Section 5: Radiation Detection & Measurement

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The North Carolina Chapter of the Health Physics Society
Science Teacher's Workshop

Radiation Detection and Measurement

Because ionizing radiation cannot be detected by the unaided senses, various types of detection instruments must be used to evaluate the level of radiation and/or amount of radioactive material in an area. The proper instrumentation is essential for the accurate measurement of these quantities. Before selecting the correct instrument, the application must be considered:

1) Type of radiation and the energy range of the radiation to be monitored; i.e.: alpha or beta particles; gamma rays or X-rays; low energy or high energy

2) The purpose for which the measurement results will be used, such as:
   a) Locating contamination
   b) Evaluating external radiation hazard (i.e., checking for adequate shielding)
   c) Measurement of radiation absorbed doses, exposure rates, dose equivalents, etc., from a source or in a specified area
   d) Quantifying the amount (activity) of radioactive material in a sample
   e) Nuclide identification

Once the radiation to be measured and the purpose of the measurement are determined, several factors should be considered in selecting the right instrument for the job:

Efficiency

For locating contamination and quantifying activity, *efficiency* of the detector for the radiation(s) of interest is important. Efficiency ≡ CPM/DPM; a detector with 50% efficiency would produce 100 CPM per 200 DPM of activity in the measured sample. Table 1 shows approximate efficiencies of various detectors reported by manufacturers for various nuclides.

TABLE 1: Detector Efficiencies for Various Radiation

TYPE OF RADIATION	DETECTOR TYPE	EFFICIENCY/NUCLIDE
Low Energy Gamma	NaI Scintillator	80 - 90% / I-125
Gamma	Geiger-Mueller (GM)	5 - 10%
Beta	Thin End Window GM	10% / C-14 45% /Sr-90
	Pancake GM	10% / C-14, S-35 60% / Sr-90
	Plastic Scintillator	16-20% / C-14, S-35 85-88% / Sr-90
	Liquid Scintillator	30-60% / H-3 67-85% / C-14, S-35 90-98% / P-32

Instrument Design

A wide variety of instrument designs is available. The most commonly used types are described below.

Gas-Filled Detectors

This design includes ion chambers, gas flow proportional counters, and Geiger-Mueller detectors. These instruments rely on the detection of ionization in gases by radiation to provide charge carriers within the gas-filled chamber. These charge carriers (ions) then carry an electric current between the anode and cathode of the detector. The instrument's electronics convert this measured current flow to appropriate units, such as CPM or mR/hr. Figure 1 gives a simplified view of gas-filled detectors. These systems generally consist of a gas-filled chamber containing an electrode, a voltage supply, a resistor, and an ammeter (current flow meter). Although the gas-filled detector chamber shown has a cylindrical geometry, other shapes are available.

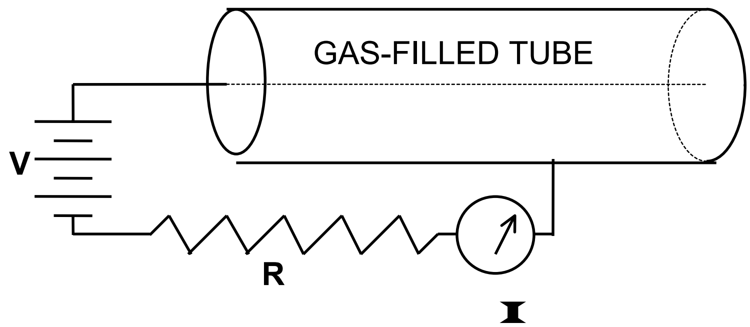


FIGURE 1: Diagram of Cylindrical Gas-Filled Detector

a. **Ion Chambers:** The simplest and lowest voltage instruments of this type are ionization chambers or ion chambers. These portable instruments usually use regular air at atmospheric pressure as gas in the detector, although some special designs may use other gases. Ion chambers are primarily used to measure radiation exposure or exposure rate. Ion chambers are rarely found in the research lab. The primary application for this design is the evaluation of external radiation hazard by radiation safety personnel.

b. **Proportional Counters:** Proportional counters operate at somewhat higher voltages than ion chambers and employ special gases such as argon-methane mixtures. The name of this detector type is derived from the fact that, although the current flow measured by the meter electronics is greatly amplified by an avalanche effect within the gas-filled chamber, the response nonetheless remains proportional to the initial ionization in the detector. Proportional counters are used in both portable and fixed installations, but they are rarely used in biomedical research labs.

c. **Geiger-Mueller Detectors:** The popularity of *Geiger-Mueller* (GM) detectors stems from this design's sturdiness, reliability, and low cost. The typical thin-end window GM or pancake GM (PGM) survey meter is adequate for detecting high-energy beta particles and high-energy gamma rays. Some of the radionuclides that may be adequately monitored by use of a GM survey meter are P-32, I-131, Co-57, Tc-99m, Sr-90, Cr-51, and Na-22.

