from the ^{238}U and ^{232}Th, and also their daughter series and naturally exists in ^{40}K [10].

All living things are exposed to natural radioactivity at different levels due to the natural radioactive elements present in each area; supported the researchers investigated the natural environmental radiation and radioactivity in soils to conduct background checks and detect environmental radioactivity [11]. The amount of radioactivity that exists in the environment is often wont to assess public dose rates and radioactive contamination, and also wont to predict changes in environmental radioactivity caused by nuclear accidents, industrial, and other human activities

[12]. Potassium-40, uranium-238, and thorium-232 and their decay products are important natural radioactive elements that contribute to an out sized part of the radiation dose received by humans; additionally, different researchers are often suggested approximately 60 abundantly distributed radionuclides have been identified.

The natural environmental radioactivity that is associated with external exposure due to gamma radiation depends basically on geological and geographical conditions. The sources of radioactivity in soils are not only of natural origin but also mainly due to extensive use of fertilizers rich in phosphates for agricultural purposes [12]. In my study of natural radioactivity in soil can provide as a reference data in observing possible future anthropomorphic impacts and associated with radiological effects on human health. The activity concentrations of radionuclides of ^{238}U and ^{232}Th, and their decay chains and from ^{40}K were determined through gamma-rays spectrometer in a low background configuration [13].

According to the IAEA(International Atomic Energy Agency), standards apply to facilities and activities that produce radiation risks, including nuclear installations, the utilization of radiation and radioactive sources, the transport of radioactive material, and the management of radioactive waste[14]. Radiological effects could cause radioactive contamination of consumer goods consumed by human begins; such as water, food, and other commodities. These possible effects, however, can lead to significant internal contamination of a large population. Large amounts of radioactive material would be required to reach high levels of contamination. The intervention measures in the aftermath of radiological effects should result in a systematic and flexible approach, taking into account the conditions and summon into action as warranted by the circumstances. In accordant with my country no scenarios that clearly induce immediate vigorous radiation injuries. Because no research was conducted on such scenarios. As globally, in order to prevent overreaction, radiological protection decisions must be proportional to the magnitude of radiological effects that faced on human begins [15].

The International Basic Safety Standards(IBSS), published by the International Atomic Energy Agency (IAEA) in 1996, provide the basis for the control of exposure to both artificial and natural sources of radiation. As reported by safety standards high doses of radioactivity can be harmful or even fatal. The three exposure situations are Planned, Emergency, and Existing, and the three categories of exposure can be occupational, public, and medical [16]. The occurrence of a change for the

worse caused by exposure to radioactivity is determined by the type of radiation, the duration of exposure, and the part of the body that is exposed. The interaction of ionizing radiation with the human body cells were arises from either external sources or internal contamination which can lead to biological effects [12]. The biological effects can also deem to be in terms of the radiation effects that confront. Such radiation effects can be either stochastic effects or/and non-stochastic effects. Stochastic effects increase with an increase duration exposure of radiation, because of dose rate. Whereas non-stochastic effect has a threshold below which there is no health effect. The radiation effects can lead to the death of a cell, impairment in the natural functioning of the cell leading to somatic effects such as cancer, and a permanent alteration of the cell which is transmitted to the future generation i.e. genetic effect. Furthermore, the human body that expose to radiation also reduces the immunity of person exposed [15, 17].

Because our country Ethiopia was one of the developing countries, it works on radiation technology and their exposure risks soon. So, to fill the gaps as soon as possible researchers and research must be needed on those issues to overcome the effects of the radiation from our societies. Therefore, my intention to study in measuring the natural radioactivity level in soil and the related radiological hazard indices come from the idea presented here above.

This study can be focused on the southeastern part of Ethiopia, Oromia, Bale Zone. From Oromia National Regional State Bale zone is the second-largest zone next to the Borena zone with a total area of $63,555 km^2$. It shares about 17.5 % you look after a total area of Oromia. Bale zone has 18 districts, 2 urban administrative centers, 20 urban kebeles, and 351 rural kebeles. Meda Welabu is one of the woredas in the Oromia Region Part of the Bale Zone, Meda Welabu is bordered on the south by the Ganale Dorya River which can separate it from the Guji Zone, on the northwest by west Arsi Zone, on the north by Mennana Harena Buluk, and on the northeast by Guradamole. Bidire is the administrative center of the woreda and also other towns in Meda Welabu was Oborso.

Based on Central Statistical Agency figures published in 2005, this woreda has an estimated total population of 85,661, of whom 42,321 were males and 43,340 were females; 2,567 or 3% of its population are urban dwellers. With an estimated area of 8,726.72 km^2, Meda Welabu has an estimated population density of 9.8 people per square kilometer [18]. So, the measurement of natural radioactivity level in the soil

sample of four kebeles(Oda, ware, Waduma, and Ganale) of Meda Welabu woreda, Bale zone, Oromia, Ethiopia. To measure the level of radioactivity in those soil samples we use a high purity germanium (HPGe) coaxial detector with a relative efficiency of 70% and multichannel analyzer of 8192 channel performance with the application of genie 2000 Spectroscopy Software.

1.2 Statement of the problem

Human begins have always been exposed to naturally occurring radiations arising from within and outside of the earth. Exposure to ionizing radiations from natural sources occurs, because of, the naturally occurring radioactive elements in the soil and rocks, cosmic rays entering the earth's atmosphere from outer space, and the internal exposure from radioactive elements through food, water, and air. The natural radioactivity in soil primarily comes from ^{238}U and ^{232}Th series and natural ^{40}K. Artificial radionuclides can also be present such a ^{137} Cs, resulting from the fallout from weapons testing and from accidents such as Chernobyl. The radiological implication of these radionuclides is due to the gamma-ray exposure of the body and irradiation of lung tissue from inhalation of radon and its daughters. Therefore, the dose assessment of gamma radiation from natural sources is of particular importance as natural radiation is the largest contributor to the external dose of the population [19].

From this point of view, naturally occurring radioactive material in the environment can exist in the soil that is used for different purposes like, agriculture. So, the measurement of natural radioactivity level in the soil sample of Bale zone, Oromia, Ethiopia has got interest of study because there are traditional miners and radiological effects that seen on them and peoples live in that environment. Meda Welabu is one of the woredas that exist in the Bale zone of the Oromia Region, Ethiopia. Part of the Bale Zone, Meda Welabu is bordered on the south by the Ganale Dorya River which separates it from the Guji Zone, on the northwest by Mirab Arsi Zone, on the north by Mennana Harena Buluk, and on the northeast by Guradamole. The administrative center of the woreda is Bidire; other towns in Meda Welabu include Oborso, based on the Central Statistical Agency published in 2005 [18].

This study was focused to provide information on the natural radionuclides that exist in that area and the radiological effect assessments are to determine what radionuclides are being released and to which part of the environment they are

being released and their activities. To undertake a realistic dose rate it is essential to obtain as much information as possible for the site being assessed. Data will need to include: Type and amount of radionuclides being in that environment, their activity level and type of release and etc [20]. So, the measurement of natural radioactivity level in the soil sampled from agricultural and virgin land of four kebeles (Oda, ware, Waduma and Ganale) and knowing the activity level and radiological effects of radioactive material in a soil sample from the selected area is important to confirm the faced cases in that area.

1.3 Objective of the study

1.3.1 General objective

The main objective of this study was to measure the natural radioactivity level in soil and computed the related radiological hazard indices sampled from Bale zone, Oromia, Ethiopia by using gamma ray spectrometer coupled with HPGe detector.

1.3.2 Specific objective

1. To measure the natural radioactivity level of radioactive element viz. Uranium-238, Thorium-232 and Potassium-40
2. To calculate the radiological hazard parameters. like, Radium equivalent activity (Ra eq.), Absorbed dose rate(DR), Annual dose rate (AD_R), External hazard index (H_{ex}) and Internal hazard index (H_{in})
3. Estimate the radiation hazards in compression with agricultural and virgin land sites soil samples.

1.4 Motivation of the study

In our country Ethiopia all most there was no research conducted on the natural radioactivity in the area that we selected. Getting information in which area the natural radioactivity exists was very important for our country because natural radioactivity has hazardous health effects upon human exposure. Because, I am working for Oromia Science Technology and Information Communication Authority, in department of Radiation Protection and Its Technological Uses there was an information about the existence of radionuclide elements in the area selected in my

study from Ministry of Mines and Petroleum. Further, I got a chance to observe this area, there are traditional miners and some health effects on them. So, the significance of this study was to determine the types of radionuclides, activity concentration level of radionuclide found in that study area and the radiological effects on the people's lives in that environment.

1.5 Scope of The Study

This study focused on measuring naturally occurring radioactive material's activity concentration and radiological hazards in the soil samples taken from agricultural and virgin lands applying gamma ray spectrometer with high purity germanium(HPGe) detector. Our study area was focused in southeastern part of Ethiopia, Oromia, Bale Zone cover four kebele's of Ganale, Waduma, Ware, and Oda that samples taken using GPS map. The number of samples that sampled were vary from one kebele to the other based on different reasons.

1.6 Limitation of the study

The Limitation for this study was resources, and methodology of our study. In the study plan, the collected samples were all most around 750km from the center(from our Institution) and the logistic is not suitable to the selected area. So, to do this study effectively and efficiently require resources (cost and time). Because of this, the collected samples have a limit in representing the sampling area. The methodology constraints are mainly originated from limited access to gamma spectrometers for laboratory work. The experiment can be done at the Ethiopian Radiation Protection Authority lab, which was a single laboratory in the country. Because of this, the time allocated for us was not sufficient to repeat the same measurements for each sample. So, one sample can be measured only once, and no opportunity to try again for the reduction of technical and statistical errors.

So, to over come those limitations we used different techniques. Like, covering all areas were not possible, but as a solution number of samples were based on size, population density, and higher mining of the kebele's area, and also to reduce the error we use laboratory guide lines effectively and efficiently as much as possible.

Chapter 2

Natural Radioactivity and HPGe Detection Mechanisms

Our universe is made up of atoms. Some atoms are naturally stable, others are unstable. Radioactivity arises when atoms can be unstable. From unstable atoms nucleus spontaneously transforms and releasing energy in the form of ionizing radiation. These unstable elements are known as radionuclides. The released radiation can be in the form of particles (including electrons, neutrons, and alpha particles), and also others can be in the form of electromagnetic gamma radiation or X-rays, all with different amounts of energy. In addition to natural radiation, it can also be generated artificially by machine or man-made sources, the largest of which is the application of X- rays in medicine. [21].

2.1 Radioactivity

The nuclei of naturally occurring heavy elements like Th, U, Ra and Po are unstable and keep on emitting spontaneously invisible rays or radiations (α, β, γ-rays), and give stable elements. These heavy elements are called radioactive elements. The property of emitting these rays is called radioactivity of the elements. The phenomenon in which the nucleus of the atom of an element undergoes spontaneous and uncontrollable disintegration (or decay) and emits α, β, γ-rays. Natural Radioactivity may occur through one of the following processes: Alpha (α)-decay, Beta(β)-decay, Orbital electron capture and Gamma(γ) -decay. Artificial Radioactivity may also include decay via proton, neutron, or fission.

Radioactive decay-is an unstable atomic nucleus that spontaneously loses en-

ergy by emitting ionizing particles and radiation. The radioactive decay or loss of energy can result in an atom of one type, which is called the parent nuclide transforming to an atom of a different type, which is known as the daughter nuclide. This is a random process on the atomic level that it is impossible to predict when a given atom will decay, but given a large number of similar atoms the decay rate. Becquerel (Bq) is the SI unit of radioactive decay . One Bq (1Bq) is defined as one transformation (or decay) per second. A sample of radioactive material contains many atoms. So, Becquerel is a small measure of activity; to measure large amounts can be by the order of TBq (Tera Becquerel) or GBq (Giga Becquerel) are commonly used. Another unit of radioactivity is the curie, Ci, which was originally defined as the activity of one gram of pure radium, isotope Ra-226, which 1Ci equal to the activity of any radionuclide decaying with a disintegration rate of $3.7 \times 10^{10} Bq$. [22]. Finally, radioactivity is a phenomenon related to unstable atomic nuclei with excess of energy and/or mass, which spontaneously decompose emitting ionizing radiation in the form of electromagnetic waves (γ rays) or streams of subatomic (α, β and particles) . Their instability,to be stable the nuclei decay of α,β, or γ emissions can be expressed as follows [23] :

Alpha(α) decay-many heavy nuclei, with $82 < Z \leq 92$ decay by α emission, in which the parent nucleus loses both mass and charge (A, Z). The α (He-nucleus) type reaction can be represented as:

$$ {}^{A}_{Z}X_{N} \rightarrow {}^{A-4}_{Z-2}Y_{N-2} + {}^{4}_{2}\alpha $$

where X represents a chemical symbol of the parent atom and Y represents the daughter. The number of protons and neutrons must separately conserved in the decay process.An example of an α-decay process is

$$ {}^{226}_{88}Ra_{138} \rightarrow {}^{222}_{86}Rn_{136} + \alpha $$

in which the half-life is 1600 years and the α particle appears with a kinetic energy of about 4.8 MeV [2, 24].

Beta(β) decay- in beta(β) particle emission, a neutron (in the nucleus) is converted into a proton, electron and an anti-neutrino.

$$ {}^{A}_{Z}X_{N} \rightarrow {}^{A}_{Z-1}Y_{N-1} + e^{-} + \bar{\nu} \quad \Longleftrightarrow \quad n \rightarrow p + e^{-} \qquad \beta^{-}\text{-decay} $$

$$ {}^{A}_{Z}X_{N} \rightarrow {}^{A}_{Z-1}Y_{N+1} + e^{+} + \nu \quad \Longleftrightarrow \quad p \rightarrow n + e^{+} \qquad \beta^{+}\text{-decay} $$

The negative β- decay or negatron decay process involved the creation and emission of an ordinary electron. Whereas positive β-decay or positron decay process was which a positively charged electron is emitted. [2]. An example of some representative β-decay processes are

$$^{131}_{53}I_{78} \rightarrow {}^{131}_{54}Xe_{77} + \beta^- + \bar{\nu}$$
$$^{25}_{13}Al_{12} \rightarrow {}^{25}_{12}Mg_{13} + \beta^+ + \nu$$

Electron capture- a parent nucleus may capture one among its orbital electrons and emit a neutrino. This is a process that competes with positron emission and has an equivalent effect on the atomic number. Most ordinarily ,it is a K-shell electron that's captured.

$$^{A}_{Z}X_N + e^- \rightarrow {}^{A}_{Z-1}Y_{N+1} + \nu \quad \Longleftrightarrow \quad p + e^- \rightarrow n \qquad \text{electron capture}(\varepsilon)$$

In the orbital electron captured process an atomic electron that strays too close to the nucleus is swallowed, allowing the conversion of a proton to a neutron. Let as seen an example in the decay of magnesium:

$$^{54}_{25}Mn_{29} + e^- \rightarrow {}^{54}_{24}Cr_{30} + \nu \quad (\text{electron capture}(\varepsilon))$$

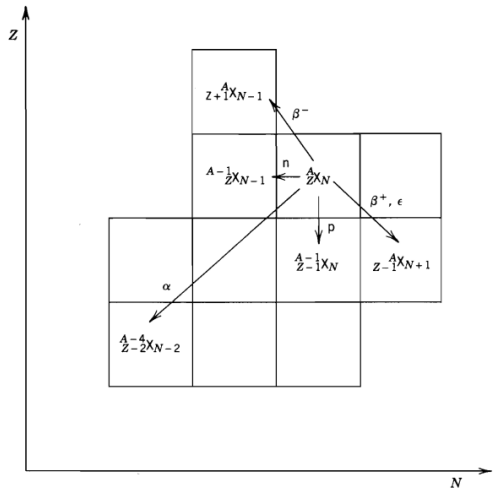

Figure 2.1: The initial nucleus $^{A}_{Z}X_N$ can reach different final nuclei through a variety of possible decay processes [2].

Gamma(γ)**decay**-in the gamma decay the nuclide is unchanged, but it goes from an excited higher energy state to a lower energy or ground state. These states are called isomeric states. Usually, the reaction is written as:

$$ {}^{A}_{Z}X^{*}_{N} \rightarrow {}^{A}_{Z}X_{N} + \gamma $$

where the star indicates an energetically excited state.

On the other hand, alpha or beta emission brings about a change in the numbers of protons and neutrons present, hence a new overall change in the resulting daughter nucleus, the new nucleus that an alpha(α) or beta(β) decay leaves behind. Moreover, it is almost always in an energetically excited state. The daughter nucleus can usually drop immediately into a state of lower energy by the emission of a gamma-ray photon. However, through the emission of a gamma-ray photon, there is also emission of alpha or beta.

Decay rates- the radioactive decay rate of a nucleus is measured in terms of

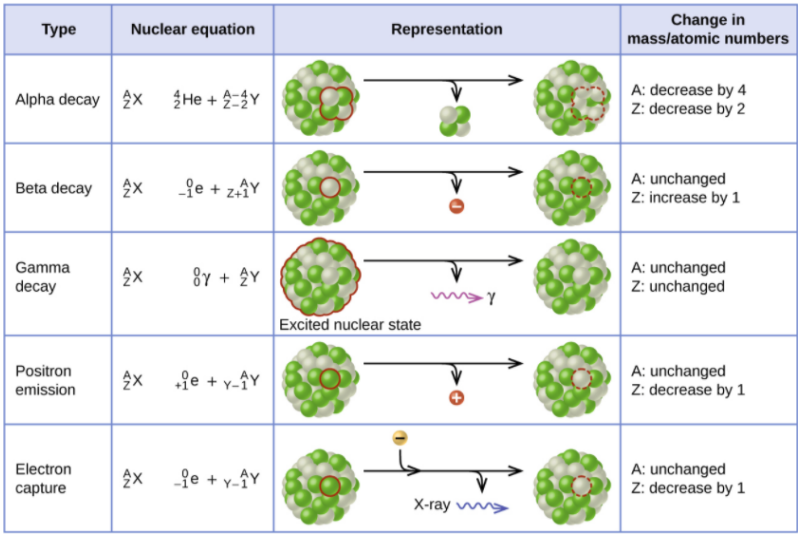

Figure 2.2: Radioactive decay type and nuclear equation[47]

the decay constant λ, which is the probability per unit time that a given nucleus will decay and this is related to its half-life. Each radioactive nucleus has its own characteristic and their own half-lives. If there are N radioactive nuclei in a sample at time t, the decay rate will be given by:

$$ \frac{dN}{dt} = -\lambda N(t) \tag{2.1} $$

The constant of proportionality λ is called the decay constant. We can also rewrite the above equation as:

$$ \lambda = -\frac{dN/dt}{N} \tag{2.2} $$

where the minus sign indicates that N is decreasing with time. The solution of this equation is

$$ N(t) = N(0)e^{-\lambda t} \tag{2.3} $$

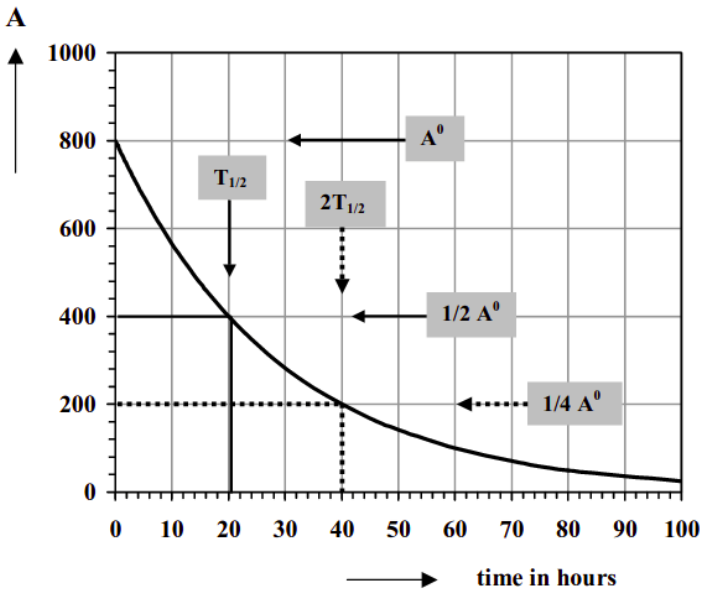

Figure 2.3: The rate of radioactive decay. After each subsequent half-life of 20 hours the number of radioactive nuclei and the original radioactivity of 800 units are divided into half[2]

Half-life ($t_{1/2}$)-the period of time in which half of the radioactivity has disappeared (half of the nuclei have disintegrated. The time during which A^0 decreased to A (age of the material) is: with N(0) being the number of nuclei present at t = 0. The half-life, $t_{1/2}$, may be expressed in terms of λ

$$t_{1/2} = \frac{ln2}{\lambda} \tag{2.4}$$

The mean life time is

$$\tau = \frac{1}{\lambda} \tag{2.5}$$

The activity A is defined as the number of decaying nuclei per unit time and it can be represented by

$$A(t) = -\frac{dN}{dt} = \lambda N(t) \tag{2.6}$$

The integration of this relation and applying the boundary conditions that at in the beginning t = 0 and $N = N_0$ can be:

$$ln(N/N_0) = -\lambda t \tag{2.7}$$

and subsequently the equation of exponential decay:

$$N = N_0 e^{-\lambda t} \tag{2.8}$$

Or from equation number (6):

$$A = A_0 e^{-\lambda t} \tag{2.9}$$

The unit is the Becquerel (Bq) with the historical unit being the Curie (Ci) where: $1Ci = 3.7x10^{10}$ decays per second and 1 Bq = 1 decay per second. In this study the results are given in terms of activity concentrations, which are expressed in units of Bq/kg [2, 24].

