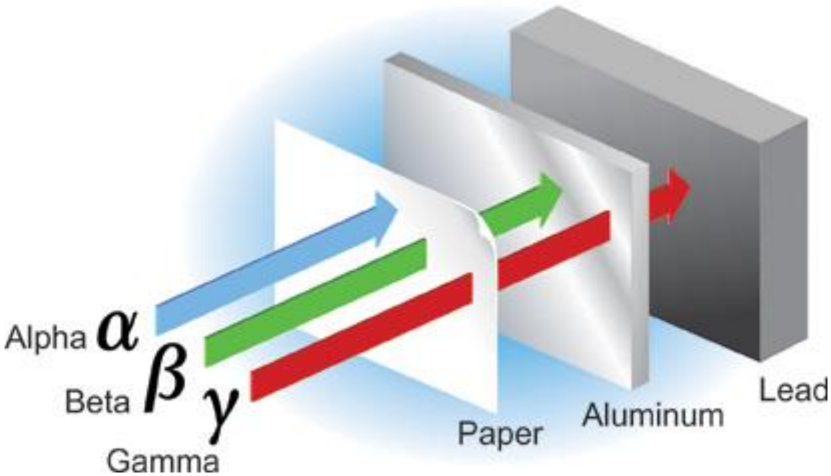
1 – Ionizing Radiation



What is Radiation?

Before we use our Geiger counter to detect and measure radiation, we ought to define what we mean by radiation.

Electromagnetic radiation includes long radio wave to ultra-short gamma rays. In this broad view radiation can include the heat given off from a candle, light emitted by an LED or from particles emitted by uranium ore. To narrow our definition of radiation for the purposes here we are confining it to what is considered ionizing radiation. Ionizing radiation is radiation that can strip electrons from atoms or molecules thereby making the resulting atom or molecule an ion.

Ionization radiation that we will be measuring and performing experiments with are gamma rays, x-rays, beta and alpha particles.

Alpha particles are massive particles consisting of two neutrons and two protons . They are equivalent to the nucleus of a helium atom. Alpha particles have a net positive charge. This radiation has a low penetration power. A few inches of air or a piece of paper can effective block alpha particles. The outer skin of our body protects us from alpha particles.

Surprisingly, if an alpha particle emitter is ingested or inhaled the alpha radiation is dangerous. (See “Q” factor) Because alpha particles are massive, they have a lot of kinetic energy. When it strikes inside our body it can damage DNA, break chemical bonds and create tissue damage. So, while its penetration is low, the local damage if ingested is considerable.

Beta particles are electrons, identical to the electrons found in atoms. Beta particles have a net negative charge. They have low penetrating power. Most beta radiation can be blocked by 1/8” (4mm) of aluminum.

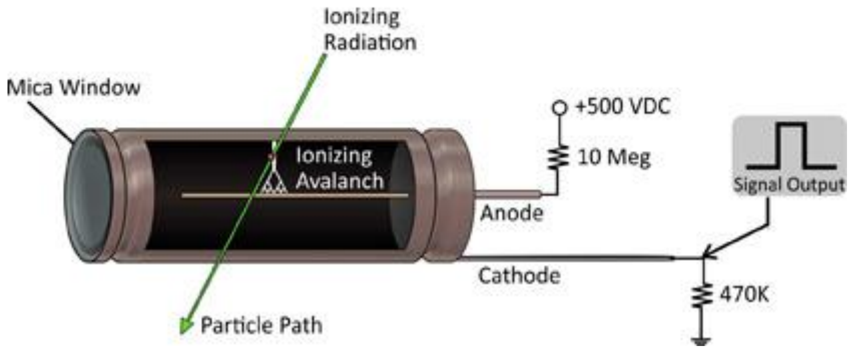
Gamma and x-rays are high energy ultrashort electromagnetic radiation. This classification of radiation has the greatest penetrating power. High energy gamma radiation are able to pass through several centimeters of lead and still be detected on the other side. Gamma radiation is attenuated by dense materials such as lead. Gamma radiation is produced naturally from the decay of some radioactive materials. X-rays on the other hand is man-made radiation used in medicine and dentistry. X-rays penetrating power is used to take internal x-ray photographs of the human body and teeth. While x-rays are manmade electromagnetic radiation, their frequency is so high that the radiation is also ionizing.

Detecting Radioactivity

There are many instruments available for detecting and measuring radioactivity. We are focused on using the Geiger counter for our detection and experiments.

