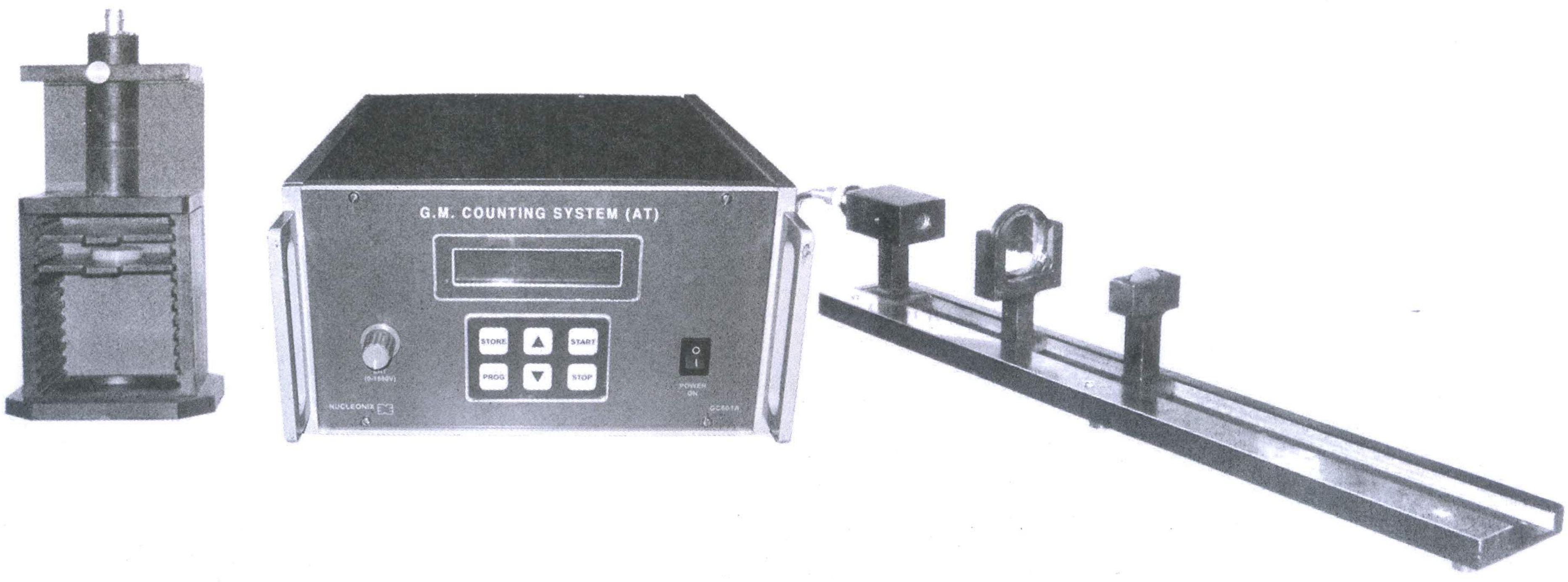

Fig.1: G.M. Counting System with G.M. Detector (End Window) stand and G.M. Detector / Sliding Bench

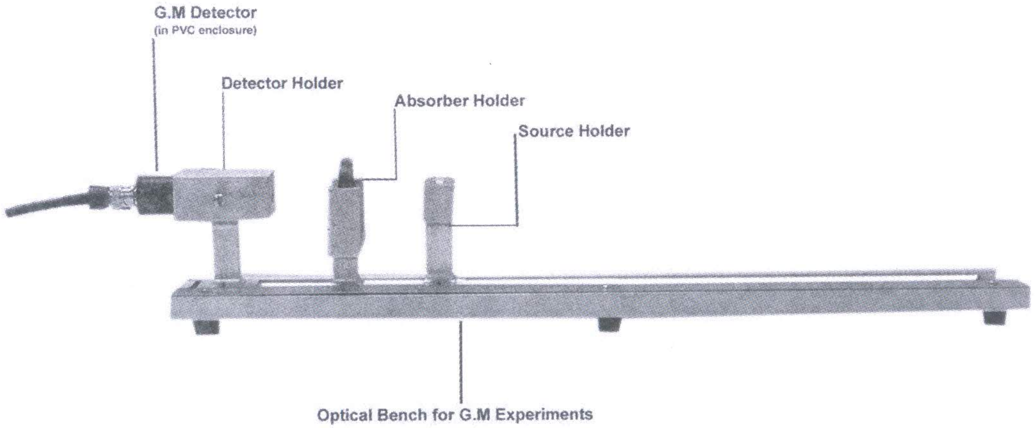

Fig. 2: Sliding bench for G.M Experiments (SB201)

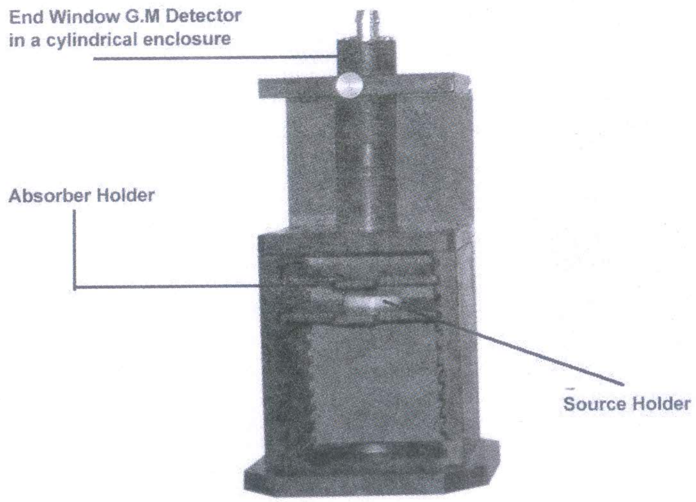

Fig 3 : G.M. Detector stand (SG200)

A. GENERAL INFORMATION

GENERAL INFORMATION ON GEIGER - MULLER TUBES

Geiger-Muller radiation counter tubes (G.M.Tubes) are intended to detect alpha particles, beta particles, gamma or X-radiation.
A G.M. tube is a gas-filled device which reacts to individual ionizing events, thus enabling them to be counted.
A G.M. Tube consists of basically an electrode at a positive potential (anode) surrounded by a metal cylinder at a negative potential (cathode). The cathode forms part of the envelope or is enclosed in a glass envelope. Ionizing events are initiated by quanta or particles, entering the tube either through the window or through the cathode and colliding with the gas molecules.
The gas filling consists of a mixture of one or more rare gases and a quenching agent.
Quenching is the termination of the ionization current pulse in a G.M.tube. Effective quenching in G.M. Tube is determined by the combination of the quenching gas properties and the value of the anode resistor.

- **The capacitance of a G.M. Tube is that between anode and cathode, ignoring the capacitive effects of general connections.**

- **OPERATING CHARACTERISTICS:**

- **Starting Voltage (V_S):**
  This is the lowest voltage applied to a G.M. Tube at which pulses just appear across the anode resistor (see Fig. 4) and unit starts counting.

- **Plateau:**
  This is the section of the GM characteristic curve constructed with counting rate versus applied voltage (With constant irradiation) over which the counting rate is substantially independent of the applied voltage. Unless otherwise stated, the plateau is measured at a counting rate of a approximately 100 counts.

- **Plateau threshold voltage (V_1) :**
  This is the lowest applied voltage which corresponds to the start of the plateau for the stated sensitivity of the measuring circuit. See Fig. 4.

- **Plateau length :**
  This is the range of applied voltage over which the plateau region extends. See Fig. 4.

- **Upper Threshold voltage (V_2) :**
  This is the higher voltage upto which plateau extends, beyond which count rate increases with increase in applied voltage.

- **Plateau Slope:**
  This is the change in counting rate over the plateau length, expressed in % per volt See Fig. 4.