2.2 Naturally Occurring Radioactive Material(NORM)

NORM (Naturally Occurring Radioactive Material) which will be found in nature understood as natural radionuclides. A natural radionuclide has been a component of the world since its existence. The radionuclides that naturally occurred or released from the method of materials may constitute a risk to workers, the general public, or the environment. These radionuclides that exist in minerals or/and ores originally found within the environment are commonly referred to as naturally occurring radioactive material(NORM). The most origins of NORM are the primordial, cosmic rays, and man-made sources. As the researcher states by taking different institutions research as a benchmark, the human bodies are exposed externally to gamma rays as a result of radionuclide decay from naturally occurring radionuclides (such as ^{238}U, ^{232}Th and ^{235}U) and their products and ^{40}K. These radionuclides occur in soil and building materials with different concentrations [25].

The activity concentrations of the radionuclides in rocks and soil found in nature are generally low. Certain minerals, including some that are commercially exploited, contain uranium, thorium, or potassium at elevated concentrations. The worldwide effective dose rate of public exposure because of radionuclides that occur in:

- Soil (mean activity concentrations of 35, 30, and 400 Bq/kg) and
- In building material (50, 50, 500 Bq/kg) for ^{238}U, ^{232}Th, and ^{40}K respectively [21, 26]

Living organisms are continuously exposed to a wide range of ionizing radiations from naturally occurring radioactive materials(NORMs) and there's also a radionuclide generated from human activities referred to as artificial radionuclides [27]. Whereas, human bodies are also internally exposed due to the existence of certain radionuclides within the body like ^{40}K or through inhalation of ^{222}Rn. The worldwide average annual effective doses (mSv) from external sources (such as cosmic rays and terrestrial gamma rays) are 0.4 and 0.5 mSv respectively, with the typical range of 0.3-1 and 0.3-0.6 mSv respectively. From internal exposure, inhalation and

Table 2.1: Average radiation dose from natural sources[1]

Source	**Worldwide average annual effective dose (mSv)**	**Typical range (mSv)**
External exposure		
Cosmic rays	0.4	0.3 - 1.0
Terrestrial gamma rays	0.5	0.3 - 0.6
Internal exposure		
Inhalation (mainly radon)	1.2	0.2 - 10
Ingestion	0.3	0.2 - 0.8
Total	2.4	1 - 10

ingestion the average values are 1.2 and 0.3 mSv respectively, with typical ranges of 0.2-10, 0.2-0.8 mSv respectively [21, 26]. The IAEA(International Atomic Energy Agency) publication mentioned that if the activity concentration is less than 1Bq/kg there is no need for regulatory control and it is under exemption from regulatory requirement and also if the occupational exposure is less than 1mSv/y [28]. Naturally occurring radioactive materials(NORM) where human activities have increased the potential for exposure in comparison to the unaltered situation. Activity concentrations may or may not be increased [20].

2.3 Radioactivity in the Environment

Radionuclides are found everywhere in the environment. Any living things that leave on earth are naturally exposed to ionizing radiation because of radionuclides can exist everywhere. Nobody can avoid it and also arises from naturally occurring sources present in nature, independent of human activity. Natural environmental radioactivity arises mainly from primordial radionuclides such as ^{40} K, and therefore the radionuclides from the ^{232} Th and ^{238} U series and their decay products, which occur at trace levels altogether ground formations [29]. Especially peoples are constantly exposed to varying degrees of radiation from naturally occurring radioactive materials (NORMs) within the environment and the degrees of radiation generated from radionuclides increases by human activities which was called technologically enhanced naturally occurring radioactive materials (TENORM) [30].

2.4 Types of environmental radioactivity

Radioactivity in the world can often categorize consistently into three different types, those are primordial, Cosmogenic, and anthropogenic nature [24].

- **Primordial radionuclides** – these have half-lives sufficiently long that they need to exist since the formation of the earth, and from the radioactive decay of these, secondary radionuclides are produced (e.g. ^{40}K, ^{232}Th, and ^{238}U)
- **Cosmogenic radionuclides** – primary radiation (protons and other heavier nuclei), originating from outer space, called cosmic rays continuously bombard stable atoms in the atmosphere and make radionuclides (e.g. ^{22}Na, ^{7}Be and ^{14}C). When cosmic rays strike the atmosphere, they produce a nuclear cascade or a sudden downpour of secondary particles. Most of these are eventually stopped before they reach the surface of the earth except for energetic muons (μ), and neutrons (n), which may penetrate all the way into the earth.
- **Anthropogenic radionuclides** – these are man-made radionuclides released into the environment through, for instance, the testing of nuclear weapons, nuclear reactor accidents (e.g. Chernobyl) and in the radio-isotope manufacturing industry (^{137}Cs, ^{90}Sr and ^{131}I).

2.4.1 Primordial radionuclides

Primordial radionuclide which was also called terrestrial radionuclides found in nature is related primarily to the fact that these isotopes themselves have very long half-lives or are created in decay chains with the top parents having very long half-life [31]. Natural radioactivity within the soil comes from uranium and thorium series and natural potassium. The world average abundances of the continental upper crust for ^{238}U, ^{232}Th and ^{40}K are respectively 2.7 ppm , 10.5 ppm and 2.3 percent [32].The study of the distribution of primordial radionuclide allows the understanding of the radiological implication of those elements due to the gamma-ray exposure of the body and radiation of lung tissue from inhalation of radon and its daughters [27]. Primordial radionuclides that now exist are those that have half-lives comparable to the age of the Earth, especially the primordial radionuclides and their decay products are present in almost all types of soils, rocks, and drinking water and building materials (e.g. ^{238}U, ^{232}Th and ^{40}K). Naturally occurring radionuclides can be divided into those that occur individually and those that are

components or chains of other radioactive decay. In nature, the radioactive nuclide occurs as heavy nuclides within the uranium and thorium decay series that depends on Z, N, and decay types. Some radionuclides exists naturally in the environment and there characteristics as follows: [24, 33]

Uranium-238

Natural uranium was mainly constituted by ^{238}U, ^{235}U and ^{234}U created in ^{238}U decay chain, having natural isotopic ratios 99.2745%, 0.730% and 0.0055%, respectively. ^{238}U is the head of a series of 14 principal nuclides. The decay chain of ^{238}U includes 8 alpha decays and 6 beta decays. This can be divided into sub-series in which the activity of the precursor controls to a large degree the activities of the decay products: ^{238}U - ^{234}U, ^{230}Th, ^{226}Ra; ^{222}Rn - ^{214}po; and ^{210}Pb - ^{210}Po. In the atmosphere, the main natural source of uranium, as well as any other precursor of one of the radon isotopes, likely to be the re-suspension of dust particles from the earth. Taking a dust loading of about 50 $\mu g\ m^{-3}$ in surface air of populated areas and assuming an average ^{235}U activity mass concentration in airborne dust as in soil of 25 Bq kg^{-1}, the activity concentration in ground-level air is estimated to be about 1.2μBq m^{-3}. The corresponding annual intake by adults through inhalation is approximately 0.01 Bq[31].

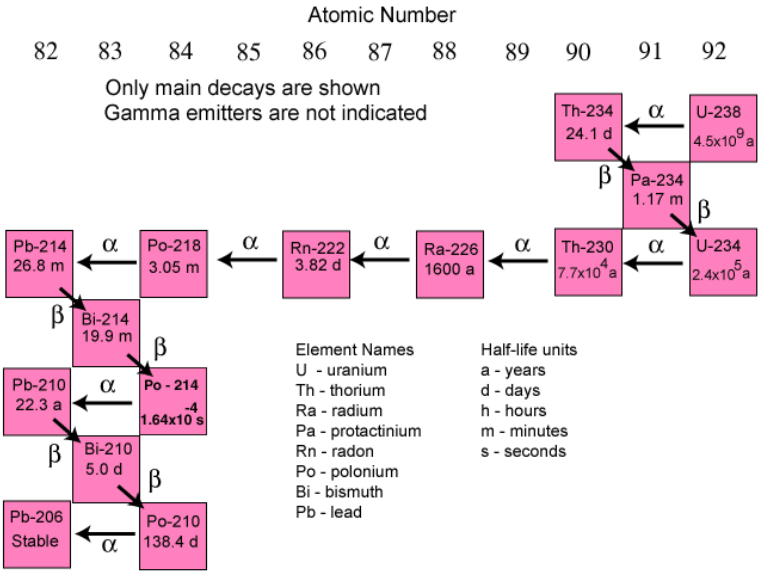

Figure 2.4: Uranium-238 decay series. Source: U.S.Environmental Protection Agency

Thorium-232

Natural thorium has just one primordial isotope that of 232-Th having an natural isotopic ratio of 100%. Thorium(^{232}Th), is that the most abundant of the heavy

elements, that present in several minerals and contributes to the general background radioactivity. Thorium mainly originated from igneous rocks, as disseminated and discrete minerals. It is not as soluble as uranium and is thus not as mobile in chemically solvent environments. Thorium is about three times more abundant than uranium in nature .

The decay chain of ^{232}Th includes 7 alpha decays and 4 beta decays. Thorium-232 is the head of a series of 11 radionuclides. The ^{232}Th series has been divided into three sub series: ^{232}Th itself, ^{228}Ra - ^{224}Ra, and ^{220}Rn - ^{208}Pb. The activity mass concentration of ^{232}Th in soil is estimated to be on average 25 Bq kg-1, the same as that of ^{238}U and its decay product ^{230}Th. The annual intake from inhalation is estimated to be 0.01 Bq while that from ingestion, recently measured in the United States for the first time, is about 2 Bq. Wrenn and his collaborators found the activity mass concentrations of ^{232}Th in the body to be lower than those of ^{230}Th by a factor of about 2. On the basis of their measurements, the body content of ^{232}Th would be about 80 mBq, 60% of which is in the skeleton. The annual effective dose equivalent is calculated to be about 3μ Sv. The dose calculations have assumed that ^{232}Th remains on bone surfaces. A volume distribution would yield an annual effective dose equivalent of about 1 μSv [31, 34].

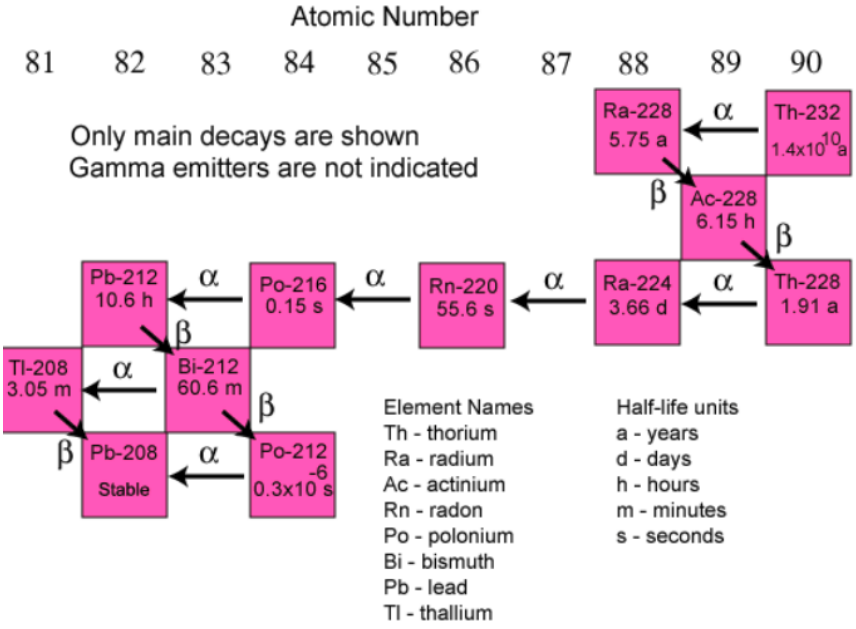

Figure 2.5: Thorium-232 decay series. Source: U.S.Environmental Protection Agency

Potassium-40

K-40 was a naturally occurs isotope with an isotopic (^{39}K, ^{40}K,^{41}K) where the

abundance of ^{40}K is 0.0118%. It disintegrates by beta minus emission to the Ca-40 fundamental level for 89.25 %, by electron capture to the 1460 keV level of Ar-40 for 10.55%, to the ground state level of Ar-40 for 0.2 (1) percent and by beta plus for 0.00100 %. Potassium is an important element that's under close homeostatic control within the body. The average mass concentration for an adult male is about 2g of potassium per kg of body weight. The isotopic ratio of 40-K is $1.18\text{x}10^{-4}$ and the average activity mass concentration of ^{40}K in the body is about 60 Bq kg^{-1}. The distribution of potassium in various tissues and organs of the body has been used to determine the concentrations of ^{40}K in those tissues and organs, that corresponding to absorbed dose rates. The highest annual absorbed dose (270μGy) is received in the red bone marrow and the lowest in the thyroid (100μGy). The annual effective dose equivalent was estimated to be 180 Sv. The variation of the concentration of potassium within the entire body reflects the amount of relative potassium free adipose tissue that is present in lean body mass at different ages: it is found to vary between about 1 and 2.5 g kg^{-1} [3, 31].

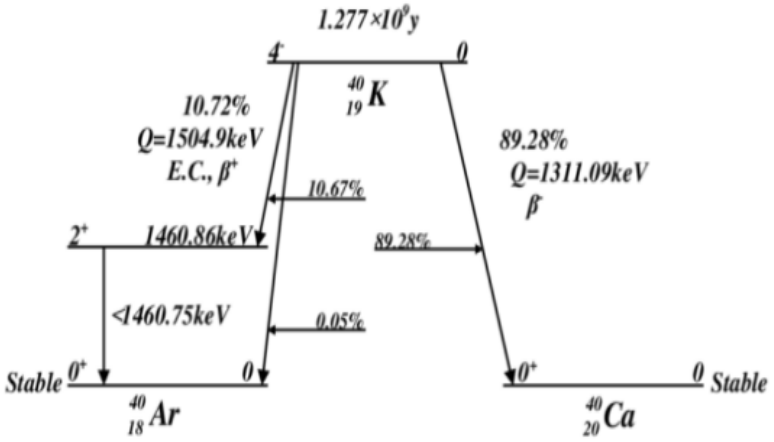

Figure 2.6: Decay scheme of Potassium-40 [3]

2.5 Natural radioactivity in the soil

Soil and rocks are the major source of radiation that population expose to it and also a means of radionuclide migration into the environment [27]. The natural radioactivity present in soil derives from the members of the radioactive decay series of ^{238}U (55.8 percent),^{232}Th (14 percent), along with ^{40}K (13.8 percent). produces gamma radiations in the environment and changes the background radiations level[35]. Ev-

eryone on the planet was exposed to these background levels of ionizing radiation. External exposure occurs as a result of irradiation and internal exposure because of inhalation and ingestion [36]. Radionuclides may be transferred from soils to plants, animals, and finally to man. From the soil contribution of radiation to human exposure was either as whole body due to external radiation originating directly from primordial radionuclides present in soil or internal due to inhalation and ingestion [37]. Just about 15 and 0.6 percents are from cosmic radiation and cosmogenic radionuclides, respectively. Human's exposure pathways to natural radiation have two distinct components: the external component due to the γ-ray emissions and the internal one partly due to radon and its decay products which are α-particles emitters [35]. Exposure to natural background radiation is the highest component of their total radiation exposure. Although the sources of radiation are naturally from every where, exposures are affected by human activity of which the simplest example is living in a house. Building materials provide shielding against radiation from the ground but may they contain radionuclide's that increase exposure to the human being live in [38].

2.6 Radiation Detectors

Radiation is the emission of energy in the form of waves or particles through space or a material medium. It is ionizing or non-ionizing depending on the energy. Radiation of Naturally Occurring Radioactive Materials(NORMs) was low-level energy, as observed from their facts of long-term effects on life. So, radiation detectors have become dominant over other detector types because of their inherently good resolution and linearity in detecting low energy level radiations. Although the varied kinds of radiation detectors differ in many respects, several common criteria are wont to evaluate the performance of any detector type. The criteria used for this purpose are as follows:

- **Sensitivity of the detector**-What types of radiation will the detector detect? For example, solid scintillation detectors are normally not accustomed detect α-particles from radioactive decay because the α - particles cannot penetrate the detector covering.

- **Energy resolution of the detector** - Was the detector measure the energy of the radiation striking it, and if so, how accurately and precisely does it do

this?

- **Time resolution of the detector or its pulse-resolving time**-How high a counting rate will be measured by the detector without error? How accurately and precisely measure the time of arrival of a particle a the detector?
- **Efficiency of the detector**-If 100 γ-rays strike a detector exactly how many will be detected [39]?

The radiation detectors can be: Gas filled, Solid state or Charge coupled detectors.

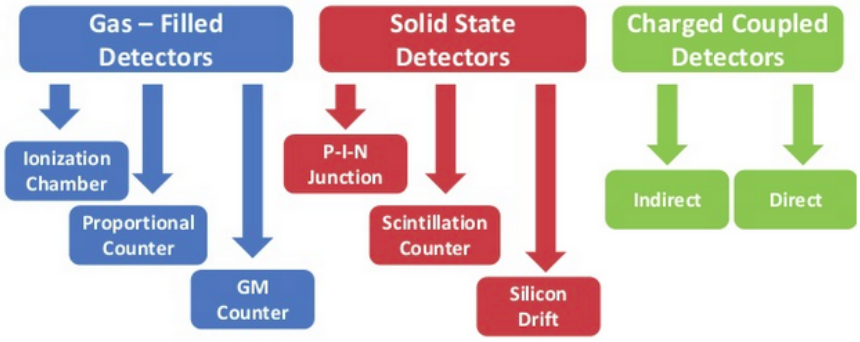

Figure 2.7: Types of radiation detectors[4]

2.7 Semiconductor Detectors (Solid State Ionization Chambers)

In the case of using semiconductors as radiation detectors, incident radiation interacts with the detector material, a semiconductor like Si or Ge, to make hole electron pairs. These created hole electron pairs are collected by charged electrodes with the electrons moves to the positive electrode and thus the holes to the negative electrode, thereby creating an electrical pulse. Such pulses contain information on the sort of energy, time of arrival, and therefore the number of particles arriving per unit time. The important characteristics of semiconductor detectors are their higher energy resolution due to their lower ionization potential and compact size.

There are two kinds of silicon and germanium semiconductor detectors, N-type and P-type. Silicon and germanium are the foremost common semiconductors wont to construct "solid-state ionization chambers". When a positive voltage is applied to the n-type material and negative voltage to the p-type material, the electrons are pulled further faraway from this region creating a far thicker depletion region.

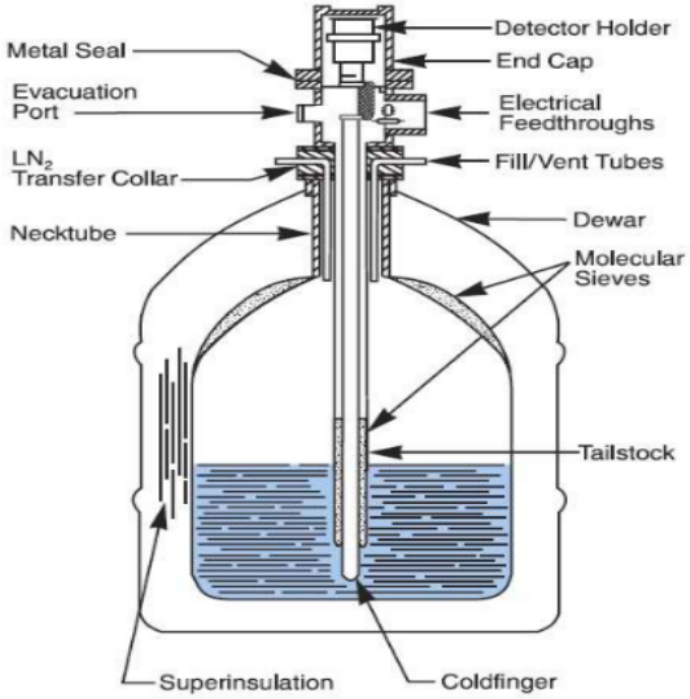

Figure 2.8: Diagram of semiconductor detector with freezing liquid containing Dewar[3]

2.7.1 Gamma Ray Spectrometer with HPGe Detector

A High Purity Germanium (HPGe) detectors are made by highly refining the element germanium and growing it into a crystal. The crystal goes through a series of processing steps culminating within the attachment of positive and negative contacts which turn it into an electronic diode. The special property of this diode is that it conducts current in proportion to the energy of a photon (gamma-ray) depositing energy in it. The relationship between energy and current is so precise in HPGe detectors that energies are determined to raised by 1/10th of 1 percent. An HPGe detector-based gamma spectroscopy system consists of an HPGe detector, high voltage power supply, pre-amplifier (which is typically sold as a part of the detector), amplifier, Analogue to Digital Converter (ADC), and Multi-Channel Analyzer (MCA). The function of the electronic system is that the collection of the electrons produced from the signal pulses and therefore the processing of these pulses and sorting them by height or energy. This process will be described by the subsequent steps:

1. Photon interacts with the detector crystal
2. Applied bias voltage over electrons from crystal
3. Signal pulse electrons formed by produced current
4. Size of the pulse is increased with a pre-amplifier
5. Pulse is furthermore intensified and shaped with amplifier
6. ADC used to convert pulse intensity into a numerical value
7. Definite quantity (numerical values) are sent to MCA

- **Pre-amplifiers-**The charge created within the detector after the photon interaction with the detector crystal is collected by the pre-amplifier. Additionally, the pre-amplifier also serves to supply a match between the high impedance of the detector and therefore the low impedance of coaxial cables to the amplifier, which may be located at larger distances from the pre-amplifier.
- **High Voltage Power Supply-** The High Voltage Power Supply Unit supplies the required high voltage to the detectors and therefore the necessary voltages to the remainder of the system components. These units are usually able to supply up to 5000 V. Typical HPGe detectors require about 3000V.

