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A Comparative Study of NaI(Tl) and HPGe Detectors on Determination of the Activity Concentrations of ^{40}K, ^{232}Th and ^{238}U in Soil Samples

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Abstract: **This work is undertaken to compare the efficiency of NaI(Tl) and HPGe detectors on determination of the activity concentrations of the primordial radionuclides in the soil samples. NaI(Tl) and HPGe set-up located at National Institute of Radiation Protection and Research (NIRPR), University of Ibadan, Nigeria were used for the analysis. The activity concentration of ^{238}U, ^{232}Th, and ^{40}K in the soil samples ranged from 8.82 - 44.22 Bq/kg, 11.02 - 43.96 Bq/kg, and 57.45 - 527 Bq/kg respectively for HPGe analysis, and from 0.16 - 11.28 Bq/kg, 0.10 - 7.31 Bq/kg, and 113.26 - 589.01 Bq/kg respectively for NaI(Tl) analysis. HPGe detector recorded higher activity concentrations of ^{238}U and ^{232}Th, hence more efficient in detecting nuclides with low energies than the NaI(Tl) detector. Whereas, NaI(Tl) detector recorded higher activity concentration of ^{40}K, and is more efficient in detecting nuclides of high energies than HPGe detector. Therefore, we conclude that HPGe detector is more efficient in detecting gamma rays of low energy, but less efficient in detecting gamma ray of high energy compare to the NaI(Tl) detector.**

Keywords: **NaI(Tl) detector, HPGe detector, Activity Concentrations, Efficiency.**

1. INTRODUCTION

Gamma ray spectrometers are instruments for measuring and producing spectrum of the intensity of gamma radiation against the photon's energy. Gamma ray detection is based on the effect of a gamma ray interacting with the diode. It interacts by photoelectric absorption, Compton scattering and pair production [1]. The photon energies of the gamma rays emitted can be used to identify particular elements and isotopes. The ability of a gamma ray detector to differentiate gamma rays of similar energy is an essential consideration in a complex spectra analysis, and is characterized by the ability of the instrument to resolve spectra i.e., the accuracy of measuring the energy of each photon. Gamma ray emitted from a source, show up as sharp emission lines on the spectrometer's spectrum output. The energy represented in these emissions determines which elements are present, while the intensity of the spectrum shows the elements concentrations [3].

Scintillator-type detectors measure gamma rays using the excitation effect of incident photon on a scintillator material, and detecting the resultant light pulses. Sodium Iodide doped with Thallium (NaI(Tl)) detector consists of a single crystal of thallium activated Sodium Iodide optically coupled to the photocathode of a photomultiplier tube. The pulses are amplified and delivered to a measuring device - Multi-Channel Analyzer (MCA), which measures the pulse heights and sorts them into a histogram to record the energy spectrum produced by the NaI(Tl) spectrometer [5]. On the other hand, semiconductor-type spectrometers measure gamma rays using the number of charge carriers (electrons and holes) set free in the detector material arranged between two electrodes [8]. A germanium detector (e.g. HPGe) has a net impurity level

of around 10^{10}atoms/cm^3, so that with moderate reverse bias, the entire volume between the electrodes is depleted, and an electric field extends across this active region [1]. When radiation interacts with the electric field of the active region of HPGe detector, it produces charge carriers which are swept by the electric field to their collecting electrodes, where a charge sensitive preamplifier converts this charge into a voltage pulse proportional to the energy deposited in the detector [8]. The pulses are delivered to a measuring device - Multi-Channel Analyser (MCA), which measures the pulse heights and sorts them into a histogram to record the energy spectrum produced by the HPGe detector. The major characteristics of the HPGe spectrometers are high resolution, low impurity concentration (large depletion depth), low ionizing energy required to produce an electron hole pair, and relative simplicity of operation [7]. As the requirements for greater accuracy, efficiency, or sensitivity increases, so does the complexity of the spectrometer and its operation [9]. In this study, sodium iodide doped with thallium NaI(Tl) and high purity germanium HPGe detectors are compared through their abilities to measure activity concentration in the soil samples.

2. EXPERIMENTAL METHOD

The analyses were carried out at National Institute of Radiation Protection and Research (NIRPR), University of Ibadan, Nigeria. Seventeen soil samples were used to verify the detection abilities of both NaI(Tl) and HPGe detectors. The samples were prepared according to the IAEA standards for preparation of sample for spectrometric analysis. The samples were dried to remove available moisture in the samples at temperature range of 100 ^oC to 120 ^oC for 12 hours, and were packed and sealed into standard 500 ml Marinelli beakers to prevent radium from escaping. The sealed samples were stored for a period of 30 days, to allow radium and its progeny attain secular equilibrium.

