Authorized User / Radiation Safety Officer Training for Veterinary Users

Module 4: Radiation Detection and Measurement

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Introduction

- This module focuses on the measurement and detection of ionizing radiation.
- The instruments covered will be the most commonly used in research nuclear medicine.
- After completing this module, the reader will be able to measure radiation and quantify radioactivity using several different methods.
- Assigned reading:

4.1. Ludlum instrument specification compilation
4.2. AAPM Report No. 181: Dose Calibrators

Outline

- Units of Measure for Ionizing Radiation
- Measurement Instruments: Gas-Filled Chambers
  - Ionization Chamber
  - Well Counter and Dose Calibrator
- Measurement Instruments: Scintillation Detectors
  - Ludlum 44-3
- Measurement Instruments: GM Counters
  - Ludlum 44-88
  - Ludlum 44-9
  - Ludlum 44-38
  - Ludlum 26-1
- Quiz

Units of Measurement

Radioactivity Quantity Units	
Becquerel (Bq)	Curies (Ci)
SI unit	Customary unit
Decays per second (dps)	3.7 x 10^{10} Bq

Units Describing Radiation Field		
Roentgen (R)	Radiation Absorbed Dose (rad)	Roentgen Equivalent Man (rem)
Photon ionization in air (exposure)	Amount of energy deposited in unit mass of medium	Biological effect of energy deposited by radiation in system
2.58E-4 C/kg	SI unit: Gray (Gy) = 100 rad Gray = J/kg	SI Unit: Sievert (Sv) = 100 rem Sv = Rad*QF

Where: C = Coulombs J = Joules QF = Quality Factor

Ionizing radiation refers to the phenomenon of emission of high energy electromagnetic waves or particles by elements. Radioactivity refers to the property of certain isotopes of elements to emit ionizing radiation, in order to attain nuclear stability. Not everything that emits radiation is radioactive. For example, an x-ray machine emits ionizing radiation, but is not radioactive.

Mathematical Notations: Prefixes		
giga	G	10^{9}
Mega	M	10^{6}
kilo	k	10^{3}
milli	m	10^{-3}
micro	µ	10^{-6}
nano	n	10^{-9}

Useful Conversion Factors

1 mCi = 37 MBq = 0.37 GBq

1 MBq = 27 µCi = 0.027 mCi

1 mR/h = 0.88 mrem/h

1 mrem/h = 1.136 mR/h

How To Use Various Units of Measurement

Units Describing Radiation Field		
Exposure	Contamination	Occupational Dose
Roentgen (R)	dpm, mCi, Bq	Roentgen Equivalent Man (rem)

- Use Roentgen (R) when describing an exposure in air or mR/h for exposure rate in air.
    - "Exposure" measures how much radiation is present in air.
    - Measured with an ion chamber or a GM ratemeter.
    - Used for daily surveys or release measurements.
- Use dpm when describing how much radioactivity or contamination is present.
    - Dpm is "disintegrations per minute." 1 mCi = 2.22E6 dpm; 1 Bq = 1/60 dpm
    - Use a GM ratemeter to quantify contamination on a wipe sample (See Module 7 for more details).
    - Dpm = cpm/eff; where cpm is the counts per minute on the GM ratemeter and eff is the efficiency for the isotope in question.
- Use rem or Sievert (Sv) when describing "occupational dose," or biological effect to the human body as a system.
    - These units are used to communicate risk in terms of cancer induction probability.
    - Note, the US still recognizes the rem (1 Sv = 100 rem).
    - This is the unit you will see on your dosimetry or occupational badge report.
- While it is recognized that exposure (mR) and dose (mrem) are different concepts, the units are often interchanged for radiation safety purposes. This builds an additional layer of conservatism, given that 1 mR = 0.88 mrem. If a particular standard in mrem is met with an mR measurement, it ensures that the requirement is met with 'room to spare'.

Relationship between radioactivity and dose rate

- The exposure rate of gamma emitting radioisotopes can be determined by using their Exposure Rate Constants, or Gamma (Γ) values. These are generally quoted in R/h at 1 cm for 1 mCi of the radioisotope. Based on this value, exposure rates and dose rates for any activity can be determined.
- Gamma constant for ^{131}I = 2.2 R/h per mCi at 1 cm. For ^{117m}Sn = 1.69 R/h per mCi at 1 cm
- Since ^{90}Y is a pure beta embitter, it does not have a specific exposure rate constant.

Example 1: What is the exposure rate, and dose rate from 3 mCi of ^{131}I at 1 cm?

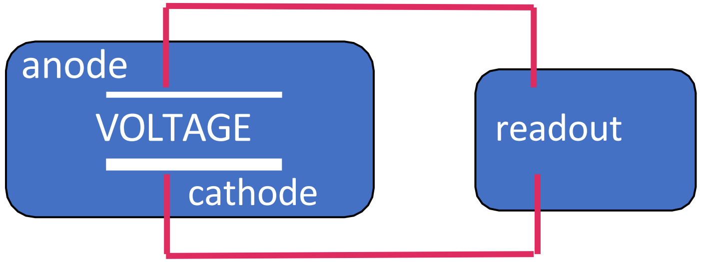
Exposure rate: 2.2 R/h per mCi x 3 mCi = 6.6 R/h = **6600 mR/h**

Dose rate: $6600\ \text{mR/h} \times \dfrac{1\ \text{mrem/h}}{1.136\ \text{mR/h}}$ = **5809 mrem/h**