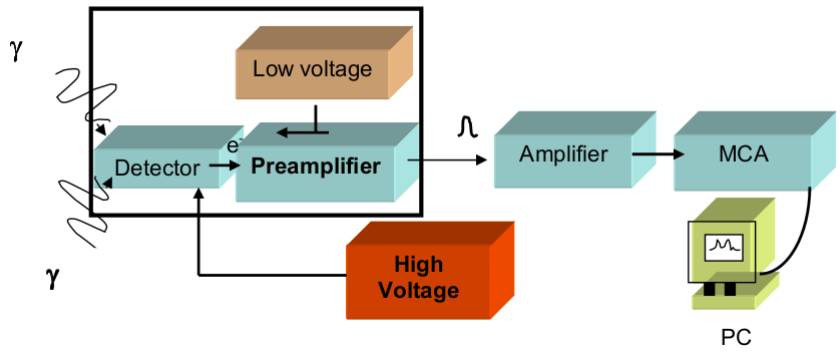

Figure 2.9: Block diagram of a basic gamma spectrometry system [5].

- **Amplifier-**The amplifier serves to shape the pulse in addition as further amplify it. during this module, the size (height) of the pulses is increased, and their form carefully manipulated to eliminate problems with electronic noise, shifts within the baseline, and pulses "riding" on the tails of these preceding them.

- **Multichannel Analyzer (MCA)-** The multichannel analyzer (MCA) is experimental measurements. It performs the essential functions of collecting the information, providing a visible monitor, and producing output, either within the variety of final results or data for later analysis. The multichannel analyzer (MCA) consists basically of an analog-digital converter (ADC), control logic, memory, and display. The multichannel analyzer collects pulses altogether voltage ranges at once and displays this information in real-time.

- **Analog to Digital Conversion (ADC)-** The analog-to-digital conversion module(ADC) forms the heart of the gamma spectrometer. It converts the analog information from the pulse train into a digital format which will be stored and processed by a computer. for every analog pulse received by the ADC, a number is generated that's proportional to the peak of the pulse [5].

High purity germanium is consistently the detector of choice when conducting gamma-ray spectroscopy due to the wonderful energy resolution that it provides. High Purity Germanium detectors are semiconductor diodes having a P-i-N structure during which the intrinsic (I) region is sensitive to ionizing radiation. In the case of reverse bias, an electric field extends across the intrinsic or depleted region. When photons interact with the material within the depleted volume of a detector, charge carriers (holes and electrons) are produced and are swept by the electric field to the

P and N electrodes. This charge, which is in proportion to the energy deposited within the detector by the incoming photon, is converted into a voltage pulse by an integral charge-sensitive pre-amplifier. The sensitivity of an HPGe spectrometer system depends on several factors, including detector efficiency, detector resolution, background radiation, sample constituency, sample geometry, and counting time [5, 40, 41].

- **Detector Efficiency-** An HPGe system is going to be in direct proportion to the detector efficiency. The efficiency of a detector could be a measure of what number of pulses occur for a given number of gamma rays, i.e., the fraction of all the photons that are emitted by the source of sample(A), which cause an incident within the detector(N). This is the efficiency of that detector. Efficiency can depend on the gamma-ray energy, geometry, density, height of soil sample, and characterization of detectors. The counting efficiency of HPGe detectors is controlled by three major considerations[42]:

  1. Size of the detector
  2. Photon energy
  3. Casing material

  The efficiencies are classified into two classes: absolute and intrinsic. Absolute efficiencies can be defined as

  $$\epsilon_{abs} = \frac{number \quad of \quad pulses \quad recorded}{number \quad of \quad radiation \quad quanta \quad emitted \quad by \quad source} \tag{2.10}$$

  that not only depends on detector properties but also on the details of the counting geometry (primarily the distance from the source to the detector). The intrinsic efficiency is defined as

  $$\epsilon_{int} = \frac{number \quad of \quad pulses \quad recorded}{number \quad of \quad radiation \quad quanta \quad incident \quad on \quad detector} \tag{2.11}$$

  solid angle is no longer includes but subtended by the detector as an implicit factor. The two efficiencies are simply related for isotropic sources by

  $$\epsilon_{int} = \epsilon_{abs}.(4\pi/\Omega) \tag{2.12}$$

  where Ω is the solid angle of the detector seen from the actual source position. The type of standard sources that used for calibration (^{241}Am, ^{133}Ba, ^{137}Cs, ^{22}Na and ^{60}Co) were used to estimate the efficiency of the HPGe-detector.

There's a certain probability of coincidence losses of cascade gamma-rays when the sources are put closer to the detector. To eliminate the coincidence loss, all sources were one by one placed at 25cm far from the surface of the detector [43]

- **Detector Resolution-** Resolution could be a measure of the width (full-width at half maximum, FWHM) of one energy peak at a selected energy, that may be either expressed in absolute keV (as with Germanium Detectors) or as a percentage of the energy at that particular point (Sodium Iodide Detectors). Better (lower FWHM value) resolution enables the system to more clearly segregate the peaks within a spectrum.

$$Resolution(R) = \frac{FWHM}{E_o} \tag{2.13}$$

  where E_o is energy at maximum peak

- **Background radiation and sample constituency-**Interference of the background in gamma spectra originates either from within the sample being counted (Compton-produced) or from the environment. If the sample being analyzed incorporates a high content of high-energy gamma-emitting radioisotopes, the Compton produced background will easily outweigh the environmental background. For very weak samples,the environmental background becomes more significant. Obviously, massive shielding will do little to improve system sensitivity for low-energy gamma-rays within the presence of relatively intense higher energy radiation. However, Compton suppression is often very effective in reducing this background.

- **Sample geometry-**HPGe detector sensitivity is that the sample geometry. For a given sample size, the sample should be distributed so on minimize the gap between the sample volume and therefore the detector itself. It does rule out favor of using re-entrant or Marinelli-beaker-type sample containers, which distribute a part of the sample around the circumference of the detector.

2.8 Gamma(γ)-ray interaction with matter

The γ-rays are high-energy photons emitted by exited nuclei in their transition to lower-lying nuclear levels. A γ-ray does not necessarily interact with matter: the

Figure 2.10: Marinelli-beaker-type sample container

photon has a probability to interact by various mechanisms, depending on its initial energy and the nature of the absorbing material. After the interaction it can either disappear leaving all its initial energy, or scatter leaving partially its energy. The γ-ray interaction itself is not detected, but it generates secondary electrons, which ionize the surrounding material, enabling its detection. Figure 11: shows the relative cross sections of relevant processes of γ-ray interaction in germanium, in the energy range of interest for γ-ray spectroscopy, i.e. from few keV to several MeV. As the energy increases, three major processes are dominating: photoelectric absorption up to $\sim$150 keV, Compton scattering up to $\sim$8 MeV and pair creation for higher energies [3, 6, 41].

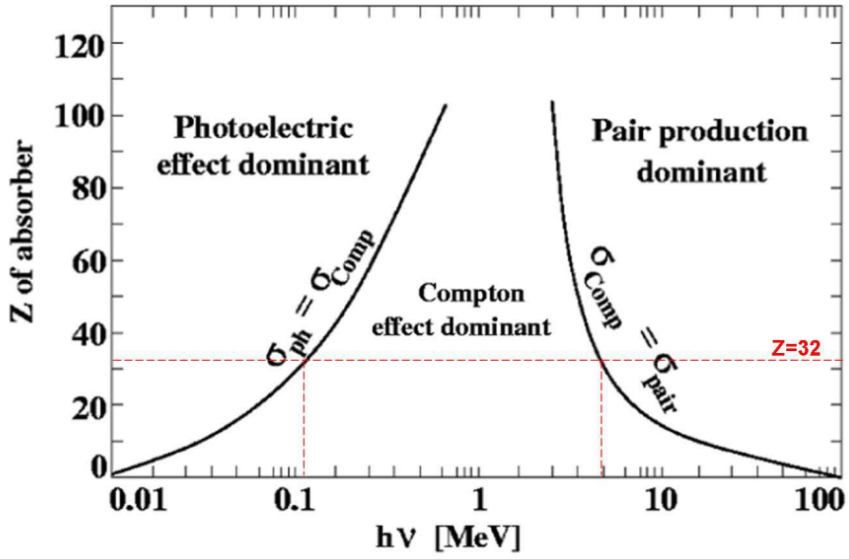

Figure 2.11: Relative cross-sections for the different process of photon interaction in high-purity germanium [6]

- **photoelectric absorption**-In this interaction, the γ-ray transfers all its energy E_0 to one of the orbital electron of an atom from the absorbing material. This electrons, called a photo-electron is produced from one of the electron shells of the absorber atom with a K.E. given by the incident photon energy $h\nu$ minus the binding energy of the electron in its original shell(E_b)

$$E_{e^-} = h\nu - E_b \tag{2.14}$$

where E_i is the ionization energy of the considered atomic shell. The condition for a photoelectric absorption is $h\nu >> E_b$. The photo electron leaves an ionized atom behind it. This vacancy is immediately filled with a free electron of the surrounding material, or with an electronic rearrangement.

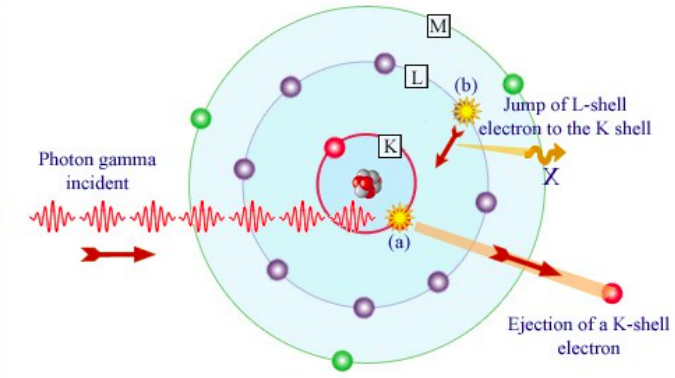

Figure 2.12: Gamma absorption by an atom

- **Compton scattering**-In the Compton effect, the γ-ray scatters off of a loosely bound electron and loses only a part of its energy. The electron recoils in one direction and therefore the gamma explodes in another direction with reduced energy.

Figure 2.13: Compton scattering

The energy of the scattered γ ray $h\nu^{'}$ in terms of its scattering angle θ is given by

$$h\nu^{'} = \frac{h\nu}{1 + (h\nu/m_0c^2)(1 - cos\theta)} \tag{2.15}$$

where m_0c^2 is the rest mass energy of the electron (0.511 MeV). The kinetic energy of the recoil electron is therefore

$$E_{e^-} = h\nu - h\nu^{'} = h\nu \left(\frac{(h\nu/m_0c^2)(1 - cos\theta)}{1 + (h\nu/m_0c^2)(1 - cos\theta)} \right) \tag{2.16}$$

- **pair creation**-In pair creation a photon of sufficiently high energy is annihilated and an electron-positron pair is formed. for free photon conservation of energy and momentum wouldn't be possible, so pair production must happen within the field of a nucleus(or of another electron) which can take up the balance of momentum. The energy threshold can be equal to $2mc^2$ or 1.02 MeV. If the incident gamma-ray energy exceeds this value, the surplus energy appears within the sort of K.E. shared by the electron-positron pair. Therefore, the method consists of converting the incident gamma-ray photon into an electron and positron kinetic energies, which totally

$$E_{e^-} + E_{e^+} = h\nu - 2m_0c^2 \tag{2.17}$$

2.8.1 Gamma Rays Attenuation

The total cross-section of the interaction of gamma rays with an atom is equal to the sum of all three mentioned partial cross-sections:

$$\sigma_{total} = \sigma_f + \sigma_c + \sigma_p \tag{2.18}$$

where σ_f, σ_p and σ_c are photoelectric effect, Compton scattering, and pair production represented respectively. The circumstances that follow the gamma radiation energy and also the absorber material, one among the three partial cross-sections may become much larger than the other two. At small values of gamma radiation energy, the photoelectric effect dominates. Compton scattering dominates at intermediate energies. The Compton scattering also increases with decreasing number of matter, therefore the interval of domination is wider for light nuclei. Finally, electron-positron pair production dominates at high energies. Further the total cross-section of the interaction gamma rays can be[41]:

$$\sigma_{total}(E,Z) = exp\left[\sum_{i=0}^{6}(lnE)^i \sum_{j=0}^{6} a_{i,j} Z^j\right] \tag{2.19}$$

where energy E is given in MeV, $a_{i,j}$ is a parameters and the equation is valid for all Z(atomic number) from 1 to 100.

Chapter 3

Method and Methodology of the Study

3.1 Materials and methods of the study

In this study for the sample analyzer, a gamma-ray Spectrometer with High Purity Germanium (HPGe) detector is used. Gamma-ray spectrometer is an analytical method that permits the identification and quantification of gamma-emitting isotopes by using a form of matrices. In a little sample preparation and with a single measurement gamma-ray spectrometry allows you to detect several gamma-emitting radionuclides within the sample. The measurement can provide a spectrum of lines, the amplitude of which is proportional to the activity of the radionuclide and its position on the horizontal axis gives a concept of its energy [5].The operation of this detector involves the following: first, the photon energy is totally or partly converted into K.E. of electrons (and positrons) by photoelectric absorption, Compton scattering, or pair production; second, the production of electron-hole pairs; third, the gathering and measurement of charge carriers.

The various components of the HPGe detector used are going to be discussed in this chapter. The method followed in executing measurements will be described. The performance characteristics of the detector will be presented.

3.1.1 Study area

The study area is located in the southeastern part of Ethiopia. The present study area is Oromia Region, Bale zone, Meda Welabu woreda of four kebeles: Oda, Ware, Waduma and Ganale. The location of the study area lies between longitude

$039^o31'273''$and $039^o81'357''$East of Greenwich meridian and latitudes $05^o99'381''$ and $06^o51'409''$ North of equator. The sample location was recorded in terms of degree, minute and second (latitudinal and longitudinal position) using hand held Global Positioning System (GPS). The source of samples study were mainly from the Bale zone southeastern part of Ethiopia as shown in Fig.[15]. So, we collected from agricultural and virgin lands of the field that related to environmental samples study. These samples were collected at few meter depth and top of earth surfaces, and our study is mainly for samples collected by means of surface sampling.

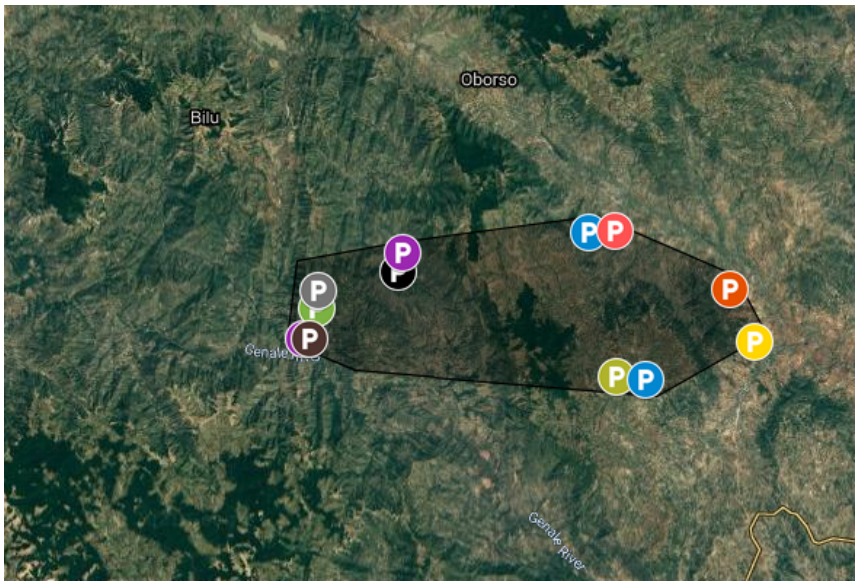

Figure 3.1: Study area from Google Maps

3.1.2 Sampling and sample preparation

The types of samples studied were mainly soil taken from Bale zone, Oromia, Ethiopia. In particular twelve(12) samples were collected six (6)from agricultural land and six (6) from virgin land from four kebeles; Oda, Ware, Waduma and Ganale. The sample collected from different depth starting from 0 to 10cm,then 0 to 20cm, and 0 to 30cm, finally, the combination of those sample coordinate of equal mass and total mass can be from 1kg to 2kg before sample preparation. The samples were packed in plastic bags from the areas of surveillance and brought to the laboratory at Ethiopia Radiation Protection Authority (ERPA) LABS. At the laboratory the soil samples were put in an oven (Labotech) and set to 105^oC to allow for drying over day and night. After drying the samples were crushed and sieved with a mesh having a hole diameter of 2 mm in order to remove organic ma-

terials, stones and lumps. Then finally, the sample was fill into Marinelli beakers of 160gram mass. The information about treatment of samples can be obtained from the general guide [ISO03]. The samples were weighed on a digital weighing balance with a precision of $+/-0.01g$; and after sealing with silicon sealant in Marinelli beakers, the samples were allowed to stand for several days (about 21 to 28 days) for secular equilibrium to be reached. The following is a table of sample information.

Table 3.1: The sampling area name, cite, code and location coordinates

Sample Area Name	**Sample Cite**	**Sample Code**	**Coordinates**	
			Latitude (East)	**Longitude** (North)
Gand Ganale(GG)	Agricultural land	AL-1	$06^o01'284''$	$039^o31'548''$
Gand Ganale(GG)	Virgin land	VL-2	$06^001'789''$	$039^o52'566''$
Gand Waduma(GWa)	Agricultural land	AL-3	$05^o99'526''$	$039^o46'039''$
Gand Waduma(GWa)	Virgin land	VL-4	$05^o99'381''$	$039^o47'421''$
Gand Ware(GW)	Agricultural land	AL-5	$06^o51'409''$	$039^o31'273''$
Gand Ware(GW)	Virgin land	VL-6	$06^o01'842''$	$039^o31'549''$
Gand Ware(GW)	Agricultural land	AL-7	$06^o04'970''$	$039^o81'357''$
Gand Ware(GW)	Virgin land	VL-8	$06^o04'713''$	$039^o31'913''$
Gand Oda(ODA-1)	Agricultural land	AL-9	$06^o06'286''$	$039^o44'734''$
Gand Oda(ODA-2)	Virgin land	AL-10	$06^o06'353''$	$039^o45'947''$
Gand Oda(ODA-3)	Agricultural land	AL-11	$06^o01'179''$	$039^o52'566''$
Gand Oda(ODA-4)	Virgin land	AL-12	$06^o03'597''$	$039^o51'357''$

3.2 HPGe experimental set up and measurements

The detector design includes each of the following main components; For all measurements taken, the sample (source) placement was strictly maintained.

i. The sample (source) was located axially with respect to the detector element. Care was taken to confirm that source was position along the center line of the detector crystal. The center line must be axial with the inner diameter of the detector, for a coaxial detector,

ii. The sample (source) was carefully measured to ensure that it was 25 cm from the face of the detector crystal face.

Figure 3.2: Gamma spectrometry mounted with HPGe detector and DSA circuit (ERPA-Laboratory)

iii. The sample (source) was positioned such that it was parallel with the face of the detector element.

iv. There was nothing but air in between the sample (source) and the detector assembly.

The measurements were performed using a p-type high purity germanium (HPGe) coaxial detector with a relative efficiency of 70% and multichannel analyzer of 8192 channel performance. The number of photons sources must be minimize out of the sample we can studied, to do this a detector is covered in a lead of 100-mm thickness, cadmium of 2-mm, and copper of 2.5-mm thicknesses. The 100 mm thick lead is used to reduce soft parts of cosmic rays to a very low level. Copper layer suppresses X-ray emitted from the lead (specially with energy 73.9keV), by its interaction with external radiation. The cadmium layer absorbs thermal neutrons produced by cosmic ray (Photo-neutron and alpha-neutron sources). There is also an effect of scattered radiation from shielding materials. This can be controlled by fixing the detector at a center of shielding materials itself. After fixing all, we connected the

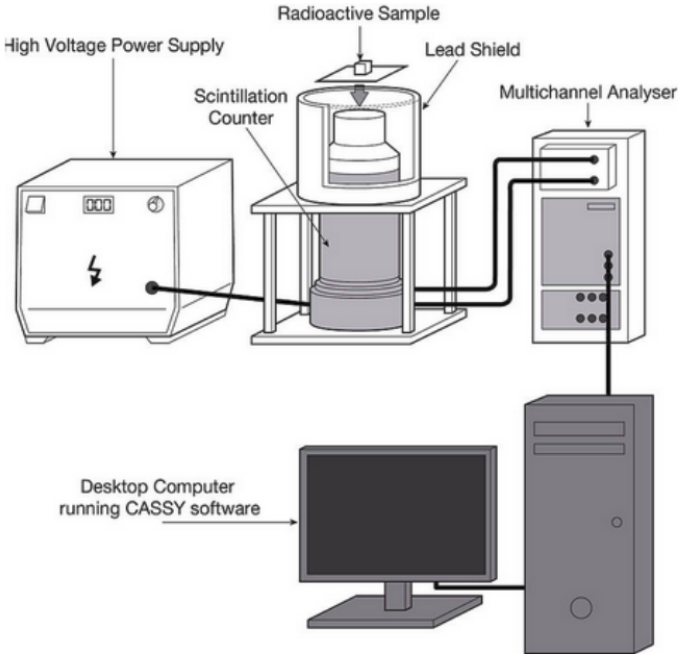

Figure 3.3: **(a)** Block diagram of the gamma spectrometer experimental setup

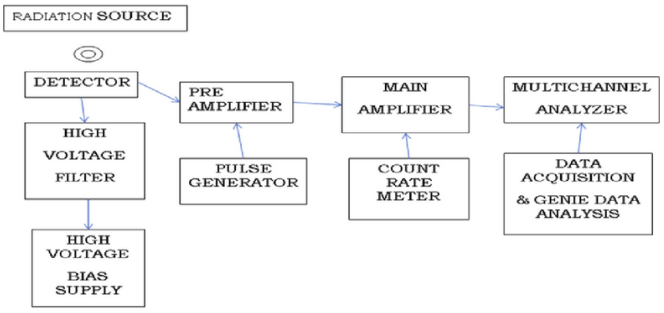

Figure 3.4: **(b)** Block diagram of the experimental setup[7]

detector to DSA and computer that uses $Genie^{TM}$ 2000 Spectroscopy Software.

