HPGe DETECTOR MANUAL

CENTER FOR MEDICAL & RADIATION PHYSICS

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CHAPTER-I

INTRODUCTION

High-purity germanium (HPGe) detectors are the best solution for precise gamma and x-ray spectroscopy. Compared to silicon detectors, germanium is much more efficient for radiation detection due to its atomic number being much higher and low average energy necessary to create an electron-hole pair (3.6 eV for silicon and 2.9 eV for germanium). Due to higher atomic number, Ge has a much larger linear attenuation coefficient, which leads to a shorter mean free path. Moreover, the depletion region of silicon detectors cannot be thicker than a few millimeters. At the same time, germanium can have a depleted, sensitive thickness of centimeters and, therefore, can be used as a total absorption detector for gamma rays up to a few MeV.

The HPGe detectors must operate at very low temperatures of liquid nitrogen (-200°C) to achieve maximum efficiency because, at room temperatures, the noise caused by thermal excitation of electrons is very high.

HPGe Detector – Principle of Operation

HPGe detector is a semiconductor type solid state detector, whose operational principle is summarized in the following points:

- Ionizing radiation enters the detector's sensitive volume (**germanium crystal**) and interacts with the semiconductor material.
- A high-energy photon passing through the detector ionizes the atoms of the semiconductor, producing electron-hole pairs. The number of electron-hole pairs is proportional to the energy of the radiation incident to the semiconductor.
- Since germanium has a depleted region and sensitive thickness in the order of centimeters, it can **absorb high-energy photons totally** (up to a few MeV).
- Under the influence of an electric field, electrons and holes travel to the electrodes, resulting in a pulse that can be measured in an outer circuit.
- This pulse carries information about the energy of the original incident radiation.

CHAPTER-II

HPGe Detector Construction and Cryostatic Cooling

In addition to the electrons that are excited within the crystal as a function of gamma-ray interactions, further excitation can occur as a result of thermal energy. This additional excitation and electron activity produces background noise in the system. In order to reduce the effect of this phenomenon, detectors are usually operated at very low temperatures. For practical reasons, this is usually achieved by cooling detectors with liquid nitrogen.
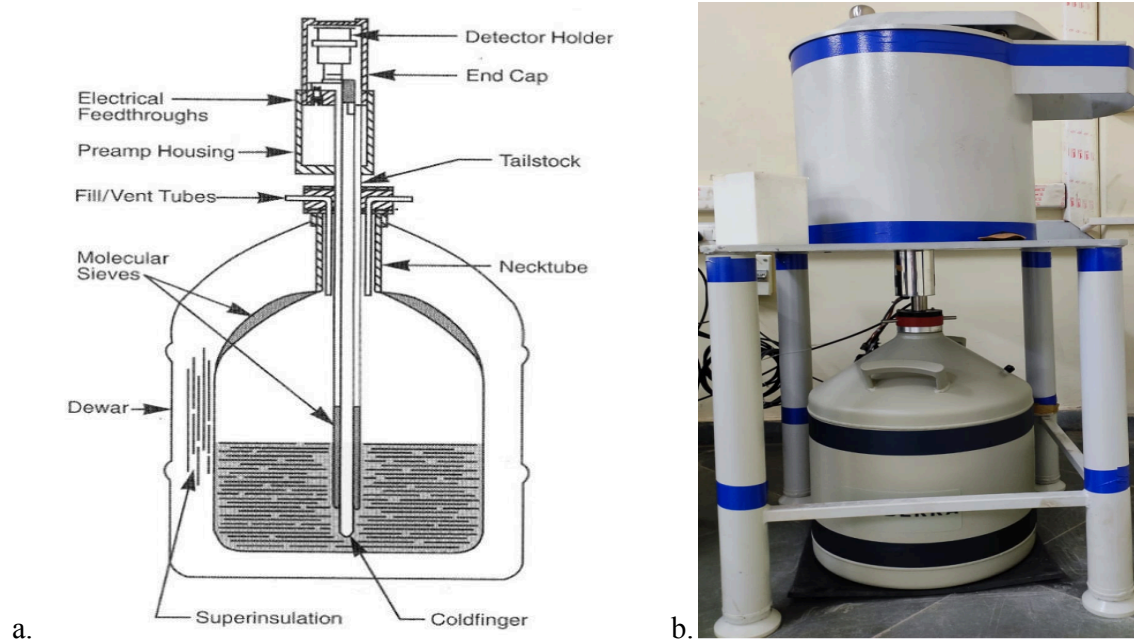
a.

b.

c.

d.

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

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.

Detector Specification:

Detector Model	GC3018
Detector serial number	11943
Preamplifier Model / Serial Number	iPA-SL10 / 220817-1068
Cryostat Model	7500SL
Relative Efficiency	≥30% relative to NaI detector
Resolution	≤ 1.80keV FWHM at 1332keV
Peak/Compton	≥ 58:1
Depletion Voltage	+2400Vdc
Recommended Bias Voltage	+2900Vdc
LN2 loss Rate	< 1.8L/D

Physical Characteristics:

Diameter	61.7mm
Length	40.0mm
Distance from window	4.9mm
Window Thickness	1.50mm
Window material	Aluminum
Active Volume	113.0cc
End Cap Size / Length	3.00 inch dia / 5.25 inch length

CHAPTER-III

Electronic Components Associated With HPGe Gamma-Spectroscopy Systems:

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.