3. EXPERIMENTAL SET-UP

The set-up consist of two spectrometers, Sodium Iodide doped with Thallium detector (model: 802) of dimension 7.62 cm by 7.62 cm housed in a 6cm thick lead shield and lined with cadmium (Cd) and copper (Cu) sheets in order to resist background radiation, and a coaxial p-type high purity germanium (HPGe) detector manufactured by Canberra (Model: GC 8023; Serial Number: 9744) with end cap diameter of 78 mm and length of 69.8 mm, a relative efficiency of 80% and an energy resolution (FWHM) of 2.3 keV for the 1.33 MeV gamma-ray emission of ^{60}Co. Both were connected to a personal computer-based data acquisition system, which has Genie 2000 (VI.3) software from Canberra through 16,000 Multi-Channel-Analyser (MAC).

The detectors were calibrated before using for the analysis. Energy and efficiency calibrations were performed. The energy calibration of the both detectors were done using different gamma sources of ^{60}Co (1173.2 and 1332.5 keV), ^{137}Cs (661.9 keV) and ^{22}Na (511 and 1274 keV). The full width at half maximum (FWHM) corresponds to the resolution for the both detectors, and it has been shown that the resolution of a detector is directly proportional to the gamma ray energy [4]. On the other hand, their efficiency calibration were calculated using Equation (1) [2], from each gamma ray energy emitted by the ^{22}Na, ^{54}Mn, ^{60}Co and ^{137}Cs radioactive isotopes for NaI(Tl) and ^{155}Eu, ^{125}Sb, ^{54}Mn, ^{65}Zn and ^{40}K radioactive isotopes for HPGe. Nevertheless, the efficiency of a detector decreases exponentially with increases in gamma ray energy [4].

$$\varepsilon = \frac{N_C}{N_S} \qquad (1)$$

where, ε is the efficiency of the detector, N_c is the number of counts recorded by the detector, and N_s is the number of radiation emitted by the source.

4. SAMPLE ANALYSIS

The soil samples were analysed with the both detectors. The samples were placed on the NaI(Tl) detector and each sample was set to counting time of 29,000s, whereas for HPGe detector, each sample was set to counting time of 10,800s. These times are long enough for the detectors to analyse the spectrum with the peaks of interest clearly shown and well distinguished. The background count was estimated by empting the container and count in a closed detector using the same container lid geometry as in the previous count. This procedure was maintained throughout the analysis. The count rate in count per second (CPS) was obtained for each radionuclide in every sample analysed and the background count was subtracted for every count.

In NaI(Tl) analysis, the count rate of ^{238}U in the soil sample was estimated from the gamma-ray peak of ^{214}Bi (1.760 MeV), ^{232}Th from gamma-ray peak of ^{208}Tl (2.615 MeV), and ^{40}K from gamma-ray peak of ^{40}K (1.460 MeV) itself. While for HPGe analysis, ^{238}U count rate was measured from 351.9keV gamma-ray peaks of ^{214}Pb and 609.31 keV and 1120.3

keV gamma-ray peaks of ^{214}Bi. ^{232}Th count rate was estimated from the 911.1 keV gamma-ray peak of ^{228}Ac and 583.19 keV and 2614.53 keV of ^{208}Tl. ^{40}K count rate was estimated using the 1460 keV gamma-ray peak from ^{40}K itself.

5. ACTIVITY CONCENTRATION

The count rates under the photo peak of each of the primordial radionuclide for both detectors were converted to activity concentration, A using the equation (2) [6]:

$$A\ (Bq/kg) = \frac{C}{\varepsilon TPM} \qquad (2)$$

where C is the count rate under the corresponding photo peak, ε is the absolute efficiency of detector, P is the absolute transition probability of the specific gamma-ray, M is the mass of each sample in kg, and T is the live time of the measurement in s.