- **Recommended Supply Voltage : (Operating Voltage)**
  This is the supply voltage at which the G.M.Tube should preferably be used. This voltage is normally chosen to be in the middle of the plateau. See Fig.4.

- **Background : (BG)**
  This is the counting rate measured in the absence of the radiation source. The BG is due to cosmic rays and any active sources in the experimental room.

- **NOTES :**
- **Dead Time (T_d):**
  This is the time interval, after the initiation of a discharge resulting in a normal pulse, during which the G.M.Tube is insensitive to further ionizing events. See Fig.5.

- **Resolution (resolving) time (T_R)**
  This is the minimum time interval between two distinct ionizing events which enables both to be counted independently or separately. See Fig.5.

- **Recovery Time (Tre):**
  This is the minimum time interval between the initiation of a normal size pulse and the initiation of the next pulse of normal size. See Fig.5.

- **Anode resistor :**
  Normally the tube should be operated with an anode resistor of the value indicated in the measuring circuit, or higher. Decreasing the value of the anode resistor not only decreases the dead time but also the plateau length. A decrease in resistance below the limiting value may affect tube life and lead to its early destruction.

  The anode resistor should be connected directly to the anode connector of the tube to ensure that parasitic capacitances of leads will not excessively increase the capacitive load on the tube. An increase in capacitive load may increase the pulse amplitude, the pulse duration, the dead time and plateau slope. In addition the plateau will be shortened appreciably. Shunt capacitances as high as 20 pF may destroy the tube, but lower values are also dangerous.

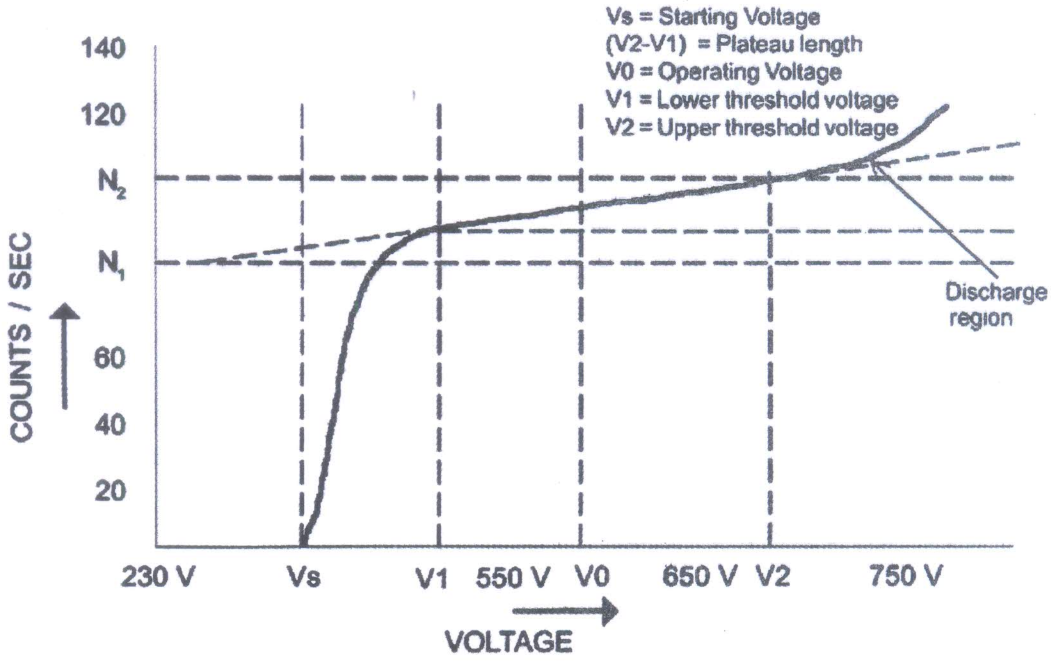

FIG 4 : TYPICAL G.M. CHARACTERISTICS

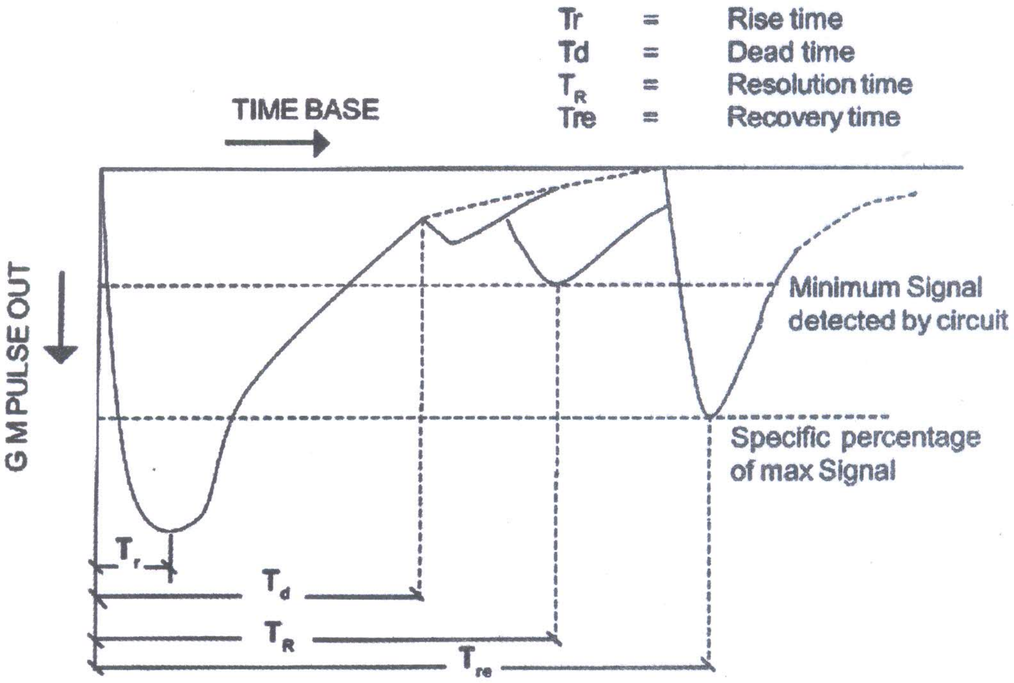

FIG 5 : TYPICAL G.M. PULSE OUTPUT SEEN ON AN OSCILLOSCOPE

- **Maximum Counting Rate :**

  The Maximum counting rate is approximately $1/T_d$ (T_d = dead time). For continuous stable operation, it is recommended that the counting rate is adjusted to a value in the linear part of the counting rate/dose rate curve.

- **Tube sensitivity at extremely high dose rates :**
  At dose rates exceeding the recommended maximum, a G.M.Tube will produce the maximum number of counting pulses per second, limited by its dead time and the circuit in which it is incorporated.
  However, due to the characteristics of a specific circuit, the indicated counting rate may fall appreciably, even to zero.
  If dose rates exceeding 10 times the recommended maximum for window tubes, or 100 times for cylinder tubes, are likely to be encountered, it is advisable to use a circuit that continuously indicates saturation.

- **Dead Time Losses :**
  After every pulse, the tube is temporarily insensitive during a period known as the dead time (T_d). Consequently, the pulses that occur during this period are not counted. At a counting rate of N count/s the tube will be dead during NxT_d of the time, so that approximately $NxNxT_d$ of the counts will be lost.

  In an experiment if the inaccuracy in counts due to dead time must be <1%, N should be less than 1/100 Td counts. Example: If T_d= 20m sec, an inaccuracy of 1% is reached at a counting rate of approximately 500 counts/sec.

- **Background:**
  The most important sources of background count are:
  a. Gamma radiation from the environment and from cosmic radiation.
  b. Mesons from cosmic radiation
  c. Beta particles from contamination and impurities of the materials from which the detector itself is made.
  d. Spontaneous discharge or pulses in the detector and the counting circuit that do not originate from radiation (Electronic noise).