Genie 2000 could also be a comprehensive set of capabilities for acquiring and analyzing spectra from Multichannel Analyzers (MCAs). Its functions include MCA control, spectral display, and manipulation, basic spectroscopy, and reporting. The comprehensive spectrometry used for alpha and gamma spectroscopy, quality assurance, system automation, and turnkey packages for specific, dedicated applications. The core of the Genie 2000 software may be a module referred to as the Virtual Data Manager or VDM. The VDM man-ages all information flow within the system. it's liable for communications with both data files and MCA devices and for presenting information from them to the subsequent layers of software in an exceedingly consistent manner .

The time needed to detect the Samples that placed over the detector was from

28,800sec(8hrs) to 36, 000 sec(10hrs) for measurements.The spectra were analyzed for energies; 911keV of ^{228}Ac for ^{232}Th radionuclide identification, 351keV of ^{214}Pb and 609keV of ^{214}Bi for ^{238}U radionuclide identification, and 1460.9keV gamma energy for ^{40}K radionuclide identification. Levels of activity were measured for these identified radionuclides from their photo peaks.

3.2.1 Background Radiation measurement by HPGe detector

The HPGe-detector background results from the combination of four main components, as follows [44]:

- Environmental radioactivity, including radon, with gamma rays from natural series, neutrons from natural fission and from the(α,n) reaction;
- Radioactive impurities in the detector and shielding materials;
- Cosmic rays, with relevant contributions from muons and neutrons; and
- Electronics and microphonics noise

Before the counting process of the samples, the gamma background was determined with an empty Marinelli beaker of 160 grams for 56hrs in the same manner that used for samples. The background was subtracted from the measured gamma-ray spectra of each sample.

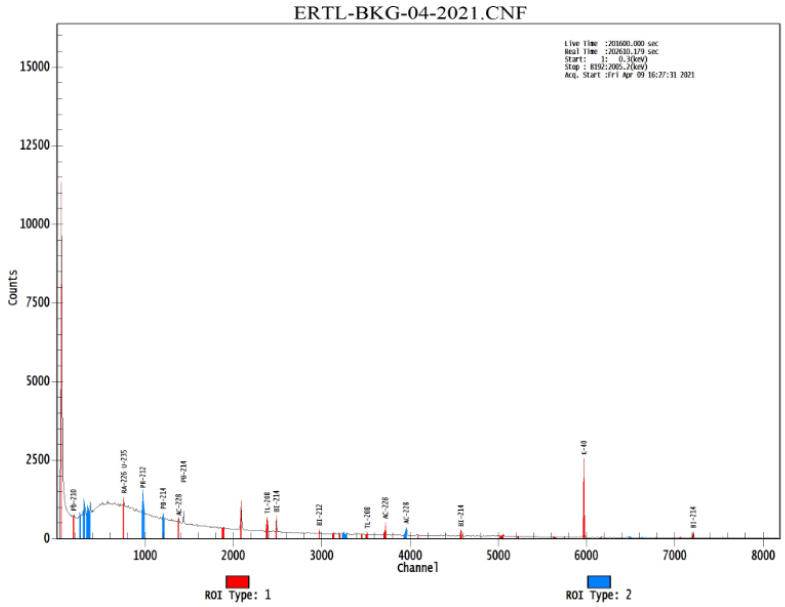

Figure 3.5: The graph of back ground radiation

3.2.2 Energy Calibration of HPGe detector

Energy calibrations were performed by measuring the spectrum of source emitted gamma-rays of precisely known energy and covering a wide range of energies. The type standard Gamma reference sources (^{133}Ba, ^{137}Cs, ^{22}Na, ^{60}Co, ^{57}Co, ^{241}Am) were used for energy calibration. Detector Calibration is predicated on the ways described in IEEE standard 325-1996 test procedure [43]. For detector calibration spectrum was recorded for 1hr(3600sec) for every source with amplifier overall gain. The energy calibration consists of the experimental determination of a function, normally a first-degree polynomial that describes the energy dependence of the channel number in the spectrum. In the ERPA laboratory, they use standard reference geometry CBSS2 that have artificial gamma-rays emitting source of ^{241}Am at 59.49KeV, ^{137}Cs at 661.7KeV, ^{60}Co at 1332.5KeV, and ^{60}Co at 1173.5KeV for energy calibrations in 10minutes.

$$E_\gamma = A + B.ch \tag{3.1}$$

where E_γ is the gamma-ray energy, ch-is the number of spectral channels for the center of the peak corresponding to E_γ(the channel with the maximum number of counts), A and B are constants to be determined for calibration [45]. The number of channels and the associated peaks was recorded. The graph between channel number and the energy was plotted based on the following equation.

$$E(keV) = 6.638x10^{-2}(keV) + 0.2447 * ch \tag{3.2}$$

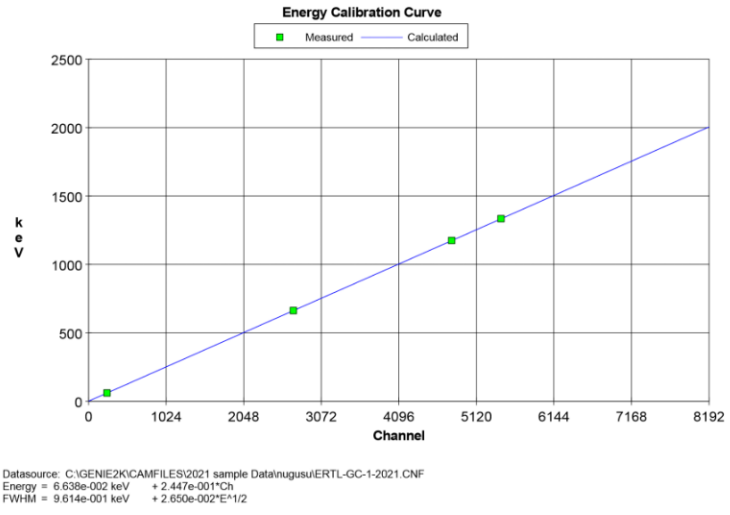

Figure 3.6: Energy calibration relation between channel numbers and corresponds to energy

3.2.3 HPGe detector Energy Resolution

Energy resolution of a gamma ray spectrometer is the ability to separating two adjacent energy peaks with slightly different energy. The energy resolution is the ratio of the full width at half maximum of a given energy peak to the peak height.

$$Resolution(R) = \frac{FWHM}{Peak \quad Height \quad Channel} * 100\% \tag{3.3}$$

$$FWHM = 2\sqrt{2ln2}\sigma \approx 2.355\sigma \tag{3.4}$$

where σ is the standard deviation. The HPGe detector we use in the lab was represented by energy resolutions (FWHM) of energy 1.9KeV at 1332.5KeV.

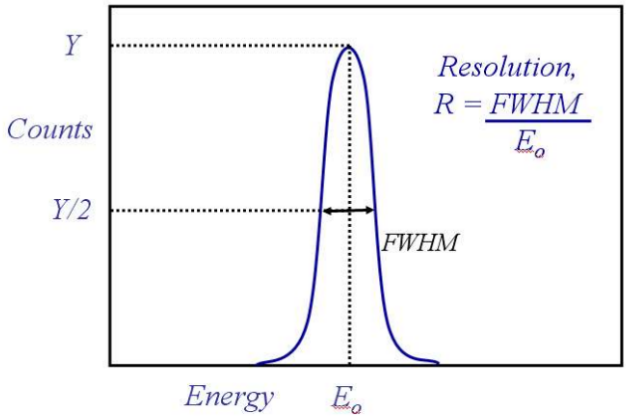

Figure 3.7: Energy Resolution[5]

3.2.4 Efficiency calibration of HPGe detector

Radiation measurement requires accurate knowledge of the detector's spectral performance, which is known by detector efficiency. The efficiency of a detector was the measure of how many pulses happen for a given number of gamma rays, i.e., the fraction of all the photons that are emitted by the source or sample, which cause an event in the detector. The detection efficiency depends on the volume and shape of the detector active material, absorption cross-section, attenuation layers in front of the detector, and distance and position from the source to the detector. Detector efficiency is related to emitted gamma radiation quanta and radiation quanta counted by the detector. The efficiency calibration consists in determining a function detection efficiency versus the γ-rays energy, E_γ. The absolute efficiency (Full Energy Peak Efficiency) of the detector was measured using the following equation

for the same sampled geometry as follow [5]:

$$\varepsilon_i = \frac{A_i}{C_i * I_\gamma * t * M} \tag{3.5}$$

where A_i is net peak area corresponding to E_i , C_i is deduced activity by certified radionuclide, I_γ indicates the probability of E_i photon emission per decay, and t is counting time, M mass of the radionuclide. The photo peak efficiencies from samples of measurement coincide with this efficiency curve and the curve is shown below.

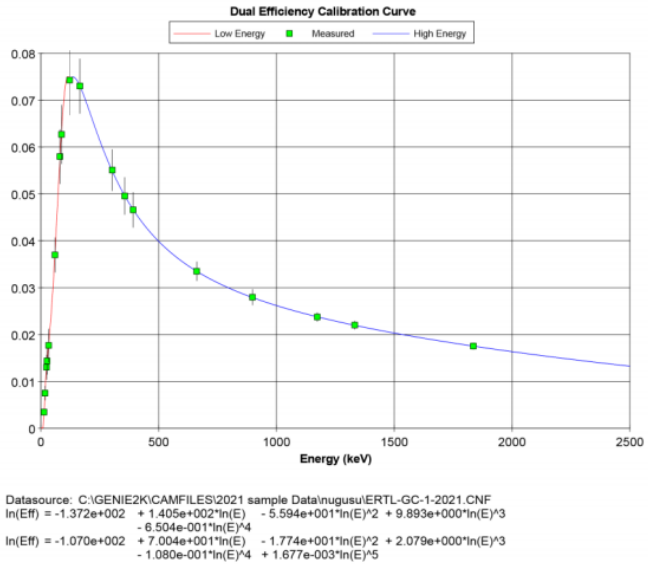

Figure 3.8: Efficiency calibration curve verses Energy

3.3 Activity and elemental concentration equations

The activity of a radioisotope source was defined as its rate of decay and IS given by the fundamental law of radioactive decay

$$\left.\frac{dN}{dt}\right|_{decay} = -\lambda N \tag{3.6}$$

where N is that the number of radioactive nuclei and λ is defined as the decay constant. The standard unit of activity is becquerel; which is $1Bq = 2.703X10^{-11}$ci The specific activity of a radioactive source can be expressed as the activity per unit mass of the radioisotope sample. The specific activity concentration of spectrum analysis, for photo peaks representing decay progenies of Uranium, Thorium and photo peak of Potassium, level of activities were calculated using the equation of the specific activity [41]

$$(Specific \quad activity)C_{Ei}(Bq/Kg) = \frac{Activity}{mass} \tag{3.7}$$

Thus, implies that

$$C_{Ei}(Bq/Kg) = \frac{A_i}{\varepsilon_{Ei} * I_\gamma * t * M_{Ei}} \tag{3.8}$$

Further, we can expand equation (27)

$$C_{Ei}(Bq/Kg) = \frac{N_{Ei}}{\varepsilon_{Ei} * I_\gamma * t * M_{Ei}} \tag{3.9}$$

where N_{Ei} is the net peak area of a peak at energy E, ε_{Ei} is the detection efficiency at energy E, t is the counting live time, I_γ is the number of gamma's per disintegration of this nuclide for a transition at energy E, and M_{Ei} is the mass in kg of the measured sample at energy E. The activity concentrations of ^{238}U , ^{232}Th, and ^{40}K in the samples were determined by standard gamma spectrometer using a p-type high purity germanium (HPGe) coaxial detector with a 70% relative efficiency and a resolution of 1.9keV for the 1332.5keV ^{60}Co gamma spectrum and MCA with of 8192 channel performance.The analysis of activity concentration for natural radionuclides by using Genie 2000 software.

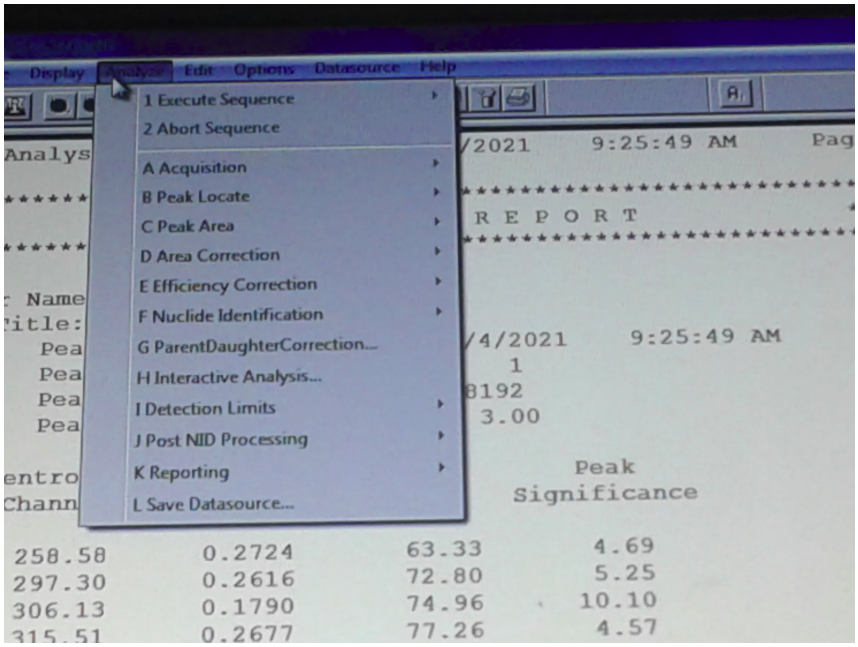

Figure 3.9: Steps for analysis of measuring activity concentration for radionuclides by Genie 2000 software

3.4 Radiological hazards indices equations

3.4.1 Radium equivalent equation

The radiation hazard by means of the Radium equivalent activity (Ra.eq.)is a widely used hazard index and it is calculated through the following equation. Gamma ra-

diation hazards from specific radio nuclides can be evaluated using different indices. (Ra eq), is one of an indicator, which is the weighted sum of activities of the three radio nuclides based on the supposition that 370 Bq kg^{-1} of ^{238}U, 259 Bq kg^{-1} of ^{232}Th, and 4810 Bq kg^{-1} of ^{40}K produce equal gamma-ray dose rate:

$$Ra_{eq}(Bqkg^{-1}) = C_U + 1.43C_{Th} + 0.077C_K \tag{3.10}$$

where C_U, C_{Th}, and C_K are the activity concentrations of ^{238}U, ^{232}Th and ^{40}K in Bq kg^{-1} respectively[46].

3.4.2 Absorbed dose rate(DR)

The mean energy absorbed from any type of radiation per unit mass of the absorber is defined as the absorbed dose. The historical unit of absorbed dose has been the rad, defined as 100 ergs/gram. The rad has been replaced by its SI equivalent, the gray (Gy) defined as 1joule/kilogram. The two units were simply related by: 1Gy = 100rad [41]. Calculating the absorbed dose rate is the first basic step for evaluating the health risk. With regard to biological effects, the clinical and radiological effects are directly related to the absorbed dose rate [47]. Absorbed dose rate(DR) is measured at a distance of 1m above the surface that ensures a uniform distribution of the three radionuclides for almost the same activities. At this distance the absorbed Dose rate (DR) can be calculated:-

$$D_R = 0.427C_U + 0.623C_{Th} + 0.043C_K \tag{3.11}$$

Where the dose rate, D_R is in nGy/h and C is activity in Bq/Kg for ^{238}U, ^{232}Th and ^{40}K. The population-weighted value of the absorbed dose rate in outdoor from radiation emitted by radionuclides in environmental materials. The limit for this dose is $59nGy/h$ [48].

3.4.3 Annual effective dose rate(AD_R)

The annual effective dose rate(AD_R) can be calculated to assess the health effects of the absorbed dose in a year. Mathematically it can be represented as:-

$$AD_R(mSv/y) = D_R(mGy/h)*8760h/y*0.2*0.7Sv/Gy*10^{-6} \leq 0.07mSv/y \tag{3.12}$$

$$AD_R(mSv/y) = D_R(mGy/h)*8760h/y*0.8*0.7Sv/Gy*10^{-6} \leq 0.41mSv/y \tag{3.13}$$

where AD_R is in mSv/y and 0.7Sv/Gy is to transform absorbed dose in air to the effective dose received by humans at 1m height, 0.2 is an outdoor occupancy of 20%

and 0.8 or 80% for the indoors.This factor may be changed according to the patterns of life by humans in the study area. The world wide average value calculated by UNSCEAR was 0.07mSv/y for outdoor and 0.41mSv/y for indoor [3, 48].

3.4.4 External hazards(Hex) and Internal hazards(Hin)Indexes

External hazards(Hex) Indexes

The external radiation hazard index, H_{ex}, corresponding to the investigated radionuclides is calculated using the following equation:-

$$H_{ex} = \frac{C_U}{370Bq/Kg} + \frac{C_{Th}}{259Bq/Kg} + \frac{C_K}{4810Bq/Kg} \tag{3.14}$$

The maximum value of H_{ex} should be 1 corresponding to the maximum value of Ra_{eq} , which is 370Bq/Kg. In order to keep the radiation hazard insignificant, the values of H_{ex} should be lower than one.

Internal Hazard(H_{in}) Indexes

The hazard levels from inhaled alpha(α) particles emitted from radon short-lived radio nuclides such as ^{222}Rn and daughter products can be quantified by internal hazard index, H_{in} as:-

$$H_{in} = \frac{C_U}{185Bq/Kg} + \frac{C_{Th}}{259Bq/Kg} + \frac{C_K}{4810Bq/Kg} \tag{3.15}$$

The measured values of H_{in} should also be less than or equal to one, i.e. $H_{in} \leq 1$. This can be greatly important to keep the concentration levels of radon and its short-lived daughters low enough for the respiratory organs of humans living in the dwellings, comparable to or even lower than the assigned international levels of $40Bqm^{-3}$ [3, 49, 50].

Chapter 4

Result and Discussion

4.1 Results and Discussion on activity concentration

The results of gamma spectrum analysis on activity concentration of ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs radionuclides in soil samples for different locations of the study area are presented in table 1.can be analyzed by ISO11929 reports. The activity concentrations of ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs in the samples were determined by standard gamma spectrometer using a p-type high purity germanium (HPGe) coaxial detector with a 70% relative efficiency and a resolution 1.9keV for the 1332.5keV ^{60}Co gamma spectrum and MCA with 0 to 8192 channel performance. The HPGe spectra were analyzed for energies; (911.21,and 968.97)keV of ^{228}Ac for ^{232}Th radionuclide identification, (295.21, and 351.92)keV of ^{214}Pb and (609.31, 1120.29, and 1764.49)keV of ^{214}Bi for ^{238}U radionuclide identification, 1460.9keV gamma energy for ^{40}K radionuclide identification, and 661.65keV gamma energy for ^{137}Cs radionuclide identification. Ra-226 concentrations were obtained indirectly by measuring the activity of ^{214}Bi, the progeny of ^{226}Ra with photon peak at 609.3keV.

The samples and the background radiation were counted for 28,800s-36,000s. The net count rate under the most prominent photo peaks of all radionuclides daughter peaks were calculated by subtracting the respective count rate from the background spectrum was valid for the same counting time. Then the activity of radionuclide in the soil is calculated from the average daughter radionuclides from the background subtracted area prominent gamma ray energies [51].

