

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

Md. Shafiul Islam¹, M. O. Rahman¹, M. Joynal Abedin², S. Akter³

¹Dept. of Physics, Jahangirnagar University

²AFD, Atomic Energy Centre, Dhaka

³Chemistry Division, Atomic Energy Centre, Dhaka

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 ¹³⁷Cs and ⁶⁰Co point sources. ¹³⁷Cs emits γ -rays of 661.66 keV and ⁶⁰Co emits 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 ⁴⁰K 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

This Experiment 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;

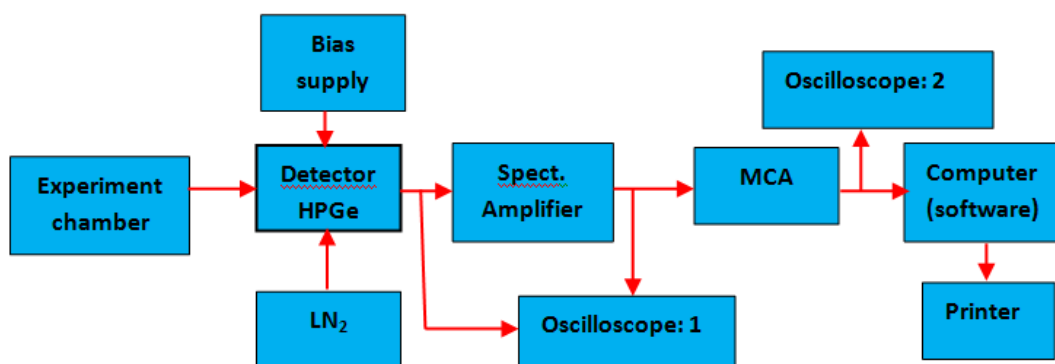


Figure no 2: Block diagram of major units of gamma data acquisition setup.

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 °K for this purpose LN₂ 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.

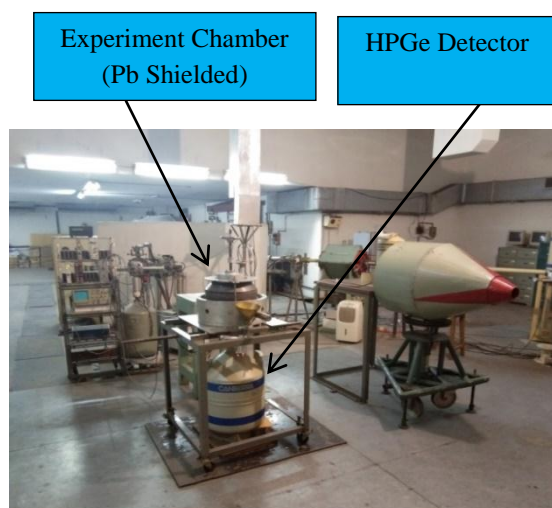


Figure no 3: Photograph of 'Lead Shielded Chamber with detector

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 ¹³⁷Cs (1.109 μ Ci, #214-17-103, dated: 04-01-88), and ⁶⁰Co (0.958 μ Ci, #214-17-153, dated: 04-01-88). The experiment shows; 661.7 keV, 1173.5 keV and 1332.7 keV energy lines for ¹³⁷Cs and ⁶⁰Co respectively (Abedin et al., 2021). The energy calibration spectra with analyzed data are projected in figure 4.