  From published experimental data, the gamma contribution accounts for approximately 70% of the background and a further 25% (approximately) is due to cosmic mesons. For the majority of G.M. tube applications, the background may be reduced to an acceptable level by shielding the tube with lead or steel. Thus most of the gamma contribution is eliminated. The values given in the data in count per minute are derived from averages over a long duration.

- **LIFE:**

- **Storage life:**
  If stored in a cool dry place, free form continuous or severe vibration, there is hardly any deterioration in the tube's characteristics. A storage life of years is not unusual.

- **Warning:**
  Generally, life end of a G.M. tube is indicated by an increasing slope and a shorter plateau. For older tubes, operation is recommended at the first third of the plateau.

- **Operational life:**
  The operational life of a G.M. Tube is expressed in counts (discharge). Theoretically the quenching gas, ionized during a discharge, should be re-combined between discharges. However, minute quantities will be chemically bound, no longer taking part in the quenching process. This will lead to a gradual reduction of the plateau length and for a given working voltage to an increased counting rate. This will culminate in a continuous state of discharge of the tube rendering it useless.

  Apart from the accumulated number of counts registered the ambient temperature during operation is of prime importance to the life of the tube. At temperature above 50°C, changes in the gas mixture may occur, possibly reducing the total number of counts attainable. Short periods of operation (not exceeding 1h) up to approximately 70°C should not prove harmful, but life will progressively decrease with increasing temperature.

  Thus, depending on application and circumstances, the quenching gas could be exhausted in as little as a few hours or theoretically last for many years.

  For these reasons G.M. Tubes cannot be guaranteed unconditionally for a specified period of time.

B. EXPERIMENTS ILLUSTRATING THE PRINCIPLES OF NUCLEAR PHYSICS

Exp: 1. STUDY OF THE CHARACTERISTICS OF A GM TUBE

1.1 PURPOSE

To study the variations of countrate with applied voltage and thereby determine the plateau, the operating voltage and the slope of the plateau.

1.2 EQUIPMENT / ACCESSORIES REQUIRED

- G.M. Counting System GC601A / GC602A with A.C. main chord.
- G.M Detector (End window) stand (or) G.M Detector/source holder bench (optical bench).
- G.M. Detector (in PVC cylindrical enclosure) with connecting cable.

1.3 PROCEDURE

- Make the connection between counting system to G.M. Detector by MHV to UHF co-axial cable. Also connect the mains chord from the counting system to 230V A.C. Power (refer to Fig.1).
- Place a Gamma or Beta source facing the end window of the detector, in the source holder of G.M. stand or optical bench at about 2 cms (for Gamma source) or 4 cms (for Beta source) approximately, from the end window of the detector. (For Beta source ensure that countrate is less than 200 CPS at 500V)
- Now power up the unit and select menu options to PROGRAM on the keypad of the G.M. Counting System and select 30sec preset time typically (It can be in the range of 30 to 60 sec.) [For all command button functions, refer to G.M. Counting System GC601A /GC602A user manual.]
- Now press - "START" button to record the counts and gradually increase the HV by rotating the HV knob till such time, the unit just starts counting. Now, press "STOP" button.
- Now take a fresh reading at this point (STARTING VOLTAGE) and record the observations in the format as given in Table 1.
- Also record for each HV setting, corresponding background counts without keeping the source.
- Continue to take these readings in steps of 30V and for the same preset time, keep observing counts & tabulate the data, with and without source.
- Initially within 2 to 3 readings, counts will steeply increase and thereafter remain constant with marginal increase (may be within 10%). After few readings, one will find a steep increase as one enters the discharge region. Take just one or two readings in this region and reduce the HV bias to 0 volts. <u>It is important to note that operating the G.M detector in discharge region for longer time can reduce the life of tube or can result into permanent damage of the detector.</u>

- Now tabulate the readings and plot a graph of voltage against counts (corrected counts). This graph should look as shown in Fig. 6.
- Identify from the graph / tabulated data
  i) Starting Voltage
  ii) Lower threshold voltage (V_1)
  iii) Upper threshold voltage (V_2). It is called Breakdown threshold voltage
  iv) Discharge region.
- Calculate **plateau, percentage slope**, and **plateau length, operating voltage,** etc.

Table - 1 : G.M. Characteristics Data

S.No.	EHT (Volts)	Counts 30 sec N	Background Counts 30 sec N_b	Corrected Counts $Nc = (N-N_b)$ 30 sec
1	330	0	0	0
2	360 (V_1)	1710	35	1675(N_1)
3	390	1728	35	1693
4	420	1743	35	1708
5	450	1784	36	1748
6	480	1792	36	1756
7	510	1802	37	1765
8	540	1818	39	1779
9	570 (V_2)	1821	40	1781 (N_2)
10	600	2607	76	2531
11	630	3475	76	3399

1.4 ANAYSIS & COMPUTATIONS

Estimate from the tabulated readings

- V_1 = Starting voltage of plateau = 360 V
  (Just after rising edge of knee)

- V_2 = Upper threshold of the plateau = 570 V
  (Just before the start of discharge region)

- Plateau length VPL = $V_2 - V_1$ = (570-360) = 210 V

- Operating voltage $V_0 = \frac{(V2 + V1)}{2} = \frac{(570+360)}{2} = 465$ V

- The slope of the plateau is given by

$$\text{Slope (Percentage)} = \frac{N2 - N1}{N1} \times \frac{100}{(V2 - V1)} \times 100$$

$$= \frac{(1781 - 1677)}{1677} \times \frac{100}{(570 - 360)} \times 100 = 2.95\ \%$$

Where N1 and N2 are the count rates at the lower and the upper limits of the plateau and V1 and V2 are the corresponding voltages.
Slope less than 10% is desirable.

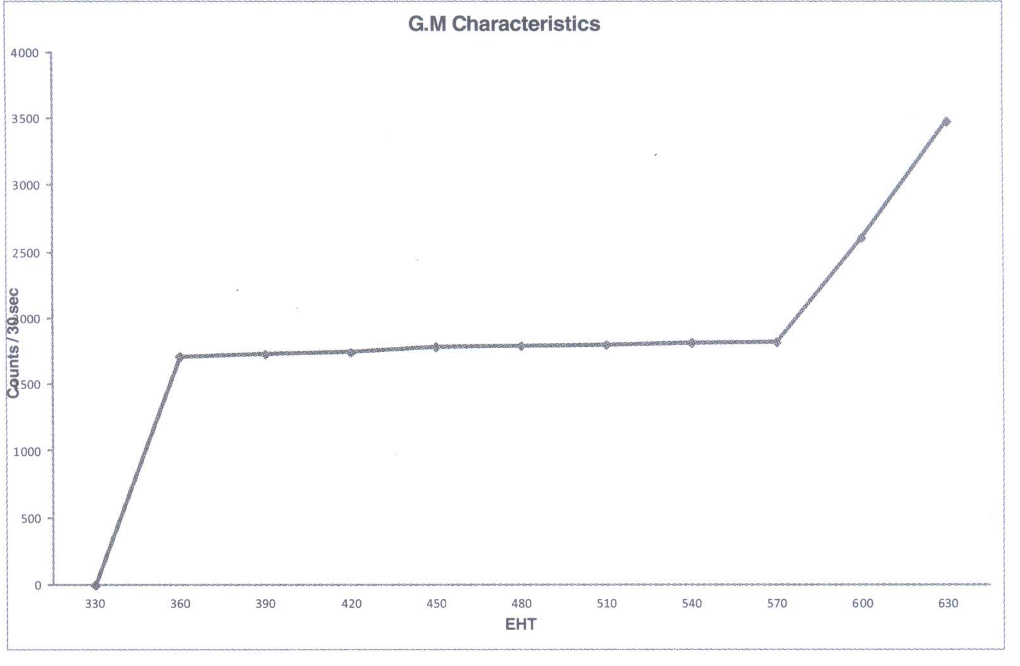

Fig. 6 : Plot of counts Vs EHT

1.5 CONCLUSIONS

- From the plateau, it can be noticed that mid point of the characteristics of the GM tube is defined as operating voltage and is to be used for counting applications. The tube is operated at this voltage when used in Radiation Monitors for measurements.

