Experimental Manual
MCA with Anuspect

NUCLEONIX SYSTEMS PVT. LTD

CONTENTS

CHAPTER – I

INTRODUCTION

NaI Scintillation detector based gamma ray spectroscopy system with 8K/ 4K / 1K MCA consists of the following consistent units.
MINBIN with power supply (MB403)
High Voltage (HV501)
Spectroscopy Amplifier (SA524) or Linear Amplifier (LA520)
8K / 4K / 1K Multi channel Analyzer with processing software
NaI Scintillation detector (2"x2" / 3"x3" Flat / Well type) Llead shielding (40mm)
Personal computer system
Gamma Reference Sources Set
This system finds wide applications in Gamma Ray Spectroscopy measurements. Highly recommended for various Health Physics Labs of Nuclear Power Plants, Environmental survey labs & other labs for basic & applied research purposes. System also can be used in teaching labs of Nuclear Sciences & Engineering.
Multi-Channel Analyzer (MCA) is an important part of nuclear spectroscopy system. The major requirement of MCA is for nuclear pulse height analysis in energy spectroscopy. The USB-MCA presented here, incorporates state of art technologies like FPGA, USB bus interface and precision analog electronics to meet the stringent system requirements in nuclear pulse spectroscopy. The resolution supported by the USB-MCA ranges from 256 channels to 8K channels selectable via software, making it suitable for all spectroscopy applications from low resolution (e.g. NaI-PMT) to high resolution (e.g.HP-Ge) systems.
The USB bus interface of the MCA provides an excellent connectivity with most of the new PCs and lap-top computers. The PHAST application software provided with the USB-MCA, seamlessly integrates with the hardware, featuring a range of standard functions required for analysis and acquisition.

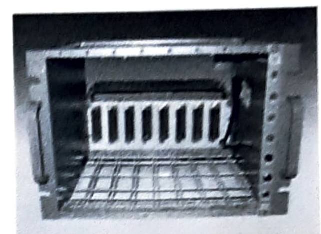
FEATURES :

- Excellent MCA performance in terms of DNL: +/- 1%; INL : +/- 0.05% of F.S. resolution etc.
- Supports both PHA & MCS modes of operation.
- Universal connectivity to a wide range of PCs and notebook computers.
- Gamma Ray Spectroscopy System uses Spectroscopy Amplifier or Linear Amplifier, HV module and Scintillator Detector including instrumentation BIN & power supply.
- Excellent processing software features.
- System can be used with different sizes of NaI scintillation detectors.

CHAPTER - II

DESCRIPTION AND SPECIFICATION OF THE CONSTITUENT UNITS

1. MINIBIN AND POWER SUPPLY (MB 403)



MINI BIN : Accommodates SIX / EIGHT single bit modules or combination of multiple widths with Amphenol connectors. Minibin is primarily designed with the objective of conserving bench space and to achieve significant saving in cost of the Minibin based systems. Bussed wiring is provided to the power connectors to distribute +/- 12V and +/- 24V. A control panel with ON/OFF switch, low voltage test sockets is provided on the right extreme side of the bin.

Minibin Dimensions : 11.75"width X 11.00 depth (upto connectors) X 8.75" height.
Power supply : This is either two and half bit module or a compact box type enclosure fitted at the back of this bin, which generates highly regulated D.C voltages.
Input : (230V + 10%) A.C, 50Hz.
D.C Output : +12V @ 1A, -12V @ 1A, +24V @ 0.5A, -24V @ 0.5A 48 watts maximum.
Regulation : Better than +/- 0.1%
Noise & Ripple : Less than 3 mV
Stability : +/- 0.5% after a 24 hr warm-up at constant line, load & ambient temp.

2. HIGH VOLTAGE UNIT (HV 501) :

a. Output voltage variable continuously from 0V to 1500 volts
b. Output current (max) 1mA
c. Load & Line regulations : Better than 0.005% of full scale
d. Indefinite over load & short circuit protections and self recovery
e. Output ripple less than 20mv.
f. Dimensions : Single / Two bit module

3. SPECTROSCOPY AMPLIFIER (SA524) :

Spectroscopy Amplifier is a high performance nuclear pulse shaping amplifier, ideally suited for use with all types of detectors such as germanium, silicon surface barrier and Si(Li) detectors. This is a single width NIM module with pile-up rejector (PUR), gated baseline restorer (BLR), auto threshold, diode limited unipolar output, BUSY and count-rate output as some of the key features designed into it. Some of the main applications of spectroscopy amplifier involve nuclear pulse height spectroscopy, nuclear timing spectroscopy, Counting Systems etc.
The input to SA524 can be either positive or negative signal from a detector preamplifier. The output pulses, 0 to 10V for unipolar pulse and ±10V for bipolar pulse.

A. PERFORMANCE

Gain Range : Continuously variable from X4 to X1500.
Pulse Shaping : Quasi-gaussian and quasi-triangular.
Shaping time : 0.5, 1, 2, 3, 6 and 10 μsec
Input Noise : 5 mv r.m.s with 3 ms shaping time
Overload : Recovers to within 2% of baseline in 15x shaping time from x200 overload.
Integral Non-Linearity : < 0.05% from 0 to 10V.

B. CONTROLS

FINE GAIN : Front panel 10 turns precision potentiometer provides a continuously adjustable, gain factor from 0.5 to 1.5.

COARSE GAIN : Front panel six-position switch selects gain factors of X20, X50, X100, X200,X500 and X1000.

PZ : Screwdriver adjustment of the PZ cancellation using 20-turn potentiometer on the front panel.

POS/NEG : Front panel toggle switch for selecting either positive or negative input signals.

ATN : A front panel toggle switch selects an input attenuation factor of X1 or X2.5

SHAPING : Front panel six position switch for selecting shaping times of 0.5, 1, 2, 3, 6 and 10 μsec.

4. MULTI-CHANNEL ANALYZER (8K MCA) : Multi-Channel Analyzer (MCA) is an important part of nuclear spectroscopy system. The major requirement of MCA is for nuclear pulse height analysis in energy spectroscopy. The USB-MCA presented here, incorporates state of art technologies like FPGA,USB bus interface and precision analog electronics to meet the stringent system requirements in nuclear pulse spectroscopy. The resolution supported by the USB-MCA ranges from 256 channels to 8K channels selectable via software, making it suitable for all spectroscopy applications from low resolution (e.g. NaI-PMT) to high resolution (e.g.HP-Ge) systems.

The USB bus interface of the MCA provides an excellent connectivity with most of the new PCs and lap-top computers. The PHAST application software provided with the USB-MCA, seamlessly integrates with the hardware, featuring a range of standard functions required for analysis and acquisition.

SPECIFICATIONS :

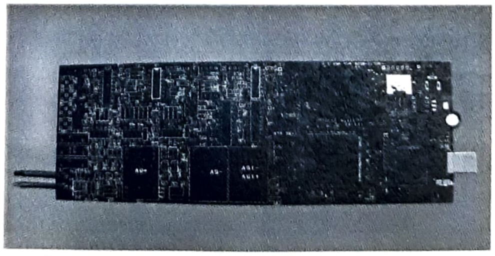
Hardware features:

- MCA resolution: 256, 512, 1K, 2K, 4K and 8K channels.
- Spectrum memory : 128K bytes single port SRAM.
- Max counts / channel: 31 bit (2 Giga counts).
- Pulse processing time : 7 μs including ADC conversion time of 5 μs.
- Pile up rejection: Active high TTL input from spectroscopy amplifier
- DNL: +/- 1%
- INL : +/- 0.05% F.S.
- MCA Input: Single channel, 0 to +10 volts
- Power requirement: 5V, ~500 mA through USB cable directly (No external power supply required)

Software features : Important software features include * spectrum display in two windows * marker selection (two) for ROI Detection & bracketing the peaks of interest, multiple ROI selection, delection of ROIs etc.,

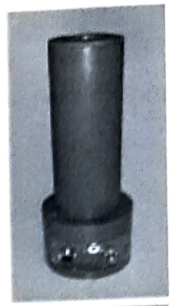
File Handling: Involves storing, loading of complete spectrum.
Print: Print of Total graph, selective graph, peak report
Acquisition: With pause option
Erase: Erasing spectrum from memory
Spectrum Analysis: Find peak, Shape calibration, Energy calibration, Approx Calib, Efficiency Calibration, Activity Calculation, etc.,
Spectrum smoothing: 3,5,7,9 &11 point smoothing functions have been provided
ROI Option: Insert, Delect, Hide Etc.,
Scale: X-axis can be chosen as Channel number (or) Energy axis (in Kev) & Y - axis has range from 256 to 64M in binary steps with auto scaling option. Y-scale can be linear or log LLD, ULD & base line are soft selectable In built Isotope library for isotope selection & matching.

USB MCA Module



USB MCA Module open form

5. SCINTILLATION DETECTORS :



Nucleonix Systems offers wide range of NaI Scintillation Detectors of different sizes both with flat & well type crystals, to meet the requirements of wide range of users for Gamma ray spectrometry measurements.

Scintillation detectors offered include 2"x2" & 3"x3" NaI integral assemblies with built-in pre-amplifiers. These detector assemblies give excellent stability, superior performance & good resolution in the range of 8.0 to 9.5% for Cs-137. Scintillation detectors of other sizes can be offered against user specific requirements also.

Important Specifications	Detector Type		
Flat/Well type NaI crystal	SD 151	SD 152/SD152 W	SD 153/ SD 153W
Crystal Sizes	1" x 1"	$\boxed{2" \times 2"}$	3" x 3"
a. Flat crystal b. Well Size (applicable for	---	0.656" dia x 1.546" deep	0.656" x 1.546" deep
Photo multiplier	R6095 of Hamamatsu or its equivalent	EMI 9857 or 9266 or its equivalent	EMI 9305 or its equivalent
Resolution (Better than)	8.5 %	8.5 %	9.5 %
Pre-amplifier	Built – in	Built – in	Built – in
Gain (Approx.)	25	25	25
Noise (RMS. referred to input)	Less than 50 μV	Less than 50 μV	Less than 50 μV
Operating Voltage	600 to 900 V	700 to 900V	700 to 900V
Out put	Positive Tail Pulse	Positive Tail Pulse	Positive Tail Pulse
Output impedance	90 Ohms	90 Ohms	90 Ohms
Power Requirement (Typical)	-12V @ 12 mA	-12V @ 12 mA	-12V @ 12 mA

6. GAMMA REFERENCE STANDARD SET (GS290) :

Gamma Reference Standard Set Type: GS290 consists of a set of FIVE Gamma sources evaporated & sealed on 25mm dia x 5mm plastic disc covering SIX photopeak energies in the range of 3 to 5 micro curie. A reference chart for this is given below. The accuracy of these sources is in the range of +/-10%. All these dics sources are enclosed in a box made of acrylic sheet and supplied.

Gamma Isotope	Energy Mev	Nominal Activity	Half life
Co-57	0.123	2-5 μci	273 Days
Ba-133	0.36 (Main)	2-5 μci	7.5 years
Cs-137	0.662	2-5 μci	30 years
Co - 60	1.17; 1.33	2-5 μci	5.3 years
Na-22	0.511;1,280	2-5 μci	2.6 years

Note : BRIT is not able to supply this Mn-54 at present. In view of this we are able to give only 5 sources in the Gamma Reference set.

7. LEAD SHIELD : This Lead Shield is designed to shield 2"x2" or 3"x3" NaI detector Scintillation Detectors of NUCLEONIX make. It is built-up of interlocking rings with bottom and top plates. The bottom ring is provided with a small opening so that the cables from the Scintillation Detector Pre-amplifier base could be taken out for connecting to the Gamma ray spectrometer counting system.

The inside of the lead shield is lined with Aluminium to minimise scattering.

Thickness 40mm, accommodate 3" scintillation detector including sample of 3" overall size.

8. PERSONAL COMPUTER SYSTEM WITH PRINTER :

Any standard pentium IV computer configuration with printer is adequate to run MCA software.

