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Characterization of Gamma Spectroscopy Setup, Efficiency Calibration of HPGe detector used for Radiological substances

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Abstract:
Background: *Contamination of radiological substances in environment is one of the most important factors and harmful for living beings if the activity is high enough with long half-life.'Gamma Spectrometry Setup' is comparatively better for detection and analysis of gamma radiations in any type of specimens. Initiating the data acquisition setup, it's essential to calibrate the entire setup for accuracy measurement.*
Materials and Methods:*The main purpose of the research work is to characterize the data acquisition setup using^{137}Cs and ^{60}Co point sources. ^{137}Cs emits γ-rays of 661.66 keV and ^{60}Coemits two different γ-rays; 1173.2 KeV & 1332.5 KeV. Setup standardization is an essential part of any research works.*
Results: *The HPGe detector used with the setup is also good enough for γ-energy detection. Detector efficiency calibration is another major task needed for activity calculation, using gamma energy lines detected in a sample detector efficiency can be calculated.*
Conclusion: *Initiating every research experiment, the setup calibration should be checked for accurate results.*
Key Word*: HPGe, MCA, Radiation, Shielding, Gamma, Efficiency, Calibration*

I. Introduction

Primitive radionuclides having long half-lives are existent in environment throughout the world in various isotopic forms, and human beings are constantly exposed to natural sources of ionizing radiation throughout the life on earth. Radiation comprises charged and uncharged particles as well as gamma radiation and X-rays those are from natural sources or artificial sources (Macdonald et al., 2000).As these are ionizing radiation, excessive exposure to them may pose a harmful threat to the human body. Globally, 85% of the ionizing radiation comes from natural sources in the environment and rest of 15% is from artificial sources (Azmal et al., 2019).A survey shows that more than 85% of radiation workers have insufficient knowledge of radiation safety and protection rules & regulations while more than 80% of the public just heard about radiation from one source to another. Reality is the medical personnel who takes the medical images of a patient using a radiation sources, does not provide any instruction about the radiation hazards to the patient. Virtually, all materials and environments even planet are naturally exposed to ionizing radiation.Artificial radionuclides can also be found in the environment, their presence resulting from human activities, including the atmospheric testing of nuclear devices that occurred over the period 1945 to 1980 (Mahat & Nor, 2014).The radionuclides transfer through the environment by various possible pathways, as for example through the atmosphere, aquatic systems and soil sub-compartments, each contributing to human exposure (Azmal et al., 2019).The natural decay series radionuclides represent the most significant sources of ionizing radiation on Earth, contributing approximately 83% to the total effective dose received by the global population (Kumar et al., 2017). The radioactive isotope ^{40}K contributes environment approximately 16% of the total effective exposure (Hpge & Ray, 2002).When an unstable nucleus decays into a more stable nucleus, the nucleus sometimes produced in an excited state. The subsequent relaxation of the daughter nucleus to a lower-energy state results in the emission of a gamma-ray photon (Paper, 2018). Gamma-ray photons are uncharged particles. The photoelectric effect occurs when a gamma ray interacts with an electron of an inner shell of an atom and a photoelectron is emitted. This is the most important effect for the detection of gamma rays with semiconductor detectors.

II. Material And Methods

ThisExperiment were done at the accelerator laboratory of AECD using gamma spectroscopy system. Data acquisition has been calibrated by IAEA provided point sources ^{137}Cs and ^{60}Co.

Figure no 1: Gamma radioactive point sources ^{137}Cs &^{60}**Co**

The initial activities of the point sources were 1.109 µCi and 0.958 µCi respectively. According to the half-life, ^{137}Cs point source has passed one half-life and ^{60}Co passed more than six half-lives. So, ^{60}Co point source is not in enough strength; but till is being used with ^{137}Cs for gamma data acquisition setup. The gamma energy line from ^{137}Cs is 661.66 keV, 1173.2 & 1332.5 keV from ^{60}Co. For setup calibration; these different energy lines are set at separate (particular) channels for projection.