- Repeat the experiment with Beta source by keeping the source slightly away from the end window when compared to gamma source and tabulate the data. Calculate slope, plateau length etc. From this, one could notice that with Beta source, the efficiency of the detector increases. Also one can notice that with higher count rates, plateau slope increases.

Exp: 2. INVERSE SQUARE LAW: Gamma Rays

2.1 PURPOSE

The Inverse Square Law is an important concept to be understood. It states that intensity of gamma radiation falls inversely as square of the distance.

2.2 EQUIPMENT / ACCESSORIES REQUIRED

- G.M. Counting System GC601A / GC602A with A.C. main chord.
- G.M Detector (End window) stand (or) G.M Detector/source holder bench
- G.M. Detector (in PVC cylindrical enclosure), with connecting cable.
- A gamma source

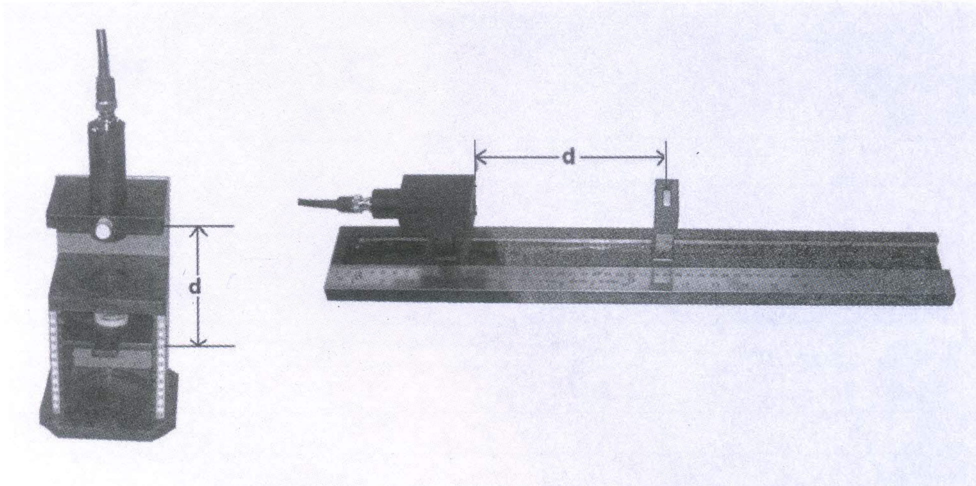

Fig. 7 : Detector, G.M. stand / holder and source arrangement

2.3 PROCEDURE

- Make detector-source arrangement as shown in the (Fig.7) and powerup the unit.
- Without source, make few (about 5 readings) background measurements and take an average of them for a preset time of say 60 sec.
  Compute Average background counts in 60sec Ba = $(b_1+b_2+b_3+b_4+b_5) / 5$.
  Compute Background rate = Ba/t (t = 60sec)
- Place a gamma source in the source holder and adjust the distance (d) from the detector end window to be 2 cm away from the centre of the source holder.
- If you have an End window detector stand, keep the source holder in the 1^{st} slot & raise the end window detector enclosed in a cylindrical shell by unscrewing the captive screw such that you get 2 cm distance from the end window to 1^{st} slot as shown in Fig.7.
- Set the HV to Operating Voltage (say 500 V), program 'preset time' to 60 sec and record the data counts by pressing 'START' button.
- Increase the Distance (d) in steps of 0.5cm (5mm) and for each step record the observations and tabulate (table 2) the data as given below till you reach a distance of 8 to 10 cms from the detector face.
- Subtract the background counts from the recorded counts which results in “corrected counts” (N) in 60sec. From this obtain Net Count Rate (R) per sec.

2.4 COMPUTATION & ANALYSIS

(a) Compute and tabulate 'Net count rate' (R), 'Distance' (d), product of ($C=R.d^2$), transformation ($1/d^2$) etc. as shown in table. (2)

Plot a graph of Net count rate (R) Vs. distance (d) in cm. (Fig 8)

Table (2) : Data for Inverse Square Law Experiment

S.No.	Distance in cm (d)	Corrected Counts N in 60sec.	Net Count Rate R in 1 sec.	Product $C=R.d^2$	Transformation $1/d^2$ in $1/m^2$
1	2.0	13440	224.0	896	2500
2	2.5	9216	153.4	954	1600
3	3.0	6133	102.2	920	1111
4	3.5	4663	77.38	952	816
5	4.0	3525	58.75	940	625
6	4.5	2750	45.83	929	493
7	5.0	2125	35.42	886	400
8	5.5	1768	29.46	891	330
9	6.0	1469	24.83	882	278
10	6.5	1194	19.90	840	236
11	7.0	1002	16.60	851	204

If the count rate obeys the inverse square law, it can be easily be shown that the product $R.d^2$ is a constant. The results of the product ($R.d^2$) are shown in the table above; allowing for statistical fluctuations, the results obey this law, with a mean value of C = 904. The observed net count rate as a function of distance is given by

$$R_d = \frac{904}{d^2}$$

(b) An alternative analysis method involves transforming the data so that the results lie on a straight line. For this purpose “Net Count Rate” (R) Vs. “Reciprocal of the distance square” ($1/d^2$) are plotted (refer to Fig.9). This will be a straight line passing through the origin (0, 0) as this point corresponds to a source-detector distance of infinity. Gradient can be estimated easily from the “net count rate” (R) corresponding to a value of ($1/d^2$) of 400 m^2.

In this example: c = 886 which is in agreement with the results of the previous method at 5cm.

$$C = Rd^2 = 35.42 \times 25 = 886$$

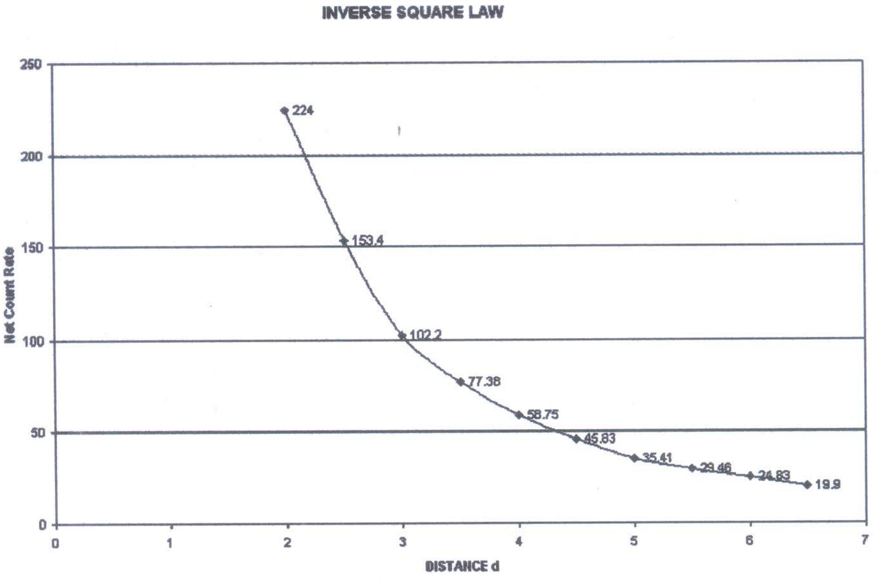

Fig (8). Plot of Net Count Rate (R) Vs Distance (d)