Gas-Filled Chambers

The general principle of a gas-filled chamber or radiation detector:

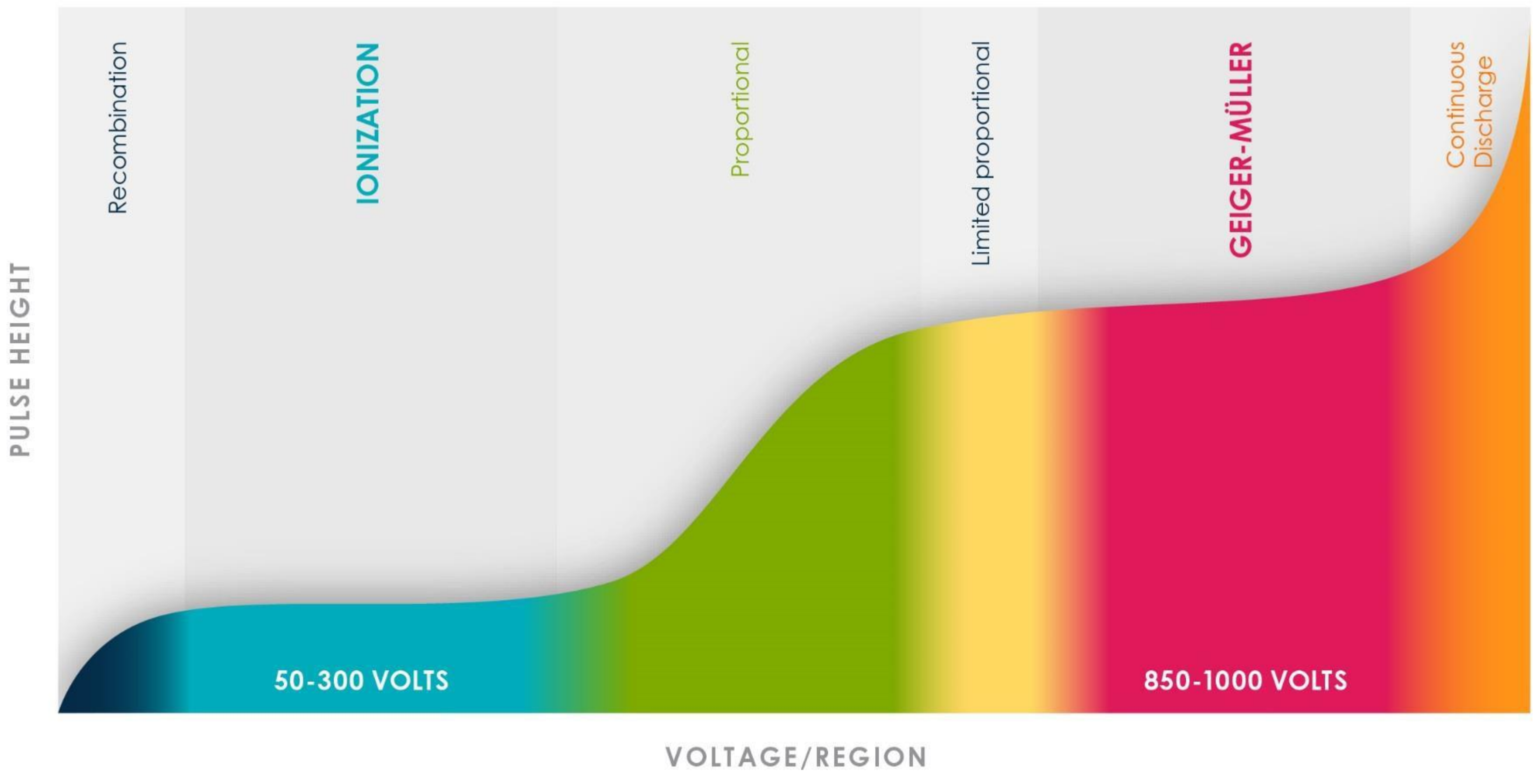
- A voltage is applied between an anode and cathode with gas in between.
    - The anode is a positively charged element and the cathode is a negatively charged element which creates a potential between the two elements.
- The ionizing radiation interacts with the gas, creating electrons which are then attracted by the positive side of the applied voltage.
- The charge is then collected and counted.



Gas-Filled Chambers *(continued)*

There are six regions as a function of voltage for gas-filled chambers. The two flat regions are of interest: the **ionization chamber region** and the **Geiger-Müller (GM) region**.

