# Geiger-Muller (GM) Counter-I

Biswaranjan Meher
*Integrated M.Sc.*
*Roll No.-2011050*
*School of Physical Sciences*
*National Institute of Science Education and Research, Bhubaneswar*
(Dated: April 11, 2023)

A Geiger-Muller counter (also known as a GM counter) is an electronic instrument used for detecting and measuring ionizing radiation. It is widely used in applications such as radiation dosimetry, radiological protection, experimental physics, and the nuclear industry. This experiment is based on familiarizing ourselves with the most basic particle or radiation detectors, the GM counters. We performed the experiment in various steps, determining the operational voltage, efficiency, verification of inverse square law, etc. by measuring different required quantities.

## I. OBJECTIVES

- Determination of the operating voltage of GM counter from the GM characteristic curve.
- Verification of the inverse square law for the $\gamma$ rays as a simple application of the GM counter.
- Determination of the efficiency of GM counter.
- Analyzing the nuclear counting statistics.

## II. THEORY

### A. GM Counter

The Geiger-Muller (GM) counter is a type of particle detector that measures ionizing radiation. It consists of a gas-filled tube with a central wire electrode and a surrounding electrode, which form the anode and cathode, respectively.
When ionizing radiation enters the tube, it ionizes the gas atoms and creates free electrons and ions. The ionization event creates a potential difference between the electrodes, causing a discharge to occur, which is detected as a pulse of electrical current.
The theory behind the GM counter relies on the principles of ionization and electrical discharge. The ionization of gas atoms by ionizing radiation creates a current pulse, which is proportional to the amount of ionizing radiation entering the tube. The discharge of the current pulse is detected and recorded, allowing for a measurement of the ionizing radiation.
It's important to note that GM counter tubes are designed to be sensitive to a specific type of ionizing radiation, such as $\alpha$, $\beta$, or $\gamma$ rays. This sensitivity is determined by the type of gas used, the pressure of the gas, and the potential difference between the electrodes.

### B. GM Counter Operating characteristics

#### 1. Starting voltage ($V_s$)

This is the lowest voltage applied to a GM counter at which pulses just appear across the anode resistor and the unit starts counting.

#### 2. Plateau

The section of the GM characteristic curve over which the counting rate is independent of the applied voltage.

#### 3. Plateau threshold voltage ($V_1$)

The voltage at which the plateau region begins for a particular sensitivity of the measuring circuit.

#### 4. Plateau length

The range of voltage over which the plateau region extends.

#### 5. Upper threshold voltage ($V_2$)

The higher voltage up to which the plateau region extends, beyond which the count rate increases with an increase in applied voltage.

#### 6. Plateau slope

The small change in counting rate over the plateau region, it is usually expressed in % per volt.

*7. Operating voltage*

The supply voltage at which the GM counter should preferably be used.

*8. Background*

It is the counting rate measured in the absence of the radiation source. It is due to cosmic rays and any active sources in the experimental lab.

*9. Dead time ($T_d$)*

It is the time interval after the initiation of a discharge resulting in a normal pulse, during which the GM counter is insensitive to further ionizing events.

*10. Resolution time ($T_R$)*

It is the minimum time interval between two distinct ionizing events which enables both to be counted independently.

*11. Recovery time ($T_{re}$)*

It is the minimum time interval between the initiation of a normal-size pulse and the initiation of the next pulse of normal size.