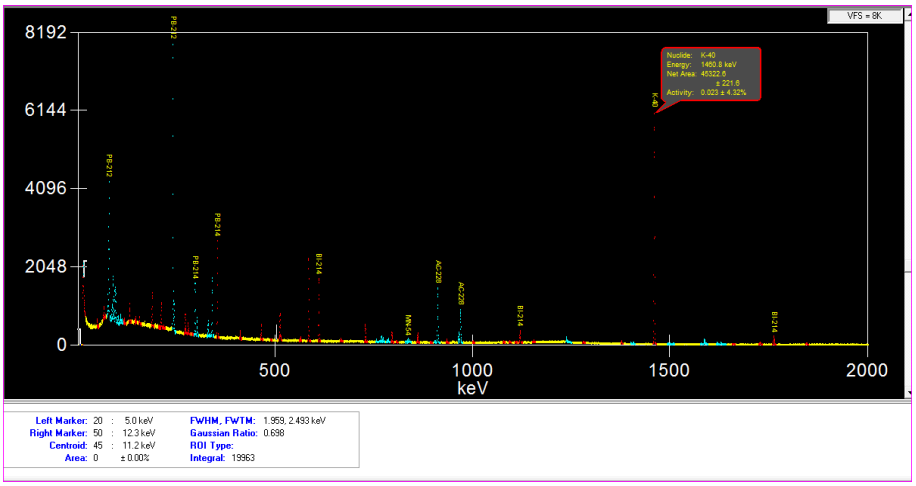

Figure 4.1: Spectrum of soil sample from GG-1 channel verses energy

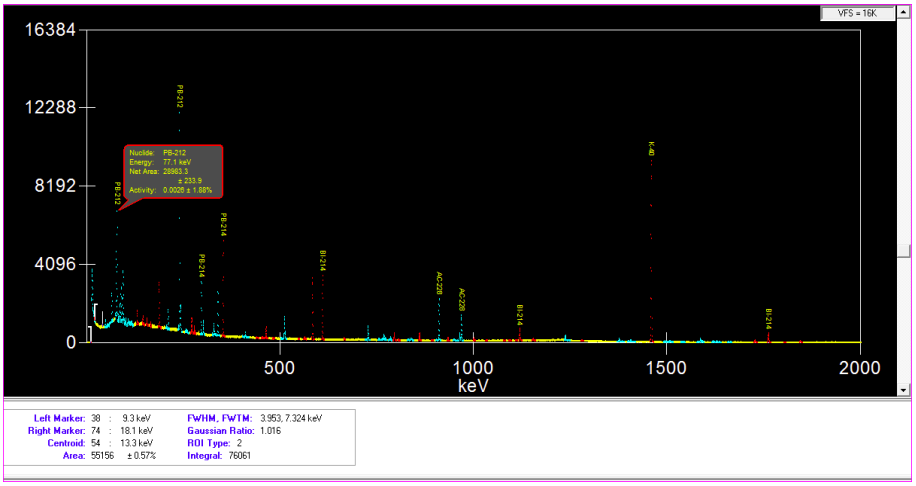

Figure 4.2: Spectrum of soil sample from ODA-3 channel verses energy

As we have seen from the above Table:3, the value of measured activity concentration of ^{238}U, ^{232}Th, ^{40}K, and ^{137}Cs were varied from 6.565± 0.206Bq/Kg to 41.15±0.748Bq/kg , 26.2±0.767Bq/Kg to 122±2.57Bq/Kg , 413±7.01Bq/Kg to 2180±3.21Bq/Kg and 0.451±0.507 Bq/Kg to 2.19±0.151Bq/Kg respectively. The average activity concentration of ^{238}U, ^{232}Th and ^{40}K were 20.31±0.618, 70.83±2.163, 877.17±3.598 Bq/Kg, respectively. These values were higher than the recommended world average values for ^{238}U, ^{232}Th, ^{40}K, respectively which are 35, 30 and 400 Bq/Kg for ^{238}U, ^{232}Th, and ^{40}K respectively of taken from UNSCEAR report by [52]. It is also observed that the measured activity concentration of ^{40}K exceeds markedly the values of both Uranium and Thorium, as it is the most abundant radioactive element under consideration. Moreover the excessive use of the Potassium containing fertilizers in the area adjacent to the sampling sites may contribute to the higher values of ^{40}K activity. The activity concentrations of the artificial

Table 4.1: The measured Activity concentration levels of natural radionuclides per Kg sampled soil from Agricultural and Virgin land collected from different sites of sampling area

Sample Code	**Sample mass(kg)**	**Activity Concentration of radionuclides**			
		^{238}U (Bq/kg)	**^{232}Th (Bq/kg)**	**^{40}K (Bq/kg)**	**^{137}Cs (Bq/kg)**
AL-1	0.8	26.95±1.191	82.5±3.73	839±3.493	....
VL-2	0.71	30.25±1.34	88.9±404	752±3.17	....
AL-3	0.63	20.65±40.455	75.3±1.72	1110±1.69	....
VL-4	0.70	20.8±0.407	121±2.55	808±1.21	....
AL-5	0.58	21.85±0.486	79.3±1.82	935±1.45	0.801±0.768
VL-6	0.86	26.85±1.188	69.7±3.17	762±3.17	2.19±0.151
AL-7	0.815	6.565±0.206	45±1.09	2180±3.21	.....
VL-8	0.995	7.535±0.378	47.6±2.18	526±2.19	0.451±0.507
AL-9	0.64	13.25±0.325	26.2±0.767	555±8.94	1.45±0.754
VL-10	0.60	15.35±0.366	36.2±0.963	413±7.01	1.56±0.785
AL-11	0.645	41.15±0.748	122±2.57	1050±1.56	.....
VL-12	0.61	12.55±0.321	56.2±1.35	596±9.58	1.80±0.847
Mean	0.72	20.31±0.618	70.83±2.163	877.17±3.598	1.542±0.635
Range	0.6-	6.565±0.206-	26.2±0.767-	413±7.01-	0.451±0.507-
	0.995	41.15±0.748	122±2.57	2180±3.21	2.19±0.151

radionuclide ^{137}Cs were measured for all collected soil samples in order to assess the amount of fallout radionuclide in such locations; but the activity concentration did not detected for some samples they are given in Table 3. The obtained activity concentration values of ^{137}Cs in all collected soil samples were found to range from 0.451 ± 0.507 Bq kg^{-1} to 2.19 ± 0.151 Bq kg^{-1} with an mean value of 1.542 ± 0.635 Bq kg^{-1}. The minimum activity concentration value of ^{137}Cs was obtained for a soil sample collected from virgin land, similarly, the maximum value was measured in a soil sample collected from virgin land site. Thus, the impact of the artificial radionuclide and the corresponding additional external radiation exposure to the population were almost negligible. Consequently, the measured activities of ^{137}Cs confirmed no hazard effects due to ^{137}Cs radionuclides to the people living around the sites where soil samples were collected.

The analyzed data can be expressed using the chart of bar graph by compering the results of the activity concentration of naturally occurring radioactive materials in relation to samples that can be sampled from different area which was labeled by

different sample code together. The activity concentration of each radionuclides in

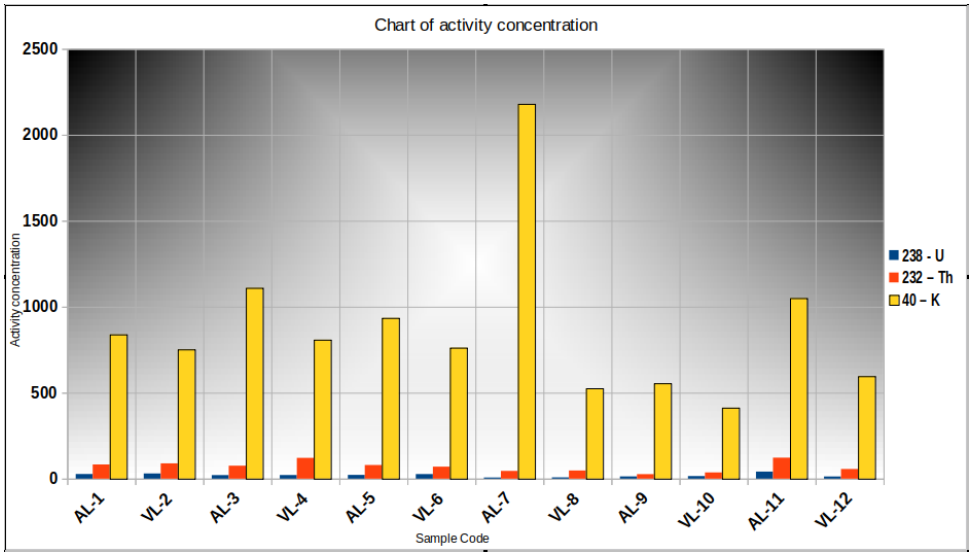

Figure 4.3: Bar graph of activity concentration

relation to the samples can be expressed by using bar graph individually as shown in figures below.

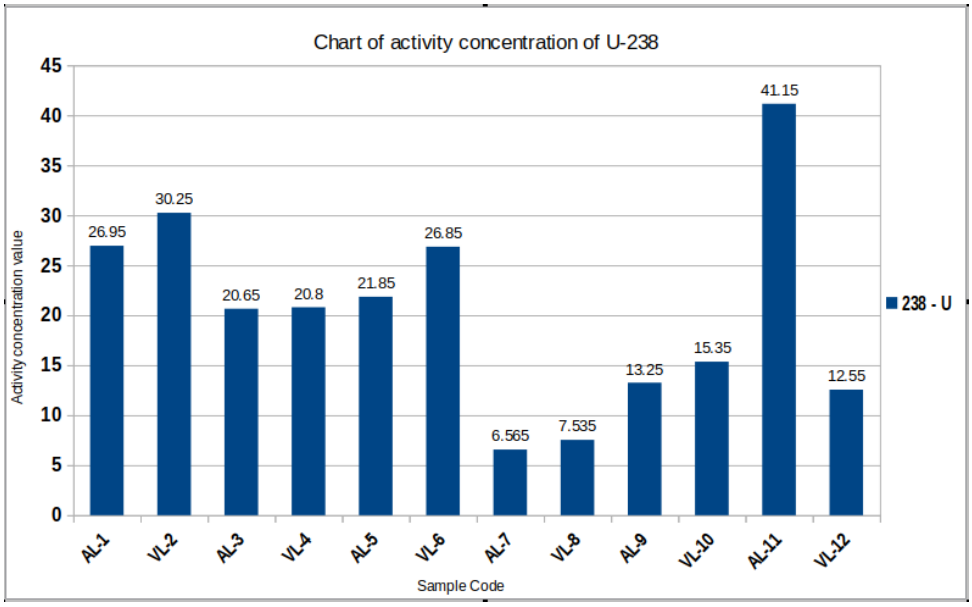

Figure 4.4: Bar graph of activity concentration U-238

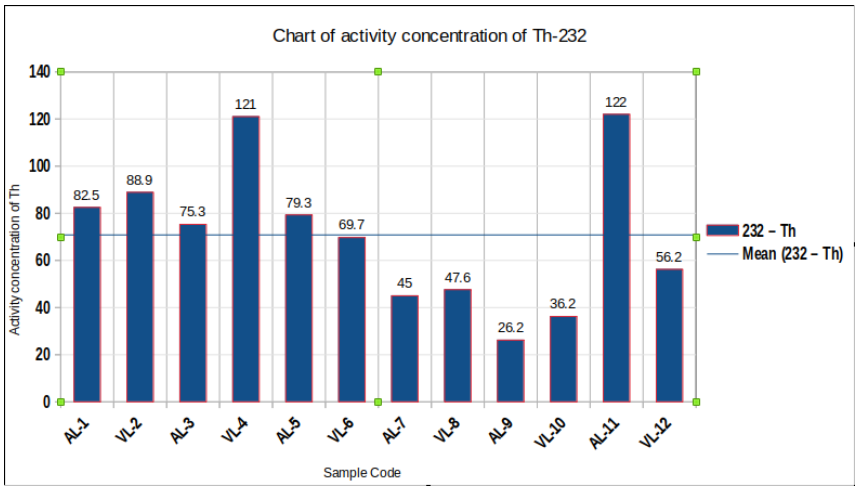

Figure 4.5: Bar graph of activity concentration Th-232

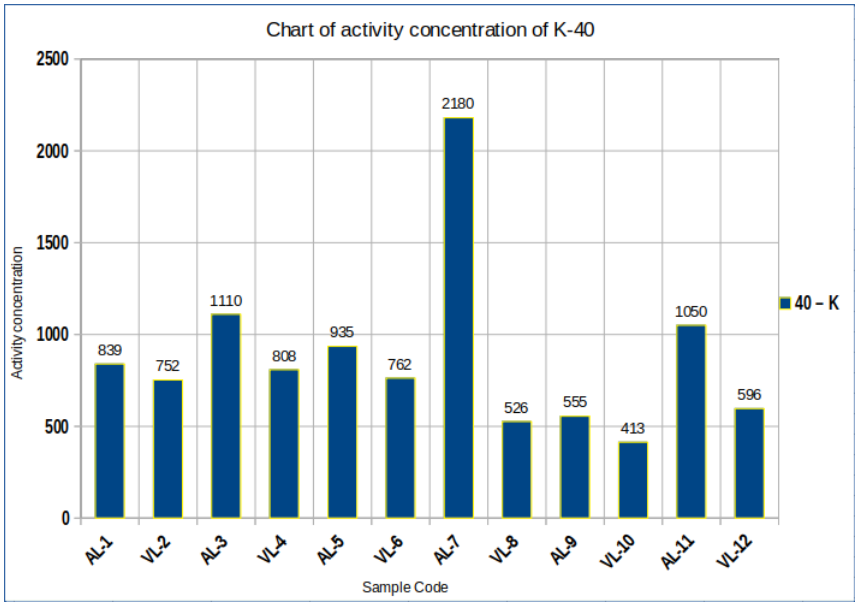

Figure 4.6: Bar graph of activity concentration K-40

Further more, the data can be analyzed and expressed by categorizing the samples based on the sample sites, i.e. agricultural, and virgin lands that a samples were collected from and the mean value were presented in the tables-4, 5 and 6 as shown below, and also presented in figure 29, 30 and 30 by using line and bar graphs. Finally, the mean value of activity concentration of radionuclides occurred in soil samples that sampled from agricultural and virgin lands were compered. The mean value of activity concentration of naturally occurring radioactive materials, like ^{238}U, ^{232}Th and ^{40}K that occurred in the soil samples that sampled from agricultural land was greater than the mean value of activity concentration occurred in the soil samples that sampled from virgin land, i.e. the mean value of activity concentration

of those radionuclides in a soil sample from agricultural land of ^{238}U ^{232}Th, and ^{40}K were 21.74±0.569 Bq/kg, 71.72±1.95 Bq/kg, and 1111.50±3.39 Bq/kg respectively, whereas, the mean value of activity concentration in a soil sample from virgin land of ^{238}U ^{232}Th, and ^{40}K were 18.89±0.667 Bq/kg, 69.93±2.38 Bq/kg, and 642.83±4.39 Bq/kg respectively.The activity concentration of agricultural land soil sample was greater than the activity concentration of soil sample from virgin land because of from the phosphate fertilizers added to agricultural soil.

Table 4.2: Activity concentration of radionuclides sampled from Agricultural land

Sample	**Activity concentration of radionuclides**		
Code	**40-K(Bq/kg)**	**232-Th(Bq/kg)**	**238-U(Bq/kg)**
AL-1	839±3.49	82.5±3.73	26.95±1.191
AL-3	1110±1.69	75.3±1.72	20.65±0.455
AL-5	935±1.45	79.3±1.82	21.85±0.486
AL-7	2180±3.21	45±1.09	6.565±0.206
AL-9	555±8.94	26.2±0.77	13.25±0.325
AL-11	1050±1.56	122±2.57	41.15±0.748
Mean	1111.5±3.39	71.72±1.95	21.74±0.569
Range	555±8.94 - 2180±3.21	26.2±0.77 - 122±2.57	6.565±0.206 - 41.15±0.748

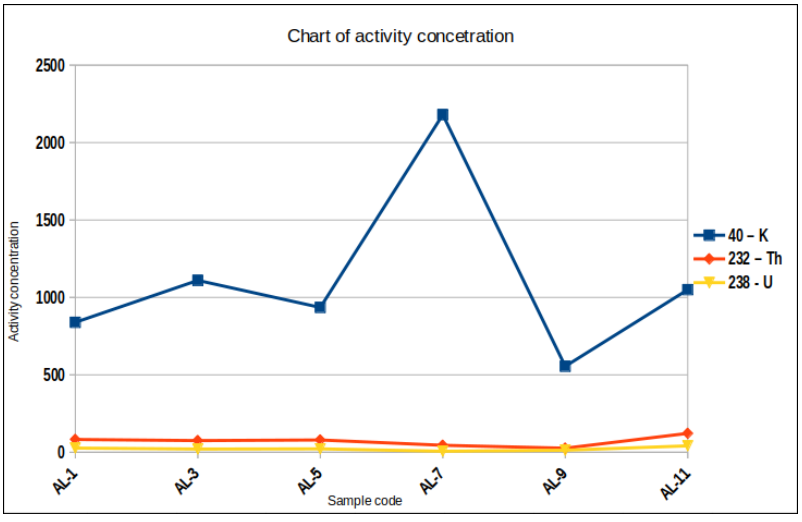

Figure 4.7: Line graph of activity concentration sampled from Agricultural land

Table 4.3: Activity concentration of radionuclides sampled from Virgin land

Sample	**Activity concentration of radionuclides**		
Code	**40-K(Bq/kg)**	**232-Th(Bq/kg)**	**238-U(Bq/kg)**
VL-2	752±3.17	88.9±4.04	30.25±1.340
VL-4	808±1.21	121.0±2.55	20.80±0.407
VL-6	762±3.17	69.7±3.17	26.85±1.188
VL-8	526±2.19	47.6±2.18	7.54±0.378
VL-10	413±7.01	36.2±0.96	15.35±0.366
VL-12	596±9.58	56.2±1.35	12.55±0.321
Mean	642.83±4.39	69.93±2.38	18.89±0.667
Range	413±7.01 - 808±1.21	36.2±0.96 - 121.0±2.55	7.54±0.378 - 30.25±1.340

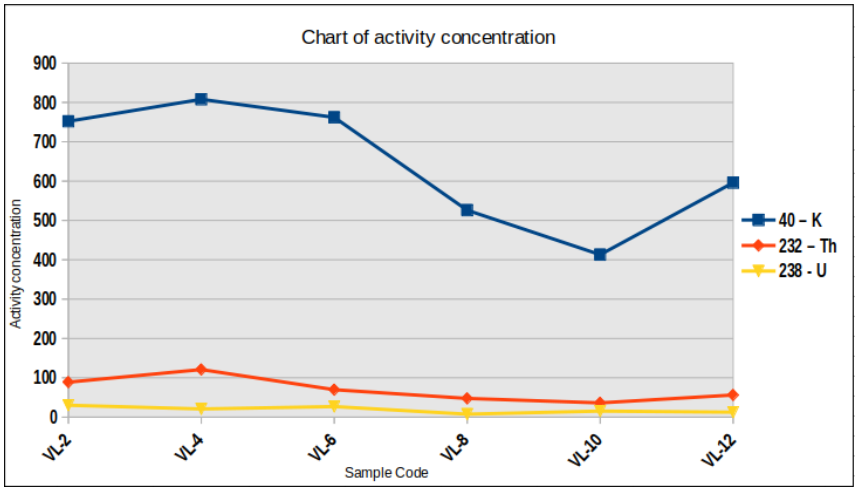

Figure 4.8: Line graph of activity concentration sampled from Virgin land

Table 4.4: Mean value activity concentration of radionuclides sampled from Agricultural and Virgin land

Sample	**Mean value activity concentration of radionuclides**			
Cite	**40-K**	**232-Th**	**238-U**	**137-Cs**
	(Bq/kg)	**(Bq/kg)**	**(Bq/kg)**	**(Bq/kg)**
Agricultural land	1111.5±3.39	71.72±1.95	21.74±0.569	1.126±0.761
Virgin land	642.83±4.39	69.93±2.38	18.89±0.667	1.5±0.573

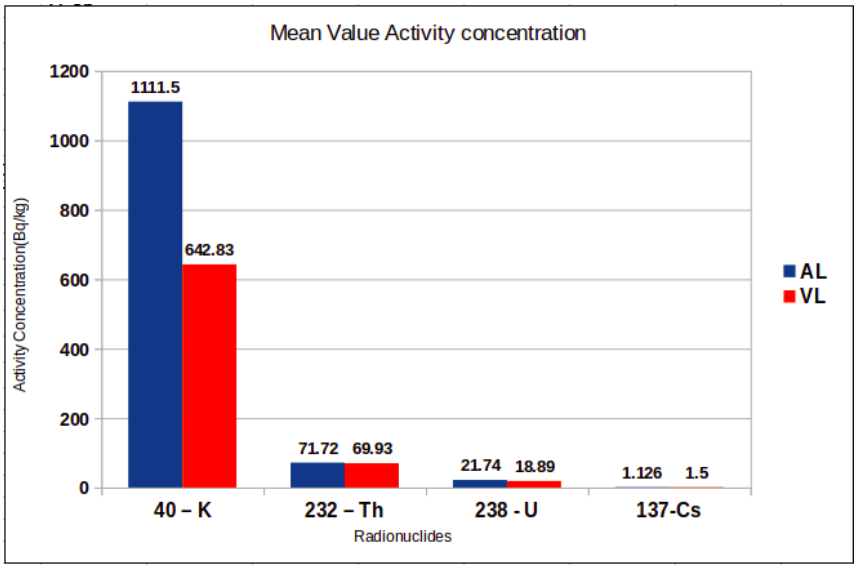

Figure 4.9: Bar graph of mean value of activity concentration sampled from Agricultural and Virgin land

4.2 Results and Discussion on Radiological hazards

In this study the location of sample was basically classified into two main parts, i.e. agricultural and virgin lands samples. So, the radium equivalent can be presented based on those sample sites and finally there mean values were compered. Radium equivalent activity (Ra_eq) was calculated by Equation (27). Based on UNSCEAR report the threshold value of radium equivalent activity (Ra_eq) must be less than 370 Bq/kg. The mean value of radium equivalent activity (Ra_eq) sampled from agricultural land is 209.88±3.617 Bq/kg and ranged from 98.92±2.283 to 256.05±4.147 Bq/kg for six stations, and the mean value of radium equivalent activity (Ra_eq) sampled from virgin land is 168.40±4.402 Bq/kg and ranged from 98.92±2.283 to 256.05± 4.147Bq/kg for six stations. Finally, when we compere the two sample sites the mean value of Ra_eq agricultural land sampled is greater then the mean value of Ra_eq from virgin land soil samples. Table-7, 8 and 9 shows the value of radium equivalent activity (Ra_eq) obtained in this study.