The second component in the system is the 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.
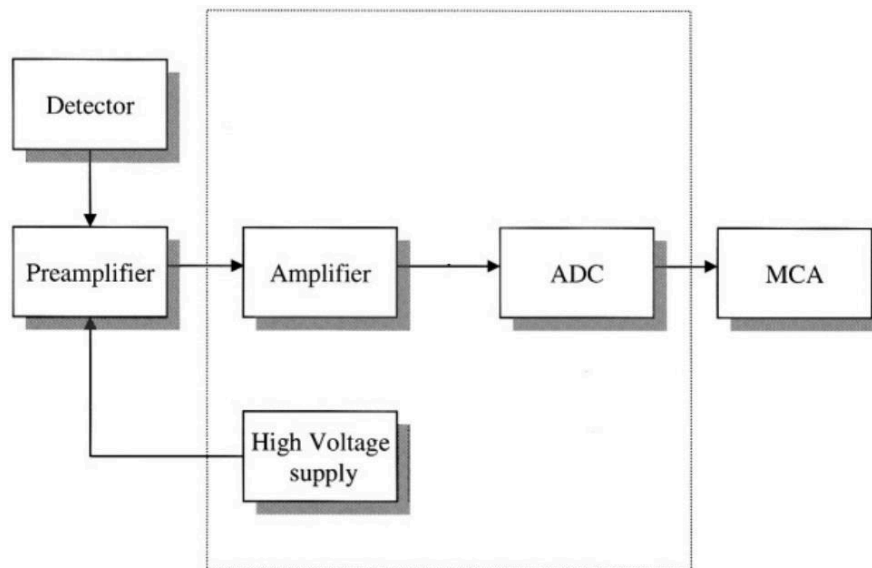
Charge collection within the germanium detector (created by interaction with gamma photons) occurs best when a bias voltage is applied across the detector volume. This is usually in the range ±1,000 to 5,000 V and is applied by a highvoltage supply unit. It is important for high voltage supplies to be stable, and in this respect most units have circuits to regulate against drift due to changes in temperature, or in mains power voltage. When using high voltage supplies in combination with preamplifiers equipped with a field effect transistor (FET), the voltage amount should be increased slowly to avoid damage to the FET. Similarly, the voltage should be decreased slowly when disconnecting the voltage supply.

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.

Energy Calibration:

In gamma ray spectroscopy with germanium detectors, the pulse height scale must be calibrated in terms of absolute gamma-ray energy, if various peaks in the spectrum are to be properly identified. The process is known as energy calibration which establishes a linear or polynomial relationship between the spectrum channels and energy levels. By calibrating each peak at each end of the spectrum, the energy of any peak can be estimated accurately.

Efficiency Calibration:

Efficiencies can be classified as absolute, intrinsic, or relative. Absolute efficiency is the ratio of the total number of photons detected to the number of photons emitted by the source. Intrinsic efficiency is the ratio of the number of photons detected to the number of photons incident on the detector surface. Absolute and intrinsic efficiencies can be expressed as the full-energy peak efficiency, which takes into consideration only the photons which result in counts in the full-energy peaks. Often, Germanium detector efficiencies are expressed as relative efficiencies. This is the efficiency relative to a Co^{60} source (using the 1332 keV peak) measured with a 3"x 3" NaI(Tl) detector at a distance of 25 cm from the detector.

CHAPTER-IV

EXPERIMENT-1: ENERGY CALIBRATION OF HPGe DETECTOR (LINEARITY STUDY BY DIRECT METHOD)

PROCEDURE:

1. Make the system interconnections and default settings.
2. Open the **GENIE** folder on desktop then click on **gamma acquisition and analysis software**. Accordingly the software will open.
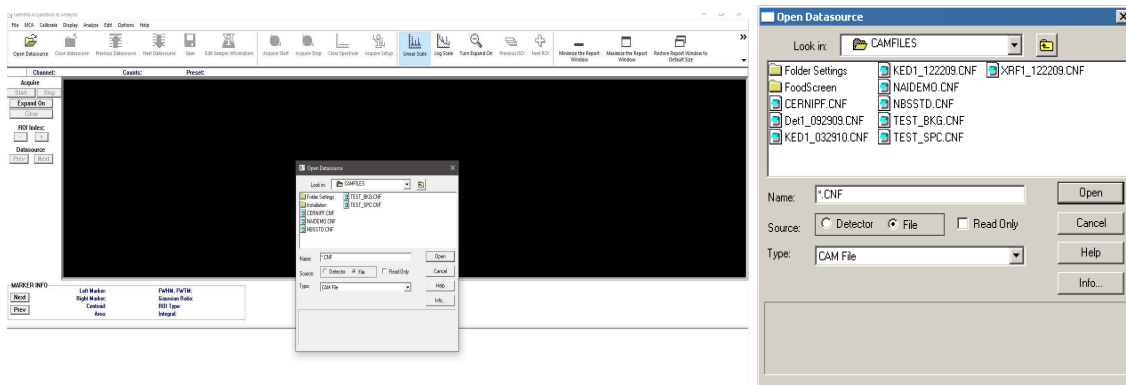

3. Open the software and click on **open datasource** in the taskbar. A popup window will appear named open datasource select the **detector**, Click on the detector name showing 'GC3018' and then press **open** to open the detector window.
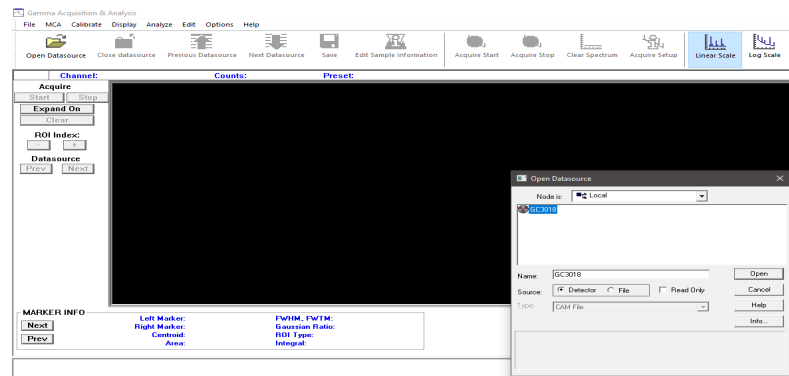