II.I Gamma-ray Spectroscopy System

Gamma spectroscopy data acquisition setup has been developed in accelerator laboratory of Atomic Energy Centre Dhaka (Mahat & Nor, 2014). This setup is good enough for the detection of radionuclides in any type of samples, like solid, liquid or gasses. Major units of the setup are shown by the block diagram projected below and explained briefly;

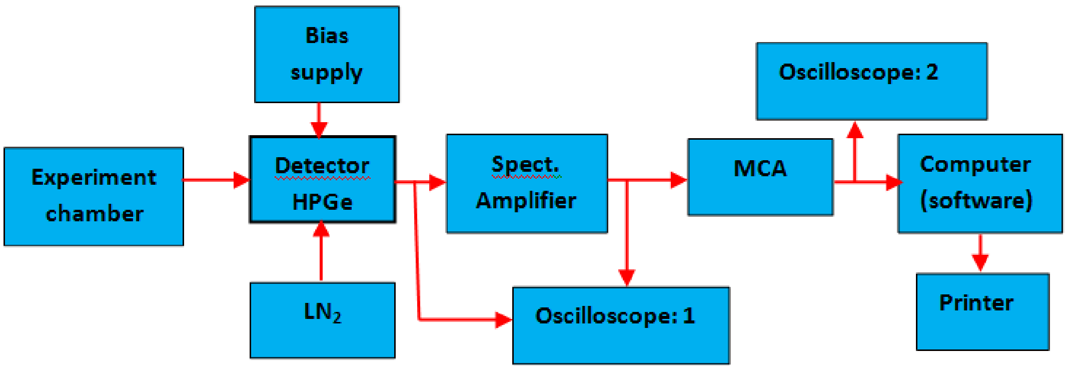

Figure no 2: Block diagram of major units of gamma data acquisition setup.

II.II Lead Shielded Chamber

The experiment chamber is designed and fabricated to shield the entrance of background radiation into the chamber and also protect the emitted radiation from sample to outside the chamber wall except the detector path. The head of the gamma detector has been entered into the lead shielded chamber and set tightly with chamber wall. LN_2 pouring apparatus is also set with the detector and chamber base. The thickness of the 'lead-wall' is about 76 mm. The top cover of the chamber has been made of lead with same thickness and is being played by thread mechanism. A sample holder has been incorporated inside the chamber vertically on the detector head. The sample is being replaced manually from the top side of the chamber.

II.III HPGe Detector

Semiconductor based photon radiation detector have been evolving for over half a century. High Purity Germanium Detector covering an extensive range of energies and for a variety of applications (Abedin et al., 2021). HPGe (vertical) solid state detector has been incorporated at the bottom of chamber-base (Hpge & Ray, 2002). The detector model: GC 12175 (CANBERRA) with 30 liters Dewar is set perpendicular to the sample-holder.To reduce the noise to the possible lowest level, the detector is being operated at very low temperature normally at 77 ^{0}K for this purpose LN_2 is used (Boson et al., 2008). 3.5 KV regulated power supply unit is connected to activate the detector. An oscilloscope is also connected for the projection of bias fluctuation, output of preamplifier & spectroscopy amplifier.