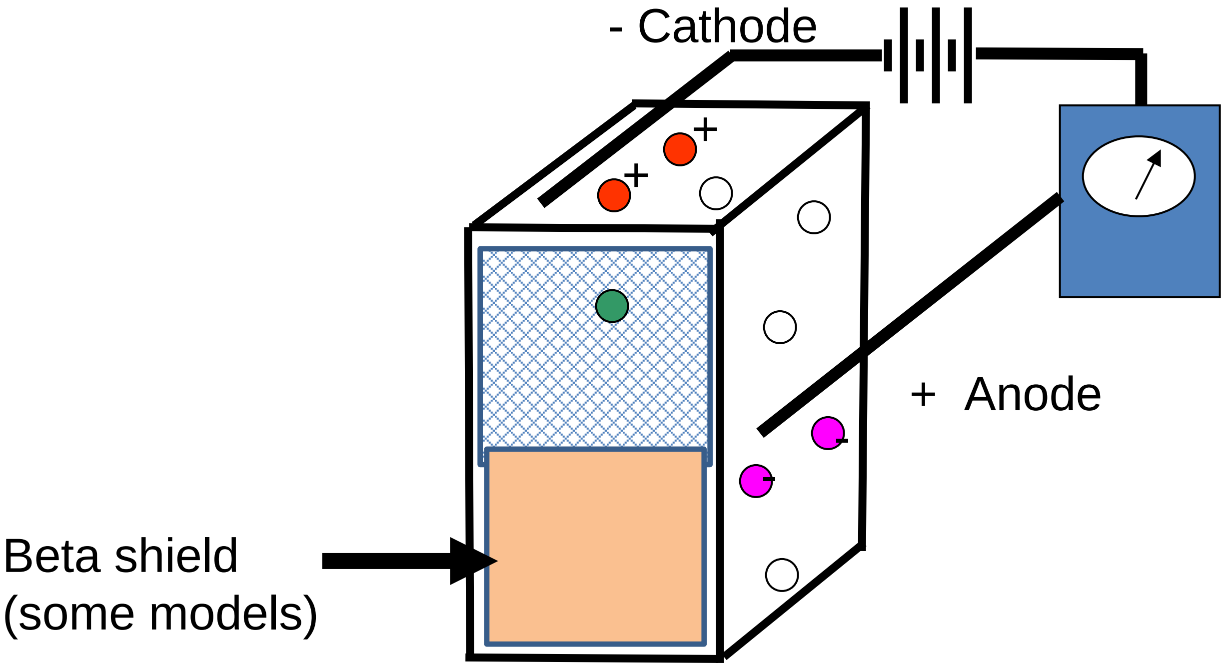
THE SIX-REGION CURVE FOR GAS-FILLED DECTORS



Ionization Chambers

The simple diagram below shows an ion chamber measuring ionization events in Coulombs (C)/kg per unit time.

- Coulombs/kg per unit time can be converted to Roentgen or milliroentgen per unit time, or mR/h for true exposure rate.



Ionization Chambers *(continued)*

Fluke P451: Pressurized ion chamber
very sensitive
reads µR/h to R/h
µR to R

Typical natural background reading: 15 to 20 µR/h

Ludlum 9DP: Pressurized ion chamber
very sensitive
reads µR/h to R/h
µR to R

Typical natural background reading: 15 to 20 µR/h

- The ionization chamber measures radiation in terms of exposure rate in mR/h.

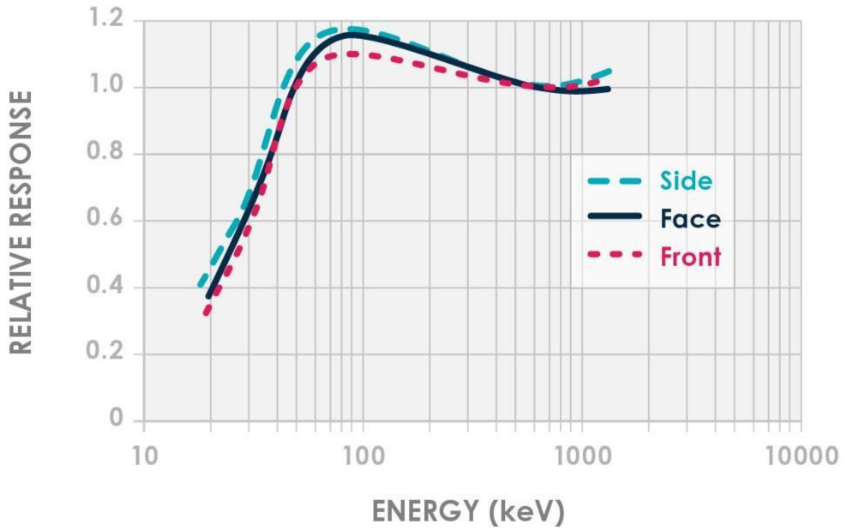
Ionization Chambers *(continued)*

- The graphs below represent the energy response curves for the Victoreen Model 451P and the Ludlum 9DP ionization chambers. The x-axis is energy in keV, and the y-axis is relative response as a percentage.

- A 1.0 value on the x-axis means that the response is 100% (*i.e.,* 'correct response'). Values lower than 1.0 mean under-response, and values higher than 1.0 mean over-response. A device with a flat energy response over a wide range of keV provides a 'true' exposure rate without the need for correction factors.