4. Then go to the **MCA tab** click on **adjust setup** and set the voltage to **+2900V** in the **HVPS** section. By doing this the HV LED on DSA will start blinking and wait a few seconds so that it will get stabilized.
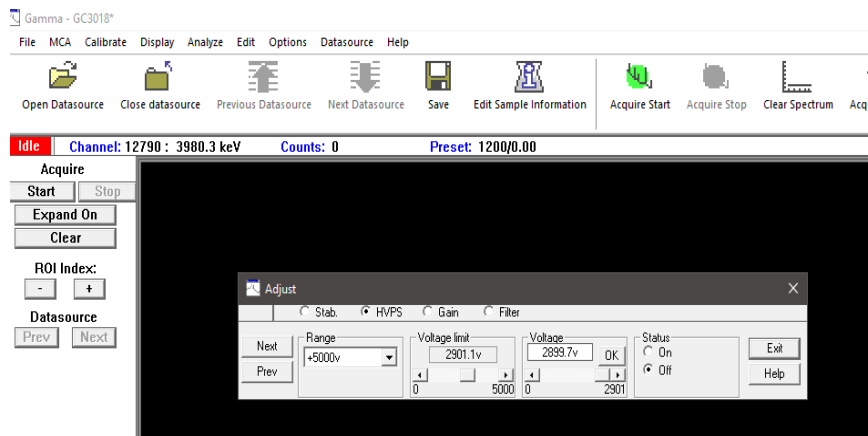
5. Wait for 10-15 minutes for warming up the detector system.
6. In the **Acquire Setup** of **MCA tab**, there is a Time Preset section. Set the time to **300 sec** in the **Live Time** as shown in figure.
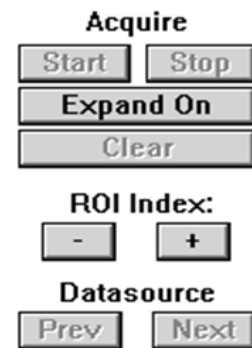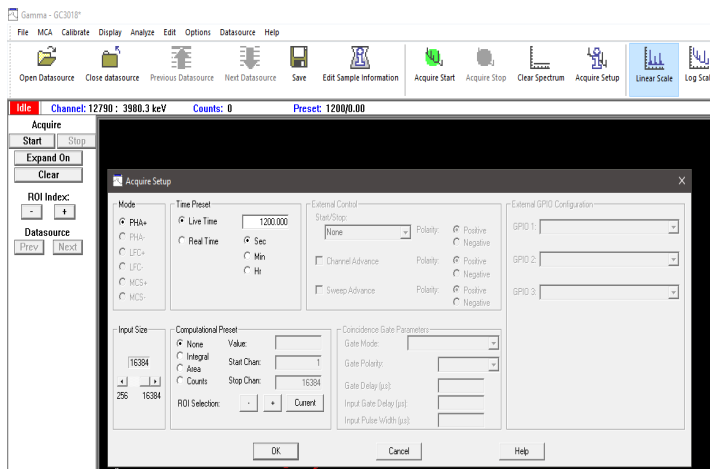

7. First take the Background measurement spectrum. For doing this click on the **start button** which is just below the **Acquire tab** in the control Panel to start acquisition. Save the file as (**by Save As**) BKG after completion of the acquisition.
8. Place different sources one by one at **25 cm** (Taking solid angle into consideration) from the detector. Measurement should be performed for a single source at a time.
9. Start with a Co-60 source. Take the spectrum. And then generate spectrum for all available known sources. Save the file by the source name so that Identification of a particular file becomes easy.
