Introduction

The CNS Ionising Radiation Workshop features the use of higher sensitivity Geiger-Müeller detectors than most high school science teachers have access to. This note illustrates the impact of using lower sensitivity instruments with weak sources – AND shows how they may be used with the more intense sources described in the Workshop Notes.

Damn lies and statistics

The collection of count data with an instrument such as a Geiger detector is made using assumptions that are important to the analysis of the data set. These include:

1. Stable background radiation level
2. Consistent geometry
3. Stable sensitivity

Lower sensitivity detectors have correspondingly lower average count rates when monitoring an ionising radiation source, including background radiation. Consequently it is difficult to detect the presence of ionising radiation sources that provide only a modest increase over the background rate. This limitation is due to the statistics of the count data.

The pulses from a Geiger counter are collected as a number of counts in a time interval, for example the number of counts in a one minute interval. These are integer values. The average number of counts over a number of one-minute counting intervals is a real number. The one-minute interval data set may be described in terms of a Poisson probability distribution. For a data set with a large number of sample intervals and a sufficiently high average number per interval the probability distribution tends toward a Normal (or Gaussian) distribution. If the average number of counts in a time interval is small, the width of the distribution will be proportionately wide. For a normal distribution, the standard deviation or full width at half-maximum is the square root of the mean.

As an example, if the average number of counts for background radiation in a time interval is 16, the standard deviation would be 4. In the presence of a source that doubles the average number of counts to 32 (the standard deviation would be ~5.7 counts) the means of the background and background plus source distributions would be 3-4 standard deviations apart. Similarly, if the average number of counts increases by only 50% to 24, the means would be ~ 2 standard deviations apart. A larger data set (more counting intervals) is required to demonstrate the presence of the weaker source above background.

Geiger Detector Instrument Scales

Commercially available Geiger detector instruments have either analog meter displays or a digital display. Many allow the user to select the scale, and some have selectable averaging time. The analogue displays may be either linear, or "logarithmic". The scales may present:

1. Counts per minute
2. mR/h (milli-Roentgen per hour) with scales of 1 or 10 …
3. mrad/h or mrem/h with scales of 1 or 10 …
4. µSv/h with range of 10 or 100 …

The Roentgen is an historical unit related to the ionisation of air by ionising radiation. Use of this unit is confused by diverse definitions and is discouraged, but it continues to appear.

The Gray is the SI Unit for dose to matter: 1 Gy = 1 joule/kilogram.

The Sievert, Sv is a human biology sensitivity adjusted dose unit that is related to the gray by weighting factors for the radiation type and tissue/organ sensitivity (type factor= 1 for gamma radiation, up to 20 for alpha and neutron radiation).

The rad is an earlier unit of dose to matter presently defined in terms of the Gray: 100 rad = 1 Gy. The rem is the related dose adjusted for human biology sensitivity for the type of radiation and is related to the rad by weighting factors). The rem is the short form for roentgen equivalent man. The rem presently defined in terms of the Sv: 100 rem = 1 Sv. The units "rad" and "rem" remain prevalent in the North American nuclear industry.

Background radiation varies with location ranging from 2 to 4 (average 3.1) mSv/year for the USA to ~ 180 mSv/year in Ramsar Iran. As 1 year = 8760 h, the background ranges from ~ 0.2 µSv/h to 20 µSv/h.

Geiger instruments that have an analogue meter display include a "low-pass filter" to integrate the number of pulses detected over a time period.

The CNS has two small Geiger tube instruments:

- a "Digilert Nuclear Radiation Monitor" and
- an Aware Electronics RM-60.

These appear to have similar Geiger tubes with an effective window diameter of 0.360 inches.

The RM-60 is compared with the larger RM-80 in the table below. The area ratio is 23.6 while the sensitivity ratio is 3.24 (neglecting any effect of the differences in energy of the reference nuclide gamma emissions).

Model	Effective diameter	Counts per s per mR/h	Reference nuclide
RM-60	0.36 inches	18.5	Cs-137
RM-80	1.75 inches	60	Co-60

In tests monitoring background radiation, the RM-60 produces an average count rate about 1/3 of that observed with the RM-80. The RM-60 and Digilert have very similar tube specifications and appear to produce similar background count levels (the Digilert data must be recorded by hand). The Digilert reference is 1000 counts per minute per mR/h (16.7 counts per second). Small variations in the Geiger tube excitation voltage may influence the sensitivity.