Geiger Counters are instruments that can detect and measure radioactivity using a Geiger Mueller tube. Geiger Mueller tubes are commonly referred to as a GM tube. The original design of the g-m tube by Hans Geiger and E.W. Mueller in 1928 hasn't changed much and the tube's sensor function remains the same.

Geiger Muller Tube



Radiation, as it passes through the GM tube, ionizes the gas within the tube. The ionization initiates a momentary avalanche of electrons accelerate by the high voltage potential used to power the GM tube. This avalanche, create a momentary conductive path between the wire at the center of the tube (Anode) and the wall of the tube (Cathode), see figure 1 resulting in a 'click' sound. By measuring the number of the clicks, the instrument indicates the radiation levels.

The GM tube sensor is the heart of the Geiger counter and to be a Geiger counter, the device has to contain a Geiger-Muller (GM) tube. The GM Tube can detect gamma and X-ray radiation, beta particles and if manufactured with a thin mica window, alpha particles as well.

Measurement of Radiation

Radiation Penetration Calculator

There are a few scales that one can use to measure radiation. Depending upon your application, one scale may be better than the others.

Radiation Measurements

Roentgen: Is the measurement of energy produced by Gamma or X-Ray radiation in a cubic centimeter of air. It is abbreviated with the capital "R". One milliroentgen, abbreviated "mR" is one-thousandth of a roentgen. One micro roentgen, abbreviated “uR” is one-millionth of a roentgen.

RAD: Radiation Absorbed Dose. Original measuring unit for expressing the absorption of all types of ionizing radiation (alpha, beta, gamma, neutrons, etc) into any medium. One rad is equivalent to the absorption of 100 ergs of energy per gram of absorbing tissue.

REM: Roentgen Equivalent Man is a measurement that correlates the dose of any radiation to the biological effect of that radiation. Since not all radiation has the same biological effect, the dosage is multiplied by a "quality factor" (Q). For example, a person receiving a dosage of gamma radiation will suffer much less damage than a person receiving the same dosage from alpha particles, by a factor of three. So alpha particles will cause three times more damage than gamma rays. Therefore, alpha radiation has a quality factor of three. Following is the Q factor for a few radiation types.

Radiation:	**Quality Factor (Q)**
Beta, Gamma and X-rays	1
Thermal Neutrons	3
Fast n, a, and protons	10
Heavy and recoil nuclei	20

The difference between the rad and rem is that the rad is a measurement of the radiation absorbed by the material or tissue. The rem is a measurement of the biological effect of that absorbed radiation.

For general purposes most physicists agree that the Roentgen, Rad and Rem may be considered equivalent.