CHAPTER – III

PROCEDURE FOR OPERATION OF MULTI CHANNEL ANALYSER

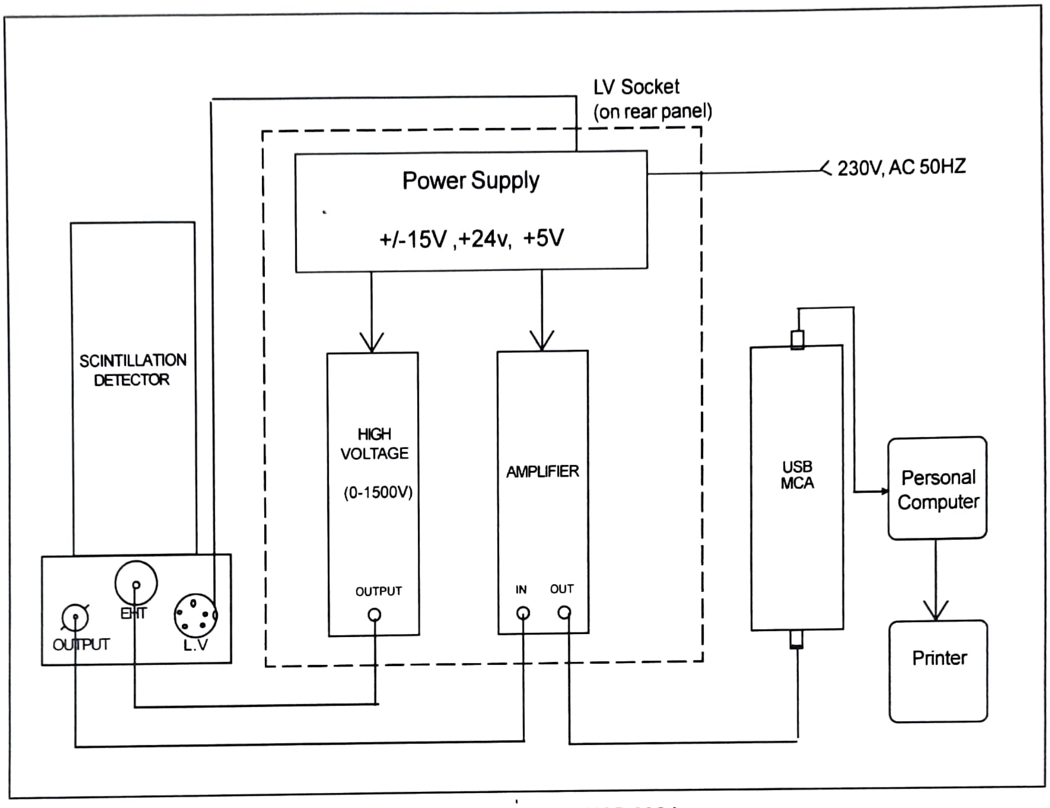


Fig.1. Block diagram USB MCA

- Make the interconnections as shown in the table given below & also in above in Fig.1.Switch on PC & Gamma Ray Spectrometer.
- Invoke the **'ANUSPECT'** software on PC by double clicking on the **'ANUSPECT'** icon on the desktop.
- Then the main screen that appears at the start of the program is shown below in Fig.2.

Table showing system inter connection details

Sl.No.	Name of the connecting cable	Connection from	Connection to
1	BNC to BNC co-axil cable	Scintillation detector	Spectroscopy amplifier INPUT
2	UHF to MHV cable	-do-	High voltage unit
3	LV cable	-do-	Instrumentation bin with power supply MB404 rear panel
4	Spectroscopy amplifier output	MCA (USB) module input	
5	USB cable	MCA module	Personal computer
6	Printer cable	PC	printer

CHAPTER - IV
EXPERIMENTS WITH ANUSPECT SOFTWARE

EXPERIMENT – 1

STUDY OF Cs-137 SPECTRUM AND CALCULATION OF FWHM & RESOLUTION FOR A GIVEN SCINTILLATION DETECTOR

PURPOSE:

Resolution is an important parameter which determines the quality of any scintillation detector. The purpose of this experiment is to calculate FWHM (Full Width at Half Maximum of the Photo peak) and resolution for a given Scintillation detector.

PROCEDURE:

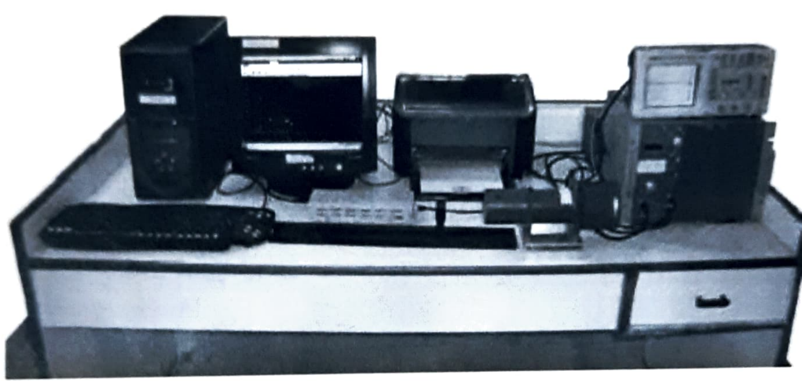


Fig 1 Experimental setup

1. Make system interconnections & default settings.

2. Place a Cs-137 radioactive standard source at a distance of 4 to 5 cm from the face of the scintillation detector.

3. Set HV on the instrument to **750 Volts**, the recommended operating voltage for the scintillation detector used for these experiments.

4. Adjust the amplifier gain such that the photo-peak of 662 keV gammas of Cs-137 will appear at approximately channel 300.

5. Accumulate the Cs-137 spectrum for a time period long enough to get a clear photo-peak. Normally 100 or 200 seconds is enough to get a good photo-peak.

6. The „Print Screen" of the spectrum is obtained using the procedure outlined in the previous section and the same will appear as shown in Fig.2

7. Take a printout of the ROI report as per the procedure outlined in the previous section. The ROI report will appear as shown in ROI report – 1.

Fig.2 Cs-137 Spectrum

Offline ROI

Report:-

Start	End	#Pks	Peak	En	FW(C)	FW (E)	TM/HM	FM/HM	Gross	Net
260	326	1	296.2694	NaN	20.6324	NaN	1.8046	2.4118	150392	145367

DATA ANALYSIS & COMPUTATIONS:

- **FWHM:** Full width at half maximum is the channel width of the Cs-137 spectrum at half the peak height.

    From the ROI report -1,

    FWHM = 20.6324channels

    Peak channel=296.2694

- **Resolution:** Resolution of a NaI scintillation detector is defined as the ratio of FWHM divided by peak channel.
- From the ROI report-1, the photo-peak is appearing at channel 306.5.

    Hence, Resolution = (FWHM/ Peak channel) = 20.6324/296.2694 = 0.069 = 6.9%

- Both resolution & FWHM are important for NaI scintillation detectors and are universally specified with a Cs-137 standard source by the manufacturer of the detector when they supply. Typically resolution for these detectors range from 7.5 % to 9.5%. Resolution is also specified sometimes in keV. This is calculated and illustrated in the later experiments.

EXPERIMENT – 2

STUDY OF Co-60 SPECTRUM AND CALCULATION OF RESOLUTION OF DETECTOR IN TERMS OF ENERGY

PURPOSE:

Sometimes the resolution of a scintillation detector is expressed in terms of energy. The purpose of this experiment is to calculate the resolution of a Scintillation detector in terms of energy (keV / Channel) with the help of Co-60 Spectrum.

PROCEDURE:

The experimental setup used is same as that shown in Fig. 1.

If Experiment-1 was performed and this is a continuation of that, then same settings are to be retained and only Cs-137 source is to be replaced by Co-60 source. If one is doing afresh this experiment, then proceed as below:

1. Make system interconnections & default settings so as to get the Cs-137 peak at approximate channel 300.

2. Place a Co-60 radioactive source preferably 2 to 3 cm away from the face of the detector.

3. Set the live time to 1000 Sec.

4. Record the spectrum.

5. Note down the channel numbers where the maximum heights of the 1.17 & 1.33 MeV photo-peaks are appearing.

6. Now assuming zero energy intercept at the origin, compute peak channel difference and energy difference from the table for calculation of keV per channel.

7. Take the „Print Screen" of the Co-60 spectrum, which appears as in Fig. 3.

8. Printout the ROI report of 1170 keV (1.17MeV) & 1330 keV (1.33MeV) peaks, which appear as in ROI reports

Sr.No	ROIStart	ROIEnd	#Peaks	Peak	Peak(kev)	FWHM	FWHM(kev)	Gross	Net	TM/HM	FM/HM	Skewness	Kurtosis
1	484	556	1	522.7048	NaN	26.6097	NaN	276719	190207	1.7372	2.1191	-0.0634	2.5559
2	557	637	1	593.3704	NaN	29.2318	NaN	210943	101054	1.7498	2.1783	0.0002	2.6572

Fig. 3. Co-60 spectrum

Co-60 spectrum

Calculation of per channel keV : Co-60 peak energies are known to be 1.17 MeV & 1.33 MeV. From the ROI report

We know that the peaks are appearing at the channels mentioned below.

1.17 MeV peak at 522.75 channel

1.33 MeV peak is at 593.37 channel

Energy difference = 1.33 -1.17 = 0.16MeV = 160keV

Channel difference = 593.37-522.75 = 70.62 channel

70.66 channels correspond to 160 KeV

1 channel corresponds to 160 / 70.62 = 2.26 KeV

From the ROI report-4, it can be observed that FWHM is 20.63 channels.

In terms of energy, FWHM = 20.63 x 2.26 = 46.71KeV

Hence, Resolution = FWHM / Peak channel energy = 46.71/662 = 0.0710 = 7.1%

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EXPERIMENT-3

ENERGY CALIBRATION OF GAMMA RAY SPECTROMETER(LINEARITY STUDY)

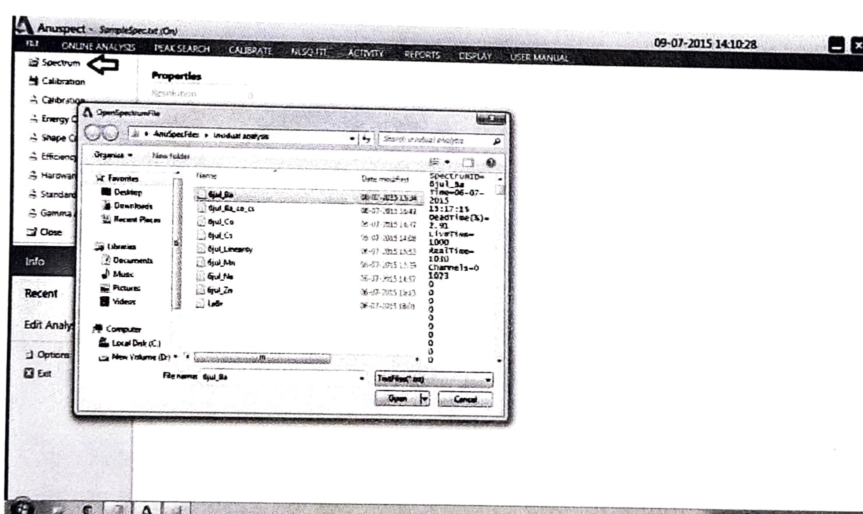
(DIRECT METHOD-FROM SOFTWARE)

Purpose:

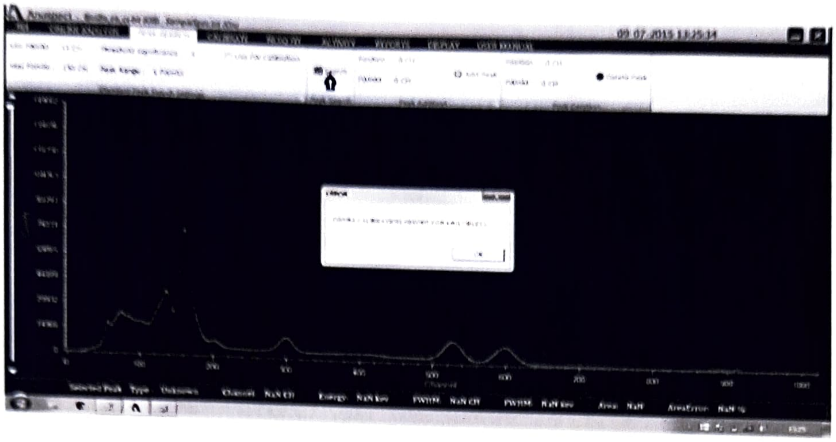
To study the behaviour of the gamma Ray Spectrometer with different energies of Gamma Sources.