Hot Balloon Experiment

A balloon was inflated, charged and hung for 30 minutes. Upon deflating it was squeezed between the Geiger windows of the two instruments.

The RM-60 count rate rose to 231 counts per minute while the Digilert count rate rose to 149 counts per minute – over 10 X background. Inserting a piece of paper reduced the count rate for the RM-60 but did not seem to have as large an effect on the Digilert. Moving the Geigers and the balloon changes the count rate. To test this further the balloon was folded to provide 8 layers over the window area. This increased the count rate to 340 CPM for the RM-60 and 245 for the Digilert.

These elevated count rates correspond to ~0.3 mR/h or 3 µSv/h. With a 1 mR/h scale this is observable. Folding the balloon at the start of the counting would provide higher levels.

NoSalt® ^{40}K Experiment

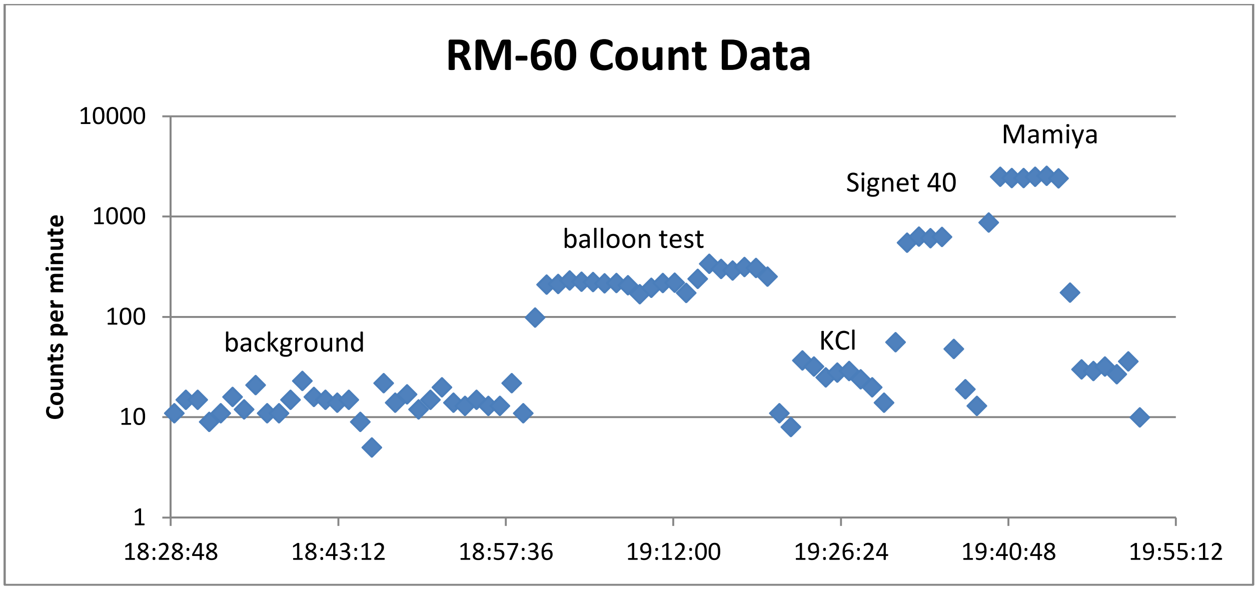
Placing the RM-60 about 1 cm above a layer of potassium chloride provided a count rate ~2 X background. A similar result was obtained with the Digilert.

Camera Lens ^{232}Th

Perching the RM-60 atop the lens of a Kodak Signet 40 camera produced a count rate of over 600 counts per minute and ~482 for the Digilert. The Geiger window is not as close to the lens as is possible with the RM-80.

Aligning the RM-60 Geiger window with the rear element of a Mamiya/Sekor 50 mm SLR lens provides ~ 2500 counts per minute and ~ 1900 counts per minute for the Digilert.

The graph below illustrates the count data collected with the RM-60 while preparing this document. The step in the balloon data corresponds to folding the balloon to increase the count rates.



Summary

It is possible to use a lower-sensitivity Geiger detector for the experiments described in the Ionising Radiation Workshop presentation and notes. A Geiger detector that interfaces with a computer such as the Aware Electronics RM-60 (RM-70, or RM-80) facilitates data logging and assists with presenting the results to the students using a projector. The results are more spectacular with the more sensitive Geiger instrument. Moreover, less time is required with the more sensitive instrument to demonstrate the increase in the average count rate when using low-activity sources.