10. Merge all the spectrum by going to the **options tab** and selecting **strip option**.Select the desired spectrum you want to merge in the current spectrum. Put -1 in the **Source-Background tab** to add a spectrum and +1 to subtract a spectrum from the current one and select the peak for each known source with the help of a cursor appearing in the interface window.
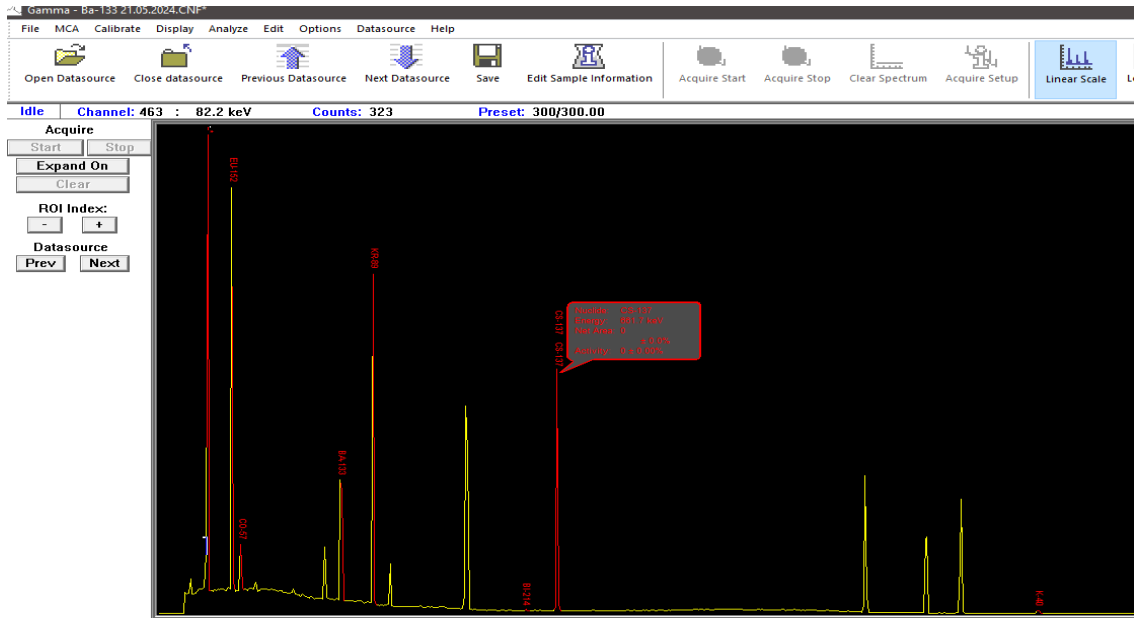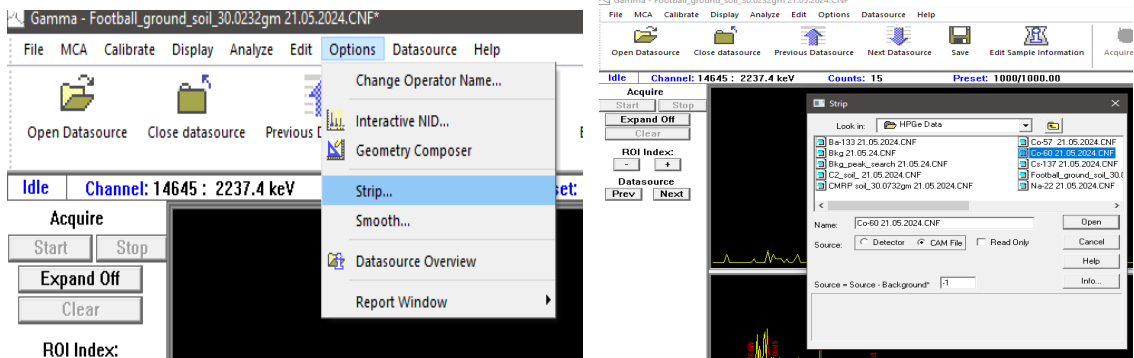
11. Go to the calibrate tab, select **Energy only calibration**. Keep the cursor on one of the peaks and it will show the corresponding channel number. Put the energy of that channel in the popup window. Press **Accept** and then add another peak information and so on . Then press show to see the calibration curve. It will be a linear curve.
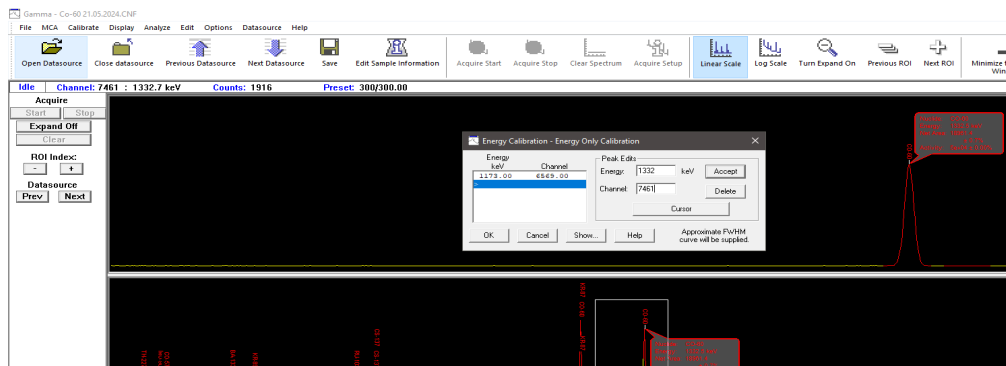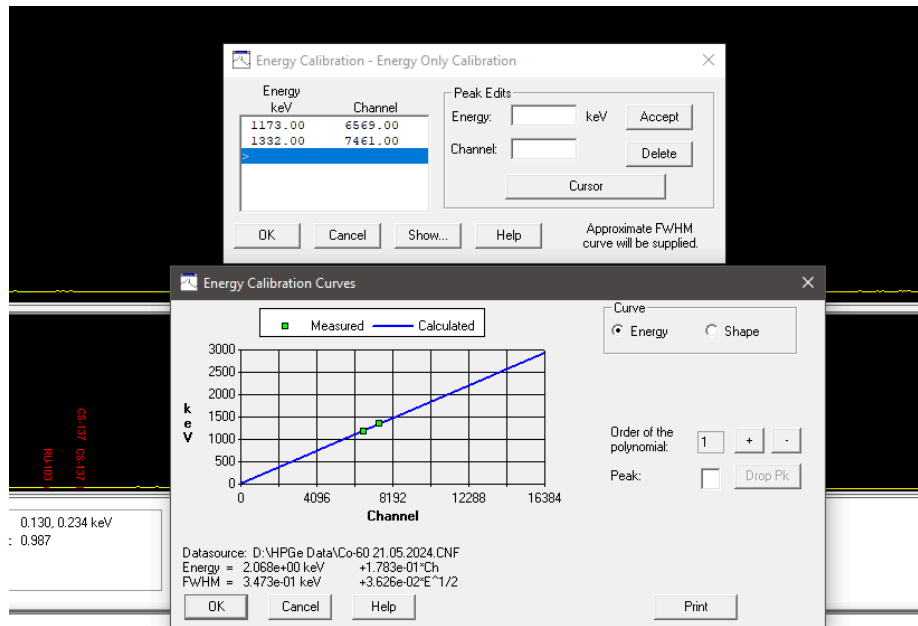
12. After the energy calibration we can see the polynomial equation related to energy and channel number just below the graph. This polynomial equation can be used in finding out energy of an unknown sample. Although two points are required to create an Energy calibration curve, it is recommended to use as many reliable peaks as you have available.