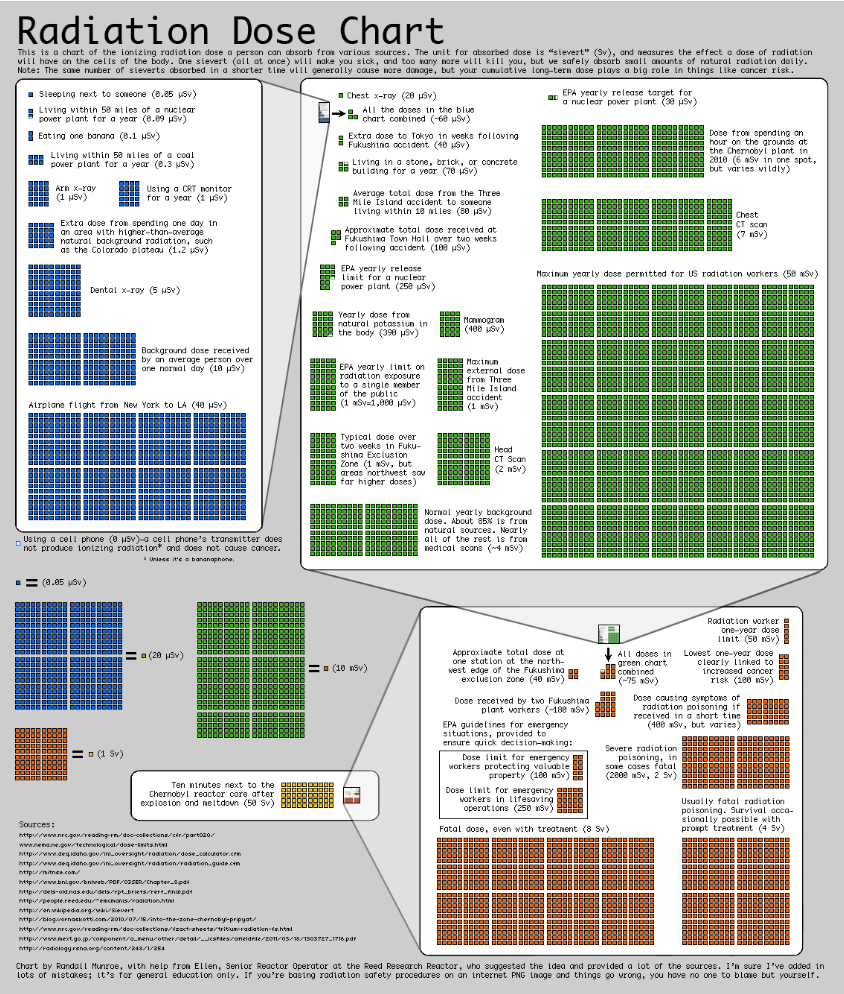
System International (SI) of Units

The System International of unit for radiation measurements is now the official system of measurements. This system uses the “gray” (Gy) and “sivert” (Sv) for absorbed dose and equivalent dose respectively.

The conversion from one system to another is simple:

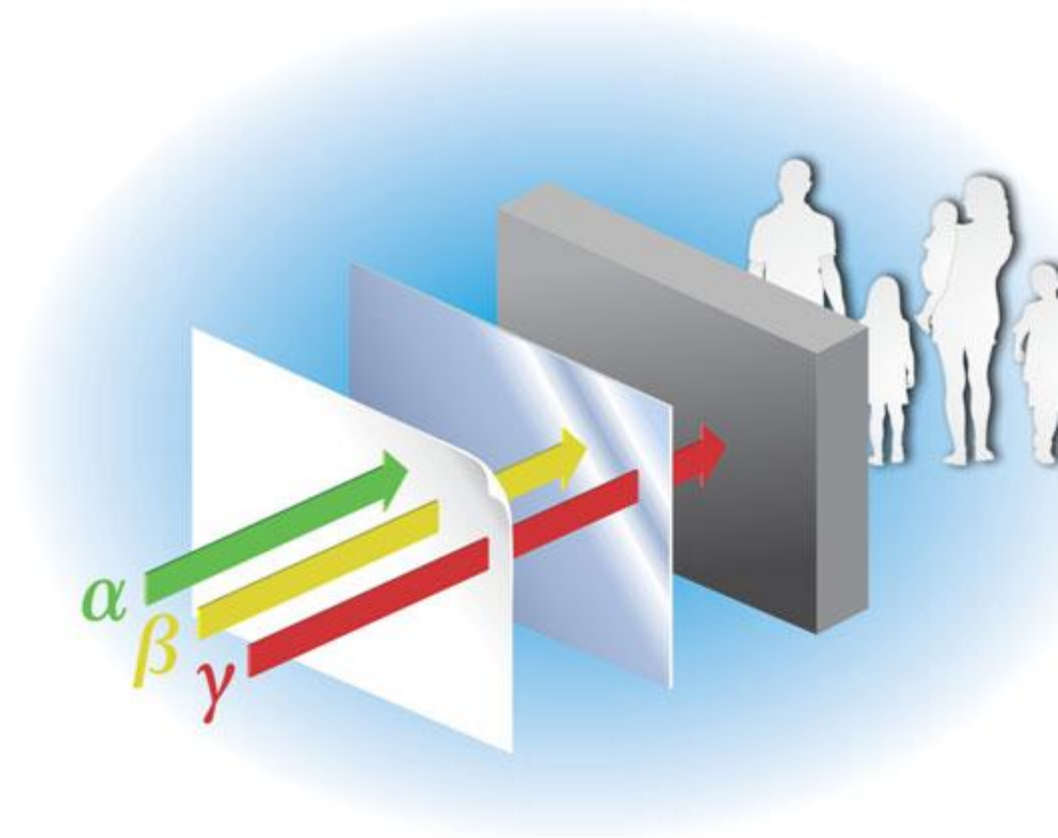
1 Sv = 100 rem	1 rem = .01 Sv
1 mSv = 100 mR (mrem)	1 mR = .01 mSv
1 Gy = 100 rad	1 rad = .01 Gy
1mGy = 100 mrad	1 mrad = .01 mGy

To get an idea of this visually try using this Radiation Dose Chart. This Radiation Dose chart is Public Domain and is intended for general public informational use only.



**Sources*

How Much Radiation is Safe?



In the United States the U.S. Nuclear Regulatory Commission (NRC) determines what radiation exposure level is considered safe. Occupational exposure for worker is limited to 5000 mrem per year. For the general population, the exposure is 500 mrem above background radiation in any one year. However, for long term, multi-year exposure, 100 mrem above background radiation is the limit set per year.