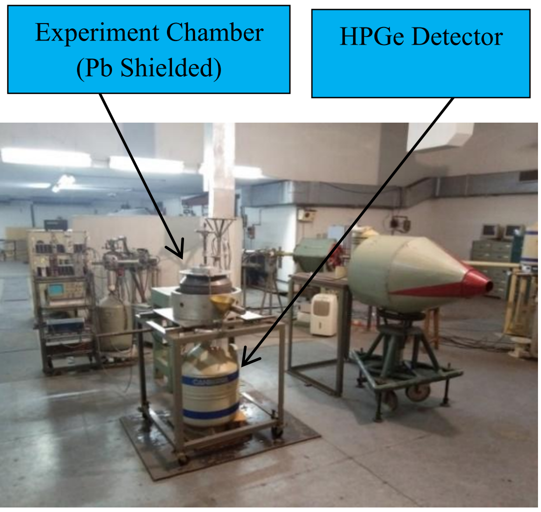

Figure no 3: Photograph of 'Lead Shielded Chamber with detector

II. IV Spectroscopy Amplifier

The NIM bin standard spectroscopy amplifier model: 671 (ORTEC) is used to shape & amplify the detected signals (voltage pulses). A lot of functions are done in this spectroscopy unit and it also has an option to provide bias supply to activate the preamplifier. Processed output of the amplifier is fitted to the input gate of the MCA.

II.V Multi-Channel Analyzer

The most essential unit of the Gamma Spectroscopy System is MCA/MCB. This unit with all other units is compatible for well regulated NIM BIN power module having the power options ± 6, ± 12 and ± 24 volts' dc. The output signal (voltage pulses) of the spectroscopy amplifier is fitted to the input gate of MCA(Celiktas, 2007). Microprocessor and memory space of MCA supports the data acquisition and I/O functions. ADC circuit of this unit converts a continuous physical quantity (voltage pulses) into digital form (binary). Also, ADC measures and sorts out the pulses according to their amplitudes. Digital signals propagate more efficiently than analog signals, largely because digital impulses, which are well-defined and orderly; are easier for electronic circuits to distinguish from noise. Output of this unit is fitted to the computer and all of its functions are controlled by the computer using software Genie-2000 (Suárez-Navarro et al., 2018).

III. Result

An essential prerequisite for research works is to standardize the experiment setup. Energy calibration of the 'Gamma Spectroscopy' setup is being done using point source ^{137}Cs (1.109 µCi., #214-17-103, dated: 04-01-88), and ^{60}Co (0.958 µCi, #214-17-153, dated: 04-01-88). The experiment shows; 661.7 keV, 1173.5 keV and 1332.7 keV energy lines for ^{137}Cs and ^{60}Co respectively (Abedin et al., 2021). The energy calibration spectra with analyzed data are projected in figure 4.

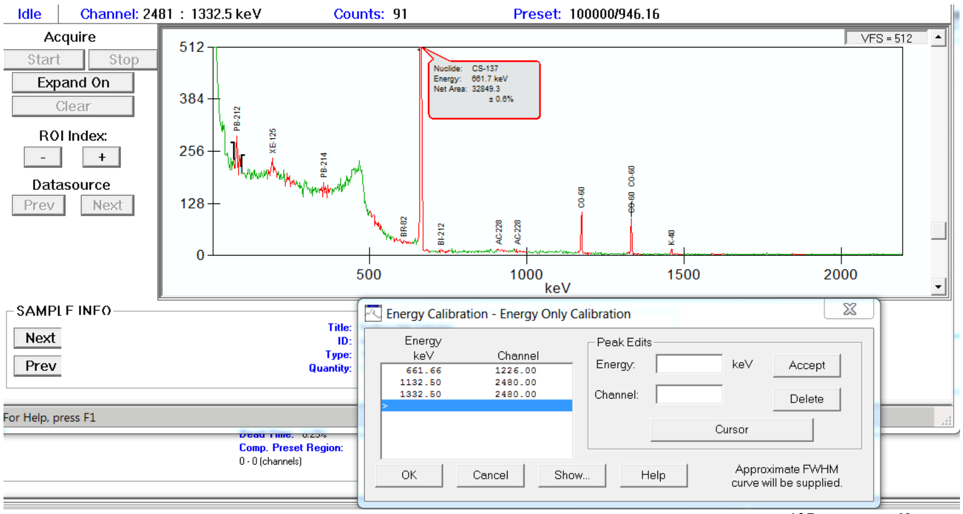

Figure no 4: Spectra of 'Gamma Spectrometry Setup' calibration using ^{137}Cs and ^{60}Co.