While the GM survey meter can detect larger quantities of radioactive material, it is not sensitive enough for smaller amounts of some radionuclides. For example, a thin-end window GM survey meter may detect large amounts of C-14, S-35, or P-33 in a small area, but when the activity is spread over a large area or there is a small quantity of the material in one spot, the survey meter may not detect it. Similarly, GM meters can only detect relatively large quantities of I-125. Therefore, I-125 users are encouraged to use more sensitive (i.e., higher efficiency) instruments. Finally, in very high radiation fields, GM tubes become "saturated" and stop responding at all. Such intense radiation fields are very unlikely in the biomedical research environment; but users should remember to turn the meter on prior to entering a radiation area so as to recognize this saturation effect in the unlikely event such high radiation levels are ever encountered.

Solid Scintillators

A variety of *solid scintillator* detectors are now available as portable radiation detection instruments and larger, more sensitive stationary designs such as gamma counters. These devices are useful for low-energy gamma radiation and are becoming more popular for monitoring beta radiation. They are much more efficient than GM meters. Low-energy gamma detectors are recommended for monitoring such gamma emitters as I-125. Liquid scintillation counters are highly recommended for monitoring C-14, S-35, and P-33.

Liquid Scintillation Counters

The most sensitive radioactive material detection technology readily available is *liquid scintillation counting*. In contrast to small portable systems, liquid scintillation counters are generally relatively large, immobile, and expensive. This technology involves putting the radioactive sample (e.g., research compound, metabolism product, or wipe test) into a vial containing *liquid scintillation cocktail*. The cocktail contains chemicals, which convert some of the radioactive decay energy into light pulses (scintillations), which are then detected by very sensitive photomultiplier tubes within the counter. Because the radioactive sample is in intimate contact with the detection medium (the liquid scintillant), even very weak radiation can be readily detected. Radionuclides which may be detected by a survey meter, but which are more adequately measured in a liquid scintillation unit in order to obtain adequate sensitivity, include C-14, S-35, P-33, and Ca-45. Liquid scintillation counting is the only readily available method for detecting some radionuclides, such as H-3 and Ni-63. Only non-RCRA [Resource Conservation and Recovery Act - USEPA] regulated LSC cocktails should be used.

Dosimetric Measurements

A survey meter used to measure radiation dose-related quantities (e.g., mR/hr, rem, mrem/hr, etc.) must not only be capable of such measurements, it must also be properly calibrated and measurement results must be interpreted with care to arrive at meaningful conclusions. Given the complexity of dosimetric measurements, they should normally be left to Health Physicists, who maintain the appropriate instrumentation and expertise.
Laboratories using unsealed radioactive sources are required to have access to appropriate operating radiation detection instrumentation capable of detecting the nuclide(s) in use.

RADIATION LAB EXERCISE

Instructor Notes

The following radiation lab exercise is designed to take about 25 minutes (5 minutes per table with 5 table experiments total.) Students may work in teams. First demonstrate to the whole class how a beta/gamma survey meter works and how to read the scales. For easy-to-follow instructions on hooking your meter up to your PC speakers, see http://www.nchps.org/CDV.pdf

Exercise #1 BACKGROUND RADIATION

TASK: Measure beta/gamma radiation background fields in the room with a survey meter. Record the value for background. Answer the question "Where is background radiation coming from?"

Supplies:

beta/gamma GM survey meter

Exercise #2 TIME AND RADIATION EXPOSURE

TASK: Use the piece of Fiestaware pottery from the Science Teacher Workshop kit. Fiestaware contains natural uranium. Measure the radiation field at 5 inches from the Fiestaware. Record the value. Assume you placed the fiesta ware on your headboard 5 inches from your pillow on your bed. If you leave it there for 1 year (365 days) and we assume that you sleep in your bed 8 hours every night, what will be the radiation dose to your head after 1 year?

Radiation Dose (mrem)=365 days/yr x 8 hrs/day sleep x _______mR/hr
(at 5" from the fiesta ware)=_________mrem to your head!

Supplies:

beta/gamma GM survey meter
fiesta ware pottery
ruler
calculator

Exercise #3 DISTANCE AND RADIATION EXPOSURE

TASK: Measure the beta/gamma radiation from a piece of pottery with radioactive glaze (fiesta ware) at 2 inches, 6 inches and 12 inches from the pottery. Record the values. Answer the question "How does distance affect radiation?"