13. Click **ok** to apply this calibration and store this calibration file by clicking the **store** option present in the **Calibrate Tab.**

EXPERIMENT - 2 : ABSOLUTE EFFICIENCY CALIBRATION OF HPGe DETECTOR (By Direct Method)

An Efficiency calibration will allow us to correlate a spectrum's count rate with nuclide activity. A detector's efficiency changes at different values of gamma-ray energy. In addition, the geometry of the sample in relation to the detector will dramatically affect the measurement efficiency. The efficiency calibration allows us to compensate for these changes.

To create an efficiency calibration, your spectrum must be energy calibrated.

PROCEDURE:

1. Repeat the procedures of experiment-1, up to step10.
2. Go to the calibrate tab. Click on **Efficiency**. All four options displayed can be used for efficiency calibration.
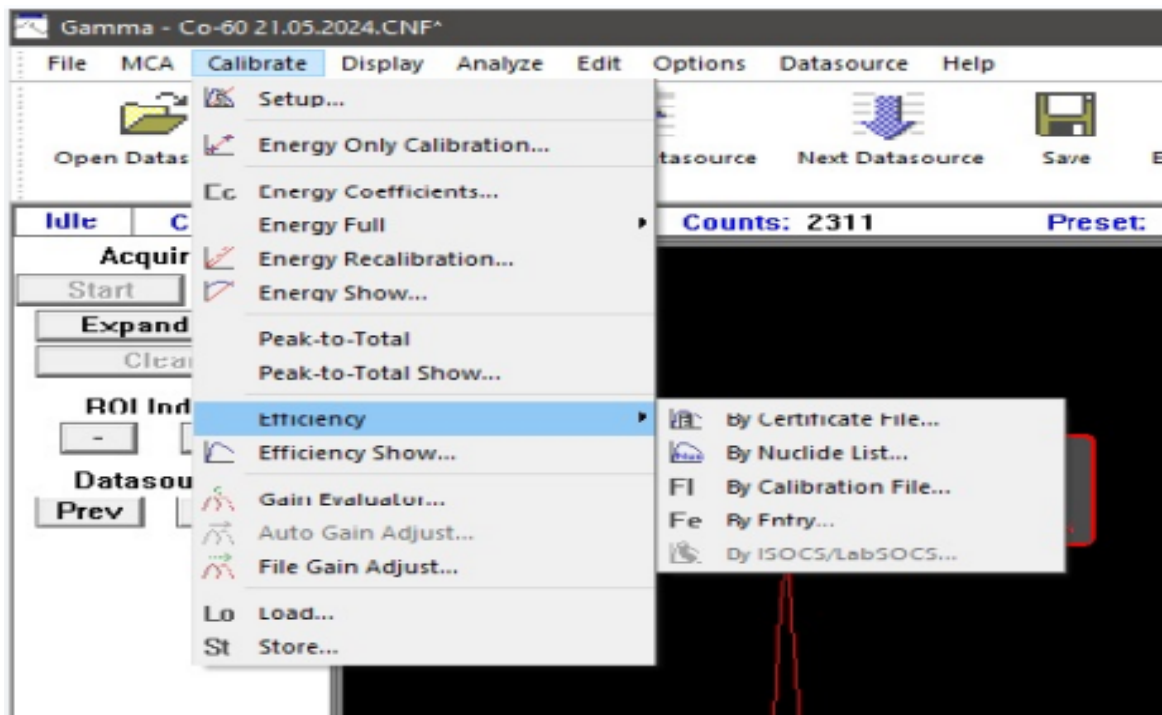
3. By selecting '**By nuclide list**' option you need to select a library first followed by desired radionuclide for which you did the measurement. Add that nuclide its activity date of issue and uncertainty manually then press show to see the calibration curve and save it for future reference. The fourth option i.e **'By Entry'** is also very much similar to the previous option. Here we need to add radionuclides one by one along with its energy, efficiency and percent error values manually without selecting any library and then do the calibration process.
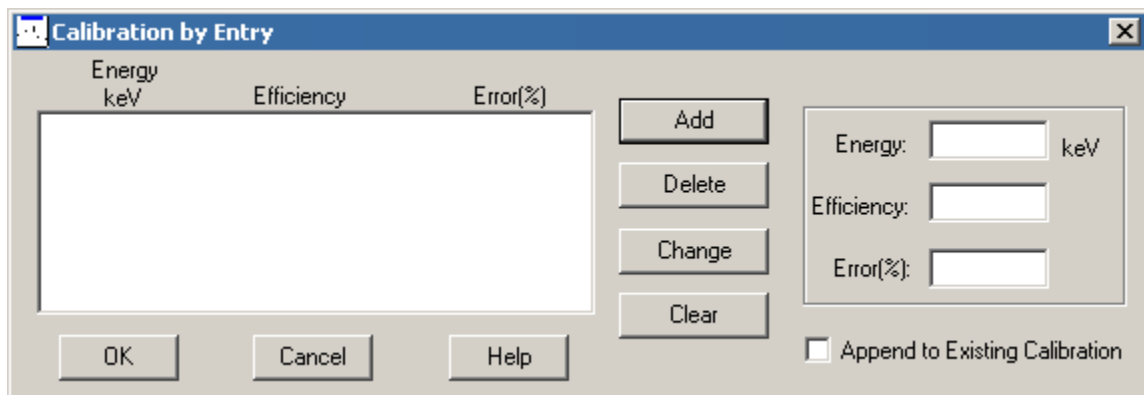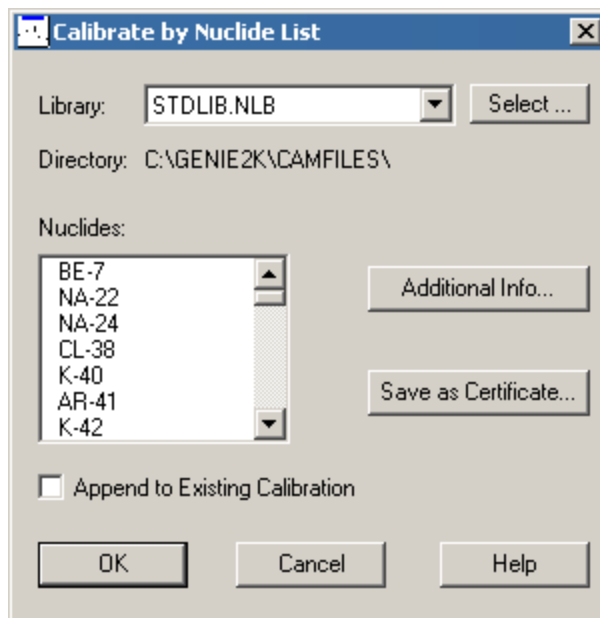
4. If one selects **By certificate file** and **By calibration file**, for these two options one needs to upload the concerned file so that a list of radionuclides appear in a pop up. We will use the option **'By Certificate File'** to perform Efficiency Calibration here. During the efficiency calibration by certification file process, we will be associating a spectrum acquired with a known source in a particular geometry with the certificate of the source to determine the efficiency for this geometry. This will allow us to determine the activity for an unknown sample in the same geometry in future measurements.

5. **Starting the Calibration using By Certificate File process**
   a. To calibrate the spectrum, we have to enter their energies and their corresponding efficiencies and uncertainties.
   b. Click on **Calibrate | Efficiency | By Certificate File.**
   c. In the Open Certificate File box, double click on **Nbsstd.ctf.** The energy lines in this file will appear in the list box, as shown in the Efficiency Calibration Dialog box.
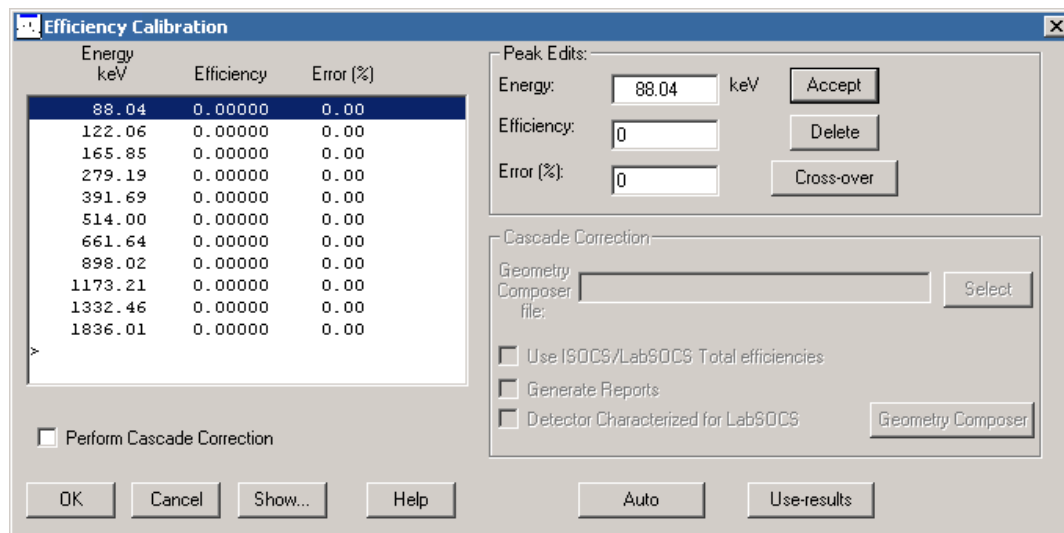
6. **Adding Efficiency Data**

   The next step is to add efficiency and percent error values to each energy in the list.
   There are two ways to do this:

   a. If you know that the current datasource contains **peak area analysis** results, you can click the **Use-results** button to populate the list box with that data. If you're not sure whether the current datasource contains peak area data, you'll have to use the second method.

   b. Click the **Auto button** to have the system automatically perform a **Peak Locate and Peak Area analysis**, then calculate and display the efficiency and percent error values for each energy in the list box. This method will use other parameters defined in the Calibrate Setup screen, including the Continuum selections.