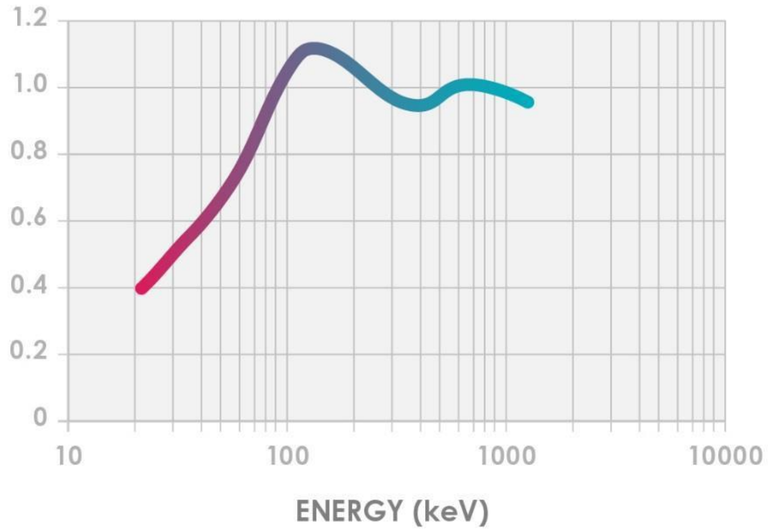
MODEL 451P

TYPICAL ENERGY RESPONSE



MODEL 9DP

EXPOSURE ENERGY RESPONSE RELATIVE TO CS-137



Ionization Chamber Use

- To properly use an ion chamber:
  1. Turn the unit on.
  2. Wait approximately 30 seconds for the unit to stabilize.
  3. Capture the background rate (usually 20 microroentgen/hour, or 20 uR/h).
  4. Make your measurements from a known distance from the source of radiation (gross rate).
  5. Capture the net rate:
     - Net Rate = gross rate – background rate
- Ion chambers are required to be calibrated annually.

Exposure rate

Power button

Dose Calibrators

- The dose calibrator a specialized ion chamber. It is the tool used to validate the activity present in a radiopharmaceutical or radiotherapeutic container.
- Dose calibrators are capable of quantifying radioactivity for radioisotopes used in nuclear medicine. Channel settings are prescribed by the manufacturer to match the emissions of the isotope to be quantified.
- The unit itself is a gas-filled well. The radioactive sample is lowered into the well, then counted on the appropriate setting/channel.
- The operator presses the proper isotope button or channel setting to quantify their sample.
- Each manufacturer is different. Refer to the user manual or contact the manufacturer to determine the proper channel for the isotopes used.

Dose Calibrator Quality Control

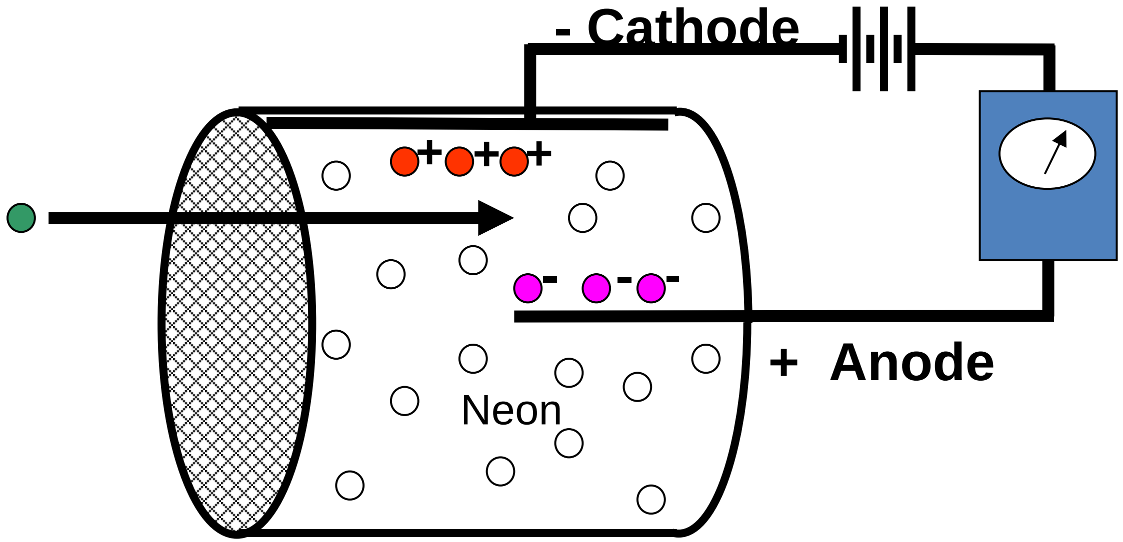
- Dose calibrators are not mandatory for veterinary practices using "**unit doses"** for therapy or diagnosis. A Unit Dose refers to a custom-made dose specific to a named patient, whose activity is pre-calibrated to the prescribed activity for the date and time of injection.
- However, should a practice decide to use a dose calibrator, quality control should follow the most recent ANSI standard N42.13:
  - Daily Background Checks
    - This test is done to capture net activity and subtract out natural background.
  - Daily Constancy Checks
    - This test is done with a ^{137}Cs standard source to verify that response is accurate over time.
  - Quarterly Linearity
    - This test is done to ensure the dose calibrator response is linear over all ranges used by the facility. Done using a source of ^{99m}Tc.
  - Annual Accuracy
    - Typically completed by a physicist, this test makes sure the each clinically used channel is accurate.
  - Initial Geometry
    - The geometry test is completed for all shapes and sizes of vials or capsules used at the facility to ensure the dose calibrator is responding appropriately for all clinically used geometries. Also done using a source of ^{99m}Tc.