Procedure:

1. Make the system interconnections & default settings so as to get the Cs-137 peak approximately at chanel 300.
2. Place different Energy sources on the detector 2cm away. (minimum 3 energies are required for Energy Calibration)
3. Acquire the spectrum to get a fine spectrum after giving the default settings and file name
4. Click file menu, spectrum and load the spectrum to be calibrated energy shape

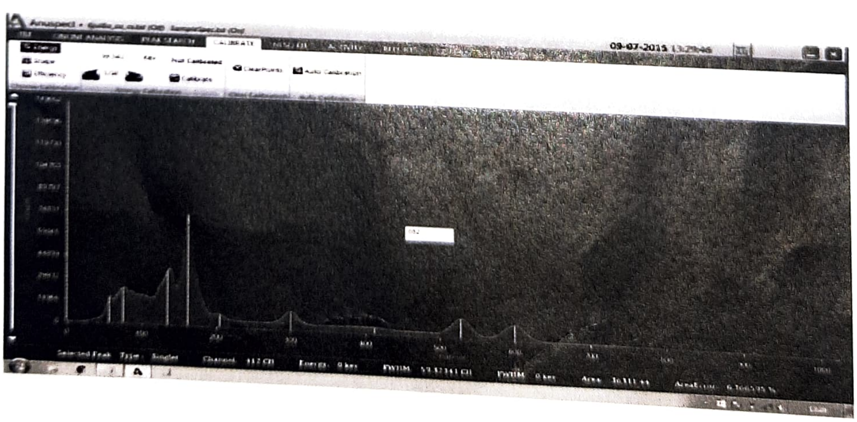


5. Click NO for loading Previous Calibration.
6. Click Peak search menu, search now all the peaks will be detected in the acquired spectrum

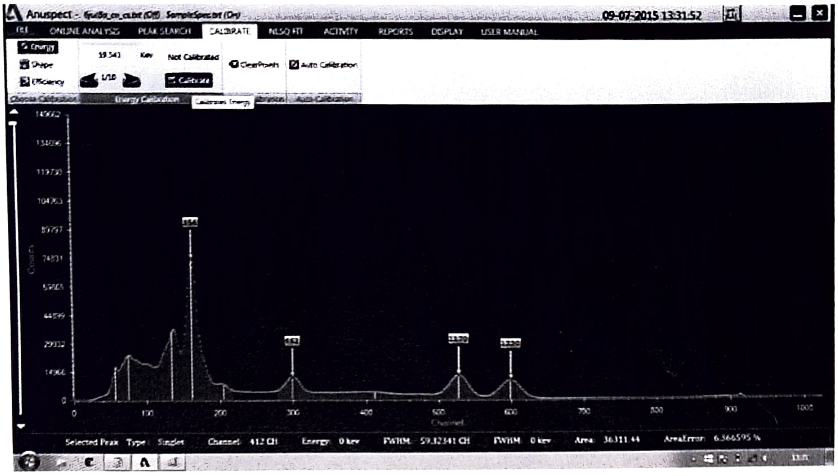


7. Go to Calibrate menu & click on energy after that right click on the spectrum, click input text box

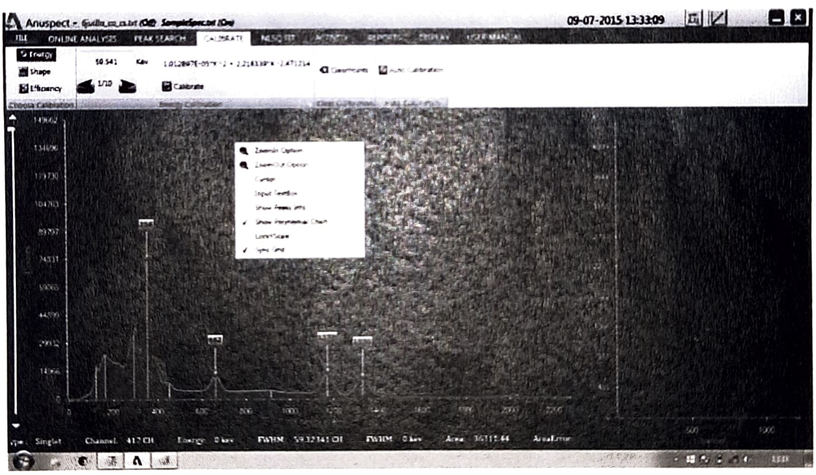
8. Enter the energy in it, and drag it to the corresponding peak.



9. Repeat it for two more peaks



10. Click on Calibrate
11. We can see the polynomial equation & we can use this equation to find out the energy of unknown sample



12. To see the polynomial chart, right click on the spectrum, select show polynomial chart.

EXPERIMENT-4

ENERGY CALIBRATION OF GAMMA RAY SPECTROMETER(LINEARITY STUDY)

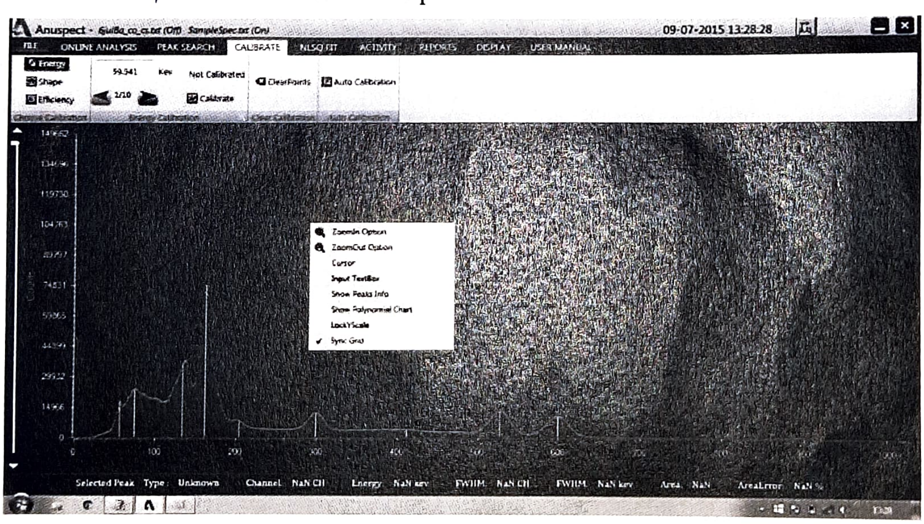
(MANUAL CALCULATION METHOD) – 3 sources

Purpose:

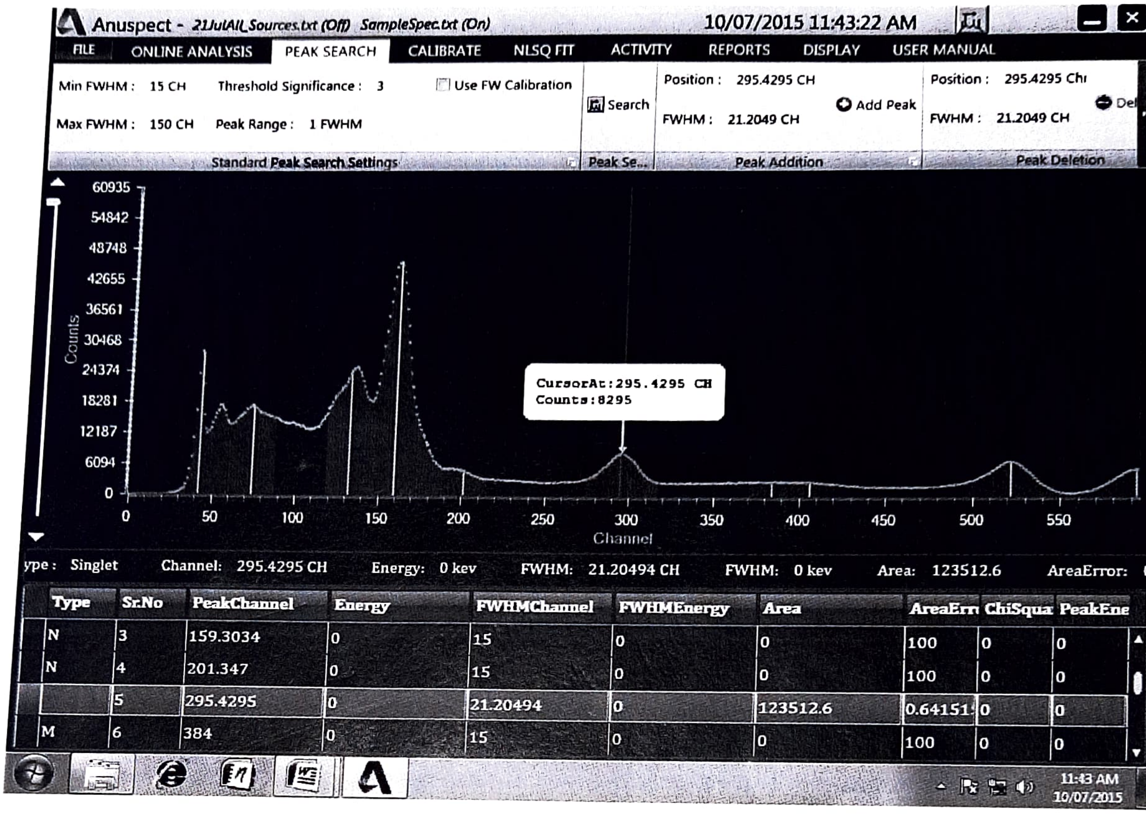
To study the behaviour of the gamma Ray Spectrometer with different energies of Gamma Sources.

Procedure:

1. Make the system interconnections & default settings so as to get the Cs-137 peak approximately at chanel 300.
2. Place different Energy sources on the detector 2cm away. (minimum 3 energies are required for Energy Calibration)
3. Acquire the spectrum to get a fine spectrum after giving the default settings and file name ~ 1500 s
4. Click file menu, spectrum and load the spectrum to be calibrated energy shape.
5. Go to Peak Search menu and search the peak



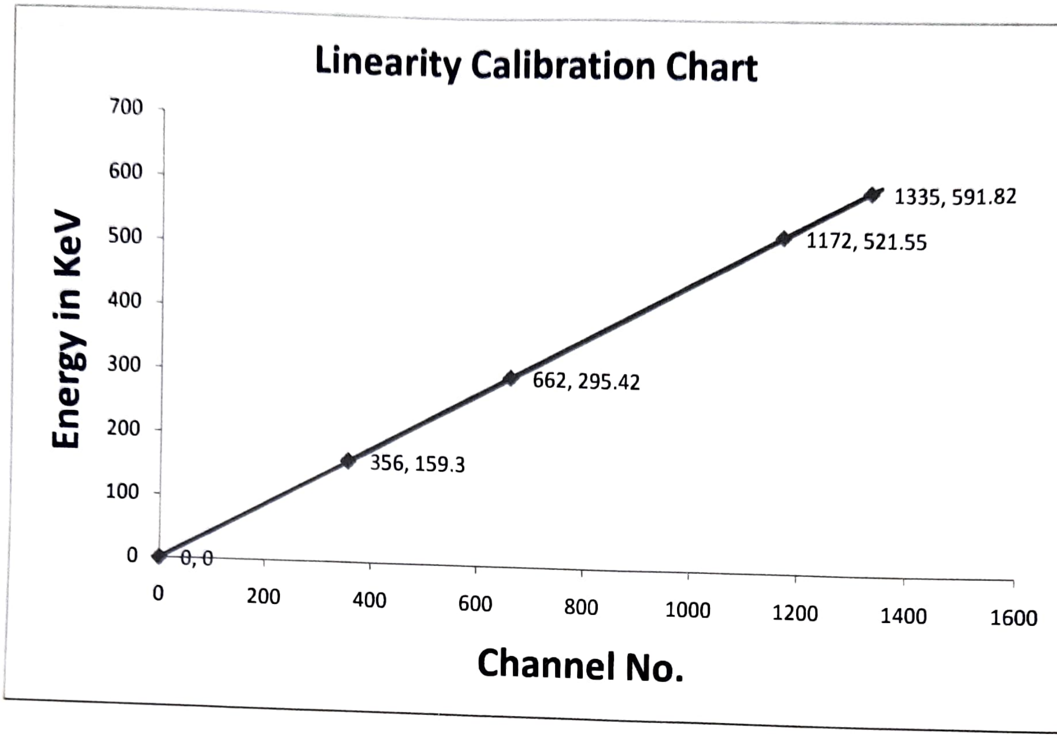
6. Right click on spectrum and select Show Peak Report/ROI, cusrsor.
7. Click on known energy peak, then corresponing peak will be selected in the peak table.



8. Note down the peak channel for that energy
9. And repeat for 2 more peaks and tabulate the data as followed

Source	Energy in KeV	Peak Channel
Ba-133	356	159.30
Cs-137	662	295.42
Co-60	1172	521.55
Co-60	1335	591.82

10. A plot is drawn between energy and channel as shown in figure



Hence, We conclude that the Peak Channel (Pulse Height) of the Gamma Rays is proportional to the energy of that Gamma Energy.

