

Experiments with HPGe Detector



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Medical Physics Laboratory I

Name: Souvik Das

Roll No: 241126007



National Institute of Science Education and Research
Jatani, Odisha, India

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Contents

1 Objective	1
2 Apparatus	1
2.1 Introduction	1
2.2 Principle of operation	1
2.3 Construction and Cryostatic colling	1
2.4 Electronics components associated	2
3 Theory	3
3.1 Energy calibration of HPGe detector	3
3.2 Absolute efficiency calibration of HPGe detector	4
3.3 Indentification of radionuclides and measurment of their activity concentration present in environmental sample	4
4 Observation	4
5 Conclusion	4
6 References	4



1 | Objective

- Energy calibration of HPGe detector
- Absolute efficiency calibration of HPGe detector
- Identification of radionuclides and measurement of their activity concentration present in environmental soil sample and tap water sample.

2 | Apparatus

2.1 | Introduction

High Purity Germanium (HPGe) detectors are semiconductor detectors widely used in gamma spectroscopy due to their superior energy resolution compared to other detector types like NaI(Tl) scintillation detectors. They are particularly effective for identifying and quantifying gamma-emitting radionuclides in various samples, including environmental samples.

Due to higher atomic number ($Z=32$), Ge has a much larger linear attenuation coefficient for gamma rays than Si ($Z=14$). Which leads to a shorter mean free path for gamma rays in Ge than in Si. This property makes Ge detectors more efficient at detecting gamma rays, especially at higher energies.

The HPGe detectors must be operate at cryogenic temperatures (typically around 77 K, the boiling point of liquid nitrogen) to reduce thermal noise and improve their performance. This cooling is necessary because germanium has a relatively small bandgap, and at room temperature, thermal energy can excite electrons across the bandgap, leading to increased noise and reduced energy resolution.

2.2 | Principle of operation

When a gamma ray interacts with the germanium crystal in the HPGe detector, it can undergo several types of interactions, including the photoelectric effect, Compton scattering, and pair production. These interactions result in the creation of electron-hole pairs within the crystal. **The number of electron-hole pairs generated is proportional to the energy of the incoming gamma ray**

An electric field is applied across the germanium crystal, causing the electrons and holes to drift towards their respective electrodes. This movement of charge carriers generates a current pulse, which is then amplified and processed by the detector's electronics. The amplitude of the pulse is directly proportional to the energy of the incident gamma ray, allowing for precise energy measurements.

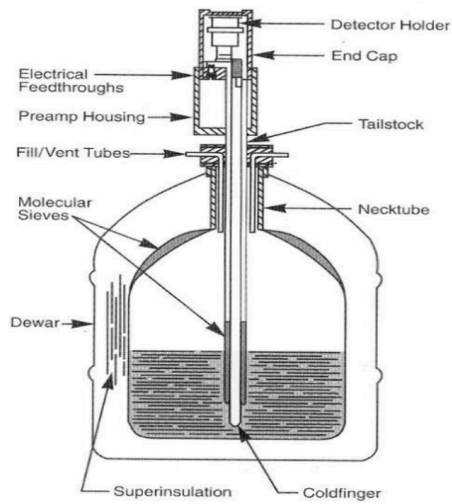
2.3 | Construction and Cryostatic colling

The HPGe detector consists of a high-purity germanium crystal, typically in the form of a cylindrical or coaxial shape. The crystal is housed in a vacuum-sealed cryostat to maintain the low temperatures required for operation. The cryostat is often cooled using liquid nitrogen, which is circulated around the detector to keep it at the desired temperature.

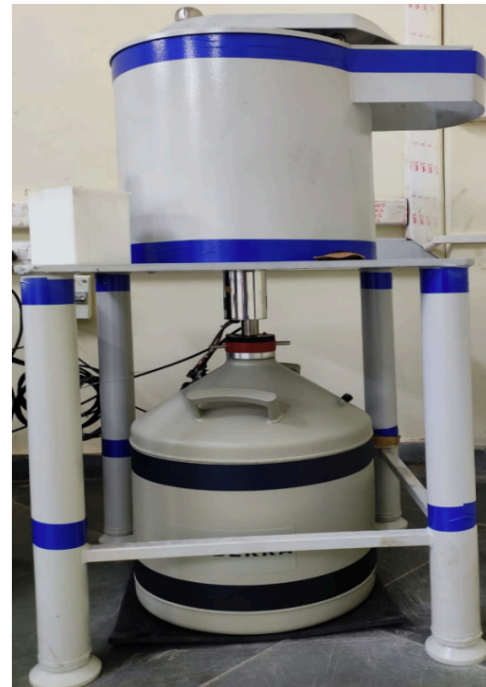
The main components of the system are the cooling rod (usually made of copper), the Dewar container (for storage of liquid nitrogen), and the fill collar (for refilling the Dewar). The cryostatic cooling systems provide the following features: cooling of the detector to obtain stable operating temperatures; high quality vacuum in the cryostat to avoid adsorption of contaminants on the detector surface and provides thermal insulation; suppression of heat transfer between cool inner parts and warm outer surface of the cryostat; mounting for the electrical contacts; and isolation from external vibration to avoid system noise interference.

The Shielding involves an outer jacket of 10 mm carbon steel, an inner shield of 100-mm-thick Lead and a graded liner of tin and copper. Such graded shielding minimizes the background noise that has a very high probability of interference with measurement data. It is manufactured for use with a detector in a vertical configuration.

Component	Specification
Detector model	GC3018
Relative efficiency	$\geq 30\%$ relative to NaI(Tl)
Energy resolution	≤ 1.8 keV at 1.33 MeV (Co-60)
Depletion voltage	+ 2400 Vdc
Recommended operating voltage	+ 2900 Vdc

Table 2.1: Specifications of the HPGe Detector System


(a) Schematic Diagram of HPGe Detector



(b) HPGe Detector unit in CMRP



(c) Upper view of Detector with graded shielding.