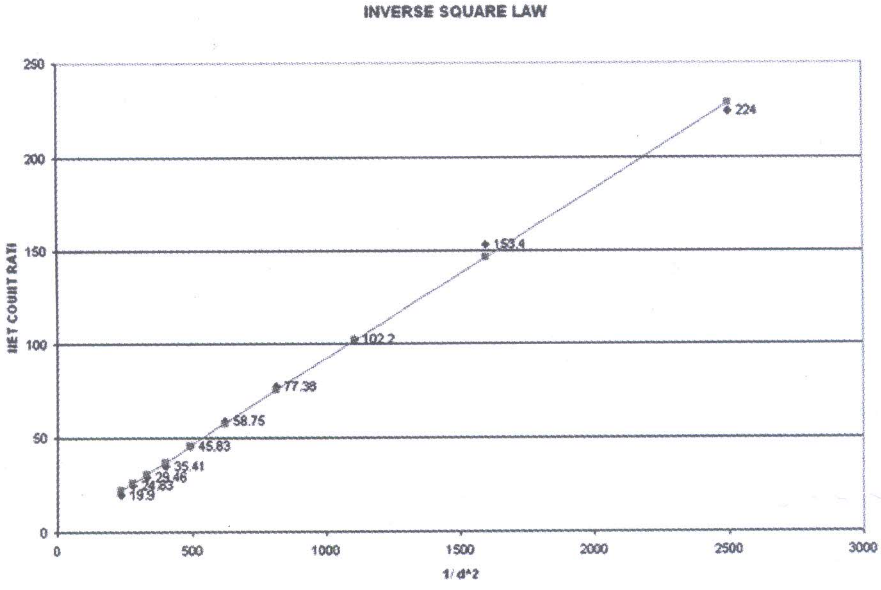

Fig (9). Plot of Net Count Rate (R) Vs Inverse Square of Distance (d)

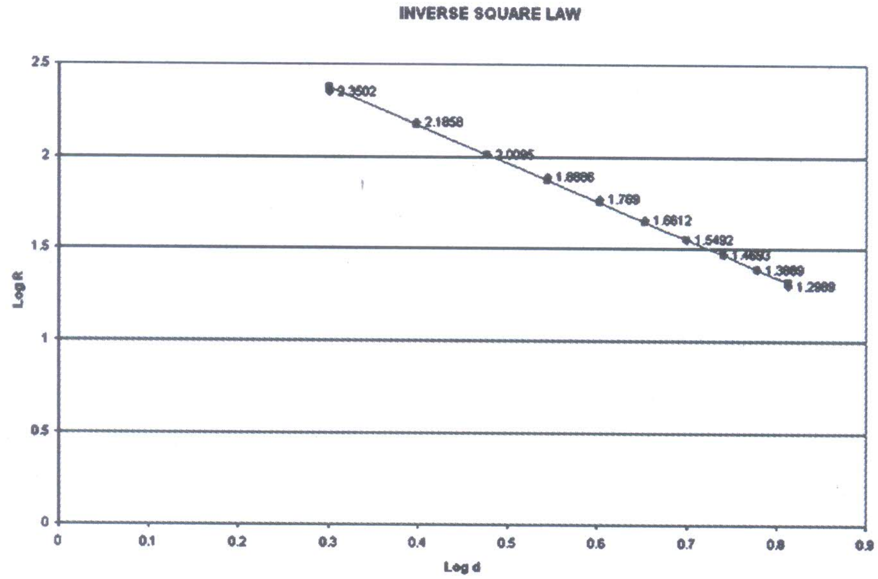

Fig (10). Plot of Log R Vs Log d

(c) Another way of data analysis is by plotting these values on a log log graph sheet or compute log values & plot them on a linear graph sheet (log R Vs. log d) as shown in fig.(10) .

Table (2.b): Table with Log R & Log d values computed

S.No.	d (cms)	Log d	R	Log R
1	2.0	0.3010	224	2.3502
2	2.5	0.3979	153.4	2.1858
3	3.0	0.4770	102.2	2.0094
4	3.5	0.5440	77.38	1.8886
5	4.0	0.6020	58.75	1.7690
6	4.5	0.6532	45.833	1.6611
7	5.0	0.6989	35.416	1.5491
8	5.5	0.7403	29.466	1.4693
9	6.0	0.77815	24.483	1.3888
10	6.5	0.8125	19.9	1.2988
11	7.0	0.8450	18.2	1.27646

Draw a line through the data points. If this is a straight line with a gradient of 2, then it proves that Inverse Square Law is obeyed.

$$\text{Gradient} = -\frac{\log R\,(d2) - \log R\,(d1)}{\log d2 - \log d1} = -\frac{1.5491-2.0094}{0.6989-0.4770}$$

$$= -2.07$$

Exp: 4. ESTIMATION OF EFFICIENCY OF THE G.M.DETECTOR

(A) EXPERIMENT TO ESTIMATE EFFICIENCY FOR A GAMMA SOURCE

4.1 INTRODUCTION

By knowing the activity of a gamma source, it is possible to record counts with the source for a known preset time & estimate the efficiency of the G.M. detector

4.2 EQUIPMENT / ACCESSORIES REQUIRED

- G.M. Counting System GC 601A/ GC602A
- G.M. Detector / source holder stand (SG200) or bench (SB201)
- Radioactive source kit (SK210)
- G.M. detector in cylindrical enclosure (GM120)
- Necessary connecting cables

4.3 PROCEDURE

- Make interconnections such as mains power cord to GC601A/602A unit and connection between G.M. detector holder mount to rear panel of GC601/602, through HV cable.
- Place a gamma source in the source holder facing the end window detector. Typically the distance between the source to end window of G.M. tube can be 10 cm.
- Now record counts for about 100 sec both background and counts with source and make the following calculations and analysis.

4.4 ANALYSIS AND COMPUTATIONS

- Let 'D' be the distance from source to the end window.
- Let 'd' is the diameter of the end window
- Lt N_S = Counts recorded with source
  N_b= Counts recorded due to background
- Now make the following measurements

Background counts in 100 sec (Average of three readings)	$N_b = 71$
Distance from source holder to end window	D=10cm
Diameter of end window	d = 1.5cm
No. of counts recorded in 100sec with the source	$N_S = 432$

From the above data, the net count rate recorded $N = (N_S - N_b/100)$ cps = 3.61CPS

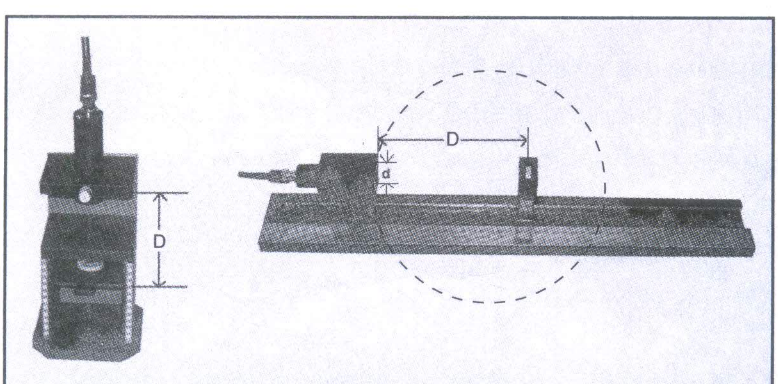

Fig. 15 : Detector source arrangement for efficiency calculation for a gamma source

Gamma source emits radiation isotropically in all directions (4Π geometry). However only fraction of it is received by the end window detector. This fraction is given by

$$= \frac{\left(\frac{\Pi d^2}{4}\right)}{4\Pi D^2} = \frac{d^2}{16D^2}$$

The present activity (A) of the gamma source used for this experiment is 111 KBQ. This gamma source is radiating isotropically in all directions. A fraction of this only is entering the G.M. Tube, which is given by

$$R = A \times \frac{d^2}{16D^2} = 111000 \times 0.001406 = 156.066$$

This is the fractional radiation entering the detector
Hence efficiency of the detector for the gamma source at a distance (D = 10 cm)

$$\text{Efficiency (E)} = \frac{CPS}{DPS} = \frac{N}{R}$$

$$= \frac{3.61}{156.066} = 0.0231 = 2.31\%$$

Note: CPS = Counts per Second
DPS = Disintegrations per Second falling on the window of the ditector.