Let's extrapolate the 100 mrem number to an hourly radiation exposure rate. There are 365 days/yr x 24 hr/day equals 8760 hours. Divide 100 mrem by 8760 hours equals .0114 rem/hr or 11.4/hr millirem. This is a low radiation level. The background radiation in my lab hovers around 20 uR/hr. Am I in trouble? No. Typically background radiation in the United

States averages 300 mrem/yr. My yearly radiation exposure from 20 uR/hr is about 175 millirem/year.

Notice that my lab readings are in microrad (uR/hr) and the exposure limit is given in microrem (urem/hr). I do not know what type of radiation (a, b or y) the Geiger counter is reading in my lab at any particular instant, so I do not know the Q factor of the radiation and therefore cannot calculate the mrem. However, for general purposes I consider them equivalent.

The US Government's EPA has an online calculator to help you determine you yearly radiation exposure:

https://www.epa.gov/radiation/calculate-your-radiation-dose

Common Radiation Exposure (General Population)

Exposure Source	Dose(conventional)	Dose (SI)
Flight from LA to NY	1.5 mrem	.015 mSv
Dental X-ray	9 mrem	.09 mSv
Chest X-ray	10 mrem	0.1 mSv
Mammogram	70 mrem	0.7 mSv
Background Radiation	620 mrem/year	6.2 mSv/year

Background radiation consists of three sources; **Cosmic** radiation from the sun and stars; **Terrestrial** radiation from low levels of uranium, thorium, and their decay products in the soil, air and water; **Internal** radiation from radioactive potassium-40, carbon-14, lead-210, and other isotopes found inside our bodies.

Radiation Safety - Lead Shielding Guide

Purchase Lead Sheet(s) for Gamma Shielding:

Shielding reduces the intensity of radiation depending on the thickness. This is an exponential relationship with gradually diminishing effect as equal slices of shielding material are added. A quantity known as the halving-thicknesses is used to calculate this. Halving thickness is relative to the energy level of the gamma radiation. Higher intensity radiation will require thicker shielding.

For instance, the gamma radiation emitted from Cobalt-60 are 1.33 and 1.17 MeV. If we look at the gamma radiation emitted from Iridium-192 are 0.31, 0.47, and 0.60 MeV. The gamma radiation from Cobalt-60 has twice the energy as the gamma radiation from Iridium-192 therefore Cobalt-60 halving thickness will be greater than the halving thickness of Iridium-192.

The halving thickness of lead is 1 cm. Which means the intensity of gamma radiation will reduce by 50% by passing through 1 cm of lead.

For example;

1) A lead shield 2.0 cm thick reduces gamma rays to 1/4 of their original intensity. (1/2 multiplied by itself two times)
2) 3.0 cm of lead reduces gamma radiation to 1/8 of their original intensity (1/2 multiplied by itself three times)

Halving thicknesses of some materials, that reduce gamma ray intensity by

50% (1/2) include:[5]

Material	Halving Thickness[cm]	Halving Thickness[inches]	Density [g/cm³]	Halving Mass [g/cm²]
Lead	1.0	0.4	11.3	12
Steel	2.5	0.99	7.86	20
Concrete	6.1	2.4	3.33	20
Packed soil	9.1	3.6	1.99	18
Water	18	7.2	1.00	18

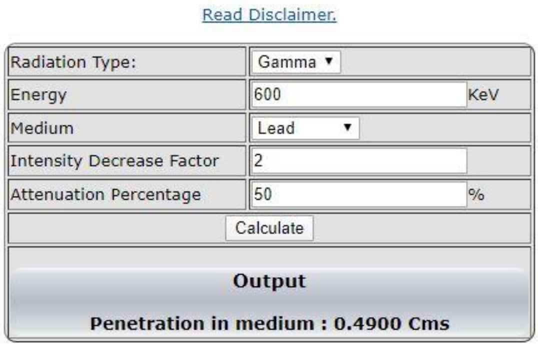
Column Halving Mass in the chart above indicates mass of material, required to cut radiation by 50%, in grams per square centimeter of protected area.

