Geiger-Muller (GM) Counter Performance Efficiency Characterization with Gamma Rays

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Abstract

The efficiency of a Geiger-Muller counter was measured using a Co-60 radioactive gamma ray source with the following results:

Co-60 expected radioactivity level 0.94 uCi
$7.66\ x10^3$ gamma rays per second expected to enter GM counter (theoretical)
71 counts/sec measured with the GM counter
GM counter efficiency measured at about 1%

GM tubes are known to have a very low detection efficiency for gamma rays (see references)

Equipment:

Spectrum techniques Geiger-Muller counter

Spectrum Techniques ST365 Radiation Counter (with internal HV power supply)

Spectrum Techniques GM tube holder and sample tray

Co-60 radioactive source

1. Choose a radioactive source with known activity and decay products; determine its current radioactivity level using the half-life formula

2. Calculate the fraction of the radiation expected to pass through the detector using the formula $\frac{1}{2} - \frac{d}{2\sqrt{r^2+d^2}}$ where *d* is the distance of the source from the detector lens, and *r* is the radius of the detector lens.

The further the source is the smaller the detector's *geometrical acceptance*, fewer particles enter the detector's lens.

3. Run two tests, one with the radioactive source present and one without, to measure the background radiation. Subtract the average background count rate from the average count rate with the source present to obtain the average count rate from the source alone.

4. Use the formula $E = \frac{number\ of\ detected\ counts\ from\ source}{number\ of\ expected\ counts\ from\ source}\ x\ 100\%$ to get the efficiency of the detector as a percentage value.

Step 1: Determining Source Activity Level

To characterize the GM tube's sensitivity to gamma radiation, we first needed to choose a radioactive source that only emitted gamma rays (γ-rays). Cobalt-60 was chosen, as its decay process only produces two γ-rays of energies 1.1732 and 1.3325 MeV. We then used the half-life formula,

$$N(t) = N_0(\tfrac{1}{2})^{t/t_{1/2}}$$

Where, since our Co-60 source had an initial 1 uCi activity, a half life of 5.27 years, and was 6 months old,

$$N_0 = initial\ activity = 1\ \text{uCi}$$

$$N(t) = remaining\ activity$$

$$t = elapsed\ time\ in\ years = 0.5\ years$$

$$t_{1/2} = half\ life\ of\ substance = 5.27\ years$$

we calculated the current activity of our source to be 0.94 uCi.

$$N(t) = N_0(\tfrac{1}{2})^{t/t_{1/2}} = (1\ \text{uCi})(1/2)^{(0.5/5.27)} = 0.94\ \text{uCi}$$

$1\ uCi = 3.7x10^4$ disintegrations per second and Co-60 decay produces two gamma rays, so we could expect our source to be emitting $6.96\ x10^4$ gamma rays per second:

0.94 uCi x $3.7x10^4$ x 2 = **6.96 x 10^4 gamma rays per second emitted from source (theoretical)**

Step 2: Calculating the fraction of the radiation expected to pass through the detector due to its *geometrical acceptance*

Our GM tube lens has a radius r = 1.05cm. Our testing setup had our source placed a distance d = 1.3cm away from the face of the GM tube. Using the formula we get

$$\frac{1}{2} - \frac{d}{2\sqrt{r^2+d^2}} = 0.5 - (1.3/3.34) = 0.11$$

https://www.vernier.com/files/innovate/determining_the_efficiency_of_a_geiger-mueller_tube.pdf

This meant that 11% of the radiation emitted from our Co-60 source is expected to enter the lens of the GM tube. Multiplying this by our source's calculated output of $6.96 \, * 10^4$ gamma rays per second, we would expect to see $7.66 \, * 10^3$ gamma rays passing through the GM tube's lens every second, which is our theoretical maximum count rate.

0.11 x $6.96 \, * 10^4$ = $\boldsymbol{7.66 \, x10^3}$ **gamma rays per second expected to enter detector (theoretical)**

Step 3: Data Collection

The GM tube had already been plateaued and found to operate best at ~850 Volts, so 850 volts was used.