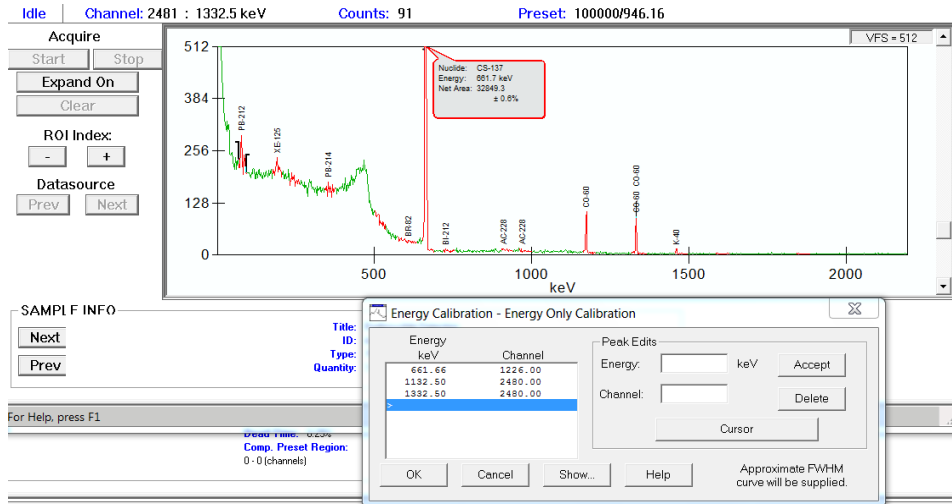


Figure no 4: Spectra of ‘Gamma Spectrometry Setup’ calibration using ¹³⁷Cs and ⁶⁰Co.

The status (activity) of ¹³⁷Cs & ⁶⁰Co point source at experiment time are calculated and defined as;
 Activity Calculation for ¹³⁷Cs; $A = A_0 e^{-\lambda t}$; where, A_0 = Initial activity of ¹³⁷Cs is 41.033kBq. t = time passed from manufactured = 33.9 yrs., A = Present activity = ? Half-life ($T_{1/2}$) of ¹³⁷Cs = 30.5 years $T_{1/2} = \frac{0.693}{\lambda}$ Or, $\lambda = \frac{0.693}{T_{1/2}}$
 $= \frac{0.693}{30.5} = 0.02272131148$ $A = 41.033\text{kBq} \times e^{-0.02272131148 \times 33.9} = 41.033\text{kBq} \times 0.473638228 = 18.99401941514 \text{ kBq}$ More than one half-life passed and total activity decreased = (41.03318.99401941514) kB = 22.03898058486 kBq Current activity of ¹³⁷Cs is 18.99401941514 kBq, near about half of the initial activity. Activity Calculation for ⁶⁰Co; $nA = A_0 e^{-\lambda t}$; where, A_0 = Initial activity of ⁶⁰Co is 35.446 kBq, t = time passed from manufactured = 32.9 yrs., A = Present activity = ? Half-life ($T_{1/2}$) of ⁶⁰Co = 5.24 years $T_{1/2} = \frac{0.693}{\lambda}$ So, $\lambda = \frac{0.693}{T_{1/2}} = \frac{0.693}{5.24} = 0.1322519084$ $A = 35.446 \text{ kBq} \times e^{-0.1322519084 \times 33.9} = 35.446 \text{ kBq} \times 0.01129562615 = 0.4003847645 \text{ kBq}$ 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 ⁶⁰Co 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:

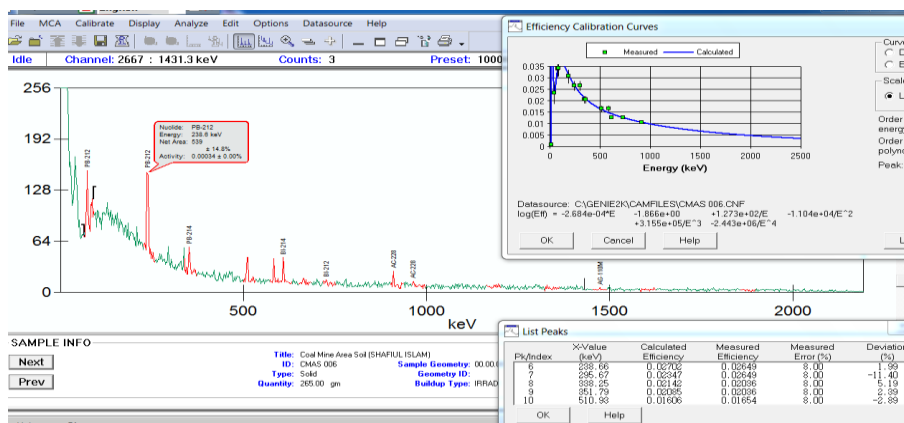


Figure no 5: Detector Efficiency Calibration curve using Coal mine area soil sample.