(d) Electronics part of HPGe Detector

Figure 2.1: Images of the HPGe Detector System[1]

2.4 | Electronics components associated

The HPGe detector system is complemented by a suite of electronic components that facilitate signal processing, amplification, and data acquisition. Key components include:

Component	Specification
Diameter of crystal	61.7 mm
Length of crystal	40 mm
Distance from crystal to front face	4.9 mm
Window material	1.5 mm thick Aluminum
Active volume	$\sim 113 \text{ cm}^3$
End cap	3.00 inch diameter \times 5.25 inch length

Table 2.2: Physical Characteristics of the HPGe Detector System

- **Pre-amplifier:** High-purity Ge detectors are usually fitted with a charge-sensitive preamplifier, which acts as an interface between the detector crystal and the pulse-processing and analysis electronics further along the gamma-spectrometric system. The preamplifier is often assembled as an integral part of the detector housing itself. It takes the charge produced from the detector (by the gamma radiation from the sample) and integrates and amplifies this to produce a step-function pulse. The amplitude of pulse is proportional to the total charge. The first stage usually includes a Field Effect Transistor (FET) circuit, which is located inside, or adjacent to the cryostat and is also cooled to reduce background-noise interference.
- **Amplifier:** The amplifier primarily takes the pulse signal from the preamplifier and considerably magnifies it. It also filters and shapes the incoming pulse to enhance the signal-to-noise ratio. This improves the resolution and shortens the response time to prevent overlap between pulses. Count rates for radionuclides in environmental samples are generally less than 100 counts per second, thus the amplifier needs to perform best in this range.
- **Analog-to-Digital Converter (ADC):** The analogue signal produced by the detector and shaped by the amplifier needs to be converted to a digital signal prior to registering in the MCA. This is undertaken using an analogue to digital converter (ADC), which effectively converts the analogue signal from the amplifier to a digital value. The pulses that emerge from the ADC are then registered in one of the channels of the multi-channel analyzer (MCA). The MCA is often hardwired into the computer system (via an electronic circuit inserted into the motherboard). The MCA provides the means by which the counts from the detector are stored according to the energy that produced them. It performs a number of tasks including collecting and sorting the input pulses, storing those data in a spectrum, providing a format to display the data on the computer screen, and performing some analysis of the data.
- **Data Acquisition System (DAQ):** Collects and stores the digital data for analysis in the software.

3 | Theory

3.1 | Energy calibration of HPGe detector

Energy calibration is the process of establishing a relationship between the channel number in the multichannel analyzer (MCA) and the corresponding gamma-ray energy. This is typically done using known gamma-ray sources with well-defined energies. The calibration process involves the following steps:

- **Selection of Calibration Sources:** Choose gamma-ray sources with known energies that cover the energy range of interest. Common calibration sources include Cs-137, Co-60, and Na-22.
- **Data Acquisition:** Place the calibration sources in front of the HPGe detector and acquire spectra for a sufficient duration to obtain clear peaks.
- **Peak Identification:** Identify the peaks in the acquired spectra corresponding to the known gamma-ray energies of the calibration sources.

- **Calibration Curve:** Plot the channel numbers of the identified peaks against their known energies. Fit a linear or polynomial function to the data points to establish the calibration curve.
- **Verification:** Verify the calibration by measuring additional known sources and checking if the measured energies match the expected values.

3.2 | Absolute efficiency calibration of HPGe detector

Absolute efficiency calibration involves determining the efficiency of the HPGe detector for detecting gamma rays at different energies. This is essential for quantifying the activity of radionuclides in samples. The calibration process includes the following steps:

- **Selection of Calibration Sources:** Use gamma-ray sources with known activities and energies.
- **Data Acquisition:** Place the calibration sources in front of the HPGe detector and acquire spectra for a known duration.
- **Peak Area Calculation:** Identify the peaks in the spectra and calculate the area under each peak, which corresponds to the number of counts detected for that energy.
- **Efficiency Calculation:** Calculate the absolute efficiency using the formula:

$$\epsilon(E) = \frac{N(E)}{A \cdot P(E) \cdot t}$$

where $\epsilon(E)$ is the absolute efficiency at energy E , $N(E)$ is the net peak area, A is the activity of the source, $P(E)$ is the emission probability for the gamma ray at energy E , and t is the counting time.

- **Efficiency Curve:** Plot the efficiency values against the corresponding energies and fit a suitable function to obtain the efficiency curve.

3.3 | Identification of radionuclides and measurement of their activity concentration present in environmental sample

To identify radionuclides and measure their activity concentration in environmental samples using the calibrated HPGe detector, follow these steps:

- **Sample Preparation:** Collect and prepare environmental samples (soil, water, etc.) ensuring they are in a suitable form for gamma spectroscopy.
- **Data Acquisition:** Place the prepared samples in front of the HPGe detector and acquire spectra for a sufficient duration to obtain clear peaks.
- **Peak Identification:** Analyze the acquired spectra to identify peaks corresponding to different radionuclides using the energy calibration curve.
- **Activity Calculation:** Calculate the activity concentration of each identified radionuclide using the formula:

$$C = \frac{N(E)}{\epsilon(E) \cdot P(E) \cdot t \cdot V}$$

where C is the activity concentration, $N(E)$ is the net peak area, $\epsilon(E)$ is the absolute efficiency, $P(E)$ is the emission probability, t is the counting time, and V is the volume of the sample.

4 | Observation

5 | Conclusion

6 | References

- [1] *Lab Report, CMRP, NISER.*