Supplies:

beta/gamma GM survey meter
fiesta ware pottery
ruler

Exercise #4 SHIELDING FOR BETA/GAMMA RADIATION

TASK: Measure the beta/gamma radiation from the surface of a piece of fiesta ware. Record the value. Put a piece of paper over the fiesta ware and measure the beta/gamma radiation field. Repeat with Plexiglas (e.g. CD holder) and then a piece of metal sheet. Record the values. Answer the question "How did the different types of shielding change the radiation field?

Supplies: beta/gamma GM survey meter
fiesta ware pottery
piece paper, Plexiglas and metal [e.g. cookie sheet, pie pan, etc.]

Exercise #5 WHICH ITEMS ARE RADIOACTIVE?

TASK: Using a beta/gamma GM survey meter, determine which numbered items are radioactive and which aren't. Record the numbers of the items that are radioactive.

Supplies: 1 beta/gamma GM survey meter

Variety of items that contain natural forms of radiation or are exempt consumer sources and some non-radioactive items.

<u>Natural and consumer items containing elevated amounts of radioactivity:</u>

- brazil nuts (elevated Ra-226 but you can detect with a hand held meter)
- NO-SALT (salt substitute from the grocery store has elevated natural K-40)
- Lantern mantles (buy at the camping store, contains thorium)
- Bananas (contains natural ^{40}K)
- welding rods (old welding rods contained thorium)
- depression glass (found in antique stores, glows under a black light, contains thorium)
- Fiestaware pottery in orange (found in antique stores, contains uranium in the orange glaze)
- Invigorators (found in antique stores, pottery contains radium, words on outside pot suggest filling with water so the radium salts can leak into the water and you can drink it)
- uranium rocks (naturally found)
- electrostatic brush (contains small sealed source of Am-241)
- smoke detector (contains sealed source of Am-241)
- old camera lenses (yellowed lenses contain thorium)
- very old dentures/eye glasses (elevated levels of uranium)

<u>Non-radioactive [i.e. contain very little detectable radioactivity] items</u>:

- battery
- floppy disk
- pressure gauge
- kids toys with "radioactive" labels on them, etc.

RADIATION LAB EXERCISE

Date:__________________

Name(s):____

Exercise #1 - Background Radiation

1. Use a Beta/Gamma GM survey meter to measure the background radiation in milliroentgens/hr (mR/hr).
   Background = ______ mR/hr

Where is this radiation coming from? Is it your teacher?

Exercise #2 - Time and Radiation Exposure

Your Grandfather just gave you an old piece of fiesta ware pottery that contains natural uranium. Measure the radiation field at 5 inches from the fiesta ware. Record the value. You place the fiesta ware on your headboard 5 inches from your pillow on your bed. If you leave it there for 1 year (365 days) and we assume that you sleep in your bed 8 hours every night, what will be the radiation dose to your head after 1 year?

Measure the radiation field at 5 inches from the fiesta ware. Record the value. _________mR/hr at 5"

Calculate: Radiation Dose (mrem)=365 days/yr x 8 hrs/day sleep x _______mR/hr
(at 5" from the fiesta ware)= ___________mrem to your head!

Exercise #3 - Distance and Radiation Exposure

DISTANCE	RADIATION READING
2 inch	_____________
6 inches	_____________
12 inches	_____________

What effect does distance have on the radiation emitted from the piece of pottery?

RADIATION LAB EXERCISE

Exercise #4 - Shielding for Beta/Gamma Radiation

1. Using the GM survey meter to measure the radiation at the surface of the Fiesta ware.
________mR/hr

2. Place a piece of **paper** over the Fiesta ware and measure the radiation level at the surface of the Fiesta ware through the paper.
________mR/hr

3. Place a piece of **Plexiglas** over the Fiesta ware and measure the radiation level at the surface of the Fiesta ware through the Plexiglas.
_________mR/hr

4. Place a piece of **metal** over the Fiesta ware and measure the radiation level at the surface of the Fiesta ware through the lead.
_________mR/hr

Question: How did the different types of shielding affect the radiation field?
____
____
____
____

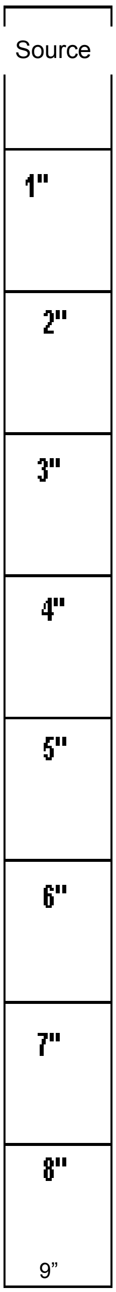
Exercises #5 - Which Items are Radioactive?