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 Tl	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

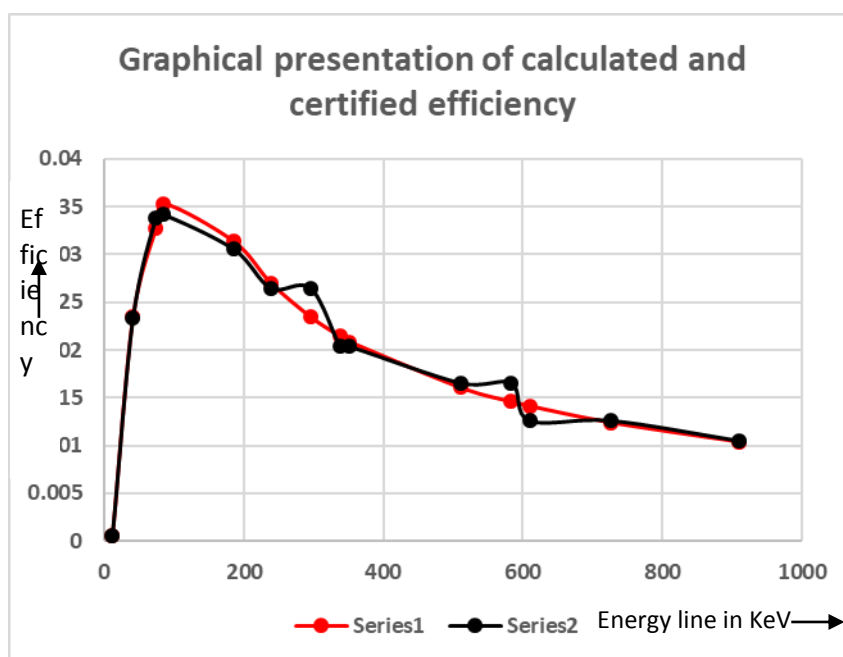


Figure no 6: Graphical presentation of calculated and certified efficiency.

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 ¹³⁷Cs and ⁶⁰Co 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.

References

- [1]. Abedin, M. J., Zamil, A. A. S., Jolly, Y. N., Akter, S., Rahman, M. O., Islam, M. S., & Arafin, S. A. K. (2021). Characterization of 226 Ra Point Source and Analysis Its Daughter Radionuclides. 81(1), 75–81
- [2]. Abu, M., & Ali, M. (2020). Distribution of natural radioactivity in soil and date palm-pits using high purity germanium radiation detectors and LB-alpha / beta gas- fl ow counter in Saudi Arabia. Nuclear Engineering and Technology, 52(6), 1282–1288. <https://doi.org/10.1016/j.net.2019.12.009>
- [3]. Azmal, M., Bhuiyan, H., Kowser, A., Islam, S. S., Levels, N. R., & District, S. (2019). Natural Radioactivity Levels and Radiological Risk Assessment of Surface Water Natural Radioactivity Levels and Radiological Risk Assessment of Surface Water of Wetland Tanguar Haor , Sunamganj District , Bangladesh. July. <https://doi.org/10.18576/jrna/040206>