The status (activity) of ^{137}Cs &^{60}Copoint source at experiment time are calculated and defined as; Activity Calculation for ^{137}Cs; $A = A_0\, e^{-\lambda t}$;where, A_0 = Initial activity of ^{137}Cs is 41.033kBq. t = time passed from manufactured =33.9 yrs., A = Present activity = ? Half-life ($T_{½}$) of ^{137}Cs = 30.5 years $T_{½} = \frac{0.693}{\lambda}$ 0r, $\lambda = \frac{0.693}{T½}$ $= \frac{0.693}{30.5}$ = 02272131148 $A = 41.033\text{kBq} \times e^{-.02272131148 \times 33.9} = 41.033\text{kBq} \times 41.033\text{kBq}\ 0.473638228 =$ 18.99401941514 kBq More than one half-life passed and total activity decreased = (41.03318.99401941514) kB = 22.03898058486 kBq Current activity of ^{137}Cs is 18.99401941514 kBq, near about half of the initial activity. Activity Calculation for ^{60}Co; $nA = A_0\, e^{-\lambda t}$;where, A_0 = Initial activity of ^{60}Cois 35.446 kBq , t = time passed from manufactured=32.9 yrs., A = Present activity = ? Half-life ($T_{½}$) of ^{60}Co= 5.24 years $T_{½}$ = 0.693⁄λ So, λ = 0.693⁄$T_{½}$= 0.693/5.24 = 0.1322519084 $A = 35.446\text{ kBq} \times e^{-0.1322519084 \times 33.9} = 35.446\text{ kBq} \times e^{-4.483339695} = 35.446\text{ kBq} \times 0.01129562615 = 0.4003847645\text{ kBq}$ More than six half-life passed and total activity decreased = (35.446 − 0.4003847645) kBq = 35.04561524 kBq is near about initial activity. So, current activity of ^{60}Co is 0.4003847645 kBq, not good enough to use for setup calibration.

IV. Discussion

Radiological assessment of any sample, detector efficiency calibration is essential and is being done applying gamma energy lines of soil sample of Coal mine area, Dinajpur, Bangladesh. The certified efficiency data file provided with the software (Genie:2000, CANBERRA) for this detector (Dryak & Kovar, 2006). The gamma energy lines, obtained efficiency curve and apart of calculated efficiencies have been projected below:

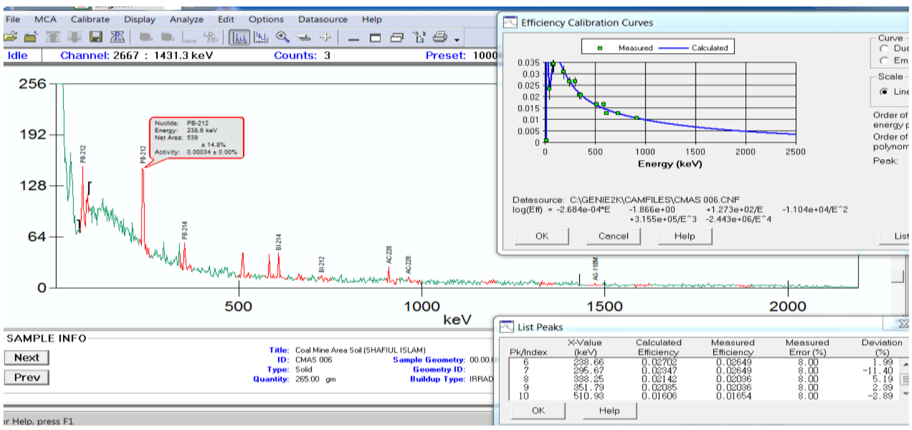

Figure no 5: Detector Efficiency Calibration curve using Coal mine area soil sample.

Table no 1: Comparison between calculated & certified efficiency of the detector.