2

EXPERIMENT: 5

UNKNOWN ENERGY OF A RADIOACTIVE ISOTOPE (Na-22)

Purpose:

Unknown masked(Covered) disc source may be given to student to find out its Energy, along with a set of atleast three known Energies

Procedure:

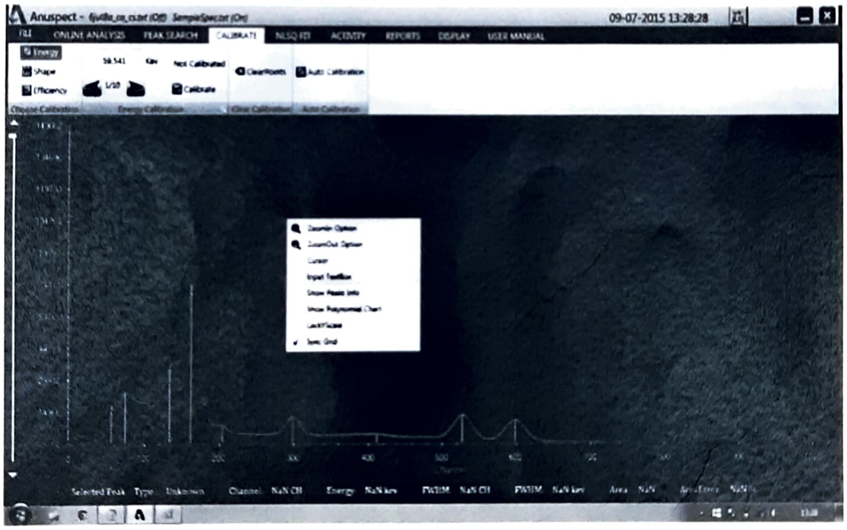
1. This experiment should be followed by the previous experiment.
2. Now acquire the spectrum for the unknown sample for same experimental set up.
3. Load that spectrum and click on the peak channel (where the height of the photo-peak is maximum) and Note down the peak channel no.
4. Now extrapolate this channel no. On to the Energy Linearity Graph to calculate the energy of the unknown peak.
5. The Energy thus obtained should be matched for a known radio active standard source

EXPERIMENT:6

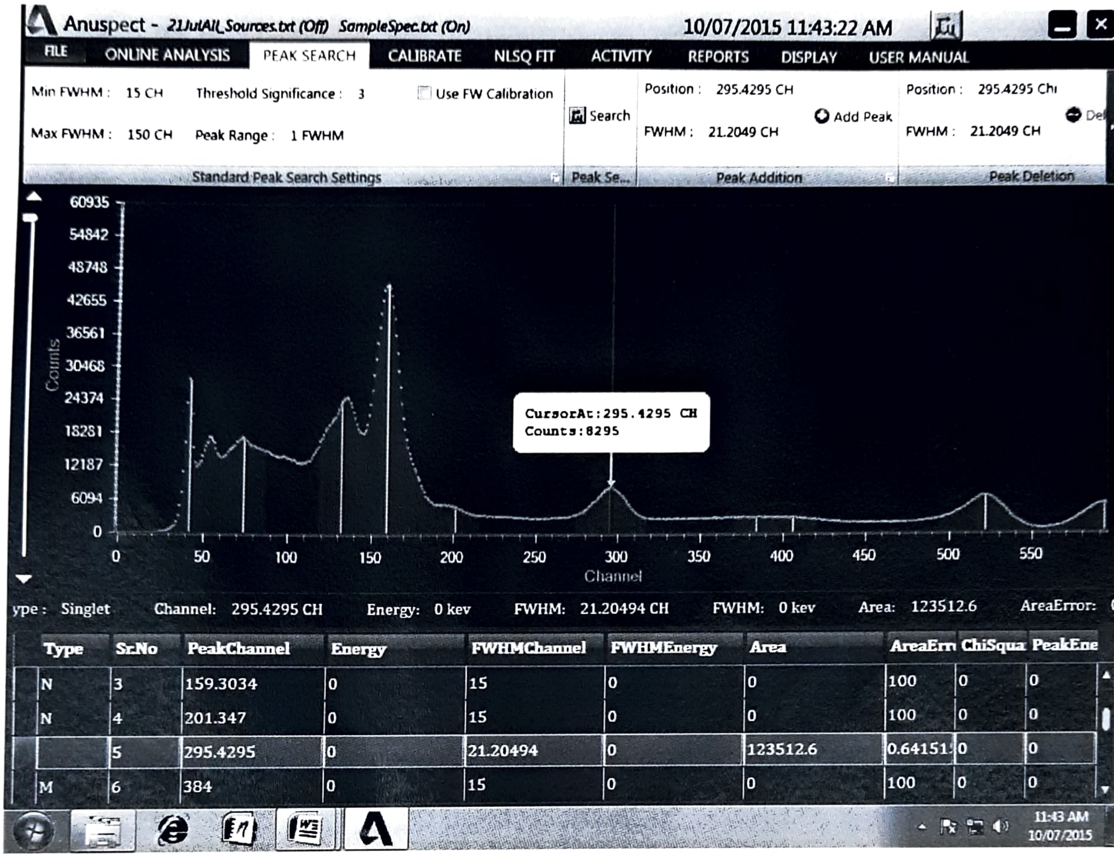
VARIATION OF ENERGY RESOLUTION WITH GAMMA ENERGY

Procedure:

1. Make the system interconnections & default settings so as to get the Cs-137 peak approximately at chanel 300.
2. Place different Energy sources on the detector 2cm away. (minimum 3 energies are required for Energy Calibration)
3. Acquire the spectrum to get a fine spectrum after giving the default settings and file name
4. Click file menu, spectrum and load the spectrum to be calibrated energy shape.
5. Go to Peak Search menu and search the peak



6. Right click on spectrum and select Show Peak Report/ROI, cusrsor.
7. Click on known energy peak, then corresponing peak will be selected in the peak table.



8. Note down the peak channel for that energy
9. And repeat for 2 more peaks and tabulate the data as followed

Data Analysis & Computaion:

Source	Energy in KeV	Peak Channel	FWHM(channels)	Resolution
Ba-133	356	160	15	9.375
Cs-137	662	296.123	20.226	6.83027
Na-22	511	374	22.948	6.135829
Na-22	1275	566.461	29.018	5.122683

Resolution (R) normally varies inversely as the sqare root of the peak energy (E)

i.e. $R \alpha 1/sqrt(E)$

$R = K/sqrt(E)$

Therfore $Rsqrt(E)=K$

Calculate K for each peak energy, find oit the average K and compute the deviation from the avergae K. And tabulate in the following table.

Energy in KeV	Sqrt(E)	Resolution	K=R*sqrt(E)	Average K	Deviation(%)
356	18.86796	9.375	176.8871		-1.31489
511	22.60531	8.080378	182.6594		1.905472
662	25.72936	6.83027	175.7385	**179.244**	-1.95573
835	28.89637	6.135829	177.3032		-1.08279
1285	35.8469	5.122683	183.6323		1.245259

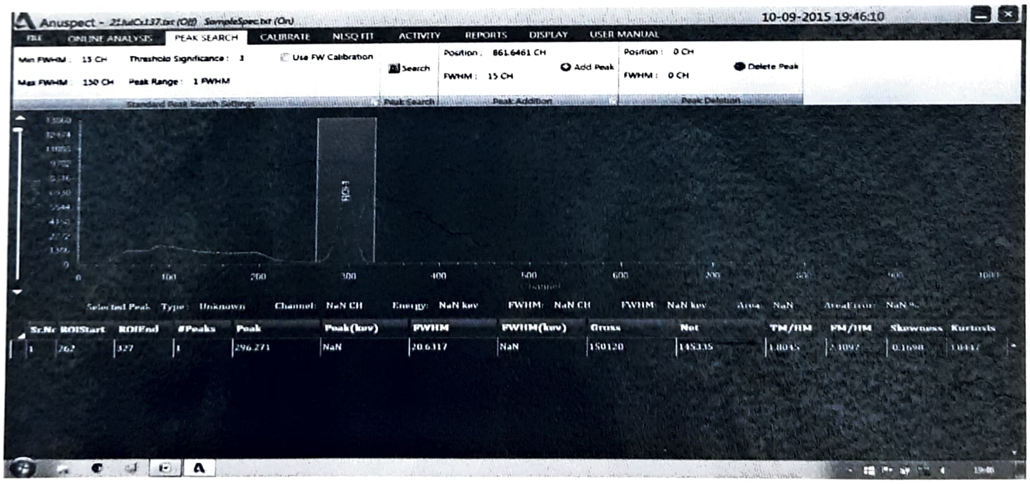
Experiment:7

Activity of a Gamma Emitter(Relative Method)

Purpose: To find the activity of unknown source/sample w.r.t known sample

Procedure:

1. Make the system interconnections & default settings so as to get the Cs-137 peak approximately at chanel 300.
2. Place the standart source S1, at a distance 2cm away from the detector face.
3. Give the file name and acuire the spectrum.
4. Remove and place the unkown source S2, at the distance
5. Give the file name acuire spectrum for the same time.
6. Now open standard source spectrum from file menu
7. Add the ROI such that complete Photo-Peak will be covered.
8. Take print from Report Menu
9. Repeat 7,8 for unknown sample.
10. For the same ROI acquire the background, without placing the sample.



Offline ROI Report for S1:-

Start	End	#Pks	Peak	En	FW(C)	FW (E)	TM/HM	FM/HM	Gross	Net
260	326	1	296.2694	NaN	20.6324	NaN	1.8046	2.4118	150392	145367

Offline ROI Report for s2:-

Start	End	#Pks	Peak	En	FW(C)	FW (E)	TM/HM	FM/HM	Gross	Net
260	326	1	296.3194	NaN	20.6424	NaN	1.8046	2.4118	250492	245476

Offline ROI Report for BG:-

Start	End	#Pks	Peak	En	FW(C)	FW (E)	TM/HM	FM/HM	Gross	Net
260	326	NaN	NaN	NaN	NaN	NaN	NaN	NaN	4432	3982

Computaion:

Gross Counts for S1=150392

Gross counts for S2= 250492

Gross counts for BG= 4432

Corrected Counts for S1=(150392-4432)=145960

Corrected counts for S2= (250492-4432)=246060

Activity of S1=0.249μci (known source)

Hence, the activity of S2 can be calculated by using the equation

(Activity of S1/ Activity of S2)=(Corrected counts for S1)/(Corrected counts for S2)

Activity of S1/activity of S2= 145960/246060=0.5931

There fore activity of S2= activity of S1/0.5931

activity of S2=0.4198μci

since the efficeincy of the detector is energy dependent, the standard sources do not have to be the same isotope. It is only necessary that their gamma energies should be approximately same($\pm$10%) in order to get a fairly good estimate of the absolute famma energy of the unknown

EXPERIMENT: 8

OBTAIN THE RELATIONSHIP BETWEEN FWHM & ENERGY OF THE GAMMA SOURCES (SHAPE CALIBRATION)

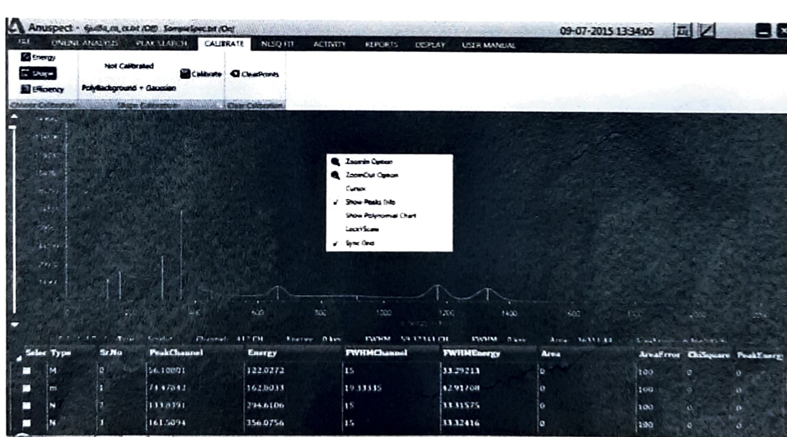
Procedure:

1. Make the system interconnections & default settings so as to get the Cs-137 peak approximately at chanel 300.
2. Place different Energy sources on the detector 2cm away. (minimum 3 energies are required for Energy Calibration)
3. Acquire the spectrum to get a fine spectrum after giving the default settings and file name
4. Click file menu, spectrum and load the spectrum to be calibrated energy by following the steps in the experiment no.