7. With either method, for each peak found that matches one in the list box, ±1.00 keV, the Efficiency Match Tolerance value, an efficiency is calculated based on the peak net area and the calibration data contained in the Certificate File.

8. **Dual Polynomial Curve**

   a. For the dual polynomial curve, the overall Efficiency Curve can be a combination of two curves, one for the lower energies and a second for the higher energies (above 150–200 keV or so).

   b. To use two curves, highlight an energy, then click the **Cross-over button** to specify the point where you want the low energy curve to end and the high energy curve to start. If no crossover point is specified, a single equation is used across the entire energy range.

   c. Click on the 165.85 keV line in the list to select it.

   d. Click the Cross-over button to put an X to the right of the peak in the list. This will mark it as the energy used as the crossover point.

9. **Viewing the Efficiency Calibration**
    a. To check the results of the Efficiency Calibration, click on the **Show button**, which will display the dual efficiency curves and the fit to the data points.
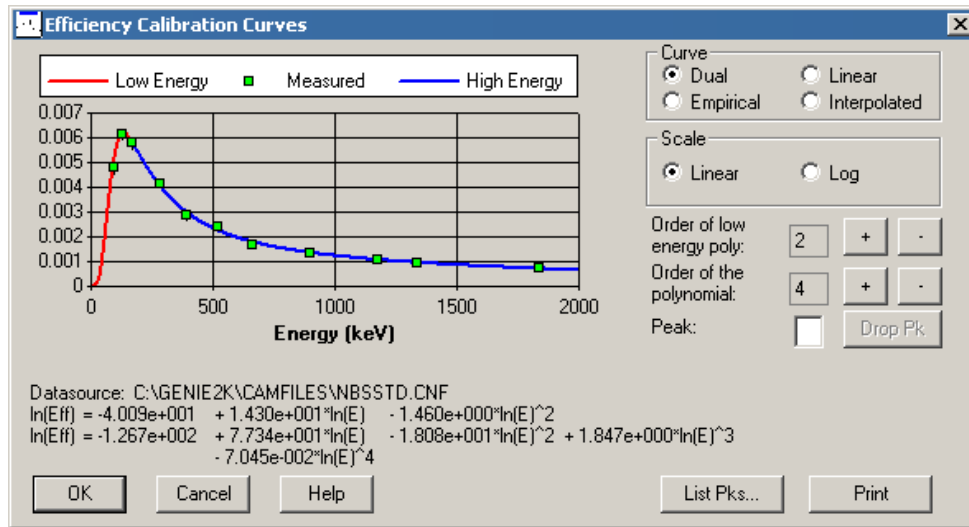
    b. For the Dual Energy Curve, the low energy curve, a **second order equation**, is shown in **red** at the bottom of the screen; the high energy curve, a **fourth order equation**, is shown in **blue**. The two share the data point at 165.85 keV to ensure continuity from one curve to the other.
    c. In addition to the default Dual Curve, you can display the calibration as an **Empirical Curve**, a **Linear Curve** or an **Interpolated Curve** by selecting the appropriate button in the **Curve section** of the data window. The order of these polynomials can be adjusted in this screen to create a good fit.

10. **Accepting & Saving the Efficiency Calibration**
    a. When you are satisfied with the calibration, click **OK** to have this calibration become your current calibration.
    b. To store this efficiency calibration for use with another spectrum, you can save this file as a ***.CAL file**.
    c. To do this, select **Store** from the **Calibrate menu** and give it a meaningful name. Then, you can select **Efficiency | Calibrate by Calibration File,** during a future measurement and select this file. This will load the efficiency calibration you have just made.

EXPERIMENT-3:IDENTIFICATION OF RADIONUCLIDES AND MEASUREMENT OF THEIR ACTIVITY CONCENTRATION PRESENT IN ENVIRONMENTAL SOIL SAMPLE AND TAP WATER SAMPLE :

There are several methods for determining the gamma-emitted radioactivity in Environmental samples like soil, food products, water samples etc. However, high-purity germanium (HPGe) detectors are used worldwide due to its high resolution gamma spectrometry techniques. In simple terms, the radionuclides within the soil emit gamma photons at known energies. These interact with the germanium detector, which in turn emits signals corresponding to the energies of the incoming photons. The signals from the detector crystal are routed through an amplifier and directed to a Multi Channel Analyser (MCA) system. Here, the signals are displayed as a spectrum in which emission counts are plotted against radionuclide energies. The Software converts the peak-count information to specific activities using calibration procedures.

Procedure:

The Procedure for the above experiment for both soil and tap water is similar. Here the steps are given for soil samples and you can follow the same steps for analysis of Tap water samples as well. The various steps for this procedure are-

1. Collect the soil sample with fine and uniform grain size from a particular location (animal grazing field or cultivation land is desired if possible otherwise you can take any soil sample from a children's playground or any field which is commonly used by peoples of locality). Avoid stones and pebbles to mix with the sample.

2. Make a fine and homogeneous sample by rubbing it in hand or grinding it (use a grinder if available) .Take **30gm** (**30mL** in case of tap water sample) of this fine sample in a beaker and measure the weight of the sample with a high precision weight measuring device.
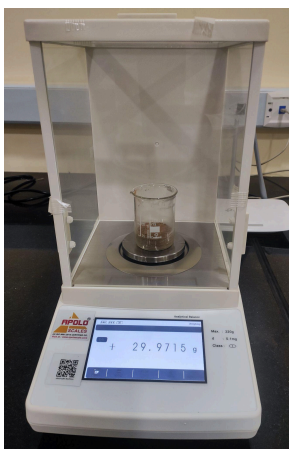

Precision Balance

3. Open the software and apply voltage **+2900V** and time of acquisition as **1000sec** and do the background measurement and save the file as BKG (Background counts).
4. Place the sample above the detector on a stand like shown in the figure.