(B) EXPERIMENT TO ESTIMATE EFFICIENCY FOR A BETA SOURCE

INTRODUCTION:

Equipment required & procedure remains the same as detailed under 5.2&5.3.

The only difference is, here we place Beta source about 2 cm close to the end window & calculate 'Intrinsic efficiency', (which do not take geometry factor into consideration)

PROCEDURE:

- Make standard arrangement & interconnections for G.M counting system, detector, G.M stand.
- Place Beta source close to End Window (approx 2cm from end window). Record counts for a minute with and without source. Take three readings; take average of them and tabulate.
- Record distance of the source from end window.
- Calculate the present day activity in DPS of the source (refer to procedure given at the end of the manual).
- Calculate net CPM/CPS counted.
- Intrinsic efficiency can be calculated as the ratio between (CPM/DPM) x 100 or (CPS/DPS) x 100. This will be efficiency of the end window detector for the given Beta Source at that distance.

DATA COMPUTATION & ANALYSIS:

Beta source used	:	Sr-90
Activity (A0)	:	5.55 KBq (as on Aug 2006)
Activity (A)	:	5.373 KBq (as on Dec 2007)
(use procedure given on pages 13 & 14)		
Background count rate	:	57 CPM
Counts recorded with source (Average)	:	14427 CPM
Corrected counts	:	14370 CPM
Net count rate	:	239.5 CPS

Efficiency (E) of the End window detector with Beta source (Sr-90) at 2.0 cm distance

$$E = \left(\frac{CPS}{DPS} \right) = 0.0446 = 4.46\%$$

4.5 EXERCISE

- By knowing the efficiency of the G.M. detector for a particular Gamma energy (at a specified distance & geometry), one can further calculate the following parameters, namely activity of the source as on the day of experimentation (of course it is assumed that activity of the standard is known as on the date of manufacture), and also the activity of the unknown source if any with the same energy.

- It can be noticed that End Window detector will have much better efficiency for Beta Source compared to a gamma source.

- By knowing efficiency for a Beta source , if an unknown activity Beta source is kept for counting one can calculate and find out its activity.

Exp: 3. STUDY OF NUCLEAR COUNTING STATISTICS

3.1 INTRODUCTION

Systematic errors control the accuracy of a measurement. Thus, if the systematic errors are small, or if you can mathematically correct for them, then you will obtain an accurate estimate of the "true" value. The precision of the experiment, on the other hand, is related to random errors. The precision of a measurement is directly related to the uncertainty in the measurement.

Random errors are the statistical fluctuations during a measurement. If these values are too close to each other, then the random errors are small. But, if the values are not too close, then random errors are large. Thus, random errors are related to the reproducibility of a measurement.

3.2 STATISTICAL ANALYSIS OF DATA

To minimize these errors, one should have good understanding on "Statistical analysis of data".

3.3. DEFINITIONS

- Mean : Mean is the average value of a set of (n) measurements in an experiment. Mathematically it is defined as

$$\overline{N} = \frac{N_1 + N_2 + N_3 + \ldots\ldots\ldots\ldots + N_n}{n}$$

$$= \frac{1}{n} \sum_{i=1}^{n} N_i$$

Mean, is also called as average value.

- Deviation : Deviation is the difference between the actual measured values and the average value. Deviation from the mean, d_i is simply the difference between any data point N_i, and the mean. We define this by

$$d_i = N_i - \overline{N}$$

When we try to look at the error or average deviation, the value probably will become zero because, we may have both positive and negative values which get cancelled. Yet an average value of the error will be desirable, since it tells us how good the data is in a quantitative way. Therefore we need a different way to obtain the measure of the scatter of the data.

- Variance (σ^2) & Standard Deviation (σ):
  One way is to obtain standard deviation (σ) which is defined as

$$\sigma^2 = \frac{d_1^2 + d_2^2 + \dots\dots\dots + d_n^2}{(n-1)}$$

$$= \frac{1}{(n-1)} \sum_{i=1}^{n} d_i^2$$

From this $\sigma = (\sigma^2)^{1/2}$, we see no negative sign and indicates average error contribution. We find that all the deviations make a contribution. We call the term σ^2 as variance.

Standard deviation is a square root of the **variance**, which is widely used to indicate about the spread of our data.

$$\sigma^2 = \frac{1}{n} \sum_{i=1}^{n} d_i^2 \quad \text{(for large samples)}$$

The definition of the standard deviation differs slightly for small samples. It is defined as follows:

$$\sigma^2 = \frac{1}{(n-1)} \sum_{i=1}^{n} d_i^2 \quad \text{(for small samples)}$$

3.4 MEASURING BACKGROUND RADIATION

In this section, several basic experiments are described to demonstrate the statistical nature of radioactive processes. The importance of statistical methods in analyzing data and estimating measurement uncertainties is also covered.

The G.M. detector registers pulses even when not exposed to radioactive sources. These pulses are caused by natural and man-made radioactive isotopes found in our environment, and also by cosmic radiation. The background radiation varies with time and depends on the local environment, the building material, shielding and the weather. Hence, the background count rate (counts per second) should be recorded before and after carrying out measurements.

In the following discussion, the total number of counts recorded for a counting period will be indicated by N (for countrate : N_0) and background counts by B (background rate : B_0). The net count rate is given by N_R = (N-B)/T (where T is the counting period in seconds).

3.5 EXPERIMENT (A)

- Make standard set up by connecting G.M. Counting System GC 601A/602A with G.M. Detector placed in the optical bench or G.M stand as shown in figure (2 or 3).
- Remove the radioactive source from the source holder and set the preset time to 10 sec and take a set of 10 readings of the Background and tabulate them as shown in table no. (3a).
- Now plot a bar graph for number of counts registered versus the Index Number as shown in fig 11.

Index No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
BG Counts/10 sec	19	14	16	15	28	19	26	16	18	23

Table 3.a : Background counts registered for 10 seconds.

Now repeat the experiment, to have large data counts. Store the data for 100 sec. and take a set of ten such measurements as shown in table (3.b)
Plot these no. of counts Vs index no. as shown in fig (12)

Index No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
BG Counts/100 sec	199	209	186	200	187	212	184	196	194	180

Table 3.b : Background counts registered for 100 seconds.

By comparing these two figures (11&12) we can deduce one of the most important laws of the measurement of radiation.

The spread in measured values decreases as the number of pulses registered increases.

* Set a Preset time of 100sec. Take a set of 100 Readings of Background Counts and tabulate them as shown in Table 3.c.