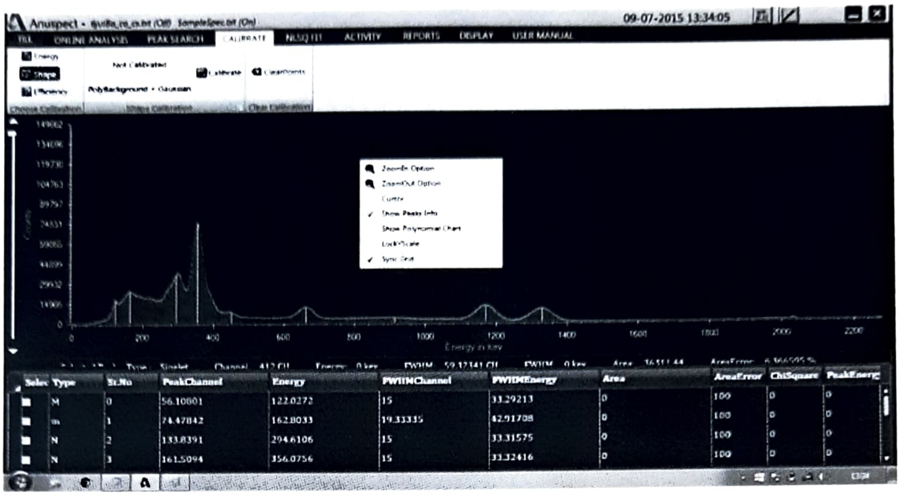
5. **Shape Calibration:**

This type of calibration is used to plot the relationship between FWHM and Energy of the Gamma Ray Spectrometer. Hence we can get proper area under the curve at any energy.

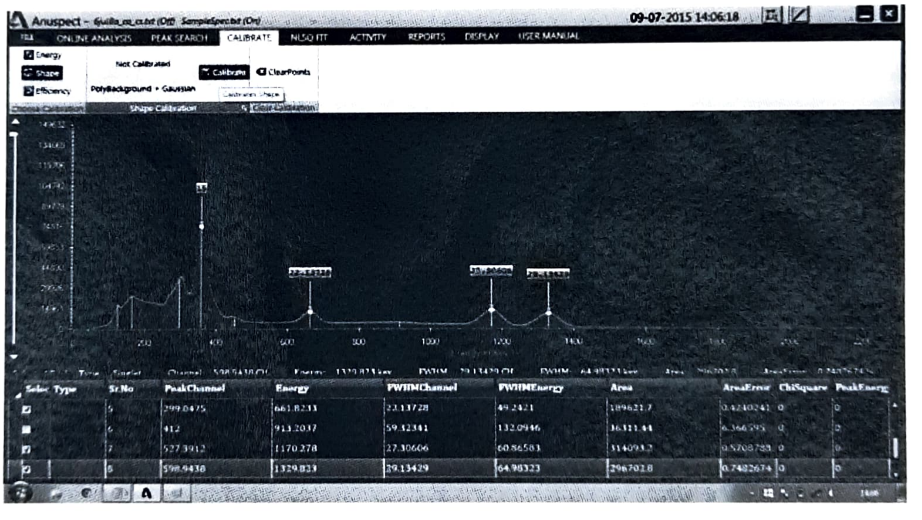
Click on "shape' in calibrate menu.



6. Right click on the spectrum and select show peaks information.

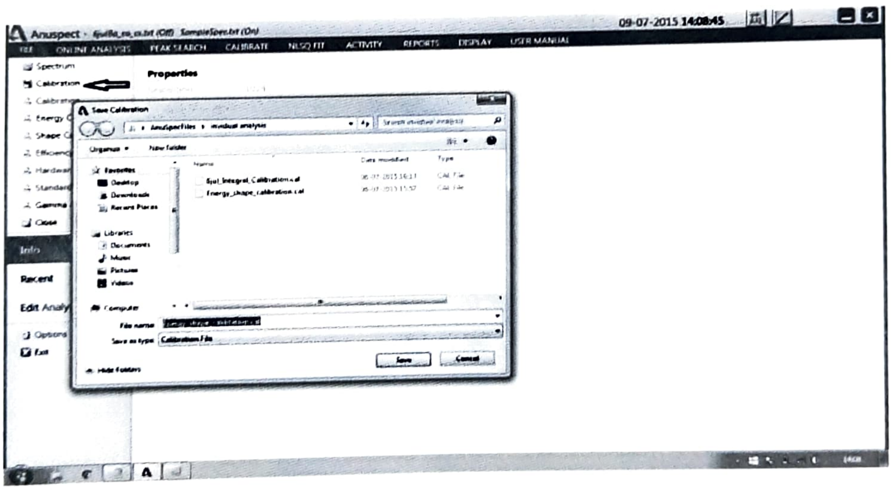


7. Select minimum three strong energy peaks from the table shown.



8. Click on calibrate to do shape calibration.
9. We can see the polynomial chart and equation by right click option
10. Click on NLSQ fit menu, to apply shape calibration to the whole spectrum by clicking" Fit" (Model Fit).

11. Click on file menu, click on calibration, save the calibration data with appropriate name. (Ex. Energy shape).



12. We can utilise this data for future analysis of spectrum for the same hardware settings.

EXPERIMENT: 9

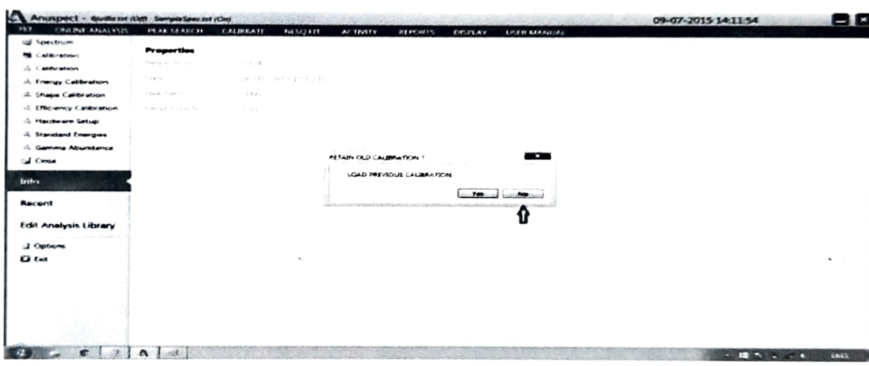
PLOT THE GRAPH BETWEEN THE EFFICIENCY AND ENERGY FOR THE GAMMA RAY SPECTROMETER (Efficiency Calibration)

Procedure:

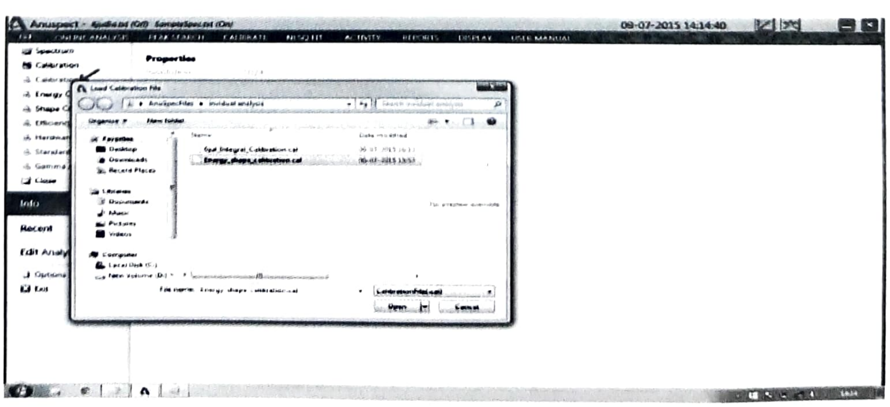
1. Do the energy and shape Calibration and save the calibration with an appropriate Name
2. **Efficiency Calibration:**

   Acquire the spectrum for different radioactive sources individually acquire for longer time in order to have fine spectrum.

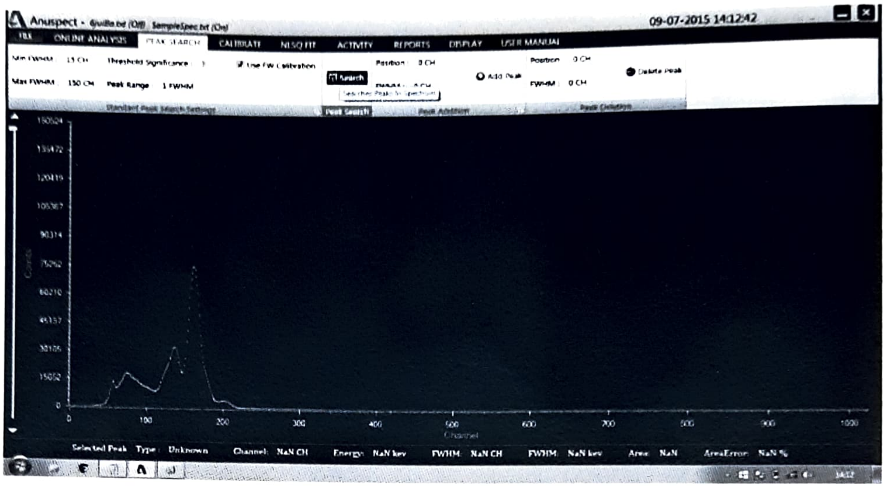
   Ex: Cs-137, Co-60, Mn-54, Zn-65 etc.
3. Click file menu, spectrum, select and load the individual spectrum to do calibration (Ex. Ba-133).
4. Click No, to reject load previous calibration.



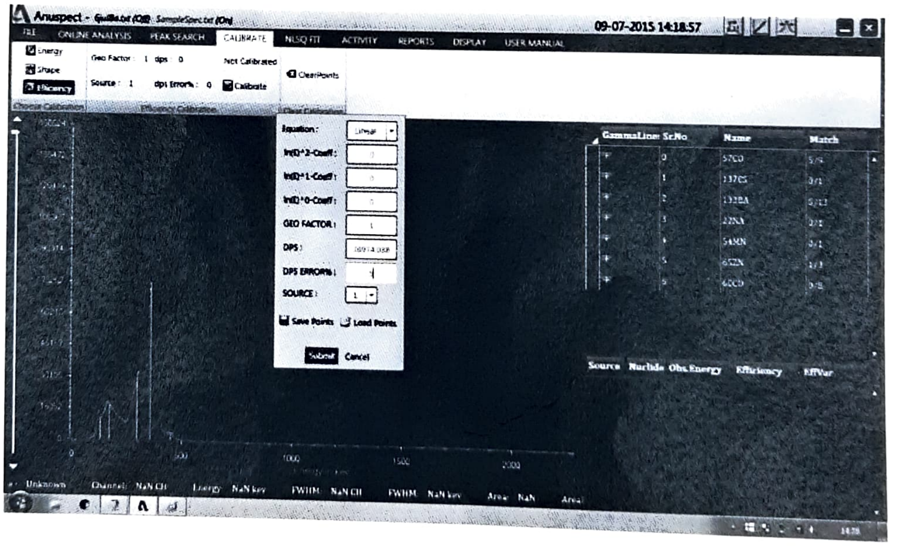
5. If the calibration file already copied in root folder, press "Yes" (for the same settings of setup).
6. Otherwise load the calibration from file menu.



7. Search peaks by selecting use FW calibration.

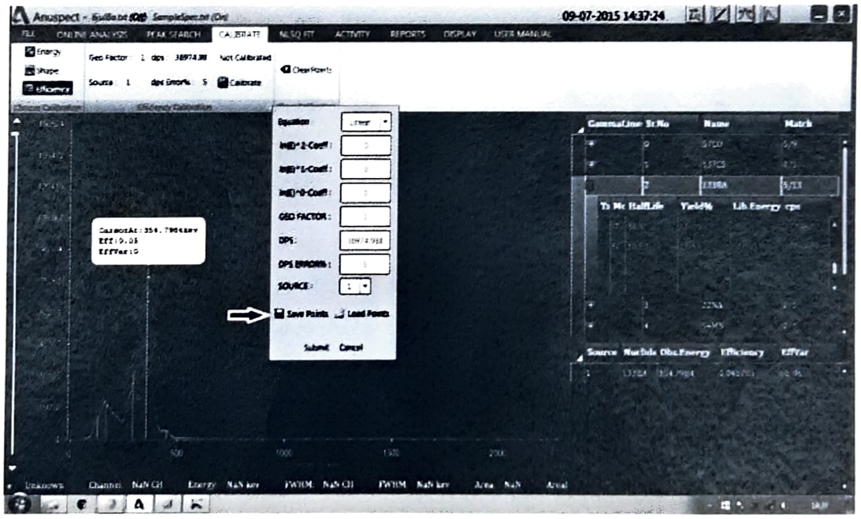


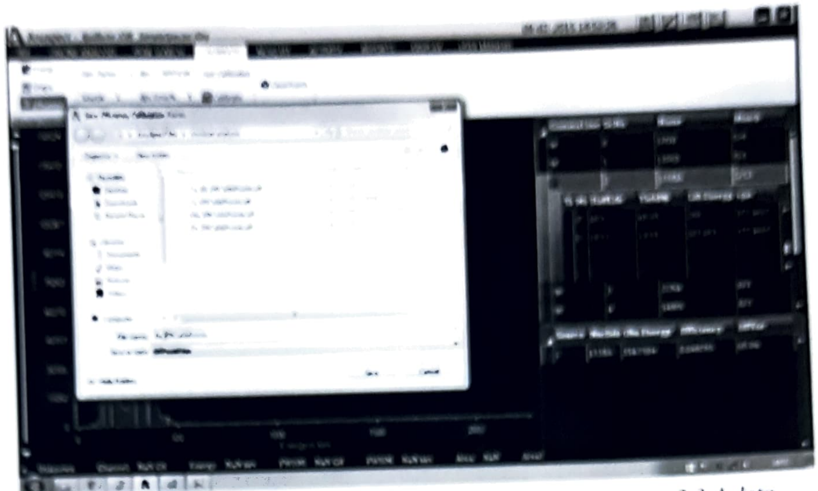
8. Click on calibrate menu, efficiency calibration-sub menu and enter the DPS, DPS error % and submit for Ba-133.