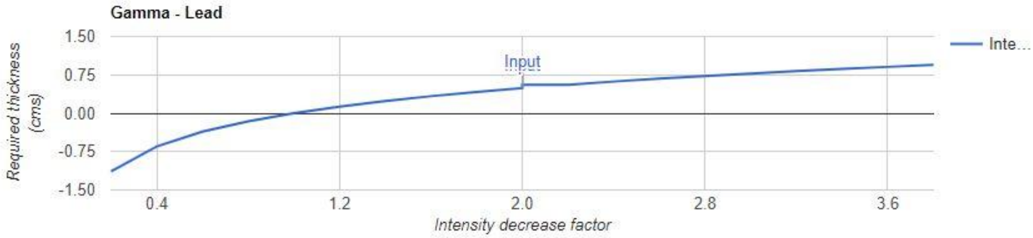
Calculating Radiation Halving Thickness

Images SI Inc. has a free online radiation penetration calculator located on its website at:

https://www.imagesco.com/geiger/cal/

Using this online calculator you can estimate the halving thickness value of various materials and radiation types. For an example I put in the high gamma radiation from Iridium-192, which is 0.60 MeV. In the calculator this is 600 keV.





The calculator estimated the halving thickness of lead at 0.49 cm thick.

I next put in the high gamma radiation of Cobalt-60, 1.33 MeV (or 1330 keV). The calculator estimated the halving thickness at 1.08 cm of lead.

Storage of Radioactive Isotopes

Many of the experiments in this book use license exempt radioactive sources. These are 1” in diameter 1/8” inch thick plastic discs with a small amount of radioactive isotope embedded within the center of the plastic.

The radioactivity of these sources are so low that the United States government allows the general public to purchase and own these sources without needing a license.

Even so, to reduce your exposure to any additional radiation you may want to purchase a lead container to hold these sources. These containers are called lead “pigs”.

You can purchased new and refurbished lead pigs here:

https://www.imagesco.com/geiger/containers.html

Other Helpful Links

U.S. Nuclear Regulatory Commission

http://www.nrc.gov/

CDC - Center for Disease Control maintains a radiation emergency web site:
http://www.bt.cdc.gov/radiation/index.asp#clinicians

Health Physics Society
http://www.hps.org

U.S. Environmental Protection Agency
http://www.epa.gov/radiation

Author and Publisher disclaimer: We do not make any warranties (express or implied) about the radiation information provided here for your particular use. All information should be confirmed and verified with local and national government organizations or recognized experts in this field before being used.

2 - Geiger Counter Buyer’s Guide

If you haven’t purchased a Geiger counter, this guide will help you make a selection. With so many Geiger counters for sale online, it's easy to become confused when comparing specification and features. First question to ask yourself is, "what is your application?" Answering this question will help refine your search for a model that will be a best fit to your need.

Why People Purchase Geiger Counters:

- Safety checks for radiation levels in your environment, home, food, water, and surroundings
- Anyone living close to a nuclear power plant.
- First responders who need a reliable and accurate Geiger counter.
- Interested in science and want to perform nuclear experiments?
- Survivalist being prepared for a nuclear accident or emergency?
- Gadget lover who wants to play with these nuclear instruments to satisfy your curiosity.
- Prospecting for uranium ore or radioactive materials.
- Collecting - checking vintage Fiesta ware plates or glow-in-the-dark clock hands for radioactivity?

What is a Geiger Counter?

Geiger Counters are instruments that can detect and measure ionizing radiation using a Geiger Mueller tube. Geiger Mueller tubes are commonly referred to as a GM tube. A GM tube is the radiation sensor used in a Geiger counter.

As explained in the last chapter, radiation, as it passes through the GM tube, ionizes the gas within the tube creating a momentary conductive path resulting in an electric pulse, heard as a 'click' sound. By measuring the number of the clicks, the instrument indicates the radiation levels.

Detection of Ionizing Radiation

Geiger counter detect the three primary radiation types; alpha, beta and gamma (x-ray) associated with radioactivity. Radioactivity is the spontaneous emission of energy from the nucleus of certain elements, most notably uranium.

Natural Background Nuclear Radiation:

Nuclear radiation is a normal part of our life on planet Earth. We are bombarded with nuclear radiation every day. Background radiation, from natural sources on earth and cosmic rays will cause the Geiger counter to click randomly a number of times every minute. In my corner of the world I have a background radiation that triggers the counter 22-34 times a minute. When performing radiation checks to see if a material is radioactive or contaminated with radioactive material, this background radiation count is usually deducted from the reading to evaluate if a material is radioactive.

What Geiger Counters Do Not Detect:

Geiger counters do not detect cell phone radiation. Do not detect radio frequency (RF) or electromagnetic field (EMF) radiation. EMF radiation is emitted from power transformers and other types of power electrical inductors. They cannot detect microwave radiation from a microwave oven. Nor can they detect neutrons.