### C. Typical GM characteristics

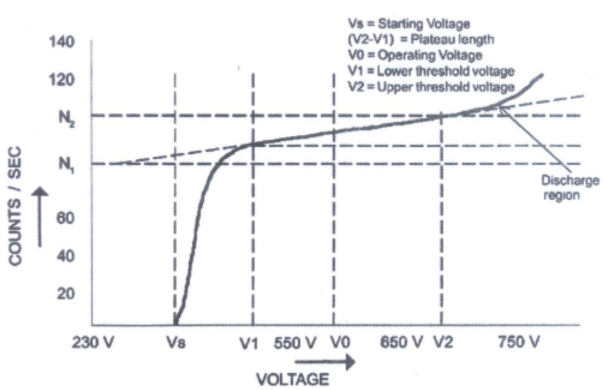


FIG. 1. Typical GM characteristics

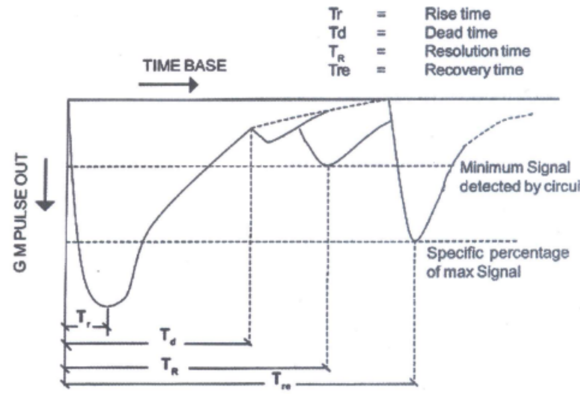


FIG. 2. Typical GM pulse output seen on an oscilloscope

## III. EXPERIMENTAL SETUP

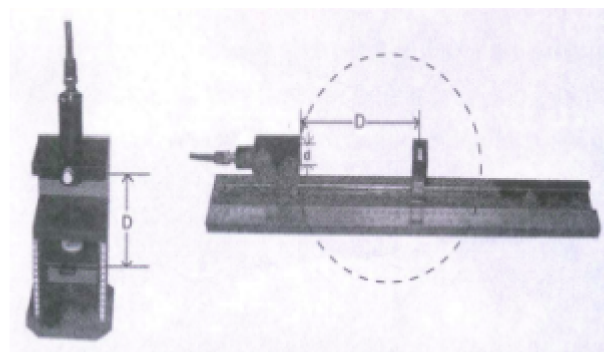


FIG. 3. Experimental setup

**Components required:**

- $Cs^{137}$**:** Source of $\gamma$ rays.
- $Tl^{204}$**:** Source of $\beta$ particles.
- **GM counting system and detector**
- **Connecting cables**

## IV. OBSERVATIONS AND CALCULATIONS

### Table 1: GM characteristics curve

| GM Characteristic plot | | | | |
|---|---|---|---|---|
| **S. No.** | **EHT (V)** | **Counts (N)** | **Background Count ($N_b$)** | **Corrected Count ($N_c$)** |
| 1 | 320 | 0 | 0 | 0 |
| 2 | 323 | 3233 | 32 | 3201 |
| 3 | 350 | 4762 | 29 | 4733 |
| 4 | 380 | 5062 | 33 | 5029 |
| 5 | 410 | 5281 | 38 | 5243 |
| 6 | 440 | 5339 | 38 | 5301 |
| 7 | 470 | 5365 | 44 | 5321 |
| 8 | 500 | 5412 | 38 | 5374 |
| 9 | 530 | 5450 | 37 | 5413 |
| 10 | 560 | 5600 | 40 | 5560 |
| 11 | 590 | 5651 | 35 | 5616 |
| 12 | 620 | 5742 | 36 | 5706 |
| 13 | 650 | 10120 | 105 | 10015 |
| 14 | 680 | 10208 | 74 | 10134 |

### Plot 1: GM characteristics curve for $\gamma$ source

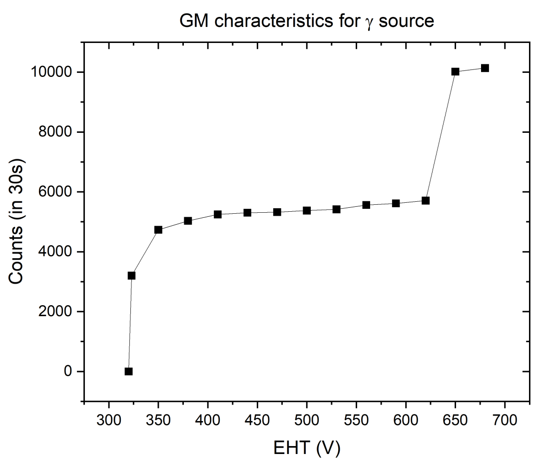


FIG. 4. GM characteristics for $\gamma$ source

From the above plot, we get:

- $V_1$ =350 V
- $V_2$ =620 V
- Plateau length = $V_2 - V_1$ = 270 V
- Operating voltage:

$$V_o = \frac{V_1 + V_2}{2} = 485V$$

Error:

$$\frac{\delta V_o}{V_o} = \sqrt{\left(\frac{\delta V_1}{V_1}\right)^2 + \left(\frac{\delta V_2}{V_2}\right)^2} = 0.00328$$

$$\delta V_o = 1.591V$$

- Plateau slope:

$$S = \frac{(N_2 - N_1) \times 100}{N_1(V_2 - V_1)} \times 100 = 7.61\%$$

### Table 2: Inverse square law

| Inverse square law | | | | | | |
|---|---|---|---|---|---|---|
| **S.No.** | **d (cm)** | **Counts** | **Corrected Count (N)** | **Rate (R) (per s)** | **C** $R.d^2$ | $1/d^2$ **(in** $1/m^2$**)** |
| 1 | 2 | 11777 | 11710.6 | 195.18 | 780.72 | 2500 |
| 2 | 2.5 | 9525 | 9458.6 | 157.64 | 985.25 | 1600 |
| 3 | 3 | 7793 | 7726.6 | 128.78 | 1159.02 | 1111 |
| 4 | 3.5 | 6241 | 6174.6 | 102.91 | 1260.6475 | 816 |
| 5 | 4 | 5107 | 5040.6 | 84.01 | 1344.16 | 625 |
| 6 | 4.5 | 4276 | 4209.6 | 70.16 | 1420.74 | 494 |
| 7 | 5 | 3602 | 3535.6 | 58.93 | 1473.25 | 400 |
| 8 | 5.5 | 3103 | 3036.6 | 50.61 | 1530.9525 | 331 |
| 9 | 6 | 2669 | 2602.6 | 43.38 | 1561.68 | 278 |
| 10 | 6.5 | 2198 | 2131.6 | 35.53 | 1501.1425 | 237 |
| 11 | 7 | 1978 | 1911.6 | 31.86 | 1561.14 | 204 |
| 12 | 7.5 | 1712 | 1645.6 | 27.43 | 1542.9375 | 178 |
| 13 | 8 | 1515 | 1448.6 | 24.14 | 1544.96 | 156 |

### Plot 2: Net counts vs distance

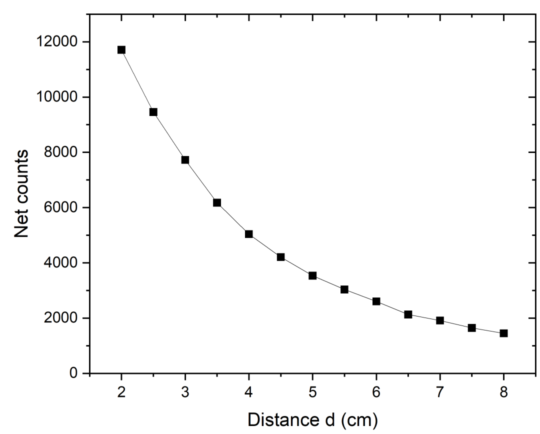


FIG. 5. Plot of net counts vs distance (d) (in cm)

From Table 2 and FIG. 5, we get:

- $C_{mean} = 0.1359 m^2/s$
- Net counts vary inversely with the distance.

- Now, we need to see whether there is a linearly inverse relation or some power relation, for which we need to plot net count rate vs $1/d^2$. Refer to FIG. (6), we got a curve which when linearly fitted gave some parameters mentioned in FIG.(7).
- Next, we see whether there is some logarithmic relation or not for which we plotted log(R) vs log(d). Refer to FIG.8.