Table-7, 8, and 9 shows the summary of the radiation hazard based on there values of absorbed dose, annual effective dose, and internal and external hazards sampled from the agricultural and virgin land sample sites. The absorbed dose rate (nGy/h) and the effective dose rate (mSv/y) in outdoor air were calculated using Equations (30) and (31), respectively. Based on UNSCEAR [12, 21], the world average value of absorbed dose (D) is 59 nGy/h and ranged from 18-93 nGy/h. In

our findings, the values of the absorbed dose rate sampled from agricultural land is ranged from 45.85±1.001-138.73±1.988 nGy/h with mean value of 101.76±1.873 nGy/h from six stations, and the values of the absorbed dose rate sampled from virgin land is ranged from 46.87±1.058 to 119.01±1.815 nGy/h with mean value of 79.28±1.954nGy/h from six stations. The absorbed dose rate almost for the samples from nine stations greater than the world average value for the two sites. However, for the three stations the value of absorbed dose rate was smaller than the world average value, but others are higher than the world average value and also out of the maximum range.

The annual dose rate was calculated by using equation (31). From agricultural land sampled the calculated mean value of annual dose rate is 0.124±0.002 mSv/y and ranged from 0.06±0.001 mSv/y to 0.17±0.002 mSv/y. And also, from virgin sampled the calculated mean value of annual dose rate is 0.098±0.002 mSv/y and ranged from 0.06±0.001 to 0.15±0.002 mSv/y. Out of twelve sample stations the only three sample stations values of annual dose rates are less than the recommended value. The world wide average value calculated by UNSCEAR was 0.07mSv/y for outdoor [21]. When we compere those two sites the higher value was from agricultural land soil sample measured, which is mean value of 0.124 ± 0.002 mSv/y as of 0.098 ± 0.002 mSv/y for virgin land sample.

Since, radon and its short-lived progeny to produce negligible hazardous effect to respiratory organs from materials (soils) to be used in construction, both the external and internal hazard index should be less than 1 and can be calculated by using equation number (32) and (33). By calculating the external hazard index (H_{ex}), the value obtained is less than 1, which is under the criterion level. From agricultural land site the external hazard index values ranged from 0.25 to 0.80 with mean value of 0.57. Whereas, from virgin land site the values ranged from 0.27 to 0.69 with mean value 0.46. However, the internal hazard index (H_{in}) values from agricultural land site sampled was ranged from 0.29 to 0.91 with mean value of 0.625. Similarly, the value of the internal hazard index (H in) from virgin land site was ranged from 0.31 to 0.75 with mean value of 0.51. Finally, when we compere those two sites the highest value of 0.80 for external hazard index (H_{ex}) sampled from agricultural land site and also 0.91 for the internal hazard index (H_{in})that sampled from the same cite(agricultural land). They did not exceed the upper limit, which is 1.

Table 4.5: The radium equivalent (Ra_{eq}), absorbed doses rate(D_R), annual dose rate (AD_R), the external hazard(H_{ex}) and internal hazard (H_{in}) indexes of soil samples collected from Agricultural land of study area

Sample code	**Ra_{eq} in Kq/kg**	**D_R in nGy/h**	**AD_R in mSv/y**	**H_{ex}**	**H_{in}**
AL-1	209.53±6.794	98.99±2.983	0.12±0.004	0.57	0.64
AL-3	213.80±3.045	103.46±2.956	0.13±0.004	0.58	0.63
AL-5	207.24±3.200	98.94±1.404	0.12±0.002	0.56	0.62
AL-7	238.78±2.012	124.58±0.905	0.15±0.001	0.65	0.66
AL-9	93.45±2.110	45.85±1.001	0.056±0.001	0.25	0.29
AL-11	296.46±4.543	138.73±1.988	0.17±0.002	0.80	0.91
Mean	209.88±3.617	101.76±1.873	0.12±0.002	0.57	0.625
Range	93.45±2.110-	45.85±1.001-	0.06±0.001-	0.25-	0.29-
	296.46±4.543	138.73±1.988	0.17±0.002	0.80	0.91

Table 4.6: The radium equivalent (Ra_{eq}), absorbed doses rate(D_R), annual dose rate (AD_R) the external hazard(H_{ex}) and internal hazard (H_{in}) indices of soil samples collected from Virgin land of study area

Sample code	**Ra_{eq} in Kq/kg**	**D_R in nGy/h**	**AD_R in mSv/y**	**H_{ex}**	**H_{in}**
VL-2	215.28±7.362	100.64±3.225	0.12±0.004	0.58	0.66
VL-4	256.05±4.147	119.01±1.815	0.15±0.002	0.69	0.75
VL-6	185.20±5.965	87.66±2.619	0.11±0.003	0.50	0.57
VL-8	116.11±3.664	55.49±1.614	0.07±0.002	0.31	0.33
VL-10	98.92±2.283	46.87±1.058	0.06±0.001	0.27	0.31
VL-12	138.81±2.989	66.00±1.390	0.08±0.002	0.38	0.41
Mean	168.40±4.402	79.28±1.954	0.098±0.002	0.46	0.51
Range	98.92±2.283-	46.87±1.058-	0.06±0.001-	0.27-	0.31-
	256.05±4.147	119.01±1.815	0.15±0.002	0.69	0.75

Table 4.7: The mean value of radium equivalent (Ra_{eq}), absorbed doses rate(D_R), annual dose rate (AD_R) the external hazard(H_{ex}) and internal hazard (H_{in}) indexes of soil samples collected from Agricultural and Virgin lands of study area

Sample Cite	**Mean Values of radiological hazard**				
	Ra_{eq} in Kq/kg	**D_R in nGy/h**	**AD_R in mSv/y**	**H_{ex}**	**H_{in}**
Agricultural land	209.88±3.617	101.76±1.873	0.12±0.002	0.57	0.625
Virgin land	168.40±4.402	79.28±1.954	0.098±0.002	0.46	0.51

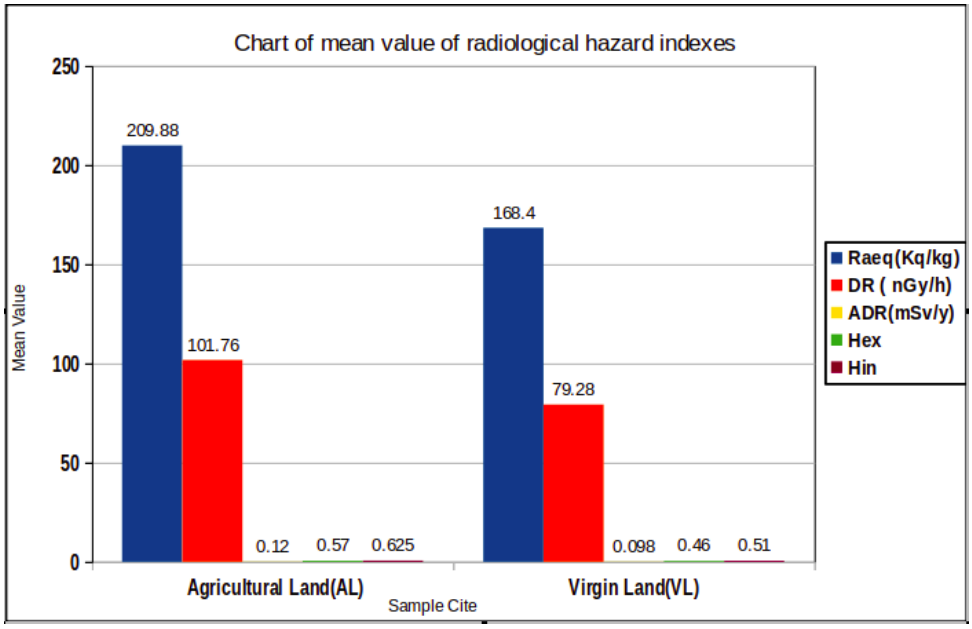

Figure 4.10: Bar graph of the mean value of radiological hazard indexes

Chapter 5

Conclusion and Recommendations

5.1 Conclusion

Based upon the result mean values of measured activity concentrations for ^{232}Th and ^{40}K in soil samples of agricultural and virgin lands are greater than the given world certified values, 30Bq/Kg and 400Bq/Kg respectively. Whereas, the mean value of ^{238}U is lower than the given world certified values of 35Bq/Kg. The mean values of activity concentration for agricultural land soil was greater than that of virgin land soil samples. This value shows that there is phosphate fertilizers added to agricultural soil sample. We observe that their range values are extremely large among the measured values of radionuclides in the sample stations. The value of activity concentration of ^{238}U in sample code AL-11 was 41.15±0.748 Bq/kg which was greater than the recommended world value, as whole their mean value was lower than that of the given world certified value as of UNSCEAR report [38]. In some parts of samples an artificial radionuclide which is ^{137}Cs that fallout from any nuclear accidents. The of maximum value of activity concentration of ^{137}Cs was 2.19±0.151, which is no any health effects on the peoples that leave around the study area.

The value of Ra_{eq} activity concentrations for agricultural and virgin soil samples was less than 370 Bq kg^{-1}, which was the permissible limit recommended by UNSCEAR[1]. The results showed that the mean value of Ra_{eq} activity concentrations was 209.88±3.617 Bq kg^{-1} in agricultural soil samples with a range of 93.45±2.110 to 296.46±4.543 Bq kg^{-1} was greater than the mean value of 168.40±4.402 kg^{-1} in virgin soil samples with a range of 98.92± 2.283 to 256.05±4.147 kg^{-1}. Nevertheless, the values for the radium equivalent activity were found to be within the

world average allowed maximum value of 370 Bq/kg.

Absorbed dose rate(DR) was measured at a distance of 1m above the surface that ensures a uniform distribution of the three radionuclides (40-K, 232-Th and 238-U) for almost the same activities. Results showed that samples from two sites (agricultural and virgin lands) were greater than the value of world average value of absorbed dose rate (DR) which is 59 nGy/h and ranged from 18-93 nGy/h as recommended by UNSCEAR [21]. when we compere the absorbed dose rate of agricultural land(AL) soil with that of virgin land (VL) soil samples, the agricultural land soil sample was greater, i.e. the mean value of AL which 101.76 ± 1.873 nGy/h with ranged from 45.85 ± 1.001 to 138.73 ± 1.988 nGy/h was greater than the mean value of VL which is 79.28 ± 1.954 nGy/h with ranged from 46.87 ± 1.058 to 119.01 ± 1.815 nGy/h as of phosphate fertilizers added to agricultural land soil.

Annual dose rate received by humans at 1m height, 0.2 is an outdoor occupancy of 20% and 0.8 or 80% for the indoors. The world wide average value calculated by UNSCEAR was 0.07 mSv/y for outdoor and 0.41mSv/y for indoor. Our result was focused only the outdoor, so, as our results indicates the mean value of these two sites were greater than the world recommended value written here above, and also as of phosphate fertilizers added to agricultural land soil the mean value of annual dose rate of agricultural land soil sample was greater than that of virgin land soil, i.e. 0.12 ± 0.002 mSv/y of agricultural land soil sample which was greater than that of 0.098 ± 0.002 for virgin land soil samples.

Finally, the external hazard index (Hex) commonly used to evaluate the radiation dose rate due to external exposure to gamma radiation from natural radionuclides and the internal hazard index (Hin) is a parameter for estimating the negative effect of radioactive materials on lungs and/or other respiratory organ. Results showed that their mean value of external hazard(H_{ex}) and internal hazard (H_{in}) of study area is found to be within the world wide average value recommended safe levels by ICRP [50], which was less than or equal to one.

5.1.1 Recommendations

This study was focused on measuring the natural radioactivity level in the soil samples from agricultural and virgin lands related to radiological hazards that sampled from Bale zone, Oromia, Ethiopia by using a gamma-ray spectrometer with high purity germanium (HPGe) detector. Based on the findings we recommend that:-

1. As we know, the effects of radiation were on current and future generations. So, to save our people from such effects, we must aware our people about radiation and its health effects or radiological hazards of naturally occurring radioactive materials for the people that live in these study areas.

2. Even if, our country's economy was hand to a mouse it should be increase the awareness of these people that live in those study areas about the health effects of radiation. After making such awareness creation refuse traditional or illegal miners in these study areas by a legal body, because radionuclides can be enhanced as excavating by those people, which what we call technological enhanced naturally occurring radioactive material(TENORM).

3. Since, there are institutions that work on radiation as the regional and federal government, their main was to save our people current and future effects that come from radiation by optimizing awareness creation, giving license to use radiation source technology, and ways of applying safety protocols. Additionally, their main aim is doing the research as regional and federal governments. So, do the further investigation by taking this study as a benchmark.

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Appendix

Reading of activity concentration of radionuclides in the soil sample by High Purity Germanium for a single sample

Filename: C: GENIE2K-CAMFILES-2021 sample Data-nigusu

ERTL-GW-4-2021.CN

Peak Locate Analysis Report 5/6/2021 11:49:42 AM Page 1

****

***** P E A K L O C A T E R E P O R T *****

****

Detector Name: B13010
Sample Title: enviromental sample
Peak Locate Performed on: 5/6/2021 11:49:42 AM
Peak Locate From Channel: 1
Peak Locate To Channel: 8192
Peak Search Sensitivity: 3.00

Peak No.	Centroid Channel	Centroid Uncertainty	Energy (keV)	Peak Significance
1	162.86	0.3269	39.88	3.13
2	190.22	0.2276	46.57	5.95
3	236.02	0.3161	57.78	3.56
4	258.69	0.1499	63.33	12.80
5	276.98	0.3627	67.81	3.32
6	296.62	0.4154	72.61	3.57
7	305.61	0.0724	74.81	62.28
8	315.23	0.0588	77.17	86.94
9	331.27	0.2828	81.10	3.83
10	344.41	0.1294	84.31	15.27
11	356.38	0.0827	87.24	39.38
12	367.71	0.0950	90.01	32.99
13	380.46	0.0895	93.14	29.26
14	406.86	0.1688	99.60	10.54
15	430.80	0.1669	105.46	8.80
16	444.32	0.2199	108.77	5.05
17	470.47	0.2123	115.17	6.60
18	527.47	0.1080	129.12	23.13
19	587.91	0.2751	143.91	3.99
20	629.45	0.1650	154.08	10.43
21	760.05	0.0933	186.05	30.25
22	814.27	0.2564	199.32	3.74
23	825.68	0.3419	202.11	3.00
24	855.30	0.0833	209.36	38.56
25	882.18	0.2434	215.94	4.46
26	975.16	0.0396	238.70	165.18
27	986.89	0.1007	241.57	26.83
28	1032.54	0.2771	252.75	3.22
29	1058.30	0.2924	259.05	3.21
30	1104.36	0.0886	270.33	31.24
31	1133.33	0.1075	277.42	22.53
32	1176.93	0.2061	288.09	6.89
33	1206.41	0.0670	295.30	54.50
34	1226.42	0.0860	300.20	33.20
35	1340.37	0.0941	328.09	27.77
36	1358.44	0.2225	332.52	6.05
37	1382.51	0.0575	338.41	71.13
38	1394.63	0.3930	341.37	3.00
39	1438.13	0.0557	352.02	76.46
40	1673.26	0.1092	409.58	19.81
41	1793.91	0.2666	439.11	3.55

Peak No.	Centroid Channel	Centroid Uncertainty	Energy (keV)	Peak Significance
42	1850.63	0.1972	452.99	5.91
43	1892.03	0.0801	463.12	35.78
44	2087.23	0.0696	510.90	44.11
45	2298.50	0.1492	562.61	9.34
46	2383.14	0.0473	583.33	95.05
47	2489.91	0.0560	609.46	67.31
48	2719.31	0.1776	665.62	5.90
49	2971.87	0.0709	727.44	40.16
50	3019.49	0.2810	739.09	3.17
51	3086.12	0.1483	755.40	9.61
52	3119.66	0.2081	763.61	5.12
53	3139.67	0.1238	768.51	13.75
54	3155.94	0.1267	772.49	12.71
55	3194.99	0.1841	782.05	6.39
56	3210.33	0.1267	785.80	13.04
57	3248.57	0.0832	795.16	28.57
58	3293.20	0.2091	806.08	4.78
59	3393.82	0.2101	830.71	4.27
60	3415.16	0.1156	835.94	14.79
61	3433.19	0.1565	840.35	7.95
62	3516.52	0.0832	860.75	28.08
63	3651.64	0.1919	893.82	5.17
64	3695.02	0.1645	904.44	6.91
65	3723.43	0.0484	911.39	79.75
66	3817.07	0.1331	934.31	11.37
67	3917.56	0.2057	958.91	5.11
68	3942.13	0.0796	964.92	31.41
69	3959.56	0.0560	969.19	59.79
70	4090.28	0.1844	1001.19	5.74
71	4170.94	0.2699	1020.93	3.30
72	4352.95	0.2165	1065.48	3.43
73	4407.51	0.1806	1078.84	6.41
74	4469.93	0.1734	1094.11	6.18
75	4538.05	0.2157	1110.79	4.22
76	4578.09	0.0812	1120.59	27.55
77	4720.36	0.1845	1155.41	5.66
78	5059.58	0.1146	1238.44	13.35
79	5095.80	0.2209	1247.31	4.16
80	5234.15	0.1907	1281.17	5.30
81	5629.69	0.1149	1377.99	13.76
82	5661.52	0.2121	1385.78	4.33
83	5727.44	0.1621	1401.91	6.73
84	5753.66	0.1402	1408.33	9.55
85	5969.70	0.0326	1461.21	154.43
86	6113.08	0.1273	1496.31	10.21
87	6136.04	0.1533	1501.93	6.79
88	6167.48	0.1448	1509.62	8.44
89	6182.99	0.1978	1513.42	5.56
90	6248.22	0.2724	1529.39	3.02
91	6285.64	0.2092	1538.54	3.24

Peak No.	Centroid Channel	Centroid Uncertainty	Energy (keV)	Peak Significance
92	6307.39	0.2401	1543.87	3.23
93	6362.81	0.2349	1557.43	3.56
94	6457.46	0.1581	1580.60	7.31
95	6490.00	0.0876	1588.57	21.85
96	6507.95	0.1246	1592.96	11.91
97	6623.34	0.1093	1621.20	13.53
98	6641.92	0.2057	1625.75	4.64
99	6663.75	0.1027	1631.09	15.26
100	6695.38	0.1531	1638.84	7.45
101	6789.04	0.1607	1661.76	6.18
102	6811.09	0.2076	1667.16	3.90
103	7068.27	0.1129	1730.11	12.35
104	7210.92	0.0744	1765.02	28.83
105	7380.86	0.2071	1806.62	3.81
106	7549.78	0.1308	1847.97	9.60

? = Adjacent peak noted

Errors quoted at 1.000 sigma

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***** PEAK ANALYSIS REPORT *****

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Detector Name: B13010
Sample Title: enviromental sample
Peak Analysis Performed on: 5/6/2021 11:49:58 AM
Peak Analysis From Channel: 1
Peak Analysis To Channel: 8192

	Peak No.	ROI start	ROI end	Peak centroid	Energy (keV)	FWHM (keV)	Net Peak Area	Net Area Uncert.	Continuum Counts
F	1	159-	169	162.86	39.87	1.13	2.44E+002	72.39	7.27E+003
F	2	182-	196	190.05	46.53	1.14	6.60E+002	77.62	9.86E+003
M	3	231-	390	237.29	58.09	1.16	6.28E+002	92.16	1.03E+004
m	4	231-	390	258.74	63.34	1.17	4.69E+003	146.18	1.11E+004
m	5	231-	390	277.18	67.86	1.18	6.45E+002	32.49	1.19E+004
m	6	231-	390	297.24	72.77	1.19	7.12E+002	22.16	1.20E+004
m	7	231-	390	305.76	74.85	1.19	3.51E+004	335.23	1.20E+004
m	8	231-	390	315.12	77.14	1.19	3.42E+004	261.92	1.21E+004
m	9	231-	390	330.83	80.99	1.20	2.26E+003	150.14	1.22E+004
m	10	231-	390	344.51	84.34	1.21	2.04E+003	51.60	1.15E+004
m	11	231-	390	356.34	87.23	1.21	2.46E+003	34.05	1.24E+004
m	12	231-	390	367.66	90.00	1.21	3.69E+003	68.93	1.24E+004
m	13	231-	390	380.35	93.11	1.22	7.80E+003	119.21	1.25E+004
M	14	396-	453	406.71	99.56	1.23	1.45E+003	92.93	1.26E+004
m	15	396-	453	430.63	105.42	1.23	1.67E+003	93.55	1.29E+004
m	16	396-	453	444.36	108.78	1.24	7.55E+002	90.77	1.30E+004
F	17	465-	475	470.51	115.18	1.25	5.95E+002	88.83	9.20E+003
F	18	520-	533	527.49	129.13	1.26	3.35E+003	107.32	1.21E+004
F	19	624-	636	629.58	154.11	1.29	1.21E+003	93.53	1.06E+004
F	20	751-	766	759.95	186.02	1.32	5.00E+003	111.78	1.18E+004
M	21	848-	887	855.33	209.37	1.35	5.66E+003	112.39	1.02E+004
m	22	848-	887	882.21	215.95	1.35	4.63E+002	82.37	9.47E+003
M	23	963-	996	975.20	238.71	1.37	5.58E+004	254.54	9.87E+003
m	24	963-	996	986.48	241.47	1.37	8.21E+003	118.24	8.39E+003
M	25	1026-	1064	1032.72	252.79	1.38	2.53E+002	70.82	7.57E+003
m	26	1026-	1064	1057.85	258.94	1.39	3.39E+002	69.96	7.17E+003
F	27	1096-	1115	1104.36	270.32	1.40	4.36E+003	96.00	8.85E+003
F	28	1127-	1144	1133.49	277.46	1.40	2.48E+003	82.99	7.37E+003
F	29	1172-	1183	1177.08	288.12	1.41	4.71E+002	66.11	4.79E+003
M	30	1194-	1233	1206.39	295.30	1.42	7.77E+003	112.15	7.32E+003
m	31	1194-	1233	1226.39	300.20	1.42	3.71E+003	91.29	6.63E+003
M	32	1332-	1399	1340.32	328.08	1.44	3.17E+003	82.98	6.10E+003
m	33	1332-	1399	1358.50	332.53	1.45	4.46E+002	62.13	6.34E+003
m	34	1332-	1399	1382.52	338.41	1.45	1.23E+004	126.75	6.16E+003
m	35	1332-	1399	1394.24	341.28	1.45	2.77E+002	60.40	4.77E+003
F	36	1430-	1446	1438.12	352.02	1.46	1.38E+004	134.55	5.11E+003
F	37	1665-	1682	1673.18	409.55	1.50	1.87E+003	68.39	4.34E+003
F	38	1787-	1806	1794.40	439.23	1.52	2.54E+002	51.08	4.36E+003
F	39	1845-	1857	1850.74	453.02	1.53	3.72E+002	50.70	2.69E+003
F	40	1881-	1901	1891.89	463.09	1.53	3.80E+003	80.38	4.28E+003
F	41	2074-	2099	2087.14	510.88	2.34	8.42E+003	112.08	5.06E+003
F	42	2288-	2307	2298.36	562.58	1.59	6.81E+002	50.82	3.23E+003