Images Scientific Instruments has a free online radiation penetration calculator you can use https://www.imagesco.com/geiger/cal/index.html

Geiger Muller Tubes

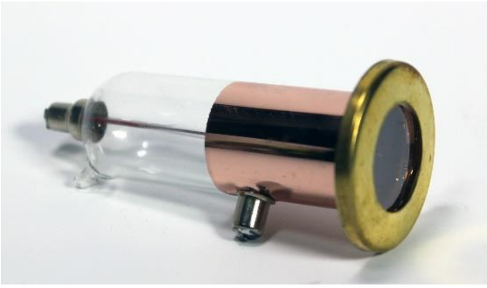
Inexpensive GM tubes like the SBM-20 Russian Geiger counter tube shown to the right, only detect beta, x-ray and gamma radiation. So, if your Geiger counter uses one of these styles GM tubes it is blind to all alpha particle radiation.

Figure 11.1

Figure 11.2

More expensive GM tubes, like the LND-712 Geiger Counter tube shown to the left have a thin mica window that allows alpha particle radiation to penetrate into the interior of the GM tube and ionize the gas for detection. It is generally more fragile than the beta-gamma GM tubes because of the thin mica window. The mica window allows one to detect the alpha radiation from radium and polonium. This type of Geiger counter may also be used for prospecting, experiments, and general field work. In addition, it can measure total radiation from materials including alpha radiation. Most laboratory grade Geiger counters use this style tube.

Here is another style tube that has an alpha window. This Russian tube requires 1000 VDC to operate.



The common thread connecting the types of radiation these Geiger counter tubes detect is that the radiation is all ionizing radiation. Meaning they are capable of ionizing the gas atoms inside a GM Tube which allows for their detection, as explained on the first page of this chapter.

Ebay Geiger Counters

EBAY is a place to find used and surplus Geiger Counters. If you search on eBay for Geiger counters, radiation detectors or radiation monitors you will run across numerous radiation detection devices. Let's look at a few. There is a lot of government surplus for sale on eBay. The CD-715 model is a popular model, see Figure 11.6.

Figure 11.3

These detectors were made to be used in a high radiation field one would find in a post nuclear attack or nuclear reactor incident. The radiation meter provides the scale of detectable radiation, see Figure 11.7.

The meter scale of the CDV-715 is rated in rads/hr. A knob provided a range of 0.1 - 0.5 Rad to 100 - 500 Rads. Today's Geiger counters are far more sensitive, and measure radiation in fractions of millirads. A millirad is 1/1000 of a rad.

Figure 11.4

The CDV-715 is not a Geiger counter. It doesn't have a GM tube, instead it uses an ionization chamber. If you open a CDV-715 you can see the ionization chamber, see Figure 11.8.

Figure 11.5

The CDV-715 only detects high levels of gamma radiation, so I would not recommend this as a purchase.

Figure 11.6

Similar is the CDV-700, which looks similar, but uses a GM tube, see Figure 11.9. The CDV-700 is more sensitive than the ionization chamber CDV-715. The CDV-700 meter shows the scale, see Figure 11.10.

Figure 11.7

The GM Tube on the CDV-700 is only beta and gamma sensitive. Since most of these units are vintage 1950-1960's I do not have any idea as to their accuracy or if they can be calibrated accurately. Now if your only reason is to purchase a working Geiger counter and can find a working unit for $50-$75.00 buy it. When you reach the $100.00 mark you can purchase an inexpensive modern Geiger Counter that has greater sensitivity.

Geiger Counter's Nuclear Radiation Readout Accuracy

Two basic types are analog and digital. The digital Geiger counter is typically more accurate as you can obtain an exact count of radioactive particles detected. Whereas the analog meters average out reading, and do not provide a display for the detected particle count. A digital readout from the GCA-06W is shown in Figure 11.11 below.

Figure 11.8

Let's discuss accuracy. Don't believe an unproven claim of accuracy. Some Geiger counter vendors will claim high accuracy for their Geiger counter when it simply is not true. Here is what you need to know, will their Geiger counter pass ANSI-STD N323A calibration? Because without passing an ANSI-STD N323A calibration their claim of accuracy means nothing. Just claiming a Geiger counter is calibrated and has an accuracy of 1%, 5%, 10%, or 20% is not proof.

Fortunately, the ANSI-STD N323A calibration is the proper accuracy standard for Geiger Counters. A NRC certificate, fig 11.12 that certifies the attached Geiger counter has passed ANSI-STD N323A calibration using a NIST traceable source from an independent government licensed lab conforming to NRC regulations 10-CFR-34, 10-CFR-35, making it suitable for regulatory inspections. Certification label photo courtesy of Images SI Inc.