Use a GM Survey meter and find which items are radioactive on the table and note them below.

____
____
____
____
____
____

Inverse Square Law

Name: ____________________
Date: ____________________



Introduction:
The radiation emitted from a small source of radioactivty decreases in intensity as a function of the inverse square of the distance from the source. This is analogous to the way that light intensity decreases as one moves farther away from a standard light bulb. Mathematically, this decrease in intensity with distance can be expressed as follows:

$$I_1 d_1^2 = I_2 d_2^2$$

Where I_1 is the radiation intensity at distance d_1 from the source and I_2 is the radiation intensity at d_2 from the source.

In this exercise, we will compare the differences in calculated intensity vx. The measured intensity at a known distance from a source using a Gieger counter.

Instructions

1. Fold the lantern mantel into a ball (may need to hold it in place using a rubber band) and place it at the edge of the line marked "source"on the ruler on the left side of this page.
2. Place the side window detector at the 2" mark and record the radiation level readout from the meter.
3. Using the mathematical formula above and the data from step2., calculate the radiation intensity at 4" from the source
4. Now place the detector at the 4# maek and reord the radiation level reading from the meter.
5. Compare the calculated vs. the measured value.
6. Using the radiation level measured at the 2" mark, calculate the radiation level 8" from the source.
7. Repeat steps 4 and 5 at the 8" mark.

Calculated intensity at 4" (Show work below) __________________________

Measure intensity at 4" ______________
Calculate intensity at 8" (Show work) __________________________

Measure intensity at 8" ________________

Discuss reasons for any differences in the calculated vs. measured values obtained in this exercise.

Statistics – the Normal Distribution Name: ___________

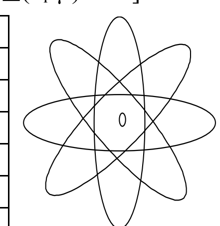
Amazingly, nearly every group of items you can measure (e.g. heights or weights of students in your class, heights of corn plants in a field, errors in a repeated measurement) has a normal (bell-shaped) distribution if plotted on a histogram*. If you collect enough (20 to 30) data points, you will see the normal distribution curve's characteristic bell shape. The more data collected, the more the histogram looks like a symmetrical bell-shaped curve. The <u>mean</u> or <u>average</u> [μ - “mu”] is the center of the normal distribution. The <u>standard deviation</u> [σ - “sigma”] indicates the variation in the population being studied. A standard deviation that’s large compared to the mean gives a wide and flat bell shaped distribution. A small standard deviation gives a tall, narrow bell curve. O*nce you know the mean and the standard deviation, you know everything about the distribution* and can predict the behavior of the group. The Radiation from a group of radioactive atoms during a set time period [e.g. counts per minute] also has a normal distribution, as shown by this exercise.

Run	Counts	cts^2
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		
18		
19		
20		
Total		

Radioactive Measurement Exercise: A container of pennies is a small sample (1 microgram) of a long half-life radioactive material (pure uranium metal). After a “one minute” measurement (i.e. after all the pennies are placed heads up in a container that’s then sealed and shaken), roughly half of the heads up pennies will have flipped to tails up; this represents radiation emitted from the sample and detected [measured] in one minute. How much will radioactivity measurements [“counts”] vary from one “minute” to the next “minute”?

1) Place 30 pennies heads up in the plastic box, close the lid, and shake vigorously. Open the box and count the number of tails up pennies. Record this number in the “Counts” column on the left side of this page. Flip all the pennies in the box back to heads up.
2) Repeat 20 times, then add all the measurement results in the “Counts” column. Enter this total at the bottom of the “Counts” column.
3) Complete the histogram below (place an “X” above each number each time that number appears in the “Counts” column; for example, if “17” appeared 3 times in the “Counts” column, place an “X” in each of the 3 boxes directly above 17 in the grid below).
4) Calculate the Mean [μ] of your distribution using the formula below.
5) Square each count and write this number in the “cts^2” column. Total at the bottom of the column.
6) Calculate your standard deviation [σ] using the formula below [an alternate expression for the more familiar $\sigma^2 = \sum(x_i-\mu)^2/n-1$].

≤ 5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	≥26



Mean [μ]= (Total of all measurement results)/(number of measurements) = Total/20 = ________________________

Standard Deviation [σ] = [Total(cts^2) – (Total Counts)^2/(no. measurements)]/(no. measurements – 1) = [Total(cts^2) – (Total Counts)^2/20]/19 = _____

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* A Histogram is a bar graph with no space between the bars; it is used in statistics to picture the frequency distribution of data that has been divided into classes (classified). The height of each rectangle is proportional to the number of observations which that class contains.