Table 3.c

Sl.No	BG Counts / 100sec (Ni)	Average Value $\overline{N}$	$Ni - \overline{N}$	$(Ni - \overline{N})^2$
1	15	19	-4	16
2	19		0	0
3	10		-9	81
4	19		0	0
5	25		+6	36
6	17		-2	4
7	15		-4	16
8	18		-1	1
9	14		-5	25
10	15		-4	16
11	13		-6	36
12	20		+1	1
13	17		-2	4
14	17		-2	4
15	17		-2	4
16	21		2	4
17	18		-1	1
18	16		-3	9
19	25		+6	36
20	19		0	0
21	23		+4	16
22	22		+3	9
23	22		+3	9
24	13		-6	36
25	20		+1	1
26	17		-2	4
27	26		+7	49
28	11		-8	64
29	16		-3	9
30	20		+1	1
31	18		-1	1
32	16		-3	9
33	17		-2	4
34	15		-4	16
35	15		-4	16
36	19		0	0
37	23		+4	16
38	19		0	0
39	15		-4	16
40	24		+5	25
41	20		+1	1
42	14		-5	25
43	18		-1	1
44	24		+5	25
45	27		+8	64
46	18		-1	1
47	22		+3	9
48	25		+6	36
49	17		-2	4
50	18		-1	1

Table 3.c continued

Sl.No	BG Counts / 100sec (Ni)	Average Value $\bar{N}$	$Ni - \bar{N}$	$(Ni - \bar{N})^2$
51	22	19	+3	9
52	18		-1	1
53	21		+2	4
54	16		-3	9
55	15		-4	16
56	20		+1	1
57	16		-3	9
58	17		-2	4
59	25		+6	36
60	16		-3	9
61	13		-6	36
62	19		0	0
63	17		-2	4
64	28		+9	81
65	30		+11	121
66	21		+2	4
67	25		+6	36
68	20		+1	1
69	18		-1	1
70	22		+3	9
71	25		+6	36
72	22		+3	9
73	15		-4	16
74	20		+1	1
75	26		+7	49
76	11		-8	64
77	12		-7	49
78	25		+6	36
79	13		-6	36
80	22		+3	9
81	12		-7	49
82	22		+3	9
83	16		-3	9
84	16		-3	9
85	21		+2	4
86	14		-5	25
87	17		-2	4
88	22		+3	9
89	28		+9	81
90	19		0	0
91	15		-4	16
92	28		+9	81
93	26		+7	49
94	17		-2	4
95	20		+1	1
96	20		+1	1
97	23		+4	16
98	14		-5	25
99	23		+4	16
100	20		+1	1

Total : 1907

Total : 1867

3.6 STATISTICAL ANALYSIS OF RESULTS

We have already defined mean, variance and standard deviation at the beginning of this chapter.

These parameters for the above set of tabulated background readings (**Table 3.c**) can be calculated as follows :

Mean Value : $\bar{N} = \frac{1907}{100} = 19.07 \simeq 19$

Variance : $\sigma^2 = \frac{1}{n} \sum_{i=1}^{n} (Ni - \bar{N})^2 = \frac{1867}{100} = 18.67$ (for large samples)

Standard Deviation : $\sigma = \sqrt{18.67} = 4.32$

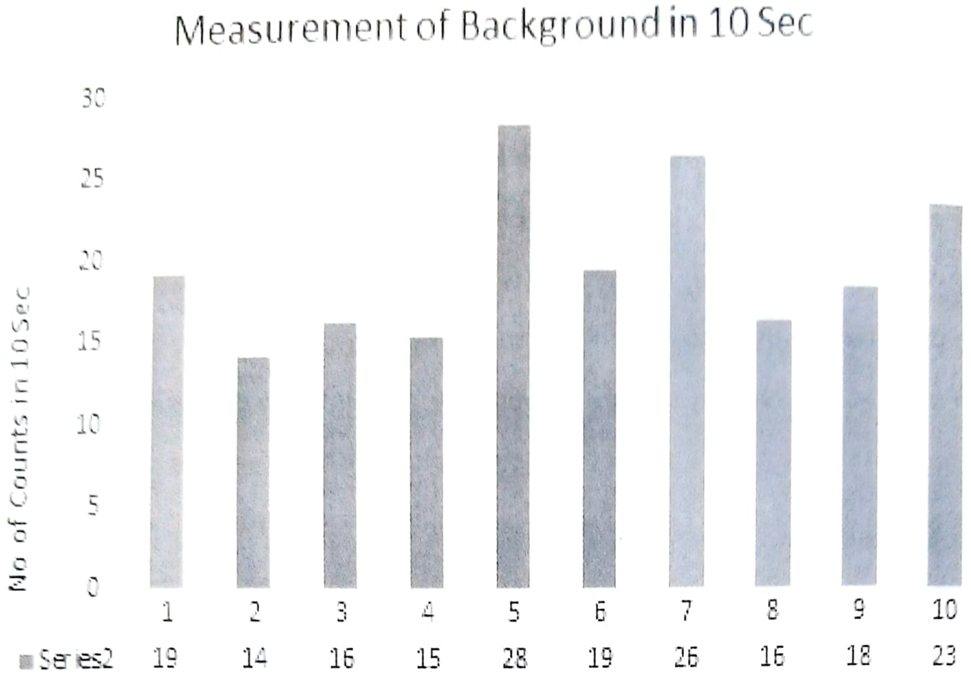

Fig. (11) Plot of no. of Counts with T=10s (for 10 measurements)

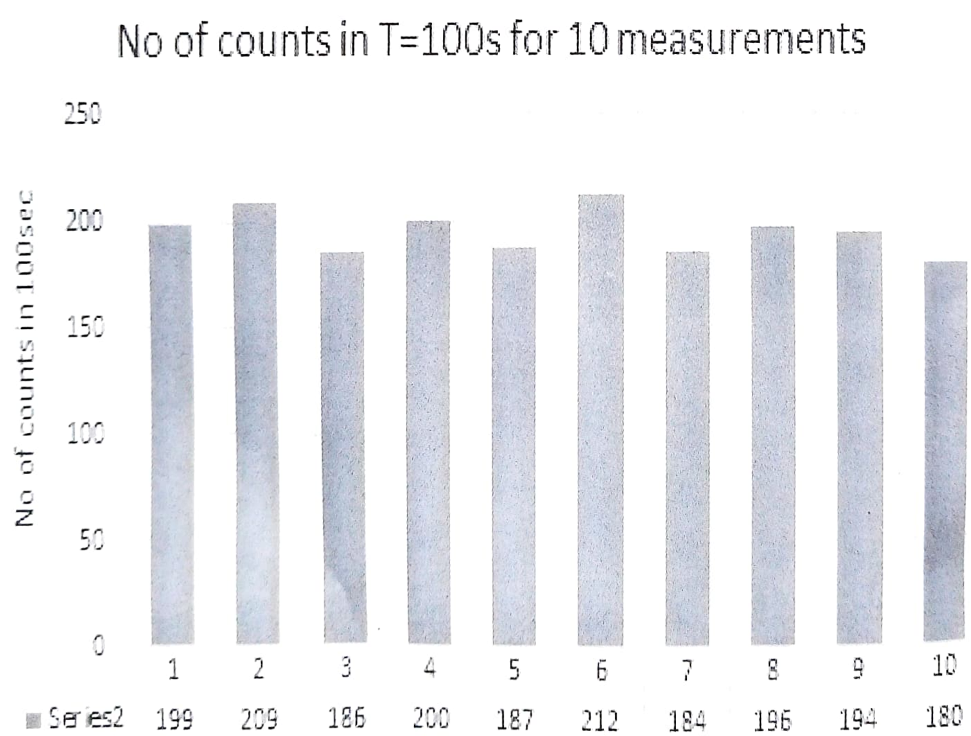

Fig. (12) Plot of no. of Counts with T=100s (for 10 measurements)

3.7 INTERPRETATION OF THE RESULTS

- The results follow a Poisson distribution on which practically all radioactivity measurements are based. The results show that the mean value $\bar{N}$ is nearly equal to the variance σ^2; this is characteristic of the Poisson distribution.

The variance in any measured number of counts is therefore equal to the mean value of counts.

- The square root of variance, the standard deviation is a measure of the scatter of individual counts around the mean value.