9. Click on (+) gamma line corresponding to Ba-133, **select and drag** the most matching energy level, which is having maximum yielding of gamma line, to selection window.

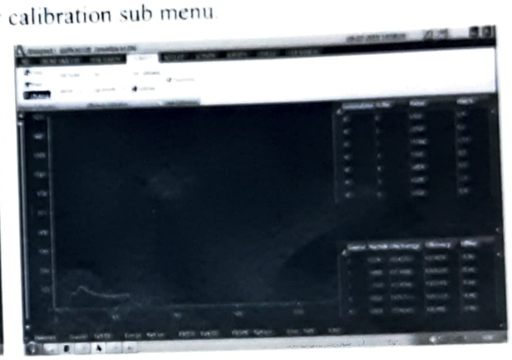
10. Go to efficiency calibration sub menu, select source 1 (1 source data) from drop down and save the points. (Ex. Ba-133effiCalib).





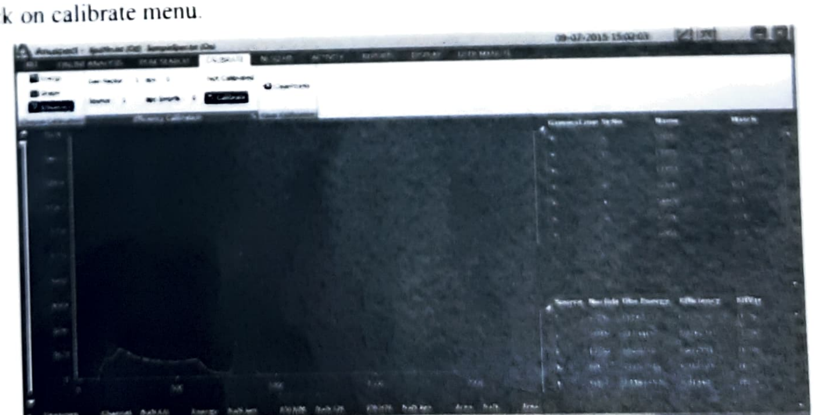
11. Repeat above steps for Co-60, Zn-65, Mn-54 and save points as source 2,3,4 data.

12. Now load the saved points from efficiency calibration sub menu.



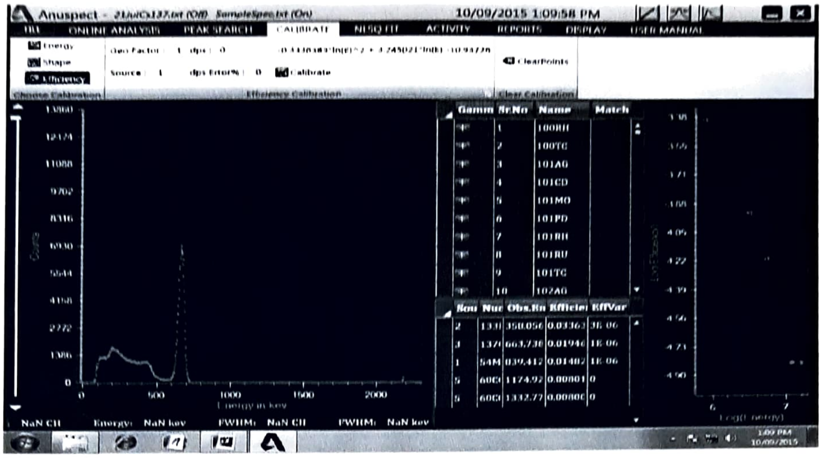
13. To remove the wrongly loaded point, double click that point in the selection table.

14. Click on calibrate menu.

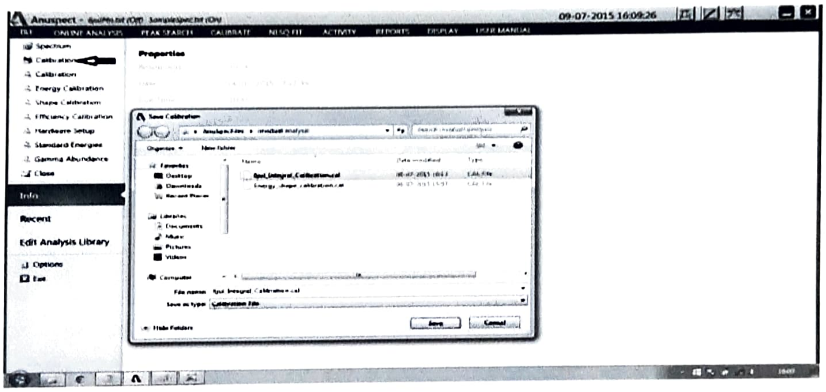


15. Polynomial equation will be shown.

16. After that right click on spectrum and select show polynomial chart to see the graph.



17. Now **save the calibration** by clicking calibration in file menu.



18. We can utilise this calibration to another spectrums for the same hardware setting to calculate the activity of unknown sample
19. This calibration data will be saved as three separate child files with the same parent name. (Ex. If we save the calibration as **fullcalibration.cal** then it will also saved as **fullcalibration.encal**, **fullcalibration.shpcal** and **fullcalibration.effcal.** we can also import the energy/shape/efficiency calibration data alone from the above child files with different prefixes)

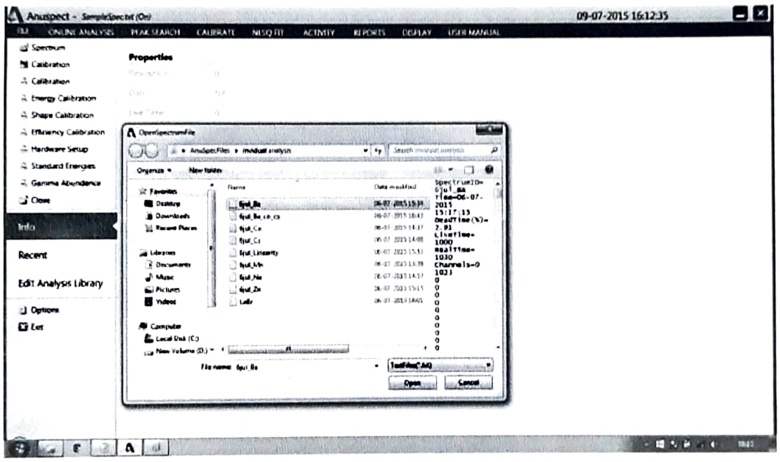
EXPERIMENT: 10

ACTIVITY CALCULATION OF UNKNOWN SOURCE.

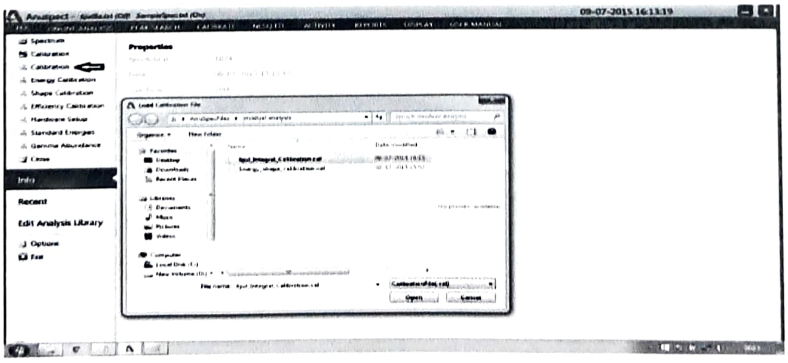
Purpose: To calculate the activity of Unknown gamma isotope with reference std. isotopes

Procedure:

1. Make the same system interconnections & default settings, those were used at the time of calibration of the system.
2. Do the energy, shape & efficiency calibration as explained previously.
3. Save the calibration with an appropriate file name.
4. **Activity Calculation:**
   Now acquire the spectrum for the given sample (acqure for long time if it is low active).
5. Load the spectrum from file menu, spectrum.



6. Load the appropriate calibration from file menu.



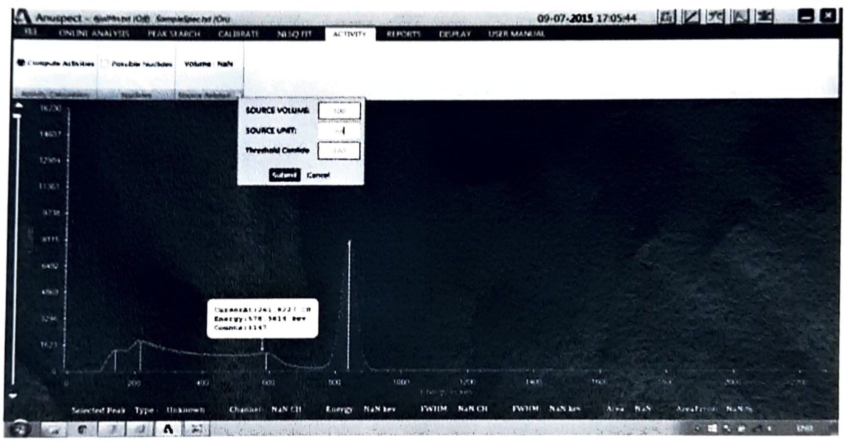
7. Search the peaks by selecting "USE FW Calibration",
8. Fit the spectrum in NLSQ fit (model fit)
9. Enter sample volume and unit in activity menu, source selected sub menu.

sample volume: It is defined as the portion/percentage of the volume using for the calucation activity w.r.t stdard volume used at the time of calibration.

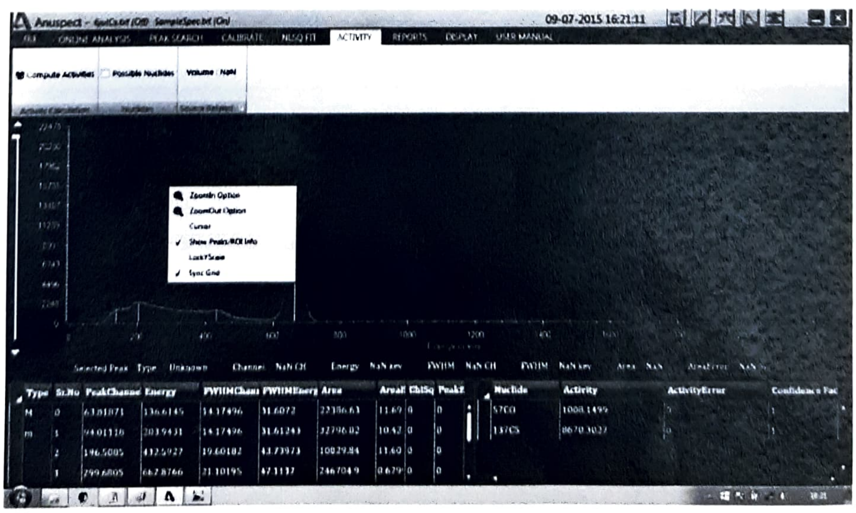
Ex. 5ml of std. Sources are used for the calibration and we want to find out the activity of 1ml unknown sample activity.