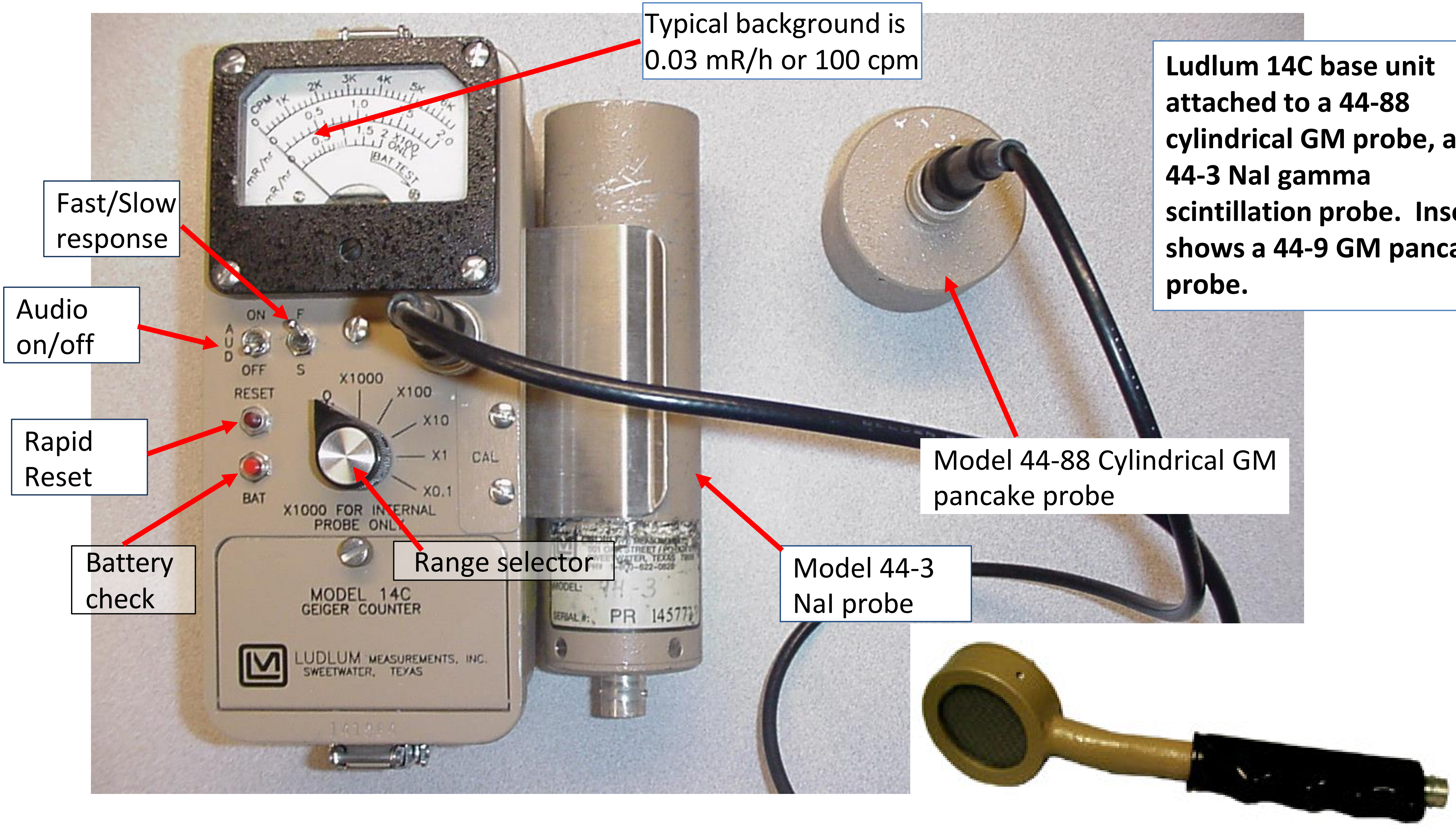
Geiger-Müller (GM) Survey Meters

- The GM ratemeter or survey meter is the quintessential device used to detect radiation. It is rugged and versatile, and it is capable of detecting very energetic alpha particles, beta particles (electrons), and photons.

- Most survey meters have a base unit, to which a variety of probes (detectors) can be attached. Common base units are the Ludlum model 3 or the model 14C. Examples of Ludlum probes are models 44-88 cylindrical GM, 44-9 Pancake GM, 44-38 energy compensated GM, and the 44-3 low energy NaI scintillation probe. On some models such as the Ludlum 26-1, the base unit and probe are condensed into one device.

- GM probes contain inert gas, and two electrodes (positively charged anode and negatively charged cathode) that are maintained at very high voltage (>600 V) via 2 D-cell batteries and a transformer in the base unit. When radiation enters the probe, it causes ionization, creating free electrons which attracted to the anode, and positive ions that are attracted to the cathode. This sets up a current, that is measured using a potentiometer and displayed in units of mR/h and cpm.





Ludlum 14C base unit attached to a 44-88 cylindrical GM probe, and 44-3 NaI gamma scintillation probe. Inset shows a 44-9 GM pancake probe.

Typical background is 0.03 mR/h or 100 cpm

Fast/Slow response

Audio on/off

Rapid Reset

Battery check

Range selector

Model 44-3 NaI probe

Model 44-88 Cylindrical GM pancake probe

Geiger-Müller (GM) Survey Meters *(continued)*

- The Model 14C base unit has a manual range selection switch. When set to the x0.1 multiplier, the meter reads 0.01 to 0.2 mR/h (middle readout scale in the picture on the previous page; multiply observed reading by 0.1). If the needle pegs to the right, shift over to the x1 multiplier: now the meter reads 0.1 to 2.0 mR/h. If the needle pegs to the right, shift over to the x10 multiplier: the meter now reads 1.0 to 20 mRh/h. If the needle pegs to the right, shift over to the x100 multiplier: the meter now reads 10 to 200 mR/h, but only on the lower, logarithmic scale. If the needle pegs to the right, shift over to the x1000 scale: now the meter reads 100 to 2000 mR/h (middle scale), but for this multiplier, the base unit contains an internal GM probe that must be used: the connected probes such as 44-88 or 44-9 will be saturated, and will not function at such high dose rates.