- [4]. Abedin, M. J., Zamil, A. A. S., Jolly, Y. N., Akter, S., Rahman, M. O., Islam, M. S., & Arafin, S. A. K. (2021). Characterization of 226 Ra Point Source and Analysis Its Daughter Radionuclides. 81(1), 75–81.
- [5]. Abu, M., & Ali, M. (2020). Distribution of natural radioactivity in soil and date palm-pits using high purity germanium radiation detectors and LB-alpha / beta gas- flow counter in Saudi Arabia. *Nuclear Engineering and Technology*, 52(6), 1282–1288. <https://doi.org/10.1016/j.net.2019.12.009>
- [6]. Azmal, M., Bhuiyan, H., Kowser, A., Islam, S. S., Levels, N. R., & District, S. (2019). Natural Radioactivity Levels and Radiological Risk Assessment of Surface Water Natural Radioactivity Levels and Radiological Risk Assessment of Surface Water of Wetland Tanguar Haor , Sunamganj District , Bangladesh. July. <https://doi.org/10.18576/jrma/040206>
- [7]. Boson, J., Ågren, G., & Johansson, L. (2008). A detailed investigation of HPGe detector response for improved Monte Carlo efficiency calculations. *Nuclear Instruments and Methods in Physics Research, Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, 587(2–3), 304–314. <https://doi.org/10.1016/j.nima.2008.01.062>
- [8]. Celiktas, C. (2007). Instrumentation Science & Technology Improving the MCA Spectra of BC - 400 Plastic Scintillation Detectors at Room Temperature. October 2014, 37–41. <https://doi.org/10.1080/10739140701750052>
- [9]. Dryak, P., & Kovar, P. (2006). Experimental and MC determination of HPGe detector efficiency in the 40-2754 keV energy range for measuring point source geometry with the source-to-detector distance of 25 cm. *Applied Radiation and Isotopes*, 64(10–11), 1346–1349. <https://doi.org/10.1016/j.apradiso.2006.02.083>
- [10]. Hpge, G., & Ray, G. (2002). Distribution of Natural and Anthropogenic Radionuclides in Soil and Beach Sand Samples of Kalpakkam using Hyper Pure Distribution of natural and anthropogenic radionuclides in soil and beach sand samples of Kalpakkam (India) using hyper pure germanium (. July. [https://doi.org/10.1016/S0969-8043\(01\)00262-7](https://doi.org/10.1016/S0969-8043(01)00262-7)
- [11]. Kumar, A., Kumar, S., Singh, J., Singh, P., & Bajwa, B. S. (2017). Journal of Radiation Research and Applied Sciences Assessment of natural radioactivity levels and associated dose rates in soil samples from historical city Panipat , India. *Journal of Radiation Research and Applied Sciences*, 1–6. <https://doi.org/10.1016/j.jrras.2017.05.006>
- [12]. Macdonald, R. W., Barrie, L. A., Bidleman, T. F., Diamond, M. L., Gregor, D. J., Semkin, R. G., Strachan, W. M. J., Li, Y. F., Wania, F., Alae, M., Alexeeva, L. B., Backus, S. M., Bailey, R., Bewers, J. M., Gobeil, C., Halsall, C. J., Harner, T., Hoff, J. T., Jantunen, L. M. M., ... Yunker, M. B. (2000). Contaminants in the Canadian Arctic: 5 years of progress in understanding sources, occurrence and pathways. In *Science of the Total Environment* (Vol. 254, Issues 2–3). [https://doi.org/10.1016/S0048-9697\(00\)00434-4](https://doi.org/10.1016/S0048-9697(00)00434-4)
- [13]. Mahat, R. H., & Nor, R. M. (2014). Soil-to-root vegetable transfer factors for in Malaysia Th , K , and. *Journal of Environmental Radioactivity*, 135, 120–127. <https://doi.org/10.1016/j.jenvrad.2014.04.009>
- [14]. Paper, T. (2018). A Copper Shield for the Reduction of X- γ True Coincidence Summing in Gamma-ray Spectrometry. 43(4), 137–142.
- [15]. Suárez-Navarro, J. A., Gascó, C., Alonso, M. M., Blanco-Varela, M. T., Lanzon, M., & Puertas, F. (2018). Use of Genie 2000 and Excel VBA to correct for γ -ray interference in the determination of NORM building material activity concentrations. In *Applied Radiation and Isotopes* (Vol. 142, pp. 1–7). <https://doi.org/10.1016/j.apradiso.2018.09.019>