Then sample volume should be entered= sample vol./std. Volume

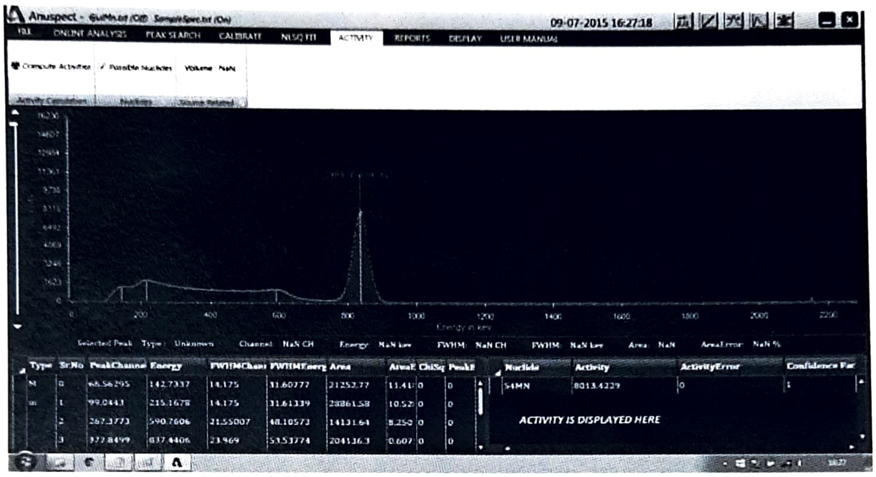
i.e=1/5=0.2



10. Click on compute activities.



11. Right click on spectrum, select "**ROI/Show peak info** " and we can see the activities of the sample.



Experiment : 11

Experimental data

The following Imported sources are used to calibrate the system. And to perform the experiments

Efficiency Calibration done by adding Cs-137, Mn-54, Co-60,Zn-54 **single source** data points by using **3"X3" NaI** scintillation Detector Well type

Default settings:
HV: 550V
Software:
SPECTRUM ID: CS-137
SPEC FORMAT: txt
SPEC PATH: Brows the location
MCA Mode: PHA
TIME MODE: LIVE
RESOLUTION: 1024 CHNLS
BASE LINE: 0V
ULD:10V
LLD:0.1V

s.no	Nuclide	Activity	Calculated	%Error in activity
1	Cs-137	8776.3038	8670.3	-1.20784
2	Co-60	24310.0767	22200.01	-8.6798
3	Ba-133	36974.988	31885	-13.766
4	Na-22	19516.353	18225	-6.61677
5	Zn-65	7138.854	7500.5	5.065883
6	Mn-54	7782.765	8013.4	2.963407
7	Cd-190	12529.125	peak not found	

Efficiency Calibration done by Mn-54, Zn-65, Na-22 and Cs-137 sources placing **at a time** by using 3"X3" **NaI** scintillation Detector Well type

s.no	**Nuclide**	**Activity**	**Calculated**	**%Error in activity**
1	Cs-137	8776.304	9886	12.64423
2	Co-60	24211.32	36977	52.72
3	Na-22	19381.53	23119	19.28367
4	Zn-65	6839.154	9098	33.02815
5	Mn-54	7577.41	8623	13.79878
6	Cd-190	12529.125	peak not found	

EXPERIMENT – 12

MASS ABSORPTION COEFFICIENT

PURPOSE : The purpose of the experiment is to measure experimentally the mass absorption coefficient in lead for 662-keV gamma rays.

THEORY : It is well known that gammas interact with matter primarily by photoelectric, Compton, or pair-production interactions. The total-mass absorption coefficient can be measured easily with a gamma-ray spectrometer. In this experiment we will measure the number of gammas that are removed from the photo-peak by photo-electric or Compton interactions that occur in a lead absorber placed between the source and the detector.

From Lambert's law the decrease of intensity of radiation as it passes through an absorber is given by

$$I = I_0 e^{-mx}, \qquad \text{---------------------------} \quad (7)$$

Where

I = intensity after the absorber,

I_0 = intensity before the absorber,

m = total – mass absorption coefficient in cm^2 / g,

X = density thickness in g / cm^2.

The density thickness is the product of the density in g/cm^3 times the thickness in cm. The half –value layer (HVL) is defined as the density thickness of the absorbing material that will reduce the original intensity by one-half.

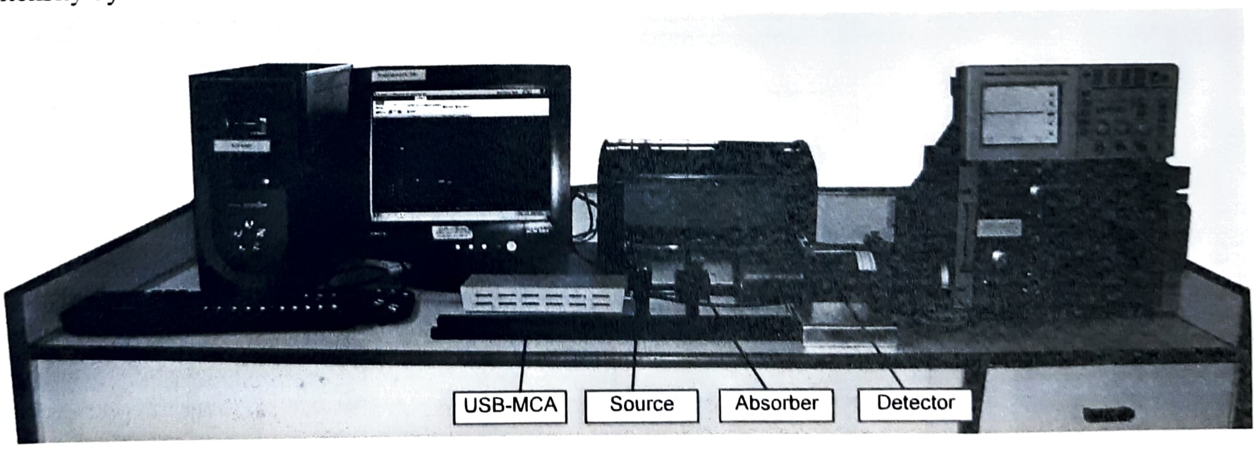


Fig. 22. Experimental setup

PROCEDURE:

1. Make system interconnections and default settings.
2. Set HV to 750volts.
3. Adjust the amplifier gain such that the photopeak of 662 KeV gammas will appear at approximately channel 300.
4. Set a live time of 250 Sec.
5. Insert the first piece of lead absorber (1.5 mm thick) between source and detector. Acquire the spectrum.
6. Repeat with additional pieces of lead absorber in increments of 1.5 mm until the gross area under the 662 keV photopeak falls upto 2000. Acquire spectrum for each thickness of lead absorber.
7. Obtain the background spectrum for the set live time of 250 Sec.
8. Take ROI reports pertaining to 662 keV peak of Cs-137, for the respective absorber thicknesses.
9. From the ROI reports, obtain the gross counts pertaining to 662 keV peak, against each absorber thickness.
10. Obtain the gross background counts from the ROI report pertaining to background.
11. Calculate the net counts for each absorber thickness. (net counts = gross counts – background counts).
12. Tabulate the data as shown in the following Table -7.

DATA : Table-7 **(FOR LEAD)**

Background counts for 250 sec = 3080

Data for Mass Absorption Coefficient of Lead	
Thickness (mm)	Net counts
0	260193
1.5	216338
3.0	183417
4.5	153091
6.0	130285
7.5	110772

9.0	92732
10.5	77957
12.0	65243
13.5	54355
15.0	45207
16.5	37627
18.0	31805
19.5	26515
21.0	22077
22.5	18218

EXERCISE A : (FOR LEAD)

- Plot the Net Counts versus Absorber thickness in 'mm' as shown in the Fig. 22 and determine the Half Value Thickness or Half Value Layer (HVL) in terms of thickness (mm) from the Curve.
- The Half Value Layer (HVL) is also expressed in terms of Density thickness **(gm/cm^2)**. Density thickness is the product of density in **gm/cm^3** times the thickness in **cm**.
- Determine the HVL in **gm/cm^2** and calculate the Mass Absorber Coefficient **m** from Eq. 10. How does your value compare with the accepted value of **0.105 cm^2/gm**?

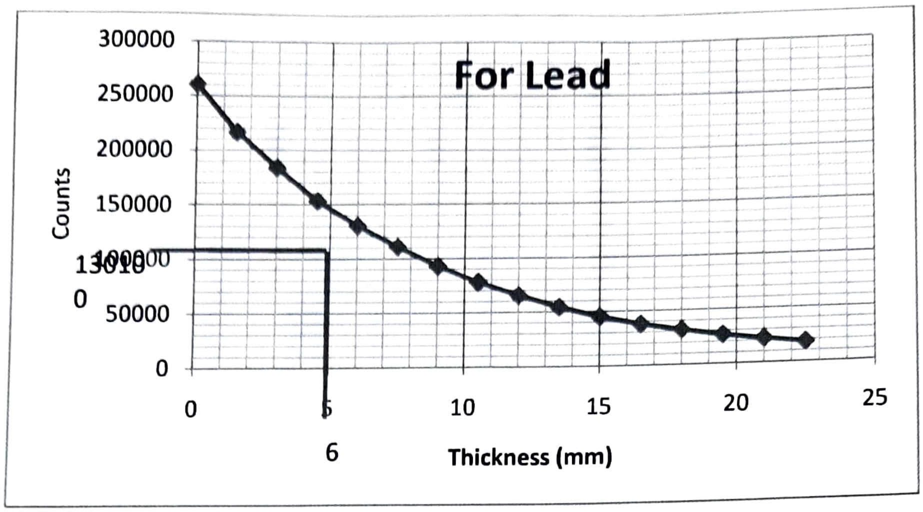


Fig. 22 Graph showing variation of counts with Lead absorber thickness

Computation & Result :

The observed value of HVL from the graph is 6mm or 0.6 cm.

Density Thickness = 0.6 x 11.34 = 6.804 gm/cm^2. (Density of lead = 11.34 gm/cm^3).

Hence mass absorption coefficient

$$m = 0.693 / HVL$$

$$= 0.693 / 6.804$$

$$= 0.102 \text{ cm}^2/\text{gm}$$

This value 0.102 cm^2/gm is very well in agreement with the accepted value of **0.105 cm^2/gm.**

EXERCISE B: (FOR STEEL)

Procedure :

The experiment is repeated with steel absorbers in the same manner as was done with lead absorbers, except that the Cs-137 source is kept at a distance of 8 cm from the face of the detector.

In this experiment, the steel absorbers are incremented in the steps of 4 mm till a maximum thickness of 60 mm is reached.

Thickness Vs net counts are tabulated the following Table-8

DATA :

Table-8 (FOR STEEL)

Background counts for 250 sec = 3080

Data for Mass Absorption Coefficient of stainless steel	
Thickness (mm)	Net counts
0	107312
4	88212
8	74429
12	60825
16	49682
20	40378
24	32545
28	26586
32	21800
36	17893
40	14308
44	11658
48	9531
52	7372
56	6086
60	5232

- Plot the Net Counts versus Absorber thickness in 'mm' as shown in the Fig. 23 and determine the Half Value Thickness or Half Value Layer (HVL) in terms of thickness (mm) from the Curve.
- The Half Value Layer (HVL) is also expressed in terms of Density thickness **(gm/cm^2)**. Density thickness is the product of density in **gm/cm^3** times the thickness in **cm**.
- Determine the HVL in **gm/cm^2** and calculate the Mass Absorber Coefficient **m** from Eq. 10.

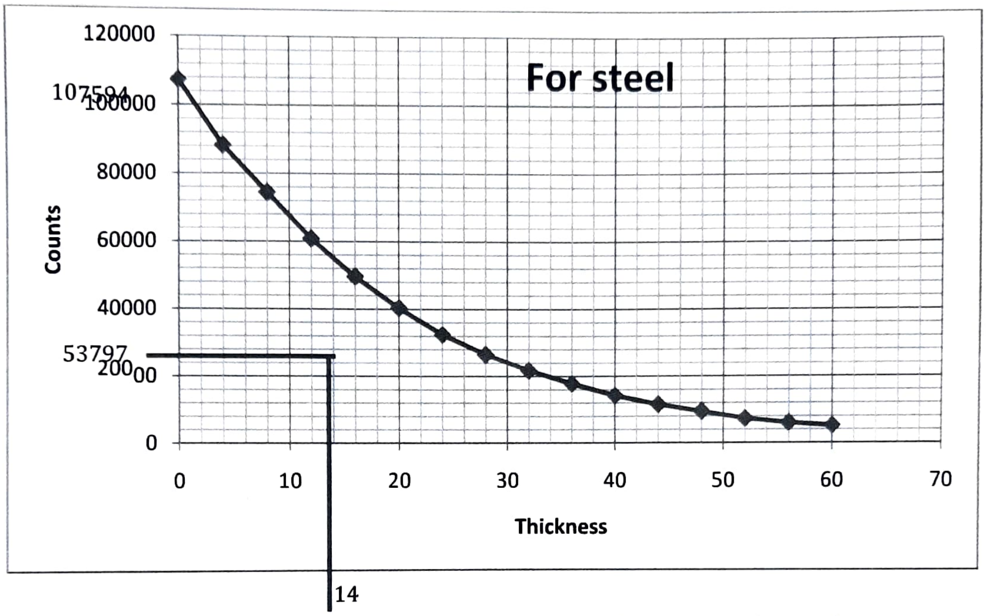


Fig.23 Graph showing the variation of counts with Steel absorber thickness

Computation & Result :

The observed value of HVL from the graph is 14 mm or 1.4 cm.
Density Thickness = 1.4 x 7.75 = 10.85 gm/cm^2. (* Density of lead = 7.75 gm/cm^3).
Hence mass absorption coefficient

$$m = 0.693 / HVL$$
$$= 0.693 / 10.85$$
$$= 0.064\ cm^2/gm$$

* **Note :** As the density of steel can vary between 7.5 and 8.0 the average value of 7.75 is considered for calculations.