- The difference between and model 14C and a model 3 is that that the model 3 does not have a x1000 multiplier and the internal GM probe.

- The fast and slow response toggle switches are used for rapid response (90% of final meter reading in 4 sec, but with more fluctuation) while scanning to detect contamination, or a more steady response (90% of final meter reading in 22 sec) for measurement of contamination.

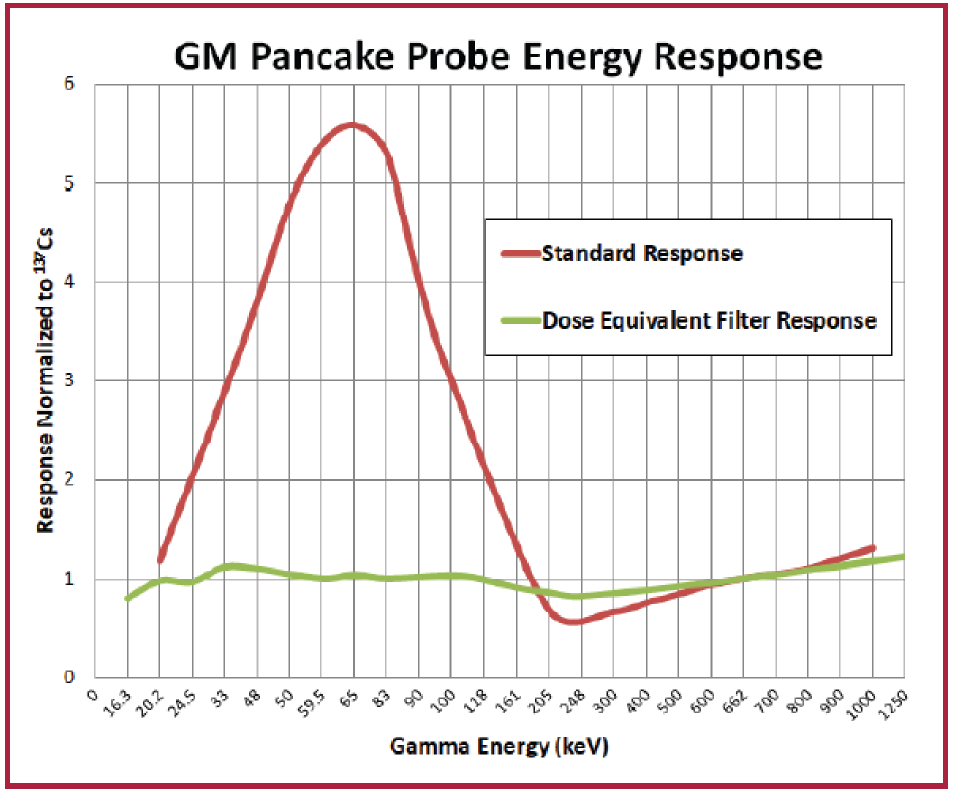
- The audio on and off toggle switch to control addible ‘clicks’ of the meter. The reset button quickly quenches the readout and brings the needle back to the left side. The Batter check function checks for battery drainage beyond specification.

Geiger-Müller (GM) Survey Meters *(continued)*

- The most common GM detectors used on the 14C or model 3 base units are the 44-9 'pancake' probe, and the 44-88 'cylindrical pancake' probe. Although they differ in shape and size, the internal counting geometry and efficiencies are similar.

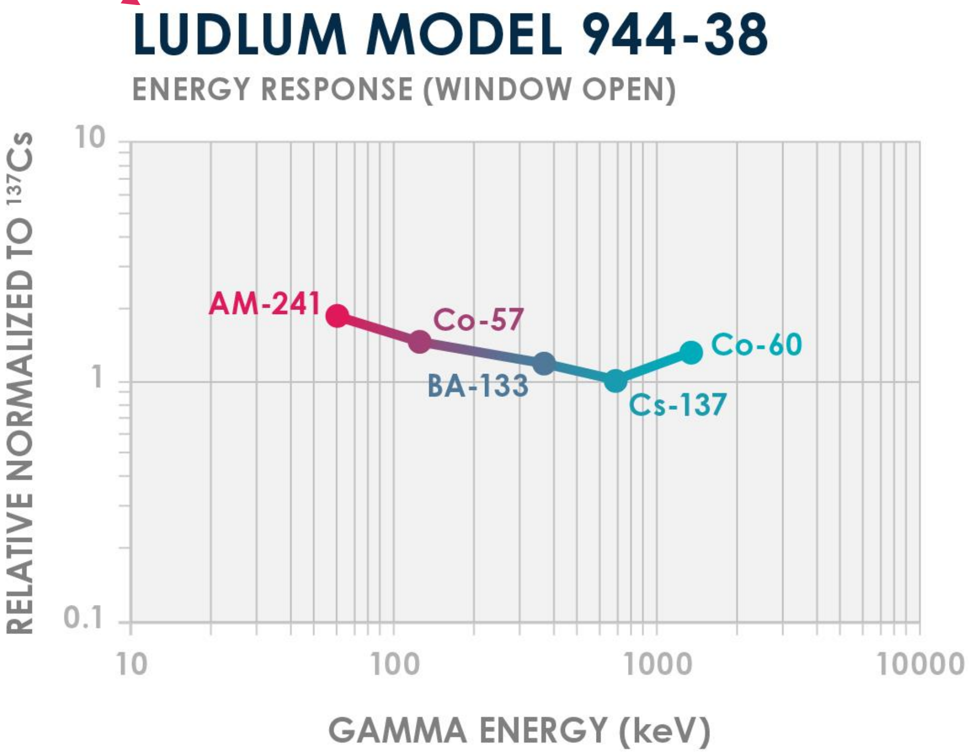
- The 44-9 has the advantage of being turned sideways while mounted on the base unit, suitable for surveying hands while working, and the probe geometry is good for surveying workbenches. The 44-88 has the advantage of being dangled vertically while surveying the floor.