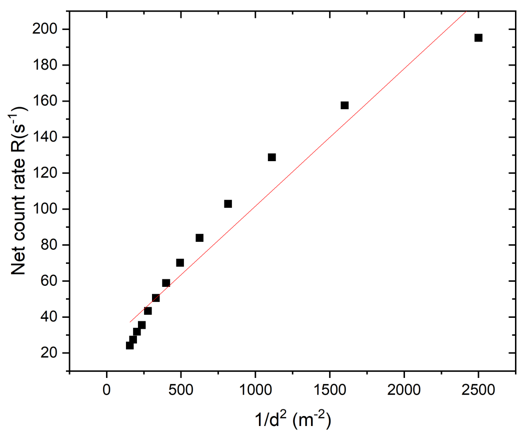


FIG. 6. Plot of net count rate (R) vs $1/d^2$

| | |
|---|---|
| Equation | y = a + b*x |
| Plot | R |
| Weight | No Weighting |
| Intercept | 25.27578 ± 5.05724 |
| Slope | 0.07637 ± 0.0053 |
| Residual Sum of Squares | 1763.36833 |
| Pearson's r | 0.97454 |
| R-Square (COD) | 0.94972 |
| Adj. R-Square | 0.94515 |

FIG. 7. Parameters obtained for FIG.6

**Efficiency of GM Counter:**

- For $\gamma$ source:
  - Diameter of the detector window, d=0.03m
  - Distance between the detector and the source, D=0.1M
  - Activity, A = 71.5 kBq
  - Net count rate, $N = 7.208s^{-1}$
  - $R = A\frac{d^2}{16D^2} = 402.1875s^{-1}$
  - Efficiency, $E = \frac{N}{R} \times 100 = 1.792\%$

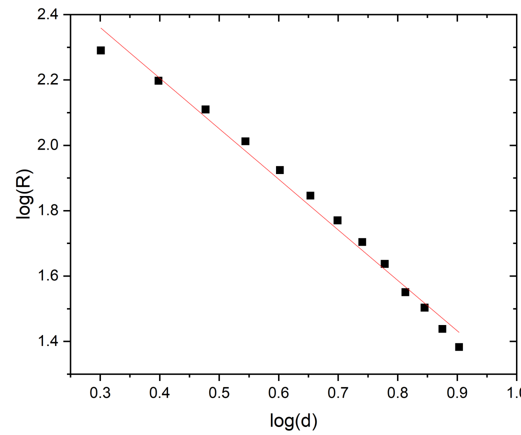


FIG. 8. Plot of log(R) vs log(d)

| | |
|---|---|
| Equation | y = a + b*x |
| Plot | log(R) |
| Weight | No Weighting |
| Intercept | 2.8246 ± 0.03652 |
| Slope | -1.54737 ± 0.05305 |
| Residual Sum of Squares | 0.01339 |
| Pearson's r | -0.9936 |
| R-Square (COD) | 0.98724 |
| Adj. R-Square | 0.98608 |

FIG. 9. Parameters obtained for FIG.8

- For $\beta$ source:
  - Diameter of the detector window, d=0.03m
  - Distance between the detector and the source, D=2cm
  - Activity, A = 7.85 kBq
  - Net count rate, $N = 40.82s^{-1}$
  - At D=2cm, $R = A\frac{d^2}{16D^2} = 1103.90625s^{-1}$
  - Efficiency at D=2cm, $E = \frac{N}{R} \times 100 = 3.698\%$

### Nuclear Counting statistics:

We now attempt to analyze the distribution in which the counts are measured by the GM counter using a statistical approach.
The various useful parameters are:

- Mean, $\bar{N} = \frac{1}{n}\sum_{i=1}^{n} N_i$
- Variance, $\sigma^2 = \frac{1}{n-1}\sum_{i=1}^{n}(N_i - \bar{N})^2$
- Standard deviation,$\sigma = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(N_i - \bar{N})^2}$

**Table 3: Background count statistics**

| Background statistics | | | |
|---|---|---|---|
| Background (in 10 s) | | Background (in 100 s) | |
| S. No. | Counts | S. No. | Counts |
| 1 | 14 | 1 | 117 |
| 2 | 6 | 2 | 127 |
| 3 | 12 | 3 | 134 |
| 4 | 11 | 4 | 104 |
| 5 | 13 | 5 | 130 |
| 6 | 11 | 6 | 114 |
| 7 | 11 | 7 | 125 |
| 8 | 9 | 8 | 132 |
| 9 | 10 | 9 | 121 |
| 10 | 11 | 10 | 114 |