CHAPTER - V

IMPORTANT DEFINITIONS OF RADIATION TERMS

□ **Absorbed dose :** The energy transferred to a material by ionising radiation per unit mass of the material.

Unit : J kg^{-1}; Name of unit : Gray (see also Rad)

□ **Activity :** Measurement of quantity of radioactive material. It is the number of nuclear transformations or isomeric transitions per unit time.

Unit : s^{-1} Name of unit : Becquerel (see also Curie)

□ **Alpha decay :** A radioactive conversion accompanied by the emission of an alpha particle. In alpha decay the atomic number is reduced by 2 and the mass number by 4. Alpha decay occurs, with a few exceptions, only for nuclides with a proton number exceeding 82.

□ **Alpha radiation :** Radiation that consists of high energy helium (^4He) nuclei emitted during alpha disintegration of atomic nuclei. Alpha particles possess discrete initial energies (line spectra) which are characteristic of the emitting nuclide.

□ **Becquerel (Bq) :** Name of the derived SI unit of activity. Number of radioactive transformations or isometric transitions per seconds s^{-1} = Bq.

1 Bq	=	27×10^{-12}	=	27 pCi
1 kBq	=	27×10^{-9}	=	27 nCi
1 MBq	=	27×10^{-6}	=	27 mCi
1 GBq	=	27×10^{-3}	=	27 mCi
1 TBq	=	27 Ci	=	27 Ci

□ **Beta decay :** Radioactive conversion accompanied by the emission of a beta particle, i.e. a negatively charged electron (□$^-$ decay) or a positively charged electron (□$^+$ decay). When a negatively charged electron is emitted, a neutron in the atomic nucleus is converted to a proton with the simultaneous emission of an antineutrino, so that the proton number Z is increased by 1. When a positively charged electron (positron) is emitted, a proton in the nucleus is converted to a neutron with simultaneous emission of a neutrino, so that the proton number **Z** is decreased by 1.

- **Beta Radiation :** Radiation that consists of negative or positive electrons which are emitted from nuclei undergoing decay. Since the decay energy (or, if it is followed by gamma radiation, the decay energy less that photons energy) is statistically divided between beta particles and neutrinos (or antineutrinos), the energy spectrum of beta radiation is continuous, extending from zero to a maximum value characteristic of the nuclide concerned. The maximum beta energy is generally termed the "beta end-point energy of the nuclide".

- **Bremsstrahlung :** Radiation that results from the acceleration/deceleration of charged particles in the Coulomb field of atoms.

- **Curie (Ci) :** Name for derived unit of activity. One Curie corresponds to 3.7 x 10^{10} nuclear disintegrations or isomeric transitions per second 1 Ci = 3.7 x 10^{10} s^{-1}.

1 Ci	=	37 GBq
1 mCi	=	37 MB1
1 □Ci	=	37 kBq
1 nCi	=	37 Bq
1 pCi	=	37 mBq

- **Dose :** See absorbed dose, exposure value, and dose equivalent.

- **Dose equivalent :** A term used in radiation protection for the radiation dose. It is the product of absorbed dose times the quality factor.
  Unit : J kg^{-1}; Name of unit: Sievert (see also Rem)

- **Dose rate :** Dose absorbed per unit time

- **Electron radiation:** Particle emission consisting of negatively or positively charged electrons.

- **Exposure dose:** The ratio of the amount of electric charge of the ions of one polarity that are formed in air by Ionizing radiation and the mass of the air.
  Unit: C. kg^{-1} (see also Roentgen)

- **Gamma radiation:** Photon radiation emitted by an excited atomic nucleus decaying to a lower energy state. Gamma radiation has a line spectrum with photon energies which are specific to the nuclide concerned. Gamma and X-rays are both electromagnetic radiation and they are distinguished only by their mode of generation.

- **Gray:** The SI unit of absorbed radiation dose. 1 Gray of absorbed dose corresponds to 1 joule of energy per kilogram of mass.
  1 Gray = 100 rad

- **Ionising radiation:** Radiation that consists of particles capable of ionizing a gas.

- **Isotopes:** Nuclides with the same atomic number but different atomic weights (Mass numbers).

- **Mass per unit area:** Product of the density of a material and its thickness.

- **Nuclide :** Generic term for neutral atoms that are characterized by a specific number of neutrons N and protons Z in the nucleus.

- **Quality factor :** A factor which in radiation protection allows for the effects of different types of radiations and energies on people.

- **Rad (Radiation Absorbed Dose):** An old unit used to measure absorbed radiation dose. 1 Rad of absorbed dose corresponds to 0.01 joule of energy per kilogram of mass (=100 ergs of energy per gram of mass).
  All measurements of absorbed dose depend on the absorbing medium as well as the level of radiation. 1R is equivalent to 0.871 rad in air.

- **RBE (Relative Biological Effectiveness)**
  The biological effect of radiation depends, not only on the energy absorbed, but also on the radiation concerned. To illustrate, the effect of 1 Gray of X-ray will be quite different from the effect of 1 Gray of neutrons. The RBE is an attempt to compensate for this variation and may be considered as a weighting factor for different type of radiation.
  RBE (for radiation of Energy E) is defined as the ratio; (Dose of 200 keV gamma rays producing a given biological effect) divided by (dose of radiation of energy E producing the same effect).

- **Radioactivity :** The property which certain nuclides have of emitting radiation as a result of spontaneous transitions in their nuclei.

- **rem (Roentgen Equivalent Man) :** The rem is an early unit used to measure the effect of a given type of radiation on living tissue, including compensation for the type of radiation involved.
  rem dose = rad dose x RBE

- **Roentgen-R :** An old unit used to measure radiation by its ability to ionize air. 1 Roentgen is that amount of radiation which releases a charge of 258 microcoulomb per kilogram of air. This measure is a specific quantity of radiation, but does not relate to the absorption by materials.

- **Sievert (Sv) :** This is the SI unit used to measure the effect of a given type of radiation on living tissue, including compensation for the type of radiation involved.

  1 Sievert = 100 rem

- **Attenuation coefficient :** The probability that a photon will be removed from the incident beam per unit thickness of material traversed.

- **Half-value thickness ($T_{1/2}$):** The thickness of material layer that reduces the initial intensity of radiation by a factor of two.

- **Linear absorption coefficient:** It is given by 0.693 / $T_{1/2}$, where $T_{1/2}$ is the half value thickness. □ is expressed in cm^{-1}.

- **Mass absorption coefficient :**It is given by linear absorption coefficient divided by density of material. It is expressed in cm^2 / gm

- **Scintillation :** The optical photons emitted as a result of the interaction of a particle or photon of ionizing radiation with a scintillator.

- **Scintillator :** The material that emits light when particles traverse it. Alternatively, the material which absorbs energy and releases its energy in the form of light photons.

- **Scintillation counter :** The combination of scintillator, photomultiplier tube and associated circuitry for detection and measurement of ionizing radiation.

- **Photomultiplier Tube (PMT) :** A photo tube with one or more dynodes between its photo cathode and output electrode (anode). It is a transducer which converts light energy into electrical pulses.

- **Photocathode :** An electrode used for obtaining photoelectric emission when irradiated.

- **Anode (in electron tubes) :** An electrode through which a principal stream of electrons leaves the interelectrode space.

- **Dynode :** An electrode which performs a useful function, such as current amplification, by means of secondary emission.

- **Full width at half maximum (FWHM) :** The full width of a distribution measured at half the maximum ordinate.

- **Peak channel :** Channel number corresponding to the peak of a distribution

- **Resolution (%):** Resolution of a NaI scintillation detector is defined as the ratio of FWHM divided by peak channel.

- **Absolute efficiency :** The ratio of number of pulses recorded to the number of radiations emitted by the source.

- **Intrinsic efficiency :** The ratio of number of pulses recorded to the number of radiations incident on the detector.

- **Background counts (radiation counters) :** Counts caused by ionizing radiation coming from sources other than that be to measured.

CHAPTER – VI

ACTIVITY & DOSERATE CALCULATION PROCEDURE

a. Activity calculation (as on date)

It is known that, given the activity at any previous date and by knowing its half-life we can calculate the present activity by using the following equation.

$$A = A_0 e^{\square\square t}$$

$$= A_0 e^{-(0.693/T1/2)\,t}$$

Where,

A	=	Present activity
A_0	=	Activity as on previous date
$T_{1/2}$	=	Half life of source
t	=	Elapsed time
$\square$	=	Decay constant

TYPICAL CALCULATION OF ACTIVITY FOR TWO BETA AND TWO GAMMA SOURCES:

BETA SOURCES:

Sr-90: (3.7 KBq, Oct 2006); Half life for Sr-90 is $T_{1/2} = 28.5$Yrs

Activity (A_0) = 3.7 KBq, as on Oct’ 2006.

= 3700 Bq

Elapsed time till Sept’ 2010 = 3years 11months = 3.9166 years

Present activity (A) = $A_0 e^{-(0.693/T1/2)\,t}$; as on Sept’ 2010

$T_{1/2}$ = 28.5yr

t = 3.9166 years

A = $3700\, e^{-(0.693/28.5) \times 3.9166}$

= 3364 Bq

Tl-204 : (11.1 KBq, Oct 2006); Half life for Tl-204 is $T_{1/2} = 4$Yrs

Activity (A_0) = 11.1 KBq, as on Oct' 2006.

= 11100 Bq

Elapsed time till Sept' 2010 = 3 years 11months = 3.9166 years

Present activity (A) = $A_0\, e^{-(0.693/T1/2)\,t}$; as on Sept' 2010

$T_{1/2}$ = 4yr

t = 3.9166 years

A = $11100\, e^{-(0.693/4) \times 3.9166}$

= 5631 Bq

GAMMA SOURCES:

Cs-137: (3.1 μCi, July' 2007) ; Half life for Cs-137 is $T_{1/2} = 30$Yrs

Activity (A_0) = 3.1μCi, as on July 2007.

= $3.1X3.7X10^{10}X10^{-6}$

= 114700 Bq

Elapsed time till Sept' 2010 = 3 years 2months = 3.1666 years

Present activity (A) = $A_0\, e^{-(0.693/T_{1/2})\,t}$; as on Sept' 2010

$T_{1/2}$ = 30yr

t = 3.1666 years

A = $114700\, e^{-(0.693/30) \times 3.1666}$

= 106609 Bq

Co-60: (3.7□Ci, July' 2007) ; Half life for Co-60 is $T_{1/2} = 5.3$Yrs

Activity (A_0) = 3.7□Ci, as on July' 2007

$= 3.7 X 3.7 X 10^{10} X 10^{-6}$

$= 136900$ Bq

Elapsed time till Sept' 2010 = 3 years 2 months = 3.1666 years

Present activity (A) $= A_0 e^{-(0.693/T_{1/2})\,t}$; as on Sept' 2010

$T_{1/2} = 5.3$yr

$t = 3.1666$ years

$A = 136900\, e^{-(0.693/5.3) \times 3.1666}$

$= 90486$ Bq

b. DOSE RATE CALCULATION

Doserate can be calculated by using the following formula

$$\text{Doserate} = \frac{\text{Source Activity x gamma constant}}{(\text{Distance})^2}$$

where

Doserate is in mR (milli Roentgen)

Source Activity is in mCi (milli Curies)

Distance is in cm (Centimeters)

Gamma constant for Cs-137 is 3300

and gamma constant for Co-60 is 13200

Examples :

1. Calculate the doserate at a distance of 20 cm from a Cs-137 source of activity 10 mCi

$$\text{Doserate} = \frac{10 \text{x} 3300}{(20)^2} = \frac{33000}{400} = 82.5\text{mR}$$

2. Calculate the distance from a Co-60 source of activity 20 mCi to obtain a doserate of 50mR

$$50\text{mR} = \frac{20\text{x}13200}{(\text{Distance})^2}$$

$$\text{i.e. } (\text{Distance})^2 = \frac{20\text{x}13200}{50} = 5280 \text{ cm}^2$$

$$\therefore \text{Distance} = \sqrt{5280} = 72.66 \text{ cm.}$$