- Both these probes tend to over-respond at low energies (20 keV to 200 keV gammas). However, the 44-9 probe comes with an Ambient Dose Equivalent Filter that flattens the energy response, and facilitates a correct response (within 20%) for the entire range of 20 keV to 1000 keV. This makes the GM probe more or less similar to an ion chamber in its response characteristics.



Geiger-Müller (GM) Energy-Compensated Counter

Another GM probe is the **Ludlum 44-38** energy-compensated probe. It has a similar energy response to that of the ion chamber and is therefore desirable for regulatory exposure rate measurements. It is also an ideal tool to use when receiving radioactive packages.

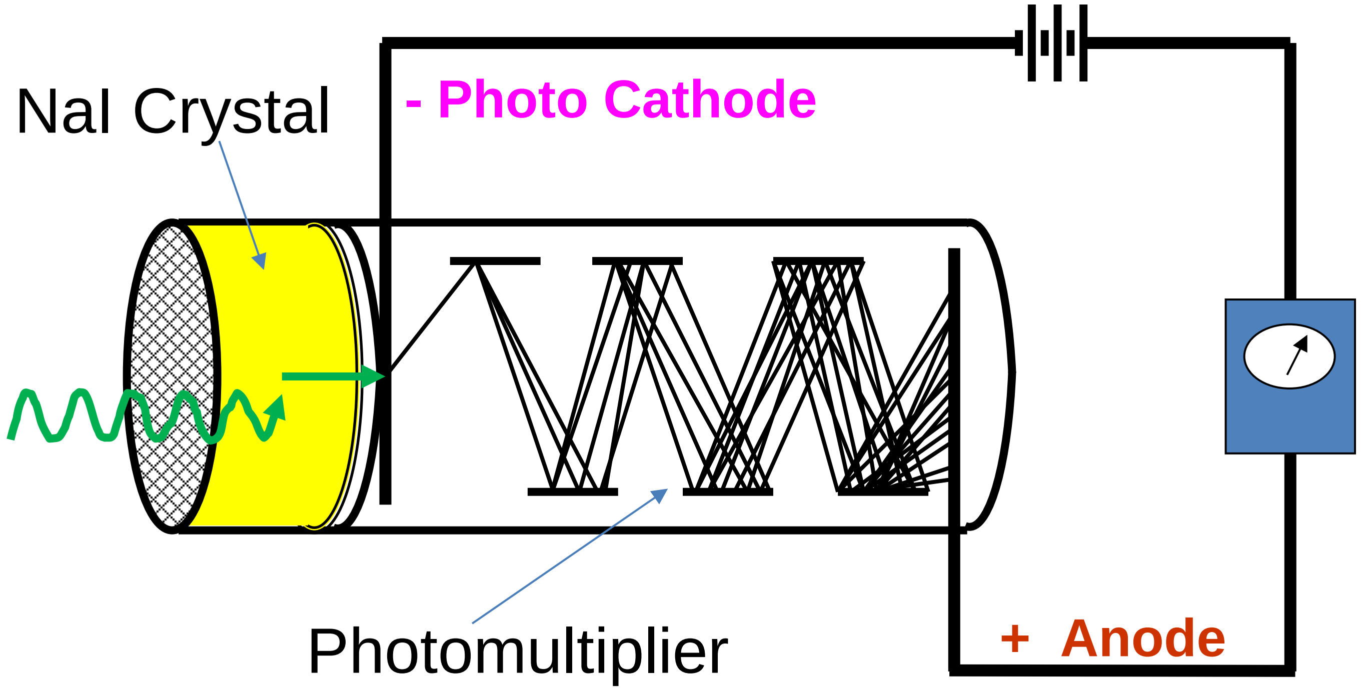


Geiger-Müller (GM) Counter: Ludlum 26-1

- This is an integrated, cableless frisker with a lightweight design. The base unit is contained in the ergonomic handle.
- It contains a GM pancake detector (similar to a 44-9), and displays exposure rate in mR/h, dose rate in µSv/h; and counts in dpm, cpm, Bq or cps. Ranges are set automatically, instead of manually, as in the model 3 or 14C.
- Audible alarms can be set for count rate, as well as exposure or dose rate
- Just two AA sized standard batteries are required for operation
- The model **26-1DOSE** comes with an Ambient Dose Equivalent Filter that flattens energy response, thereby giving 'true' exposure rates.