6. RESULTS AND DISCUSSIONS

The calculated results activity concentrations of primordial radionuclides of the samples for the both spectrometers are shown in Table 1. The activity concentrations of ^{238}U, ^{232}Th, and K-40 in the samples range from 8.82 ± 0.95 to 44.22 ± 5.78 Bq/kg, 11.02 ± 1.03 to 43.96 ± 4.64 Bq/kg, and 57.45 ± 2.85 to 527 ± 12.38 Bq/kg respectively for the HPGe analysis, and from BDL to 11.28 ± 2.15 Bq/kg, BDL to 7.31 ± 0.73 Bq/kg, and 113.26 ± 13.69 to 589.01 ± 48.26 Bq/kg for ^{238}U, ^{232}Th and ^{40}K respectively for NaI(Tl) analysis. HPGe gives higher activity concentrations of ^{238}U and ^{232}Th than NaI(Tl) as shown in fig. 1 and 2 respectively. HPGe detector is a good instrument for nuclide identification offers the advantage of resolving two closely located energy points and has the ability to detect a mixture of nuclear material [4], and in this study, it has shown that HPGe is more efficient in detecting nuclides with low energy than the NaI(Tl) detector. However, there are inconsistencies in the activity concentrations of ^{40}K recorded by both detectors (Table 1 and Fig. 3). In samples X1, X5, X9, X10, and X13, HPGe detector recorded activity concentrations of ^{40}K higher than NaI(Tl) detector, while NaI(Tl) recorded higher activity concentrations of ^{40}K in samples X2, X3, X4, X6, X7, X8, X11, X12, X14, X15, X16 and X17. From the Table 1, it is clearly seen the activity concentrations of ^{40}K are very high compare to that of ^{238}U and ^{232}Th. This may be due to the relative abundance of potassium in the soil, and both detectors were sensitive to gamma ray energies of ^{40}K, but NaI(Tl) detector gives higher activity concentration of 12 samples and even the average activity concentration for ^{40}K than HPGe detector. Therefore, NaI(Tl) detector is more efficient in detecting nuclides of high energy than the HPGe detector.

TABLE 1: Activity concentrations of ^{238}U, ^{232}Th and ^{40}K for both detectors.

Sample ID	^{238}U (Bq/kg)		^{232}Th (Bq/kg)		^{40}K (Bq/kg)	
	HPGe	NaI(Tl)	HPGe	NaI(Tl)	HPGe	NaI(Tl)
X1	27.60	1.81	19.75	3.78	488.49	352.60
X2	23.38	8.07	25.71	7.31	254.84	258.18
X3	17.28	8.28	25.56	3.55	493.19	515.10
X4	23.50	8.35	32.12	1.66	223.30	307.31
X5	13.57	4.35	19.28	2.37	163.64	115.56
X6	20.44	0.16	23.65	3.32	184.34	322.88
X7	18.05	3.17	24.55	0.66	145.44	186.13
X8	15.26	BDL	18.58	0.66	261.41	336.05
X9	44.22	4.28	18.23	BDL	527.36	425.99
X10	24.91	BDL	37.22	2.62	480.89	293.88
X11	19.33	6.90	40.44	0.89	249.25	272.75
X12	30.64	11.28	43.96	5.32	481.50	589.01
X13	8.82	BDL	11.08	0.10	234.35	212.37
X14	12.36	BDL	14.56	BDL	57.45	113.26
X15	10.46	5.93	16.71	0.39	95.15	129.09
X16	11.54	BDL	11.25	1.22	117.50	172.40
X17	8.95	BDL	12.79	BDL	108.49	200.30
Mean	**19.43**	**5.69**	**23.26**	**2.42**	**268.62**	**282.52**

