Survey Instruments

Applications of Survey Meters

Applications of Survey Meters

Survey Meters might be used to:

1. Measure Exposure or Dose Equivalent Rates (e.g., uR/hr, mR/hr, urem/hr mSv/hr, etc). This might be done to determine what type of posting (e.g., High Radiation Area) is required in a given area, or establish a boundary around a work area.

2. Locate lost or hidden gamma emitting sources, or locate contamination in soil.

3. Locate and Measure Surface Alpha or Beta Contamination (e.g., dpm/100 cm^2, Bq/cm^2). This might be done to demonstrate compliance with regulatory or license limits on contaminated materials.

1. Measuring Low Exposure Rates (uR/hr)

Best

- Micro R meter. The lowest scale might be as low as 0 – 3 uR/hr or as “high” as 0 – 25 uR/hr
- Microrem meter. The lowest scale might be 0 – 20 urem/hr

Possibly Acceptable

- Side window/wall GM. The lowest scale might be 0 – 0.5 mR/hr (500 uR/hr)
- Pressurized ion chamber, e.g. Victoreen 451P.   Can read down to ca. 10 uR/hr

1. Measuring High Exposure Rates (mR/hr – R/hr)

Best

- Ion Chamber. The highest scale might be 0 to 5, 50, 500 or 1000 R/hr

Possibly Acceptable

- Side window/wall GM. The highest scale might be 0 – 1 R/hr.
- A specialized GM detector using what is known as a "time to count" methodology is capable of measuring very high exposure rates (as long as the radiation is not pulsed)

2. Locating Lost Gamma Emitting Sources or Gamma Emitting Contaminants in Soil

Best

- Sodium iodide (NaI) scintillator with separate probe
- Plastic gamma scintillator with separate probe
- Micro R meter
- Microrem meter

Possibly Acceptable

- Side window/wall GM

3. Locating and Measuring Surface Contamination

Best

- Gas flow proportional counter (alpha and/or beta)
- Pancake GM (for beta)
- Plastic Scintillator (for beta)
- Zinc Sulfide (for alpha)

Possibly Acceptable

- Side window/wall GM (for beta)
- Pancake GM (for alpha)
- Air proportional (for alpha)

General

Ratemeter vs Scaler

Ratemeters give an instantaneous readout in cpm, mR/hr, etc. Most ratemeters employ an analog display (bouncing needle), but some are digital.

Scalers integrate counts over a selected count time. Most instruments with a scaler capability can also operate in the ratemeter mode. Scaler displays are digital.

Ratemeter

Scaler-Ratemeter Combination

Ratemeter vs Scaler

Digital Ratemeter

In most situations, it is best to measure (quantify) beta contamination with a scaler. It is always best to quantify alpha contamination with a scaler. A ratemeter might be acceptable if the level of contamination is high.

When scanning for contamination, either a ratemeter or scaler is fine because the scan is performed by listening to the audio which is independent of the display mode.

Common Problems

- Bad Batteries. The battery contacts might need to be cleaned. Leaving batteries a long time (e.g., months) in unused instrument can cause corrosion.
- Bad cable. Typically at the ends where the cable attaches to the connector. Indicated by erratic readings – especially when cable wiggled.
- Bad range switch – dirty/corroded contacts. Indicated by erratic readings, especially when changing scale. Might be cleaned by rapidly rotating the switch back and forth multiple times. Better if contact cleaner sprayed on contacts first.

Common Problems

- Light leaks in scintillators with thin window
- Needle on display frozen at one position due to static charge on glass/plastic cover. Use static eliminator of some type, e.g., wipes for drying clothes
- High voltage/gain might need to be adjusted
- Switch might be in wrong position, e.g., a window selected so that the instrument is only responding to narrow range of pulse sizes
- Moisture has gotten into the case through headphone jack
- Detector contaminated

Calibration and Performance Checks

Calibration

- Instruments used to demonstrate compliance with regulations must be calibrated at intervals specified in the regulations and/ facility license.
- Typically once or twice each year, before first use, and after any maintenance that might affect instrument performance (not battery changes)
- This means a radiological, not electronic calibration
- Some companies do it themselves, most sent them off for calibration
- If there is no backup instrument available while another is off for calibration, the facility might be out of compliance

Calibration

- There should be a label or sticker on each instrument indicating when it was last calibrated, initials indicating who did the calibration, and the date that the next calibration is required.
- Instruments that are broken or out of service need to be labeled as such
- Two types of radiological calibrations: those for instruments that read out in exposure rate or dose equivalent rate (e.g., mR/hr or mrem/hr) and those that read out in counts or count rate and are used to measure surface contamination.