View from the top of HPGe Detector

5. Press **start** to acquire the spectrum and wait for the complete acquisition.
6. Prior to this experiment make sure that the Efficiency calibration as well as energy calibration must be done previously and saved properly as we will be using these files to find out the activity and energy of radionuclide along with its concentration.
7. After completion of the acquisition, save the file with the proper name.
8. Open it in the file window.
9. Subtract the Background from the file that needs to be analyzed.
10. Go to the **Analyze tab** follow the sequences named **A,B,C,D,E and F**.
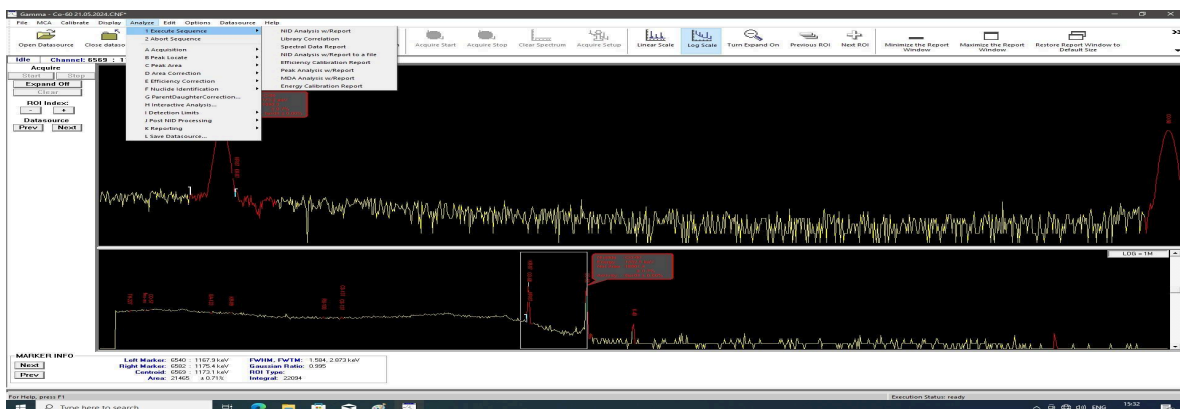
11. **Peak Locate**-Select the **VMS Standard peak search** parameter option. It will search all the peaks present in the spectra,if you want to search for a particular peak you can do it by selecting the User Specified parameter and putting the channel limits for that particular region only. Mark on **Generate Report** and Press **Execute**.
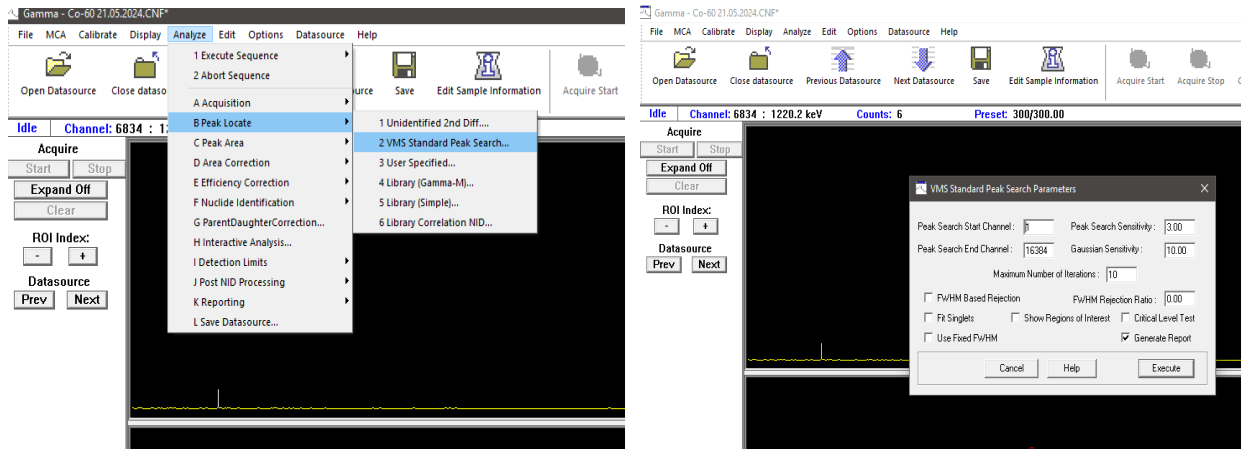