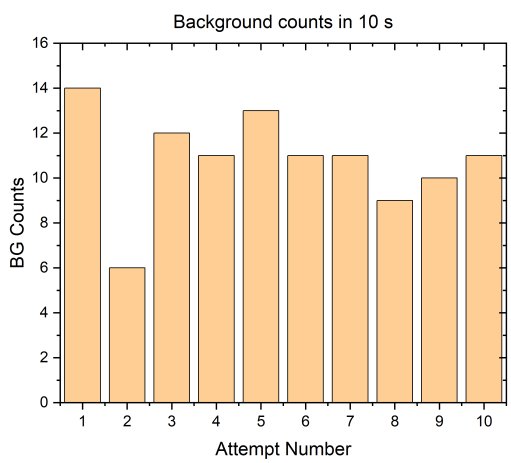


FIG. 10. Statistical plot for background counts for 10 seconds
$\bar{N} = 10.8$
$\sigma = 2.201$

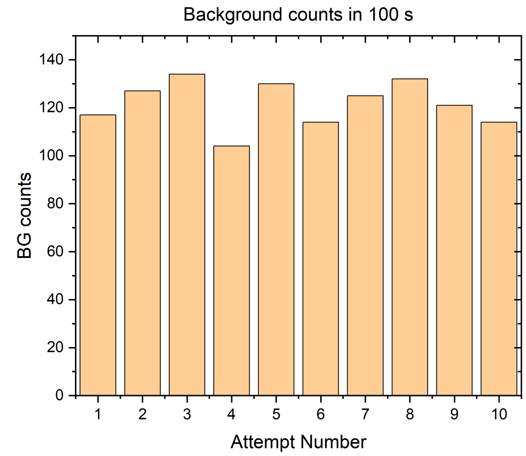


FIG. 11. Statistical plot for background counts for 100 s
$\bar{N} = 121.8$
$\sigma = 9.543$

**Table 4: Nuclear counting statistics for $\beta$ source**

| Statistical analysis with $\beta$ source | | | |
|---|---|---|---|
| S. No. | Counts Ni | S. No. | Counts Ni |
| 1 | 2115 | 26 | 2100 |
| 2 | 2090 | 27 | 2106 |
| 3 | 2086 | 28 | 2171 |
| 4 | 2169 | 29 | 2087 |
| 5 | 2178 | 30 | 2078 |
| 6 | 2088 | 31 | 2155 |
| 7 | 2058 | 32 | 2013 |
| 8 | 2112 | 33 | 2101 |
| 9 | 2121 | 34 | 2148 |
| 10 | 2096 | 35 | 2109 |
| 11 | 2170 | 36 | 2135 |
| 12 | 2102 | 37 | 2200 |
| 13 | 2129 | 38 | 2119 |
| 14 | 2155 | 39 | 2109 |
| 15 | 2161 | 40 | 2101 |
| 16 | 2176 | 41 | 2068 |
| 17 | 2178 | 42 | 2142 |
| 18 | 2119 | 43 | 2110 |
| 19 | 2079 | 44 | 2134 |
| 20 | 2076 | 45 | 2013 |
| 21 | 2040 | 46 | 2116 |
| 22 | 2048 | 47 | 2148 |
| 23 | 2078 | 48 | 2102 |
| 24 | 2101 | 49 | 2096 |
| 25 | 2101 | 50 | 2083 |

From Table 4 when the $\beta$ source was kept at a distance of 3cm from the detector, we get:

- Mean, $\bar{N} = 2111.4$
- Standard deviation, $\sigma = 41.56$

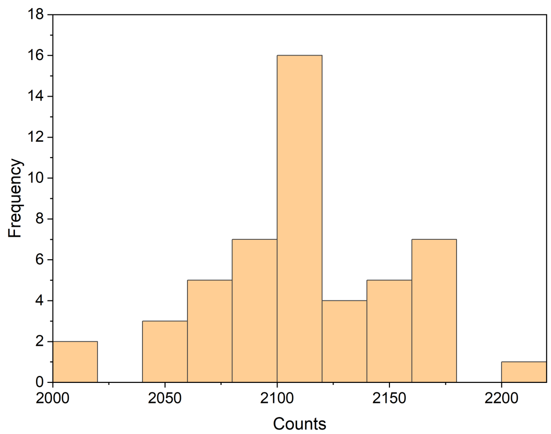


FIG. 12. Histogram of counts with beta source

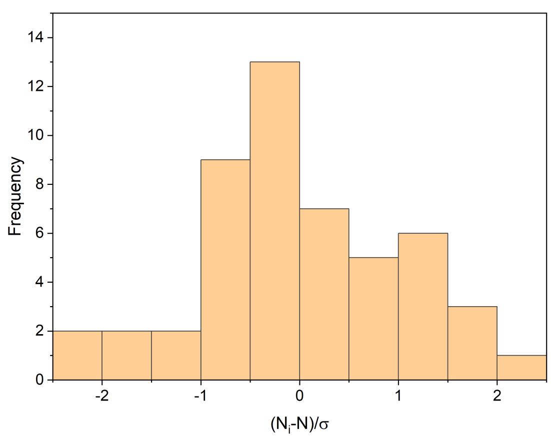


FIG. 13. Histogram of $(N_i - N)/\sigma$ with beta source

## V. RESULTS

- The operating voltage of the GM counter:

$$V_o = (485 \pm 1.591)V$$

.

- Efficiency of GM counter:
  - For $\gamma$ source: $E_\gamma = 1.792\%$
  - For $\beta$ source: $E_\beta = 3.698\%$

- Nuclear counting statistics:
  - Background(10s):
    Mean=10.8 & Std. dev. = 2.201
  - Background(100s):
    Mean=121.8 & Std. dev. = 9.543

## VI. CONCLUSIONS AND DISCUSSIONS

- We got a good knowledge of the GM counter, it's working, and its basic applications.
- First, we calculated the operating voltage of the GM counter from the characteristics curve and got an idea of how it really works.
- We got different values of efficiency of the GM counter for $\gamma$ and $\beta$ sources. This could be due to its different responses to different kinds of radiation or sources. The other possible reason could be different background conditions while taking the data.
- We also verified the inverse square law upto some extent as in our case, we got the relation to be $\approx d^{-1.547}$, and not $d^{-2}$.
- While analyzing the counting statistics, we got a Gaussian distribution for larger number of measurements.

## VII. SOURCES OF ERRORS

- Handling of the GM counter: due to its fragile nature as it contains inert gases.
- Systemic or Instrumental errors associated with the detector.
- Measurement or human errors.
- Errors due to various radiation present in the background.

## VIII. REFERENCES


- NISER Lab Manual
- `https://en.wikipedia.org/wiki/Geiger_counter`
- `https://www.studyandscore.com/studymaterial-detail/geiger-muller-counter-construction-principle-workin`

**Table - 1 : GM Characteristic plot**

| S. No. | EHT (volts) | Counts (N) | Background Co | Corrected Count (Nc) |
|---|---|---|---|---|
| 1 | 320 | 0 | 0 | 0 |
| 2 | 323 | 3233 | 32 | 3201 |
| 3 | 350 | 4762 | 29 | 4733 |
| 4 | 380 | 5062 | 33 | 5029 |
| 5 | 410 | 5281 | 38 | 5243 |
| 6 | 440 | 5339 | 38 | 5301 |
| 7 | 470 | 5365 | 44 | 5321 |
| 8 | 500 | 5412 | 38 | 5374 |
| 9 | 530 | 5450 | 37 | 5413 |
| 10 | 560 | 5600 | 40 | 5560 |
| 11 | 590 | 5651 | 35 | 5616 |
| 12 | 620 | 5742 | 36 | 5706 |
| 13 | 650 | 10120 | 105 | 10015 |
| 14 | 680 | 10208 | 74 | 10134 |

**Background**

| S.No. | Counts |
|---|---|
| 1 | 61 |
| 2 | 79 |
| 3 | 62 |
| 4 | 76 |
| 5 | 54 |
| Average Count | 66.4 |
| rate(counts/sec | 1.106666667 |