Calibration

- Instruments that read out in exposure rate or dose equivalent rate (e.g., mR/hr or mrem/hr) are checked for accuracy at two or more points on each scale (e.g., 20% and 80% of each scale)
- In some cases, not all the scales (e.g., highest scale) are calibrated. This must be indicated on the instrument.
- The accuracy requirement is in the 10% to 20% range. DOE is most restrictive. NRC less so
- Accuracy requirements are not as strict for neutron dose equivalent rate meters, e.g., rem meters such as "Snoopy" or the "Rem Ball"

Calibration

- With instruments that read out in counts or count rate (cpm) and are used for surface contamination measurements the calibration involves a determination of the detector efficiency. Activities measured using the calibration efficiency must be accurate within 10% to 20%
- As a rule, the calibration is considered to be for the detector (probe), cable and electronics as a single package. If swapping out cables or probes in the field is acceptable to the regulator, it would require documentation that the calibration holds for the new combination of equipment

Calibration

- In addition to (but not instead of) the radiological calibration, an electronic calibration might be performed on instruments that read out in counts or count rate.
- In an electronic calibration, a pulser is used to determine that the count rate on each scale is the same as the pulse rate
- This can help “tie” the radiological calibration on lower range scales to an upper range scale for which a radiological calibration was not performed

Performance Check (functional test)

- Just because an instrument was calibrated recently doesn't mean the calibration still holds
- Documented performance checks are done to ensure that the instrument worked correctly on the day it was used
- Typical components of a performance check:
  - visual inspection for obvious defects
  - high voltage setting
  - background recording
  - light leak check
  - instrument response to a check source

Performance Check (functional test)

- In most cases, the response to the check source on the day the instrument is to be used must be within 20% of the response to the check source at the time the instrument was calibrated
- The check source detector geometry must be exactly the same each time the response is determined

Common Survey Instruments

Zinc Sulfide (ZnS) Alpha Scintillator

Radiation Detected: Alphas. Can also exhibit a weak response to neutrons

Efficiency: 10 – 20% (total efficiency) usually assumed to be independent of alpha energy

Window: aluminized mylar (ca. 0.4 – 0.8 mg/cm^2)