12. **Peak Area**- after locating the peaks the software will measure the area under each peak. Select the Library option for and execute it .
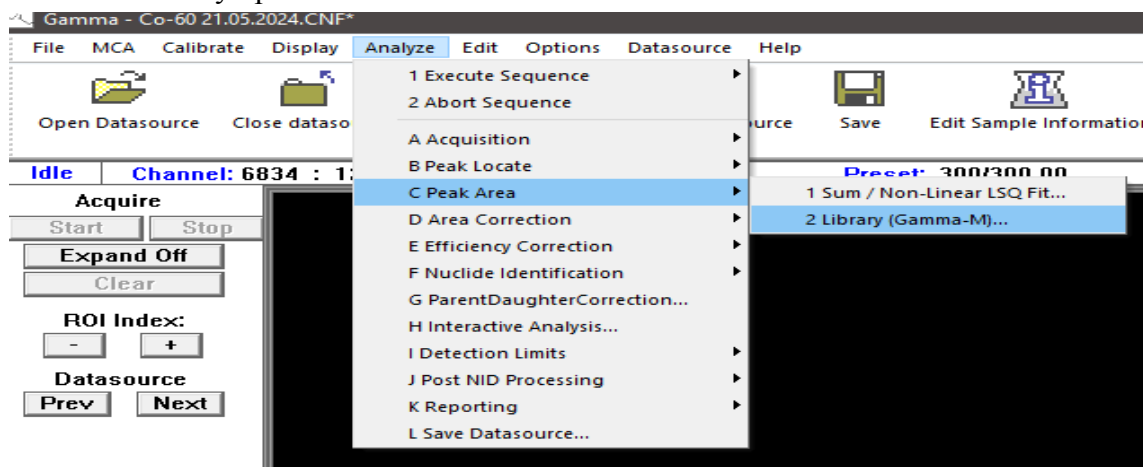
13. **Area correction**- Here the software will correct the area under peak by subtracting the background from the current spectra. In order to do this step make sure that the peak location as well as peak area step must be done for background spectra otherwise it will give an error message.Because we need to tell the software that the peaks present in background and hence the software then subtract such background peaks from the sample spectrum which is known as area correction.
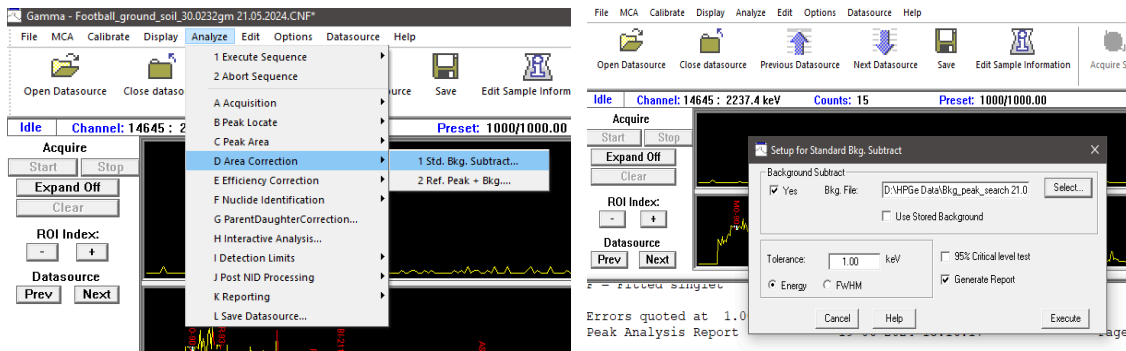
14. **Efficiency Correction** - Upload the efficiency file so that the activity concentration of the radionuclides present in the sample can be identified properly.
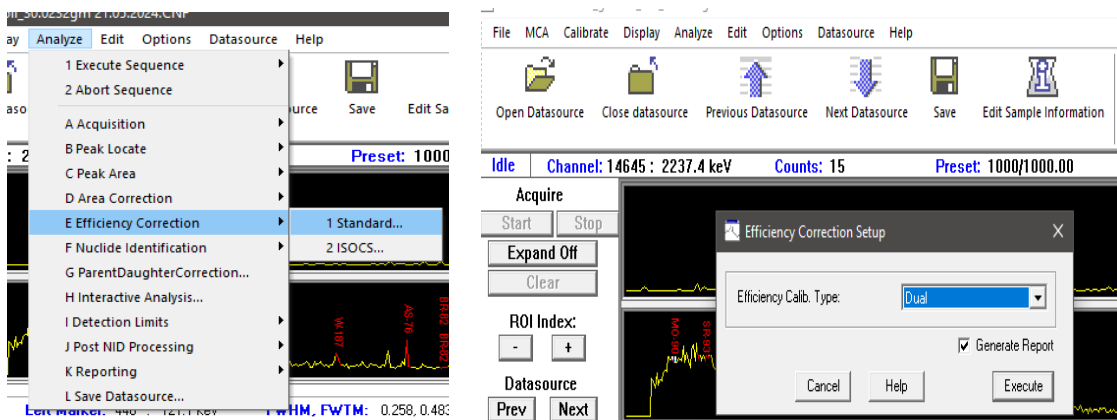
15. Nuclide Identification- for **tentative NID** the software will give a all possible radionuclides along with their energies but not the activity, where as the **last two options** will provide us the most probable radionuclide along with its activity concentration in Bq/mg, activity uncertainty, energy and yield.
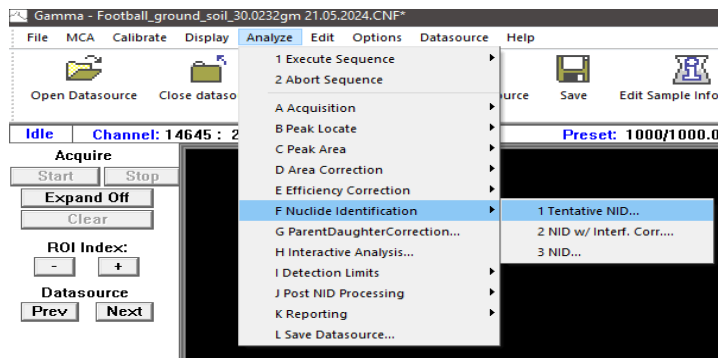
16. The result for an analyzed soil sample from the football ground of NISER campus is given below .

```
*****************************************************************************
****   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   *****
*****************************************************************************

    Sample Title:         Foodball Ground
    Nuclide Library Used: C:\GENIE2K\CAMFILES\STDLIB.NLB

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

  Nuclide    Id        Energy    Yield     Activity     Activity
  Name    Confidence   (keV)     (%)       (Bq /mg )   Uncertainty

  NA-22     0.927     1274.54*   99.94     8.9863E+00   5.0743E-01
  SB-122    0.850      563.93*   70.60     2.1233E+00   2.3235E-01
                       692.80     3.70

      * = Energy line found in the spectrum.
      Energy Tolerance :    1.000 keV
      Nuclide confidence index threshold =   0.30
      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:  19-06-2024 15:16:08
            Peak Locate From Channel:      1
            Peak Locate To Channel:    16384

   Peak    Energy      Peak Size in       Peak CPS      Peak        Tol.
   No.     (keV)     Counts per Second  % Uncertainty   Type       Nuclide

    1     253.99       1.17468E-01         14.37        Tol.       ZR-97
    2     301.17       7.87120E-02         17.41
    3     348.49       1.41349E-01         10.70
    4     541.33       8.72788E-02         13.15        Tol.       I-134
    6     815.22       7.61092E-02         13.48        Tol.       LA-140
    7     860.03       2.26837E-02         31.22
    8     863.35       3.46784E-02         23.10
    9     989.50       2.08819E-02         32.67
   11    1527.26       3.48435E-02         20.00
   12    2237.00       1.16473E-01          9.95

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

17. Generate such a report of your own Experiment and **Export Report** to **PDF** under the **File menu**, which will create a PDF file of the report in a location of your choice.

Precaution:
1. Check LN$_2$ level before starting the HPGe system. (If it is less than 30%, don't power on detector)
2. After checking LN$_2$ level, shutdown level indicator for reducing noise.
3. Start PC and MCA and check Power (**PWR**), Communication (**COM**) , High Voltage (**HV**) indication they should be green in color.
4. Check the preamplifier part of detector assembly it should show **Rate** and **HV INH** indication in green color.
5. After powering on the detector (HV ON) wait for 15 min for establishing the voltage.
6. Don't put the source on the detector surface directly.
7. Don't put the PC in sleeping mode at any time.