The above measured results of mean, variance and standard deviation follow **Poisson distribution**. Results show that the mean value ($\bar{N}$) is almost equal to the variance (σ^2) which is characteristic of the Poisson distribution.

As a thumb rule, we can say the following :

For a large number of observations of the same event,

50.0% of observations fall within the interval	**$\bar{N}$ - 0.674σ and $\bar{N}$ + 0.674σ**
68.3% of observations fall within the interval	**$\bar{N}$ - 1σ and $\bar{N}$ + 1σ**
90.0% of observations fall within the interval	**$\bar{N}$ - 1.64σ and $\bar{N}$ + 1.64σ**
95.0% of observations fall within the interval	**$\bar{N}$ - 2σ and $\bar{N}$ + 2σ**
99.0% of observations fall within the interval	**$\bar{N}$ - 2.58σ and $\bar{N}$ + 2.58σ**
99.7% of observations fall within the interval	**$\bar{N}$ - 3σ and $\bar{N}$ + 3σ**

3.8 EXPERIMENT (B)

To illustrate that for number of counts recorded being high, Poisson distribution follows closely normal or Gaussian Distribution.

PROCEDURE

- Make standard counting setup as shown in figure (1)
- Place a Beta source about 2cm from the end window of the detector.
- Record counts typically for a preset time of 25sec, and take 50 data readings.
- Compute Mean, Deviation and Standard Deviation and tabulate the readings as shown in Table 3.d Also compute other values, as indicated in the table.

Table 3.d

S.No.	N_i	$(N_i - N)$	$\sqrt{N} = \sigma$	$(N_i - N)/\sigma$	$(N_i - N)/\sigma$ (Rounded off)
1	803	13	28.1	0.46	0.5
2	782	-8	28.1	-0.25	0
3	802	12	28.1	0.42	0.5
4	775	-15	28.1	-0.53	-0.5
5	780	-10	28.1	-0.35	-0.5
6	803	13	28.1	0.46	0.5
7	800	10	28.1	0.35	0.5
8	841	51	28.1	1.81	2
9	802	12	28.1	0.42	0.5
10	763	-27	28.1	-0.96	-1.0
11	793	3	28.1	0.10	0
12	783	-7	28.1	-0.24	0
13	773	-17	28.1	-0.60	-0.5
14	785	-5	28.1	-0.17	0
15	810	20	28.1	0.71	0.5
16	802	12	28.1	0.42	0.5
17	796	6	28.1	0.21	0
18	796	6	28.1	0.20	0
19	824	34	28.1	1.20	1.0
20	786	-4	28.1	-0.14	0
21	771	-19	28.1	-0.68	-0.5
22	741	-49	28.1	-1.74	-2
23	762	-28	28.1	-0.99	-1
24	809	19	28.1	0.67	0.5
25	764	-26	28.1	-0.92	-1

Table 3.d continued

S.No.	N_i	$(N_i - N)$	$\sqrt{N} = \sigma$	$(N_i - N)/\sigma$	$(N_i - N)/\sigma$ (Rounded off)
26	773	-17	28.1	-0.60	-0.5
27	779	-11	28.1	-0.39	-0.5
28	792	2	28.1	0.07	0
29	818	28	28.1	0.99	1
30	779	-11	28.1	-0.39	-0.5
31	745	-45	28.1	-1.60	-2
32	769	-21	28.1	-0.74	-0.5
33	791	1	28.1	0.03	0
34	823	33	28.1	1.17	1
35	763	-27	28.1	-0.96	-1
36	767	-23	28.1	-0.82	-1
37	807	17	28.1	0.60	0.5
38	853	63	28.1	2.24	2
39	790	0	28.1	0	0
40	764	-26	28.1	-0.92	-1
41	762	-28	28.1	-0.99	-1
42	825	35	28.1	1.24	1
43	775	-15	28.1	-0.53	-0.5
44	791	1	28.1	0.03	0
45	822	32	28.1	1.13	1
46	784	-6	28.1	-0.21	0
47	780	-10	28.1	-0.35	-0.5
48	783	-7	28.1	-0.24	0
49	813	23	28.1	0.82	1
50	785	-5	28.1	-0.17	0

The average count rate for 'n' independent measurements is given by

$$\overline{N} = \frac{N_1 + N_2 + \ldots\ldots\ldots\ldots + N_n}{n} = 790$$

The deviation of an individual count from the mean is $(N_i - \overline{N})$. From the definition $\overline{N}$, it is clear that

$$\sum_{i=1}^{n} (N_i - \overline{N}) = 0$$

The Standard Deviation $\sigma = \sqrt{\overline{N}}$

3.9 EXERCISE

Make a plot of the frequency of rounded off events (Ni - N) Vs. the rounded off values. Fig (13) Below shows ideal situation which is a Gaussian or Normal Distribution.

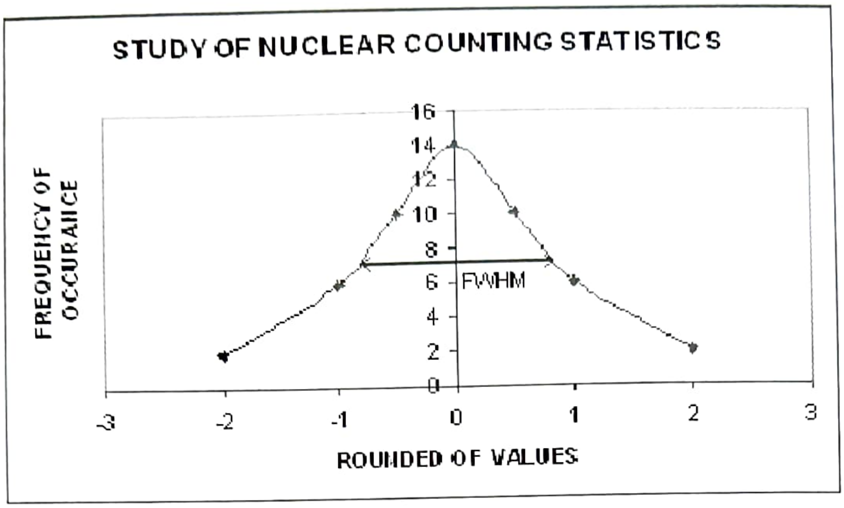

Fig (13). Plot of Frequency of Occurrence Vs Rounded of Values

Two important observations can be made at this point, about gaussian distribution & figure obtained above.

- The distribution is symmetric about the mean value.
- Because the mean value is large, the adjacent values of the function are not greatly different from each other. i.e., the distribution is slowly varying which is the expected behavior of a normal distribution.

3.10 EXAMPLES

- If a measurement of 10s duration yields 3 pulses, the result is correctly expressed as N = 3 + 1.7 in 10s or Z = (0.3 + 0.17) 1/s as $\sqrt{3} = 1.7$.
- In experiment 1 in the first 10 measurements, i.e., after 100 s, 30 pulses were counted. The result would be N = 30 + 5.5 in 100 s or Z = (0.30 + 0.055) 1/s.
- After 100 measurements in Experiment 1, i.e., 1000 s, 286 pulses were counted.The result would be N = 286 + 17 in 1000 s or Z = (0.286 + 0.017) 1/s.

If you compare the errors indicated for the count rate Z in the examples 1 and 3 you can see that a counting period which is 100 times longer (or 100 measurements) leads to a result where the measurement uncertainty is 10 times smaller. If the result is divided by the count time T :

$$\frac{N}{T} + \frac{\sqrt{N}}{T} = \frac{N}{T} + \sqrt{\frac{N}{T}} \times \frac{1}{\sqrt{T}} = Z + \frac{\sqrt{Z}}{\sqrt{T}}$$

The uncertainty in the count rate Z is therefore proportional to one over the square root of the counting period T.