Possible Nuclide	Energy lines (KeV)	Calculated efficiency	Certified efficiency	Measured error (%)	Deviation
^{154}Eu	41.19	0.02344	0.02330	20.00	0.60
^{214}Pb	74.31	0.03279	0.03381	10.00	-3.02
^{212}Pb	85.53	0.03533	0.03417	10.00	3.39
^{235}U	185.64	0.03137	0.03056	10.00	2.64
^{212}Pb	238.66	0.02702	0.02649	8.00	1.99
^{214}Pb	295.67	0.02347	0.02649	8.00	-11.40
^{228}Ac	338.25	0.02142	0.02036	8.00	5.19
^{214}Pb	351.79	0.02085	0.02036	8.00	2.39
^{133}I	510.93	0.01606	0.01654	8.00	-2.89
^{208}Ti	583.23	0.01461	0.01654	8.00	-11.68
^{131}I	609.29	0.01415	0.01260	6.00	12.31
^{212}Bi	726.47	0.01241	0.01260	6.00	-1.48
^{228}Ac	910.52	0.01038	0.01049	6.00	-1.03

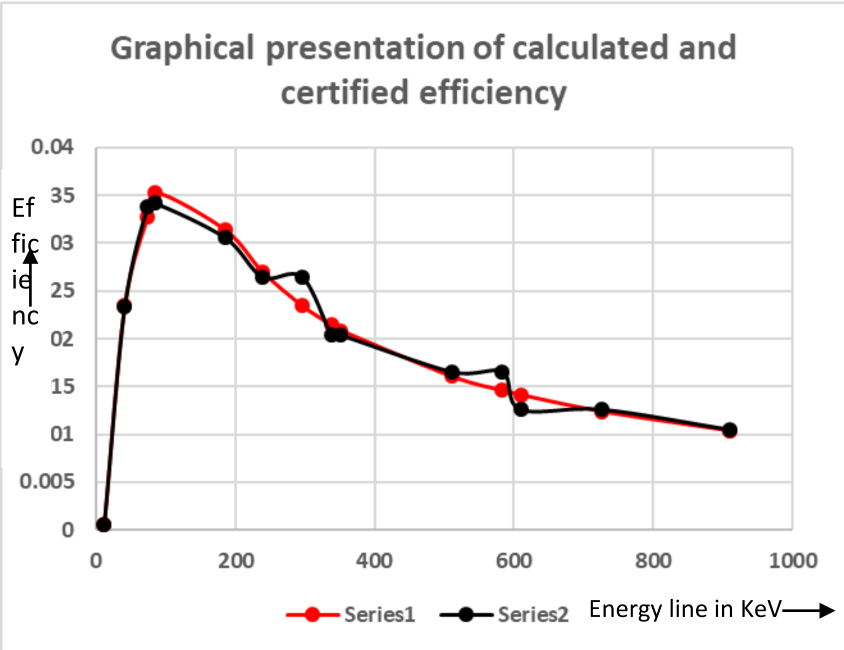

Figure no 6: Graphical presentation of calculated and certified efficiency.

V. Conclusion

'Gamma spectroscopy' data acquisition set-up of accelerator laboratory (AECD) is good enough for assessment of radiological substances accumulated in environment. Every unit of the setup is being powered and calibrated properly ensuring minimum error. Current activity of the calibration sources are being calculated assessing the strength. Energy calibration shows the spectrums, gamma emissions from ^{137}Cs and ^{60}Co are at 661.66, 1172.50 and 1332.20 keV respectively. Both of data acquisition & spectrum data analysis are done using commercial software Genie-2000. Detector efficiency for different gamma energy is an essential factor that needed for activity calculation (Boson et al., 2008). Efficiency calibration of HPGe detector is being done using certified efficiency (reference values) provided with the software (Abu & Ali, 2020). All the steps from preparation to spectra analysis should be balanced; all gamma energy lines need to be included with their uncertainties and all other relevant information needed to make best use of radiological data. Research works on environment pollution due to the contamination by radioactive substances should be a continuous program for setting database.

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