**Table - 2 : Data for Inverse square law experiment**

| S.No. | d (in cm) | Counts | Corrected Coun | Rate R (per sec | C = R.d^2 | 1/d^2 (in 1/m^2) |
|---|---|---|---|---|---|---|
| 1 | 2 | 11777 | 11710.6 | 195.18 | 780.72 | 2500 |
| 2 | 2.5 | 9525 | 9458.6 | 157.64 | 985.25 | 1600 |
| 3 | 3 | 7793 | 7726.6 | 128.78 | 1159.02 | 1111 |
| 4 | 3.5 | 6241 | 6174.6 | 102.91 | 1260.6475 | 816 |
| 5 | 4 | 5107 | 5040.6 | 84.01 | 1344.16 | 625 |
| 6 | 4.5 | 4276 | 4209.6 | 70.16 | 1420.74 | 494 |
| 7 | 5 | 3602 | 3535.6 | 58.93 | 1473.25 | 400 |
| 8 | 5.5 | 3103 | 3036.6 | 50.61 | 1530.9525 | 331 |
| 9 | 6 | 2669 | 2602.6 | 43.38 | 1561.68 | 278 |
| 10 | 6.5 | 2198 | 2131.6 | 35.53 | 1501.1425 | 237 |
| 11 | 7 | 1978 | 1911.6 | 31.86 | 1561.14 | 204 |
| 12 | 7.5 | 1712 | 1645.6 | 27.43 | 1542.9375 | 178 |
| 13 | 8 | 1515 | 1448.6 | 24.14 | 1544.96 | 156 |

**Table - 3 : Statistical Analysis**

| Background ( in 10 sec ) | | Background ( in 100 sec ) | |
|---|---|---|---|
| S. No. | Counts | S. No. | Counts |
| 1 | 14 | 1 | 117 |
| 2 | 6 | 2 | 127 |
| 3 | 12 | 3 | 134 |
| 4 | 11 | 4 | 104 |
| 5 | 13 | 5 | 130 |
| 6 | 11 | 6 | 114 |
| 7 | 11 | 7 | 125 |
| 8 | 9 | 8 | 132 |
| 9 | 10 | 9 | 121 |
| 10 | 11 | 10 | 114 |

Debarshi Das

FIG. 14. Signed data

**Table - 3b : Statistical analysis with source**

| S. No. | Counts Ni | S. No. | Counts Ni |
|---|---|---|---|
| 1 | 2115 | 26 | 2100 |
| 2 | 2090 | 27 | 2106 |
| 3 | 2086 | 28 | 2171 |
| 4 | 2169 | 29 | 2087 |
| 5 | 2178 | 30 | 2078 |
| 6 | 2088 | 31 | 2155 |
| 7 | 2058 | 32 | 2013 |
| 8 | 2112 | 33 | 2101 |
| 9 | 2121 | 34 | 2148 |
| 10 | 2096 | 35 | 2109 |
| 11 | 2170 | 36 | 2135 |
| 12 | 2102 | 37 | 2200 |
| 13 | 2129 | 38 | 2119 |
| 14 | 2155 | 39 | 2109 |
| 15 | 2161 | 40 | 2101 |
| 16 | 2176 | 41 | 2068 |
| 17 | 2178 | 42 | 2142 |
| 18 | 2119 | 43 | 2110 |
| 19 | 2079 | 44 | 2134 |
| 20 | 2076 | 45 | 2013 |
| 21 | 2040 | 46 | 2116 |
| 22 | 2048 | 47 | 2148 |
| 23 | 2078 | 48 | 2102 |
| 24 | 2101 | 49 | 2096 |
| 25 | 2101 | 50 | 2083 |

| Efficiency | | | | | |
|---|---|---|---|---|---|
| Gamma Source | | Beta Source ( Ao = 10 kBq; May 2016 | | Background | |
| S. No. | Counts | S. No. | Counts | S. No. | Counts |
| 1 | 867 | 1 | 3958 | 1 | 113 |
| 2 | 831 | 2 | 4188 | 2 | 107 |
| 3 | 836 | 3 | 4298 | 3 | 117 |
| 4 | 828 | 4 | 4294 | 4 | 114 |
| 5 | 797 | 5 | 4229 | 5 | 105 |

Debasis Das

FIG. 15. Signed data