	Peak No.	ROI start	ROI end	Peak centroid	Energy (keV)	FWHM (keV)	Net Peak Area	Net Area Uncert.	Continuum Counts
F	43	2371-	2396	2383.14	583.33	1.60	2.00E+004	151.75	4.28E+003
F	44	2478-	2500	2489.89	609.46	1.62	1.10E+004	116.21	3.56E+003
F	45	2711-	2730	2719.23	665.60	1.65	4.41E+002	45.54	2.76E+003
F	46	2958-	2982	2971.83	727.42	1.68	4.93E+003	82.67	3.13E+003
M	47	3072-	3166	3086.21	755.42	1.69	6.99E+002	47.30	2.61E+003
m	48	3072-	3166	3120.01	763.69	1.69	3.33E+002	38.82	2.52E+003
m	49	3072-	3166	3139.60	768.49	1.70	1.07E+003	49.86	2.46E+003
m	50	3072-	3166	3155.97	772.50	1.70	9.70E+002	49.78	2.41E+003
M	51	3185-	3219	3194.98	782.04	1.70	3.13E+002	41.65	2.38E+003
m	52	3185-	3219	3210.36	785.81	1.70	7.53E+002	47.36	2.36E+003
F	53	3234-	3258	3248.45	795.13	1.71	2.62E+003	64.47	2.60E+003
F	54	3287-	3301	3293.02	806.04	1.71	1.79E+002	37.68	1.56E+003
M	55	3385-	3444	3394.04	830.77	1.73	2.76E+002	39.30	1.96E+003
m	56	3385-	3444	3415.18	835.94	1.73	9.70E+002	47.61	2.13E+003
m	57	3385-	3444	3433.10	840.33	1.73	5.66E+002	42.88	2.11E+003
F	58	3502-	3530	3516.47	860.74	1.74	2.62E+003	62.72	2.54E+003
F	59	3640-	3658	3651.84	893.87	1.75	2.83E+002	37.35	1.71E+003
M	60	3685-	3735	3694.96	904.43	1.76	4.31E+002	41.31	1.93E+003
m	61	3685-	3735	3723.42	911.39	1.76	1.59E+004	133.39	2.14E+003
F	62	3809-	3825	3817.15	934.33	1.77	5.78E+002	41.97	1.49E+003
M	63	3911-	3974	3917.43	958.88	1.78	2.25E+002	36.02	1.40E+003
m	64	3911-	3974	3942.26	964.96	1.79	3.10E+003	66.12	1.80E+003
m	65	3911-	3974	3959.55	969.19	1.79	9.29E+003	104.00	1.83E+003
F	66	4083-	4101	4090.40	1001.22	1.80	3.06E+002	37.43	1.61E+003
F	67	4345-	4362	4352.66	1065.41	1.83	2.14E+002	36.08	1.51E+003
F	68	4402-	4416	4407.66	1078.87	1.83	2.35E+002	37.12	1.36E+003
F	69	4463-	4482	4470.21	1094.18	1.84	3.47E+002	38.58	1.74E+003
F	70	4532-	4548	4537.98	1110.77	1.85	1.92E+002	37.13	1.58E+003
F	71	4564-	4590	4578.07	1120.58	1.85	2.69E+003	64.68	2.57E+003
F	72	4705-	4730	4719.96	1155.31	1.86	4.09E+002	41.27	2.50E+003
M	73	5051-	5106	5059.59	1238.44	1.89	1.02E+003	51.94	2.39E+003
m	74	5051-	5106	5095.36	1247.20	1.90	2.22E+002	40.45	2.40E+003
F	75	5223-	5242	5234.07	1281.15	1.91	2.32E+002	35.87	1.48E+003
M	76	5619-	5669	5629.59	1377.96	1.95	5.98E+002	36.07	9.75E+002
m	77	5619-	5669	5661.23	1385.71	1.95	1.49E+002	25.45	7.18E+002
M	78	5718-	5763	5727.29	1401.88	1.95	2.72E+002	26.98	6.71E+002
m	79	5718-	5763	5753.55	1408.31	1.96	3.29E+002	28.90	7.36E+002
F	80	5953-	5985	5969.60	1461.19	1.98	6.61E+004	258.23	1.03E+003
M	81	6099-	6195	6113.10	1496.31	1.99	5.05E+002	27.16	3.67E+002
m	82	6099-	6195	6136.12	1501.95	1.99	3.17E+002	23.24	3.52E+002
m	83	6099-	6195	6167.93	1509.73	1.99	3.90E+002	24.53	3.35E+002
m	84	6099-	6195	6182.19	1513.22	1.99	2.28E+002	20.91	3.25E+002
M	85	6242-	6316	6248.71	1529.50	2.00	4.99E+001	16.20	2.73E+002
m	86	6242-	6316	6286.04	1538.64	2.00	1.07E+002	17.90	3.81E+002
m	87	6242-	6316	6307.17	1543.81	2.00	7.77E+001	17.61	3.42E+002
F	88	6355-	6372	6362.79	1557.43	2.01	5.34E+001	16.86	2.86E+002
M	89	6446-	6519	6458.19	1580.78	2.02	2.25E+002	22.59	4.27E+002
m	90	6446-	6519	6490.07	1588.58	2.02	1.42E+003	41.85	4.22E+002
m	91	6446-	6519	6507.51	1592.85	2.02	5.28E+002	28.42	3.88E+002
M	92	6609-	6710	6623.44	1621.23	2.03	6.58E+002	30.40	3.46E+002

	Peak No.	ROI start	ROI end	Peak centroid	Energy (keV)	FWHM (keV)	Net Peak Area	Net Area Uncert.	Continuum Counts
m	93	6609-	6710	6641.68	1625.69	2.03	1.55E+002	18.83	3.23E+002
m	94	6609-	6710	6663.61	1631.06	2.03	8.41E+002	32.93	2.80E+002
m	95	6609-	6710	6695.42	1638.84	2.03	2.72E+002	20.61	2.31E+002
M	96	6778-	6821	6788.75	1661.69	2.04	1.89E+002	20.03	3.18E+002
m	97	6778-	6821	6810.90	1667.11	2.04	7.95E+001	17.00	3.18E+002
F	98	7058-	7078	7068.21	1730.09	2.06	5.47E+002	27.10	2.25E+002
F	99	7193-	7227	7210.90	1765.02	2.08	2.45E+003	51.34	3.06E+002
F	100	7373-	7390	7381.02	1806.66	2.09	7.11E+001	15.47	1.99E+002
F	101	7538-	7564	7549.95	1848.01	2.10	3.22E+002	23.08	3.21E+002

M = First peak in a multiplet region
m = Other peak in a multiplet region
F = Fitted singlet

Errors quoted at 1.000 sigma

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***** B A C K G R O U N D S U B T R A C T R E P O R T *****
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Detector Name: B13010
Sample Title: enviromental sample
Peak Analysis Performed on: 5/6/2021 11:49:42 AM

Env. Background File: C:\GENIE2K\CAMFILES\QA\Background radia

	Peak No.	Energy (keV)	Original Area	Orig. Area Uncert.	Ambient Background	Backgr. Uncert.	Subtracted Area	Subtracted Uncert.
F	1	39.87	2.44E+002	72.39			2.44E+002	7.24E+001
F	2	46.53	6.60E+002	77.62	7.14E+001	4.02E+001	5.89E+002	8.74E+001
M	3	58.09	6.28E+002	92.16			6.28E+002	9.22E+001
m	4	63.34	4.69E+003	146.18	2.05E+002	2.00E+001	4.49E+003	1.48E+002
m	5	67.86	6.45E+002	32.49			6.45E+002	3.25E+001
m	6	72.77	7.12E+002	22.16	2.15E+002	2.10E+001	4.97E+002	3.05E+001
m	7	74.85	3.51E+004	335.23	6.55E+002	2.37E+001	3.45E+004	3.36E+002
m	8	77.14	3.42E+004	261.92	3.84E+002	2.24E+001	3.39E+004	2.63E+002
m	9	80.99	2.26E+003	150.14			2.26E+003	1.50E+002
m	10	84.34	2.04E+003	51.60	4.33E+002	2.30E+001	1.61E+003	5.65E+001
m	11	87.23	2.46E+003	34.05	2.91E+002	2.20E+001	2.17E+003	4.05E+001
m	12	90.00	3.69E+003	68.93			3.69E+003	6.89E+001
m	13	93.11	7.80E+003	119.21	5.31E+002	2.43E+001	7.27E+003	1.22E+002
M	14	99.56	1.45E+003	92.93			1.45E+003	9.29E+001
m	15	105.42	1.67E+003	93.55			1.67E+003	9.36E+001
m	16	108.78	7.55E+002	90.77			7.55E+002	9.08E+001
F	17	115.18	5.95E+002	88.83			5.95E+002	8.88E+001
F	18	129.13	3.35E+003	107.32			3.35E+003	1.07E+002
F	19	154.11	1.21E+003	93.53			1.21E+003	9.35E+001
F	20	186.02	5.00E+003	111.78	4.24E+002	2.64E+001	4.58E+003	1.15E+002
M	21	209.37	5.66E+003	112.39			5.66E+003	1.12E+002
m	22	215.95	4.63E+002	82.37			4.63E+002	8.24E+001
M	23	238.71	5.58E+004	254.54	1.09E+003	2.78E+001	5.47E+004	2.56E+002
m	24	241.47	8.21E+003	118.24	2.58E+002	2.28E+001	7.96E+003	1.20E+002
M	25	252.79	2.53E+002	70.82			2.53E+002	7.08E+001
m	26	258.94	3.39E+002	69.96			3.39E+002	7.00E+001

F	27	270.32	4.36E+003	96.00			4.36E+003	9.60E+001
F	28	277.46	2.48E+003	82.99			2.48E+003	8.30E+001
F	29	288.12	4.71E+002	66.11			4.71E+002	6.61E+001
M	30	295.30	7.77E+003	112.15	2.88E+002	2.16E+001	7.48E+003	1.14E+002
m	31	300.20	3.71E+003	91.29	8.46E+001	1.98E+001	3.62E+003	9.34E+001
M	32	328.08	3.17E+003	82.98			3.17E+003	8.30E+001
m	33	332.53	4.46E+002	62.13			4.46E+002	6.21E+001
m	34	338.41	1.23E+004	126.75	2.09E+002	1.94E+001	1.21E+004	1.28E+002
m	35	341.28	2.77E+002	60.40			2.77E+002	6.04E+001
F	36	352.02	1.38E+004	134.55	5.65E+002	2.11E+001	1.32E+004	1.36E+002
F	37	409.55	1.87E+003	68.39			1.87E+003	6.84E+001
F	38	439.23	2.54E+002	51.08			2.54E+002	5.11E+001
F	39	453.02	3.72E+002	50.70			3.72E+002	5.07E+001
F	40	463.09	3.80E+003	80.38	1.10E+002	1.53E+001	3.68E+003	8.18E+001

	Peak No.	Energy (keV)	Original Area	Orig. Area Uncert.	Ambient Background	Backgr. Uncert.	Subtracted Area	Subtracted Uncert.
F	41	510.88	8.42E+003	112.08	2.35E+003	3.03E+001	6.08E+003	1.16E+002
F	42	562.58	6.81E+002	50.82			6.81E+002	5.08E+001
F	43	583.33	2.00E+004	151.75	7.42E+002	1.91E+001	1.93E+004	1.53E+002
F	44	609.46	1.10E+004	116.21	8.39E+002	1.95E+001	1.01E+004	1.18E+002
F	45	665.60	4.41E+002	45.54			4.41E+002	4.55E+001
F	46	727.42	4.93E+003	82.67	1.71E+002	1.29E+001	4.76E+003	8.37E+001
M	47	755.42	6.99E+002	47.30			6.99E+002	4.73E+001
m	48	763.69	3.33E+002	38.82			3.33E+002	3.88E+001
m	49	768.49	1.07E+003	49.86	9.60E+001	1.17E+001	9.77E+002	5.12E+001
m	50	772.50	9.70E+002	49.78			9.70E+002	4.98E+001
M	51	782.04	3.13E+002	41.65			3.13E+002	4.17E+001
m	52	785.81	7.53E+002	47.36	5.05E+001	1.05E+001	7.03E+002	4.85E+001
F	53	795.13	2.62E+003	64.47	5.34E+001	3.58E+001	2.57E+003	7.37E+001
F	54	806.04	1.79E+002	37.68			1.79E+002	3.77E+001
M	55	830.77	2.76E+002	39.30			2.76E+002	3.93E+001
m	56	835.94	9.70E+002	47.61			9.70E+002	4.76E+001
m	57	840.33	5.66E+002	42.88			5.66E+002	4.29E+001
F	58	860.74	2.62E+003	62.72	1.53E+002	1.15E+001	2.46E+003	6.38E+001
F	59	893.87	2.83E+002	37.35			2.83E+002	3.73E+001
M	60	904.43	4.31E+002	41.31			4.31E+002	4.13E+001
m	61	911.39	1.59E+004	133.39	7.21E+002	1.68E+001	1.52E+004	1.34E+002
F	62	934.33	5.78E+002	41.97	4.29E+001	9.52E+000	5.35E+002	4.30E+001
M	63	958.88	2.25E+002	36.02			2.25E+002	3.60E+001
m	64	964.96	3.10E+003	66.12	1.32E+002	1.11E+001	2.96E+003	6.70E+001
m	65	969.19	9.29E+003	104.00	4.31E+002	1.42E+001	8.86E+003	1.05E+002
F	66	1001.22	3.06E+002	37.43	6.61E+001	9.51E+000	2.40E+002	3.86E+001
F	67	1065.41	2.14E+002	36.08			2.14E+002	3.61E+001
F	68	1078.87	2.35E+002	37.12			2.35E+002	3.71E+001
F	69	1094.18	3.47E+002	38.58			3.47E+002	3.86E+001
F	70	1110.77	1.92E+002	37.13			1.92E+002	3.71E+001
F	71	1120.58	2.69E+003	64.68	3.79E+002	1.31E+001	2.32E+003	6.60E+001
F	72	1155.31	4.09E+002	41.27			4.09E+002	4.13E+001
M	73	1238.44	1.02E+003	51.94	1.39E+002	1.04E+001	8.78E+002	5.30E+001
m	74	1247.20	2.22E+002	40.45			2.22E+002	4.04E+001
F	75	1281.15	2.32E+002	35.87	3.19E+001	7.98E+000	2.00E+002	3.67E+001
M	76	1377.96	5.98E+002	36.07	1.00E+002	8.20E+000	4.98E+002	3.70E+001
m	77	1385.71	1.49E+002	25.45			1.49E+002	2.55E+001
M	78	1401.88	2.72E+002	26.98			2.72E+002	2.70E+001
m	79	1408.31	3.29E+002	28.90	6.70E+001	7.63E+000	2.62E+002	2.99E+001
F	80	1461.19	6.61E+004	258.23	5.21E+003	3.68E+001	6.09E+004	2.61E+002
M	81	1496.31	5.05E+002	27.16	3.54E+001	5.73E+000	4.70E+002	2.78E+001
m	82	1501.95	3.17E+002	23.24			3.17E+002	2.32E+001
m	83	1509.73	3.90E+002	24.53	5.20E+001	6.39E+000	3.38E+002	2.53E+001
m	84	1513.22	2.28E+002	20.91			2.28E+002	2.09E+001
M	85	1529.50	4.99E+001	16.20			4.99E+001	1.62E+001
m	86	1538.64	1.07E+002	17.90			1.07E+002	1.79E+001
m	87	1543.81	7.77E+001	17.61			7.77E+001	1.76E+001
F	88	1557.43	5.34E+001	16.86			5.34E+001	1.69E+001
M	89	1580.78	2.25E+002	22.59			2.25E+002	2.26E+001
m	90	1588.58	1.42E+003	41.85	1.16E+002	7.52E+000	1.30E+003	4.25E+001

Background Subtract Report 5/6/2021 11:50:24 AM Page 3

Peak No.	Energy (keV)	Original Area	Orig. Area Uncert.	Ambient Background	Backgr. Uncert.	Subtracted Area	Subtracted Uncert.
m 91	1592.85	5.28E+002	28.42	7.33E+001	6.52E+000	4.55E+002	2.92E+001
M 92	1621.23	6.58E+002	30.40	6.93E+001	6.24E+000	5.89E+002	3.10E+001
m 93	1625.69	1.55E+002	18.83			1.55E+002	1.88E+001
m 94	1631.06	8.41E+002	32.93	7.09E+001	6.30E+000	7.70E+002	3.35E+001
m 95	1638.84	2.72E+002	20.61			2.72E+002	2.06E+001
M 96	1661.69	1.89E+002	20.03	3.52E+001	5.24E+000	1.54E+002	2.07E+001
m 97	1667.11	7.95E+001	17.00			7.95E+001	1.70E+001
F 98	1730.09	5.47E+002	27.10	8.10E+001	6.35E+000	4.66E+002	2.78E+001
F 99	1765.02	2.45E+003	51.34	4.36E+002	1.17E+001	2.01E+003	5.27E+001
F 100	1806.66	7.11E+001	15.47			7.11E+001	1.55E+001
F 101	1848.01	3.22E+002	23.08	5.79E+001	5.84E+000	2.65E+002	2.38E+001

M = First peak in a multiplet region
m = Other peak in a multiplet region
F = Fitted singlet

Errors quoted at 1.000 sigma
Peak Efficiency Report 5/6/2021 11:50:32 AM Page 1

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***** PEAK EFFICIENCY REPORT *****
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Detector Name: B13010
Sample Title: enviromental sample
Peak Analysis Performed on: 5/6/2021 11:49:58 AM

Peak No.	Energy (keV)	Net Peak Area	Net Area Uncertainty	Peak Efficiency	Efficiency Uncertainty
F 1	39.87	2.44E+002	72.39	1.59E-002	9.15E-004
F 2	46.53	6.60E+002	77.62	2.28E-002	7.94E-004
M 3	58.09	6.28E+002	92.16	3.52E-002	4.75E-004
m 4	63.34	4.69E+003	146.18	4.06E-002	4.70E-004
m 5	67.86	6.45E+002	32.49	4.50E-002	5.77E-004
m 6	72.77	7.12E+002	22.16	4.95E-002	7.47E-004
m 7	74.85	3.51E+004	335.23	5.13E-002	8.23E-004
m 8	77.14	3.42E+004	261.92	5.32E-002	9.05E-004
m 9	80.99	2.26E+003	150.14	5.61E-002	1.03E-003
m 10	84.34	2.04E+003	51.60	5.85E-002	1.13E-003
m 11	87.23	2.46E+003	34.05	6.04E-002	1.21E-003
m 12	90.00	3.69E+003	68.93	6.21E-002	1.27E-003
m 13	93.11	7.80E+003	119.21	6.39E-002	1.32E-003
M 14	99.56	1.45E+003	92.93	6.71E-002	1.39E-003
m 15	105.42	1.67E+003	93.55	6.94E-002	1.40E-003
m 16	108.78	7.55E+002	90.77	7.05E-002	1.40E-003
F 17	115.18	5.95E+002	88.83	7.22E-002	1.35E-003
F 18	129.13	3.35E+003	107.32	7.43E-002	1.15E-003
F 19	154.11	1.21E+003	93.53	7.38E-002	1.04E-003
F 20	186.02	5.00E+003	111.78	6.72E-002	1.78E-003
M 21	209.37	5.66E+003	112.39	6.26E-002	2.37E-003
m 22	215.95	4.63E+002	82.37	6.15E-002	2.45E-003
M 23	238.71	5.58E+004	254.54	5.82E-002	2.53E-003

m	24	241.47	8.21E+003	118.24	5.78E-002	2.53E-003
M	25	252.79	2.53E+002	70.82	5.63E-002	2.47E-003
m	26	258.94	3.39E+002	69.96	5.56E-002	2.43E-003
F	27	270.32	4.36E+003	96.00	5.43E-002	2.34E-003
F	28	277.46	2.48E+003	82.99	5.36E-002	2.27E-003
F	29	288.12	4.71E+002	66.11	5.25E-002	2.16E-003
M	30	295.30	7.77E+003	112.15	5.18E-002	2.08E-003
m	31	300.20	3.71E+003	91.29	5.13E-002	2.02E-003
M	32	328.08	3.17E+003	82.98	4.90E-002	1.71E-003
m	33	332.53	4.46E+002	62.13	4.86E-002	1.66E-003
m	34	338.41	1.23E+004	126.75	4.82E-002	1.60E-003
m	35	341.28	2.77E+002	60.40	4.79E-002	1.56E-003
F	36	352.02	1.38E+004	134.55	4.72E-002	1.45E-003
F	37	409.55	1.87E+003	68.39	4.35E-002	9.49E-004
F	38	439.23	2.54E+002	51.08	4.18E-002	7.61E-004
F	39	453.02	3.72E+002	50.70	4.11E-002	6.89E-004
F	40	463.09	3.80E+003	80.38	4.06E-002	6.43E-004
F	41	510.88	8.42E+003	112.08	3.85E-002	4.92E-004
F	42	562.58	6.81E+002	50.82	3.65E-002	4.21E-004