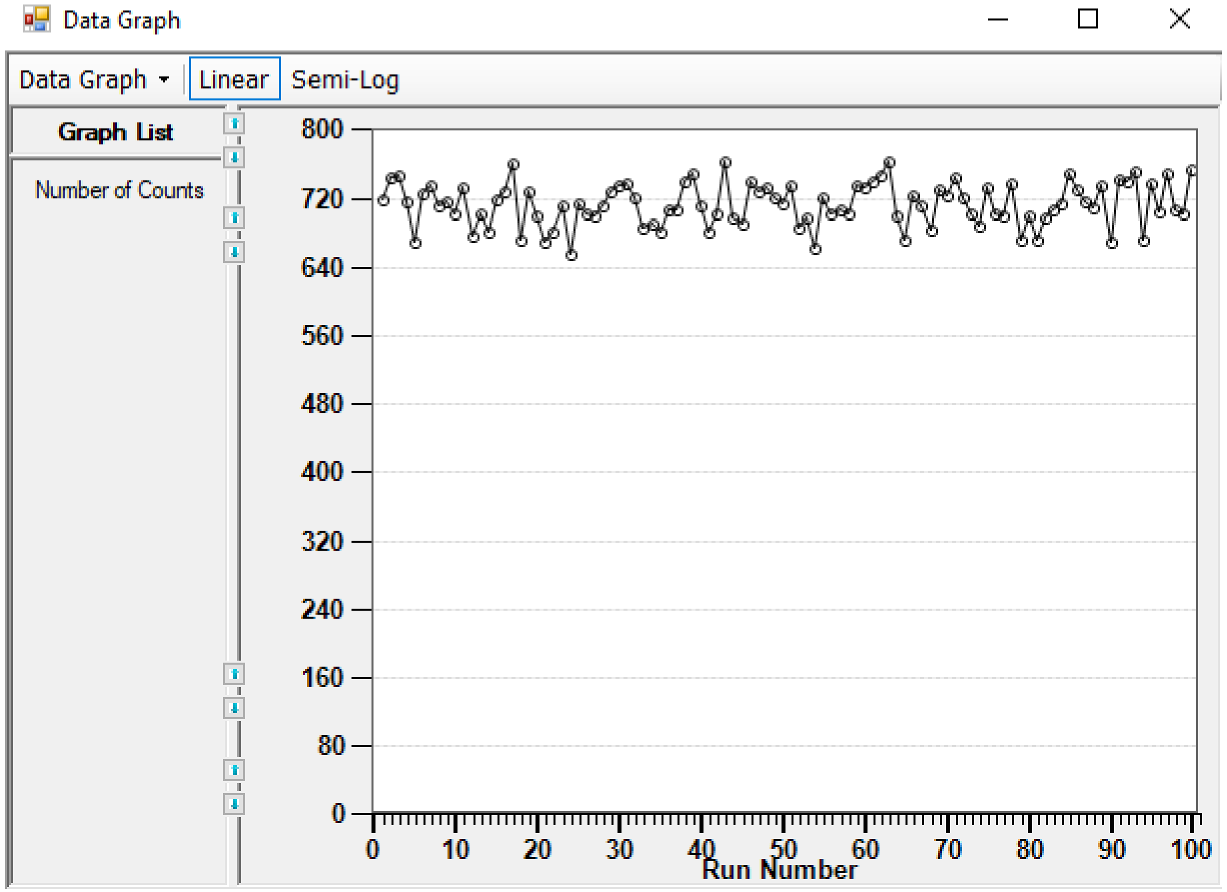
Two tests were performed:

1. Radiation levels were measured with the Co-60 test source at a distance of 1.3cm from the open end of the GM tube, and
2. Radiation levels were measured without the Co-60 test source, to measure background radiation.

Each test consisted of 100 runs lasting 10 seconds each. At the end of each 100 run test we calculated the average ten second count rate, and from there the average counts/second. The background radiation average counts/second was subtracted from the counts/sec measured when the Co-60 source was in front of the GM tube.