Scintillation Detectors

- The scintillation detector is a unique case for ionizing radiation detection that turns the ionizing radiation into visible light to enable counting of the interactions.
- A photon enters the scintillation crystal, visible light is created, then photomultipliers are used to increase the output signal.
- These instruments have outstanding response times and are very sensitive to low-level x-rays and photons (10–90 keV range).



Scintillation Detectors *(continued)*

- The scintillation detector is typically used for gross leakage, or gross contamination detection. It is an excellent inspection tool to verify that contamination has not left the nuclear medicine department. It is not the preferred tool to decide on post-treatment patient release.
- Scintillation detectors have poor or no detection capability for electrons or beta particles, but they are excellent for low-energy gamma rays and x-rays.
- The **Ludlum 44-3** is the most common handheld scintillation detector used in human and veterinary nuclear medicine. It is used for thyroid bioassays for operators after unsealed use of ^{131}I (see next page).

Scintillation Detectors *(continued)*

Using a Ludlum 44-3 Low Energy Gamma Scintillation probe with a model 3 or model 14C base unit for thyroid bioassays for handlers of ^{131}I radioiodine:

- The purpose of a thyroid bioassay is to assess whether internal contamination of a radiation worker has happened during the handling of a liquid ^{131}I dose. Inhalation, ingestion and uptake through the skin are pathways for contamination, and can occur accidentally while preparing dose or injecting at cat, or while cleaning up a spill.

- In humans, ^{131}I will accumulate in the thyroid following such contamination in 48-72 hours. A bioassay should be capable of detecting trace amounts (nCi, or nanocurie quantities) of ^{131}I in the thyroid.

- During annual calibration, the response of an NaI probe to ^{125}I and ^{131I} are measured for a human thyroid geometry, and a calibration provided on the calibration sticker as cpm/nCi.

- Measurements are done in a low-background area, away from sources of ^{131}I. A background measurement is done by holding the probe against the inner thigh, and observing the reading in cpm for 30 seconds. The thyroid measurement is then done by holding the probe against the crook of the neck, between the sternocliedomsatoid (SCM) muscles, and observing the reading over 30 seconds. .

- Example calculation: if background (thigh) reading is 120 cpm, the thyroid reading is 500 cpm, and calibration value on the meter is 23 cpm/nCi: Net reading = 500 – 120 = 380 cpm. Bioassay = 380 cm ÷ 23 cpm/nCi = **17 nCi**.

- Bioassays are covered in greater detail in module 6 and 9.

Preferred instruments for different applications

- A critical aspect of the use of ^{131}**I radioiodine** is the performance of thyroid bioassays, for which a 44-3 NaI gamma scintillation probe is ideal. Therefore, a Ludlum Model 3 base unit with two probe holders – one for the 44-3, and one for a 44-9 pancake probe with a flattening filer, is the recommended setup. The 44-9 probe is well suited for package surveys, ambient dose rate surveys and wipe tests for removable contamination. When fitted with the flattening filter, it can be used for cat release survey measurements.

- For routine use with ^{90}**Y,** the preferred instrument is the Ludlum 26-1 integrated frisker. It has a beta detection efficiency of 22% for ^{90}Y. Since it is a pure beta emitter, It can be used without a flattening filter for all purposes.

- For routine use with ^{51}**Cr,** the preferred instrument is the Ludlum 26-1 integrated frisker with or without the energy flattening filter. The 320 keV gamma will read similarly with or without the filter.

Instrument Usage – General Aspects

1. Turn on the meter
2. Check battery condition: needle should go to BAT TEST line on meter.
3. Turn range switch to the lowest scale (for Model 3 and 14C), then turn on audio function.
4. Conduct "check source" test (typically affixed to meter). Ensure that the check source readds within 10% of the reading quoted on the calibration sticker.
5. Note meter "background" reading in a location away from radiation source or radioactivity (typically 0.02 to 0.05 mR/h)
6. Place probe (window face down) about ½ inch from surface being surveyed. Never let probe touch survey surface.
7. Survey work area by slowly moving probe over surfaces, listen to audible "clicks" from survey meter speaker.
8. It is permissible to use the FAST toggle switch when performing a survey to detect contamination. When an actual measurement is being made, switch to the SLOW toggle switch, to obtain a more accurate reading.

Summary of Module 4: Radiation Detection and Measurement

- There are many different instruments used to measure and quantify radiation and radioactive material.
- “Exposure” describes how much radiation is present in air. It can be measured with an ion chamber or GM ratemeter.
- “Disintegrations per minute” (dpm) describes how much radioactivity is present in the form of contamination. It can be measured with a calibrated GM ratemeter, dose calibrator, or a scintillation detector.
- Dose calibrators are not a regulatory requirement for veterinary use of radioactive materials. If a dose calibrator is not used, unit doses are required for administration of radioactive materials.
- The GM ratemeter is the most versatile instrument for measuring both radiation and radioactivity. The Ludlum 26-1 is the preferred instrument for use in conjunction with ^{90}Y and ^{51}Cr. A Ludlum model 3 with dual probes: a 44-3 NaI scintillation probe, as well as a 44-9 GM pancake probe with an energy flattening filter is suitable for work with ^{131}I radioiodine.

Supplemental Reading Material

Assigned reading material for Module 4:

4.1. Ludlum instrument specification compilation

4.2. AAPM Report No. 181: Dose Calibrators

Upon successful completion of the Module 4 quiz, you may continue to Module 5.