BDL – Below Detection Limit

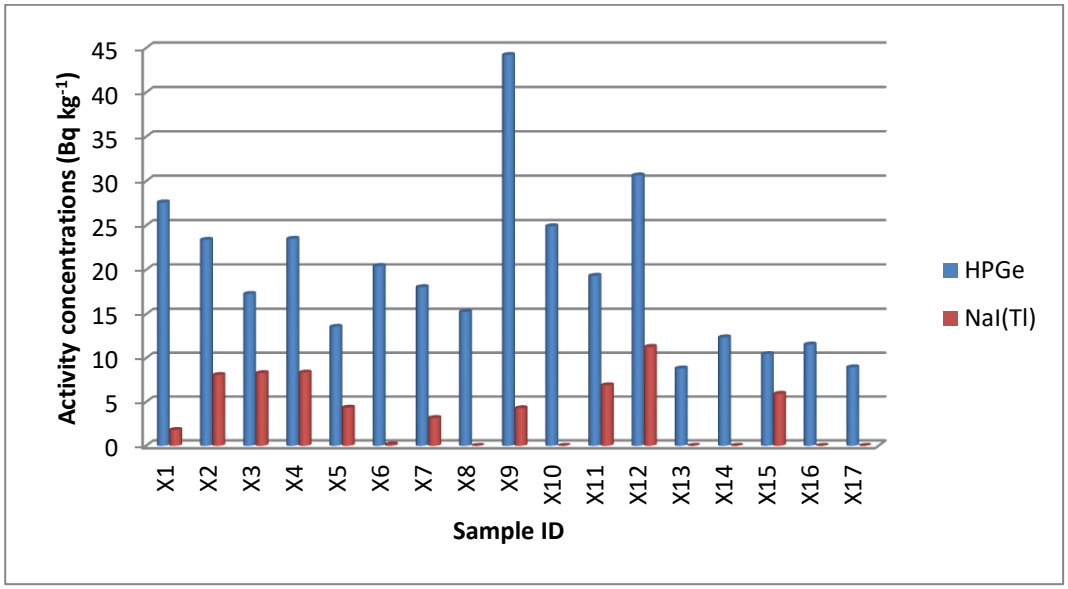

Fig. 1: Comparing activity concentration of ^{238}U measured by the detectors

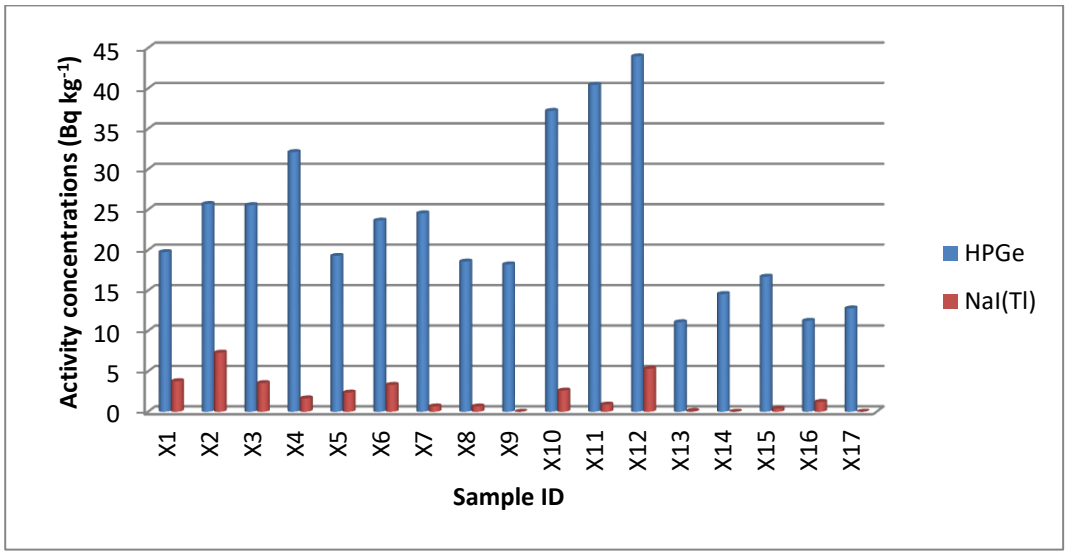

Fig. 2: Comparing activity concentrations of ^{232}Th measured by the detectors.

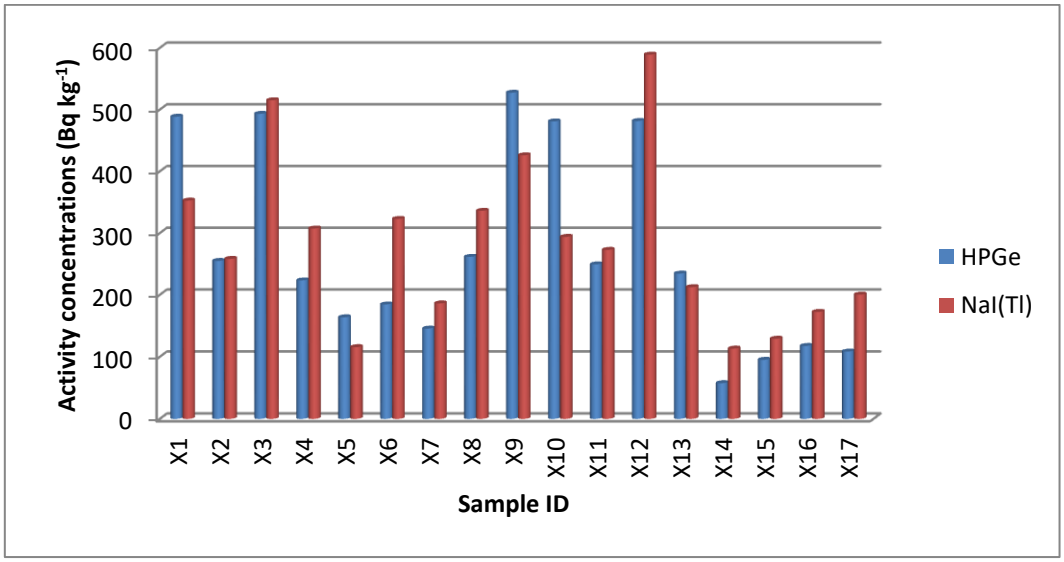

Fig. 3: Comparing activity concentrations of ^{40}K measured by the detectors.

7. CONCLUSION

HPGe detector recorded higher activity concentrations of ^{238}U and ^{232}Th, hence more efficient in detecting nuclides with low energies than the NaI(Tl) detector. Whereas, NaI(Tl) detector recorded higher activity concentration of ^{40}K on average, and is more efficient in detecting nuclides of high energies than HPGe detector. Therefore, we conclude that HPGe detector is more efficient in detecting gamma rays of low energy, but less efficient in detecting gamma ray of high energy compare to the NaI(Tl) detector.

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