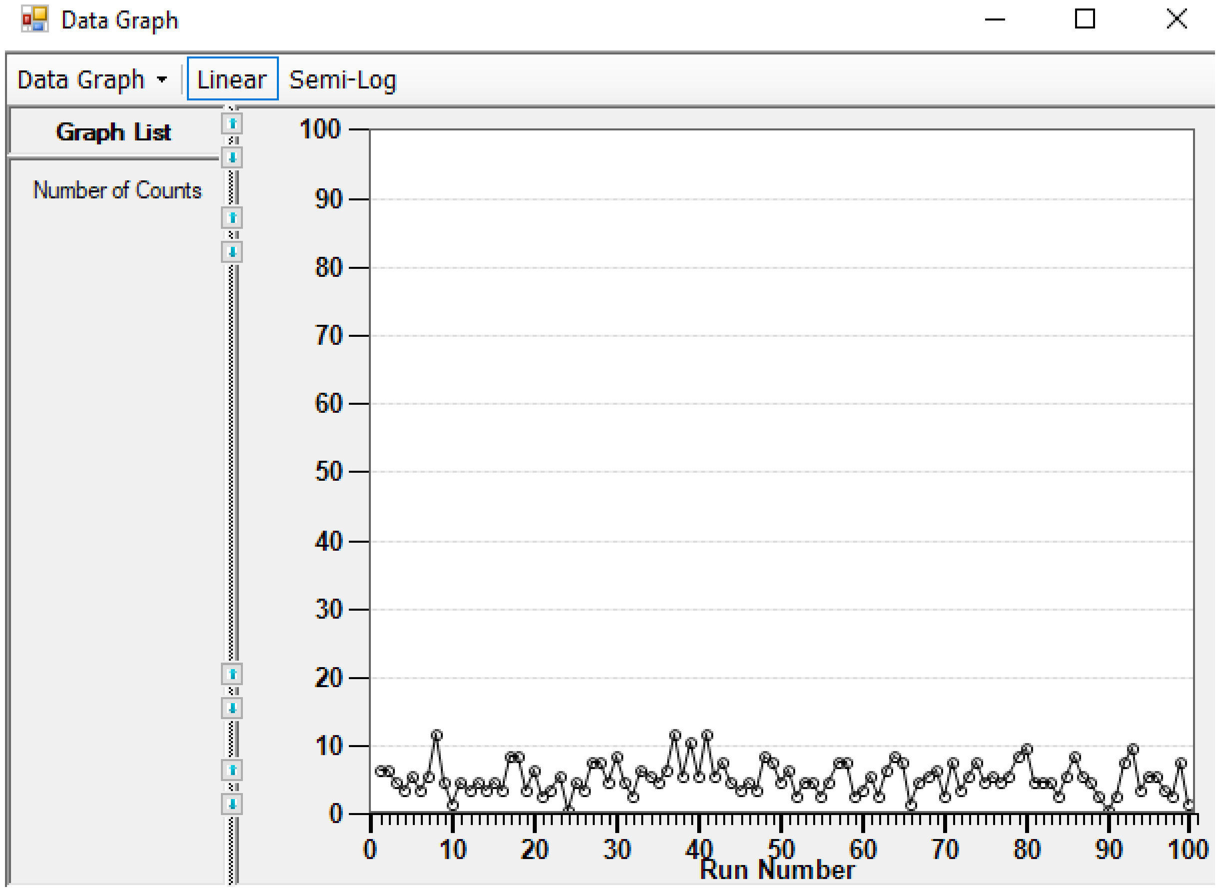
The following slide shows the plots from both tests.

GM Tube 850v: Co-60 gamma source @ 0.94 uCi activity
(Number of counts per 10s run, 100 runs)



Average 10s count: 716.39
Average counts/sec: 71.6

GM tube 850v: Background radiation
(Number of counts per 10s run, 100 runs)



Average 10s count: 5.77
Average counts/sec: 0.577

Step 4: GM counter Efficiency Calculation and Results

Our two tests resulted in an average count rate of 71.6 counts/sec with the Co60 source, and 0.577 count/sec background rate with no source. Subtracting the background we get a source-only average count rate of 71 counts per second

Calculated GM counter efficiency with Co-60 gamma rays = $\frac{\mathbf{71}}{\mathbf{7.66}\ \boldsymbol{x}\ \mathbf{10^3}}\ \boldsymbol{x}\ \mathbf{100\% = 0.93\%}$

This means our GM counter has a gamma ray detection efficiency of about 1%

Results:

Co-60 expected radioactivity level 0.94 uCi

$\mathbf{7.66}\ \boldsymbol{x}\mathbf{10^3}$ **gamma rays per second expected to enter GM tube (theoretical)**

71 counts/sec measured with the GM counter

GM counter efficiency about 1%

GM tubes are known to have a very low detection efficiency for gamma rays:

https://iopscience.iop.org/article/10.1088/1748-0221/12/06/P06005/pdf

http://www.ijsred.com/volume4/issue1/IJSRED-V4I1P84.pdf

For comparison, a similar test performed by Richard Born of Northern Illinois University, using a similar setup, measured a GM counter gamma-ray efficiency with Co-60 at 3.54%

His experiment can be viewed here:

https://www.vernier.com/files/innovate/determining_the_efficiency_of_a_geiger-mueller_tube.pdf