Figure 11.9
NRC certification label for the GCA-07W

Where to Obtain ANSI-STD N323A Calibration:

There are a number of independent laboratories that are licensed by the U.S. Government to calibrate Geiger counters to ANSI-STD N323A standard, and if it passes calibration a certification label is attached to the Geiger Counter. The certification is good for one-year.

The laboratory my company uses is:

Applied Health Physics Inc.
2986 Industrial Blvd
Bethel Park, PA 15102
(412) 835-9555

GM Tubes: Internal or External:

In the internal Geiger Counter instrument, the Geiger-Mueller tube is inside the case, enabling one hand operation, leaving the other hand free. Figure 11.13 shows the GCA-06 internal model.

Figure 11.10

Figure 11. 11

For the external instrument, the tube is located outside the case at the end of a probe or wand and connected to the instrument via a cable, see the GCA-06W shown in Figure 11.14.

This kind of instrument is more suited for ‘probing’ radiation levels in tight spots. It's easier to move a probe around to check for radiation, then it is to move the entire instrument.

How to read a Geiger Counter

The Geiger counter measures the radiation levels in different ways. Analog meters can provide a reading in Counts Per Minute (CPM) and their equivalent Radiation Level. For example, let’s look at the meter face to a common analog Geiger counter, see Figure 11.15.

Figure 11.12

At its most sensitive scale a count of 500 CPM is equivalent to a radiation level of 0.5 mR/hr. This model Geiger counter has a 10X and 100X switch to select ranges from 0.5 mR/hr to 5 mR/hr and 50 mR/hr respectively.

To obtain the Counts Per Second (CPS) divide the CPM by 60. So, a CPM reading of 300 is equal to 5 CPS (300/60 = 5).

Digital Geiger Counters

Digital Geiger Counters have a digital display. The digital display has a number of advantages, such as providing an accurate and exact count of the detected radioactive particles in either the CPS or CPM measurement and their equivalent radiation level. The analog display approximates the number of clicks per minute.

Figure 11.13

Figure 11.16 shows a digital display from a GCA-07, the Counts Per Second (CPS) on the top line of the LCD. The second line shows the equivalent radiation level. This second line's equivalent radiation level is a running three second average. This three second average smooths out the reading so it's not jumping every second in response to the changes in the CPS.

Imperial or Metric Measurement(s)

The digital display also allows you to change from Imperial measurements (mR/hr) to Metric measurements (mSv/hr) with a flip of a switch. Figure 11.16 shows a digital display from a GCA-07, the Counts Per Second (CPS) on the top line of the LCD as before. The second line shows the equivalent radiation level using metric measurements of mSv/hr. This second line's equivalent radiation level is also a running three second average, as explained before.

Figure 11.14 Switch from Imperial to Metric Measurements

CPM Measurements:

When switching to the CPM mode the digital screen changes, see Figure 11.18.