Peak No.		Energy (keV)	Net Peak Area	Net Area Uncertainty	Peak Efficiency	Efficiency Uncertainty
F	43	583.33	2.00E+004	151.75	3.57E-002	4.08E-004
F	44	609.46	1.10E+004	116.21	3.48E-002	3.98E-004
F	45	665.60	4.41E+002	45.54	3.31E-002	3.82E-004
F	46	727.42	4.93E+003	82.67	3.13E-002	3.60E-004
M	47	755.42	6.99E+002	47.30	3.06E-002	3.48E-004
m	48	763.69	3.33E+002	38.82	3.04E-002	3.44E-004
m	49	768.49	1.07E+003	49.86	3.03E-002	3.41E-004
m	50	772.50	9.70E+002	49.78	3.02E-002	3.39E-004
M	51	782.04	3.13E+002	41.65	3.00E-002	3.34E-004
m	52	785.81	7.53E+002	47.36	2.99E-002	3.32E-004
F	53	795.13	2.62E+003	64.47	2.97E-002	3.27E-004
F	54	806.04	1.79E+002	37.68	2.94E-002	3.21E-004
M	55	830.77	2.76E+002	39.30	2.89E-002	3.07E-004
m	56	835.94	9.70E+002	47.61	2.88E-002	3.05E-004
m	57	840.33	5.66E+002	42.88	2.87E-002	3.02E-004
F	58	860.74	2.62E+003	62.72	2.83E-002	2.91E-004
F	59	893.87	2.83E+002	37.35	2.76E-002	2.73E-004
M	60	904.43	4.31E+002	41.31	2.74E-002	2.67E-004
m	61	911.39	1.59E+004	133.39	2.73E-002	2.64E-004
F	62	934.33	5.78E+002	41.97	2.68E-002	2.53E-004
M	63	958.88	2.25E+002	36.02	2.64E-002	2.42E-004
m	64	964.96	3.10E+003	66.12	2.63E-002	2.39E-004
m	65	969.19	9.29E+003	104.00	2.62E-002	2.38E-004
F	66	1001.22	3.06E+002	37.43	2.57E-002	2.26E-004
F	67	1065.41	2.14E+002	36.08	2.47E-002	2.10E-004
F	68	1078.87	2.35E+002	37.12	2.45E-002	2.08E-004
F	69	1094.18	3.47E+002	38.58	2.42E-002	2.06E-004
F	70	1110.77	1.92E+002	37.13	2.40E-002	2.04E-004
F	71	1120.58	2.69E+003	64.68	2.39E-002	2.03E-004
F	72	1155.31	4.09E+002	41.27	2.34E-002	2.01E-004
M	73	1238.44	1.02E+003	51.94	2.24E-002	2.00E-004
m	74	1247.20	2.22E+002	40.45	2.23E-002	2.00E-004
F	75	1281.15	2.32E+002	35.87	2.19E-002	2.00E-004
M	76	1377.96	5.98E+002	36.07	2.08E-002	2.00E-004
m	77	1385.71	1.49E+002	25.45	2.07E-002	2.00E-004
M	78	1401.88	2.72E+002	26.98	2.06E-002	2.00E-004
m	79	1408.31	3.29E+002	28.90	2.05E-002	2.00E-004
F	80	1461.19	6.61E+004	258.23	2.00E-002	2.00E-004
M	81	1496.31	5.05E+002	27.16	1.97E-002	2.01E-004
m	82	1501.95	3.17E+002	23.24	1.97E-002	2.01E-004
m	83	1509.73	3.90E+002	24.53	1.96E-002	2.02E-004
m	84	1513.22	2.28E+002	20.91	1.96E-002	2.02E-004
M	85	1529.50	4.99E+001	16.20	1.94E-002	2.02E-004
m	86	1538.64	1.07E+002	17.90	1.93E-002	2.03E-004
m	87	1543.81	7.77E+001	17.61	1.93E-002	2.03E-004
F	88	1557.43	5.34E+001	16.86	1.92E-002	2.05E-004
M	89	1580.78	2.25E+002	22.59	1.90E-002	2.07E-004
m	90	1588.58	1.42E+003	41.85	1.89E-002	2.08E-004
m	91	1592.85	5.28E+002	28.42	1.89E-002	2.09E-004
M	92	1621.23	6.58E+002	30.40	1.87E-002	2.14E-004

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Peak No.	Energy (keV)	Net Peak Area	Net Area Uncertainty	Peak Efficiency	Efficiency Uncertainty
m 93	1625.69	1.55E+002	18.83	1.86E-002	2.15E-004
m 94	1631.06	8.41E+002	32.93	1.86E-002	2.16E-004
m 95	1638.84	2.72E+002	20.61	1.85E-002	2.18E-004
M 96	1661.69	1.89E+002	20.03	1.84E-002	2.24E-004
m 97	1667.11	7.95E+001	17.00	1.83E-002	2.25E-004
F 98	1730.09	5.47E+002	27.10	1.79E-002	2.49E-004
F 99	1765.02	2.45E+003	51.34	1.77E-002	2.67E-004
F 100	1806.66	7.11E+001	15.47	1.74E-002	2.91E-004
F 101	1848.01	3.22E+002	23.08	1.71E-002	3.20E-004

M = First peak in a multiplet region
m = Other peak in a multiplet region
F = Fitted singlet

Errors quoted at 1.000 sigma
Interference Corrected Activity Report 5/6/2021 11:51:10 AM Page 1

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***** N U C L I D E I D E N T I F I C A T I O N R E P O R T *****
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Sample Title: enviromental sample
Nuclide Library Used: C:\GENIE2K\CAMFILES\Env with outh CD-109

..... IDENTIFIED NUCLIDES .....

Nuclide Name	Id Confidence	Energy (keV)	Yield (%)	Activity (Bq /Kg)	Activity Uncertainty	Coinc Corr
K-40	0.978	1460.81*	10.67	8.07639E+002	1.21081E+001	err
PB-212	0.999	77.11*	17.50	1.03154E+002	1.93042E+000	err
		238.63*	44.60	5.97719E+001	2.61692E+000	err
BI-214	0.986	609.31*	46.30	2.00199E+001	3.26732E-001	err
		1120.29*	15.10	2.07610E+001	6.17424E-001	err
		1764.49*	15.80	2.03906E+001	6.16231E-001	err
PB-214	0.999	295.21*	19.20	2.13066E+001	9.14078E-001	err
		351.92*	37.20	2.13800E+001	6.94570E-001	err
AC-228	0.994	911.21*	26.60	1.21078E+002	3.63426E+000	err
		968.97*	16.20	1.20781E+002	3.55227E+000	err

* = Energy line found in the spectrum.
@ = Energy line not used for Weighted Mean Activity
Energy Tolerance : 1.000 keV
Nuclide confidence index threshold = 0.30
Errors quoted at 1.000 sigma
Coincidence correction performed.
free = No coincidence correction required.
miss = Nuclide energy was not found in the coincidence library.
err = Error in coincidence correction calculation.
ISOCS/LabSOCS/Coinc. Corr. Warning/error code = 537199722

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***** I N T E R F E R E N C E C O R R E C T E D R E P O R T *****
****

Nuclide Name	Nuclide Id Confidence	Wt mean Activity (Bq /Kg)	Wt mean Activity Uncertainty
K-40	0.978	8.076387E+002	1.210814E+001
PB-212	0.999	8.786661E+001	1.553481E+000
BI-214	0.986	2.021962E+001	2.614974E-001
PB-214	0.999	2.135312E+001	5.530279E-001
AC-228	0.994	1.209263E+002	2.545651E+000

? = nuclide is part of an undetermined solution
X = nuclide rejected by the interference analysis
@ = nuclide contains energy lines not used in Weighted Mean Activity

Errors quoted at 1.000 sigma

********** U N I D E N T I F I E D P E A K S **********

Peak Locate Performed on: 5/6/2021 11:49:42 AM
Peak Locate From Channel: 1
Peak Locate To Channel: 8192

	Peak No.	Energy (keV)	Peak Size in Counts per Second	Peak CPS % Uncertainty	Peak Type	Tol. Nuclide
F	1	39.87	4.8369E-003	29.70		
F	2	46.53	1.1683E-002	14.85		
M	3	58.09	1.2452E-002	14.69		
m	4	63.34	8.9004E-002	3.29		
m	5	67.86	1.2800E-002	5.04		
m	6	72.77	9.8534E-003	6.15		
m	7	74.85	6.8402E-001	0.97		
m	9	80.99	4.4866E-002	6.64	Tol.	133 Ba
m	10	84.34	3.1912E-002	3.51		
m	11	87.23	4.3062E-002	1.87		
m	12	90.00	7.3136E-002	1.87		
m	13	93.11	1.4421E-001	1.67		
M	14	99.56	2.8801E-002	6.40	D-Esc.	
m	15	105.42	3.3187E-002	5.59		
m	16	108.78	1.4984E-002	12.02		
F	17	115.18	1.1811E-002	14.92		
F	18	129.13	6.6387E-002	3.21		
F	19	154.11	2.4016E-002	7.73	Sum	
F	20	186.02	9.0881E-002	2.51		
M	21	209.37	1.1233E-001	1.99		
m	22	215.95	9.1834E-003	17.80		
m	24	241.47	1.5785E-001	1.51		
M	25	252.79	5.0113E-003	28.04		
m	26	258.94	6.7297E-003	20.63		
F	27	270.32	8.6565E-002	2.20		
F	28	277.46	4.9176E-002	3.35		
F	29	288.12	9.3444E-003	14.04		
m	31	300.20	7.1837E-002	2.58		
M	32	328.08	6.2984E-002	2.61		
m	33	332.53	8.8522E-003	13.93		
m	34	338.41	2.3958E-001	1.06		
m	35	341.28	5.5037E-003	21.78		
F	37	409.55	3.7188E-002	3.65		
F	38	439.23	5.0407E-003	20.11	D-Esc.	
F	39	453.02	7.3820E-003	13.63		
F	40	463.09	7.3109E-002	2.22		
F	41	510.88	1.2057E-001	1.91		
F	42	562.58	1.3516E-002	7.46		
F	43	583.33	3.8309E-001	0.79		
F	45	665.60	8.7430E-003	10.34		
F	46	727.42	9.4485E-002	1.76		
M	47	755.42	1.3876E-002	6.76		
m	48	763.69	6.6038E-003	11.66	Tol.	AG-110M
m	49	768.49	1.9394E-002	5.24		
m	50	772.50	1.9242E-002	5.13		
M	51	782.04	6.2048E-003	13.32		

	Peak No.	Energy (keV)	Peak Size in Counts per Second	Peak CPS % Uncertainty	Peak Type	Tol. Nuclide
m	52	785.81	1.3948E-002	6.90		
F	53	795.13	5.0975E-002	2.87	Tol.	CS-134
F	54	806.04	3.5544E-003	21.04		
M	55	830.77	5.4718E-003	14.25		
m	56	835.94	1.9244E-002	4.91		
m	57	840.33	1.1237E-002	7.57		
F	58	860.74	4.8898E-002	2.59		
F	59	893.87	5.6249E-003	13.17		
M	60	904.43	8.5591E-003	9.58	Sum	
F	62	934.33	1.0618E-002	8.04		
M	63	958.88	4.4712E-003	15.98		
m	64	964.96	5.8802E-002	2.26		
F	66	1001.22	4.7650E-003	16.08		
F	67	1065.41	4.2507E-003	16.84		
F	68	1078.87	4.6566E-003	15.81		
F	69	1094.18	6.8827E-003	11.12		
F	70	1110.77	3.8029E-003	19.37		
F	72	1155.31	8.1167E-003	10.09		
M	73	1238.44	1.7426E-002	6.03		
m	74	1247.20	4.4059E-003	18.21		
F	75	1281.15	3.9703E-003	18.36		
M	76	1377.96	9.8782E-003	7.43		
m	77	1385.71	2.9469E-003	17.14		
M	78	1401.88	5.4060E-003	9.90		
m	79	1408.31	5.1999E-003	11.41		
M	81	1496.31	9.3197E-003	5.91		
m	82	1501.95	6.2960E-003	7.32		
m	83	1509.73	6.6984E-003	7.51		
m	84	1513.22	4.5332E-003	9.15		
M	85	1529.50	9.8953E-004	32.48		
m	86	1538.64	2.1279E-003	16.69	Sum	
m	87	1543.81	1.5414E-003	22.67		
F	88	1557.43	1.0586E-003	31.61		
M	89	1580.78	4.4639E-003	10.04		
m	90	1588.58	2.5790E-002	3.27		
m	91	1592.85	9.0225E-003	6.41		
M	92	1621.23	1.1677E-002	5.27		
m	93	1625.69	3.0805E-003	12.13		
m	94	1631.06	1.5282E-002	4.35		
m	95	1638.84	5.3992E-003	7.57		
M	96	1661.69	3.0543E-003	13.45		
m	97	1667.11	1.5769E-003	21.39		
F	98	1730.09	9.2486E-003	5.97	Sum	
F	100	1806.66	1.4109E-003	21.76		
F	101	1848.01	5.2486E-003	9.00		

M = First peak in a multiplet region
m = Other peak in a multiplet region
F = Fitted singlet

Errors quoted at 1.000 sigma

Nuclide MDA Report 5/6/2021 11:51:43 AM Page 1

****
***** NUCLIDE MDA REPORT *****
****

Detector Name: B13010
Sample Geometry: 538G-E
Sample Title: enviromental sample
Nuclide Library Used: C:\GENIE2K\CAMFILES\Env with outh CD-109

	Nuclide Name	Energy (keV)	Yield (%)	Line MDA (Bq /Kg)	Nuclide MDA (Bq /Kg)	Activity (Bq /Kg)	Coinc Corr
+	K-40	1460.81*	10.67	4.7814E+000	4.78E+000	8.0764E+002	miss
	CO-57	122.06	85.51	3.5679E-001	3.57E-001	-4.2300E-001	miss
		136.48	10.60	2.8860E+000		-3.4294E+000	miss
	CO-60	1173.22	100.00	4.3885E-001	3.37E-001	5.1952E-001	miss
		1332.49	100.00	3.3656E-001		2.5079E-001	miss
	Y-88	898.02	93.40	3.6457E-001	2.25E-001	-8.4414E-002	miss
		1836.01	99.38	2.2534E-001		-1.3464E-002	miss
	Ag-108M	621.00	98.00	3.9191E-001	3.92E-001	-2.7481E-001	miss
		1050.10	14.60	3.0620E+000		-4.5133E+000	miss
	133 Ba	81.00	33.31	1.6841E+000	7.39E-001	2.0489E+001	miss
		356.01	62.05	7.3945E-001		-5.5113E-001	miss
	CS-134	569.32	15.43	2.1111E+000	4.64E-001	2.3106E+000	miss
		604.70	97.60	5.1423E-001		-2.5227E-001	miss
		795.84	85.40	4.6448E-001		2.2993E+000	miss
	CS-137	661.65	85.12	4.0211E-001	4.02E-001	6.2361E-002	miss
+	BI-214	609.31*	46.30	7.1395E-001	7.14E-001	2.0020E+001	miss
		1120.29*	15.10	2.8291E+000		2.0761E+001	miss
		1764.49*	15.80	1.6011E+000		2.0391E+001	miss
+	PB-214	295.21*	19.20	1.1711E+000	6.97E-001	2.1307E+001	miss
		351.92*	37.20	6.9732E-001		2.1380E+001	miss
+	AC-228	911.21*	26.60	1.8844E+000	1.88E+000	1.2108E+002	miss
		968.97*	16.20	2.9046E+000		1.2078E+002	miss

+ = Nuclide identified during the nuclide identification
* = Energy line found in the spectrum
> = Calculated MDA is zero due to zero counts in the region or the region is outside the spectrum
@ = Half-life too short to be able to perform the decay correction
Coincidence correction performed.
free = No coincidence correction required.
miss = Nuclide energy was not found in the coincidence library.

****
***** N U C L I D E M D A R E P O R T *****
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Detector Name: B13010
Sample Geometry: 538G-E
Sample Title: enviromental sample
Nuclide Library Used: C:\GENIE2K\CAMFILES\Env with outh CD-109
MDA Confidence Levels: Alpha = 5.00%; Beta = 5.00%

	Nuclide Name	Energy (keV)	Yield (%)	Line MDA (Bq /Kg)	Nuclide MDA (Bq /Kg)	Activity (Bq /Kg)	Coinc Corr
+	K-40	1460.81*	10.67	4.7841E+000	4.78E+000	8.0764E+002	miss
	CO-57	122.06	85.51	3.5708E-001	3.57E-001	-4.2300E-001	miss
		136.48	10.60	2.8898E+000		-3.4294E+000	miss
	CO-60	1173.22	100.00	4.3894E-001	3.37E-001	5.1952E-001	miss
		1332.49	100.00	3.3664E-001		2.5079E-001	miss
	Y-88	898.02	93.40	3.6468E-001	2.26E-001	-8.4414E-002	miss
		1836.01	99.38	2.2554E-001		-1.3464E-002	miss
	Ag-108M	621.00	98.00	3.9526E-001	3.95E-001	-2.7481E-001	miss
		1050.10	14.60	3.0877E+000		-4.5133E+000	miss
	133 Ba	81.00	33.31	1.6856E+000	7.41E-001	2.0489E+001	miss
		356.01	62.05	7.4127E-001		-5.5113E-001	miss
	CS-134	569.32	15.43	2.1121E+000	4.65E-001	2.3106E+000	miss
		604.70	97.60	5.1442E-001		-2.5227E-001	miss
		795.84	85.40	4.6466E-001		2.2993E+000	miss
	CS-137	661.65	85.12	4.0226E-001	4.02E-001	6.2361E-002	miss
+	BI-214	609.31*	46.30	7.1420E-001	7.14E-001	2.0020E+001	miss
		1120.29*	15.10	2.8297E+000		2.0761E+001	miss
		1764.49*	15.80	1.6021E+000		2.0391E+001	miss
+	PB-214	295.21*	19.20	1.1762E+000	6.99E-001	2.1307E+001	miss
		351.92*	37.20	6.9912E-001		2.1380E+001	miss
+	AC-228	911.21*	26.60	1.8884E+000	1.89E+000	1.2108E+002	miss
		968.97*	16.20	2.9101E+000		1.2078E+002	miss

+ = Nuclide identified during the nuclide identification
* = Energy line found in the spectrum
> = Calculated MDA is zero due to zero counts in the region or the region is outside the spectrum
@ = Half-life too short to be able to perform the decay correction
? = CAUTION: MDA value is inconsistent with Currie MDA at 95% confidence
Coincidence correction performed.
free = No coincidence correction required.
miss = Nuclide energy was not found in the coincidence library.
ISO11929 characteristic limits calculated.

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***** N U C L I D E I S O 1 1 9 2 9 R E P O R T *****
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	Nuclide Name	MDA (Bq /Kg)	Decision Level (Bq /Kg)	Conf Int Lower Lmt (Bq /Kg)	Conf Int Upper Lmt (Bq /Kg)	Best Est Activity (Bq /Kg)	Best Act U (Bq /
+	K-40	4.78E+000	2.37E+000	7.84E+002	8.31E+002	8.08E+002	1.21E+
+ >	PB-212	0.00E+000	0.00E+000	8.48E+001	9.09E+001	8.79E+001	1.55E+
+	BI-214	7.14E-001	3.55E-001	1.97E+001	2.07E+001	2.02E+001	2.61E-
+	PB-214	6.99E-001	3.46E-001	2.03E+001	2.24E+001	2.14E+001	5.53E-
+	AC-228	1.89E+000	9.32E-001	1.16E+002	1.26E+002	1.21E+002	2.55E+

+ = Nuclide identified during the nuclide identification
> = Calculated MDA is zero due to zero counts in the region or the region is outside the spectrum
? = MDA calculation has failed

****
***** G A M M A S P E C T R U M A N A L Y S I S *****
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Filename: C:\GENIE2K\CAMFILES\2021 sample Data\nugusu\ERTL-GW-4-2021.CN

Report Generated On : 5/6/2021 11:51:55 AM

Sample Title : enviromental sample
Sample Description :
Sample Identification : ERTL-GW-4-2021
Sample Type : SOIL
Sample Geometry : 538G-E

Peak Locate Threshold : 3.00
Peak Locate Range (in channels) : 1 - 8192
Peak Area Range (in channels) : 1 - 8192
Identification Energy Tolerance : 1.000 keV

Sample Size : 7.000E-001 Kg

Sample Taken On :
Acquisition Started : 4/14/2021 5:10:39 PM

Live Time : 50400.0 seconds
Real Time : 50693.0 seconds

Dead Time : 0.58 %

Energy Calibration Used Done On : 4/5/2021
Efficiency Calibration Used Done On : 7/7/2017
Efficiency ID :