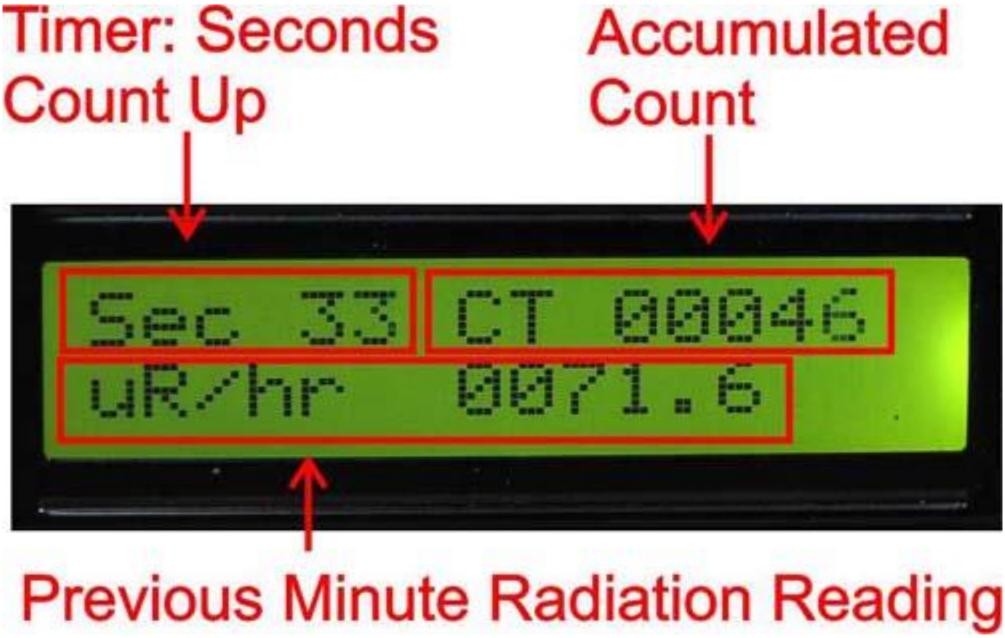


Figure 11.15

The first LCD line shows the running timer. The timer starts at 0 seconds and counts to 60 seconds (one minute). Next to the elapsed time on the first line is the accumulated count of radioactive particles detected. The timer continues to count radioactive detections until a full minute (60 seconds) has passed. At the point the display pauses for one-second to show the complete count for the minute and its relative radiation level before resetting the timer and accumulated count to zero and starting to count for the next minute.

The second line shows will continue to show radiation level until it updates again at the end of the minute.

One can also switch from Imperial measurement uR/hr to metric measurement uSv/hr in CPM mode.

Range:

The range of your Geiger counter tells you how much radiation you can measure. Typically, analog meter Geiger counters range from 1 to 100 mR/hr. Although some can go as high as 500 mR/hr. With digital Geiger counters the typical range is 1 to 200 mR/hr. However, the GCA-06 and GCA-07 series of digital Geiger counters range from 1 to 1000 mR/hr and maintain their NRC accuracy.

Ease of Use:

Having a great Geiger counter that is a pain to use is no bargain. Some Geiger counters use membrane push button to rotate through menu options to select different modes and ranges. If you read the reviews on these types of Geiger Counters most customers find this type of menu selection frustrating.

Look at Figure 11.26, all modes can be easily selected from the front panel switches. Another option that received bad reviews are membrane switches. The advantage of membrane switches are they allow a flat profile on the Geiger counter case. The disadvantage(s), the microcontroller needs to see the key press when it is pressed, or the option is not initiated. And they don't have the positive feel of a standard switch closure.

You want a Geiger counter that is easy and intuitive to use. Not one that requires you to reference a manual to make mode selections.

Warranty:

The standard warranty is one-year on parts and labor for any factory defects. An exception to the warranty is the GM tube which is fragile and could be broken easily if not handled properly.

Figure11. 16

Other Options

Data Logging / Software:

Does your Geiger Counter come with data logging or radiation charting software?

The radiation charting software allows one to chart radioactivity over long periods of time. It allows radiation data to be saved in files and pulled up into other programs like Excel. The radiation charting software for Images

SI Inc. is shown in Figure 11.19.

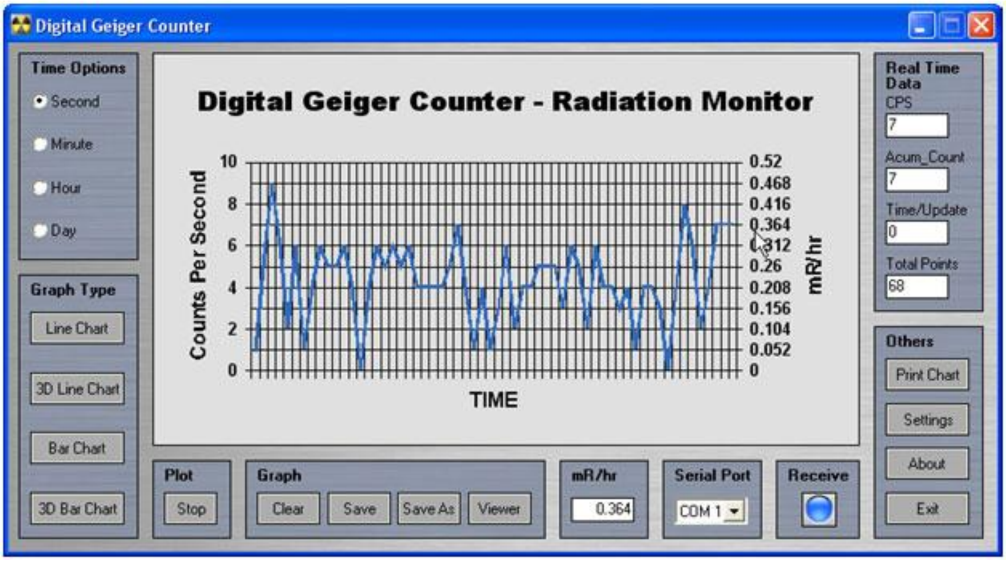


Figure 11.17