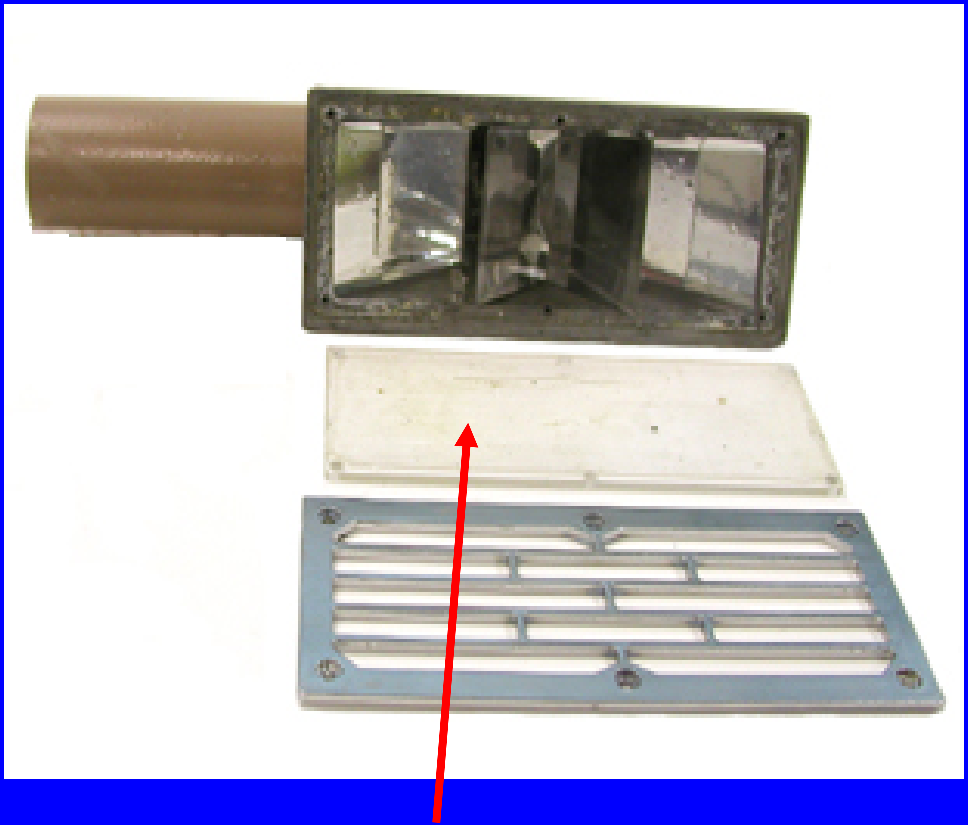
Area: ca. 50 – 100 cm^2

Background: 0 – 2 cpm

Zinc Sulfide (ZnS) Alpha Scintillator

Construction

- Directly behind the mylar window is a thin layer of tiny zinc sulfide crystals.
- When an alpha particle penetrates the window, it interacts with the zinc sulfide and produces a flash of light scintillation).



Plastic coated with zinc sulfide crystals

Zinc Sulfide (ZnS) Alpha Scintillator

Construction

- Reflectors direct the flashes of light towards the photocathode of a photo multiplier tube (PMT).

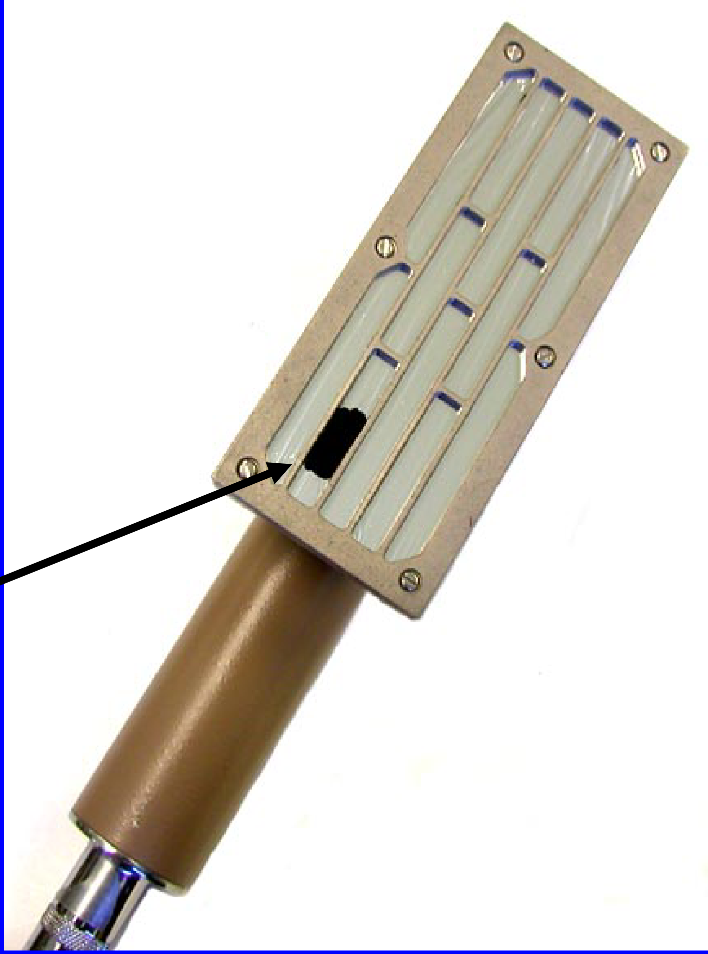
- The PMT converts each flash of light into an electronic pulse.

Zinc Sulfide (ZnS) Alpha Scintillator

Light Leaks

Light leaks, often too small to be visible, can occur in the aluminized Mylar . To test for light leaks, hold the probe up to a light source while listening to the audio for counts.

The hole is often repaired with a dab of black paint.



Beta Scintillator

Detector: plastic scintillator ca. 0.25 mm thick

Radiation Detected: Betas, alphas. Also has a fairly inefficient response to most photons. Photon efficiency greater at lower energies

Window: aluminized mylar 1.2 mg/cm^2 sometimes a thicker window is used to eliminate the alpha response

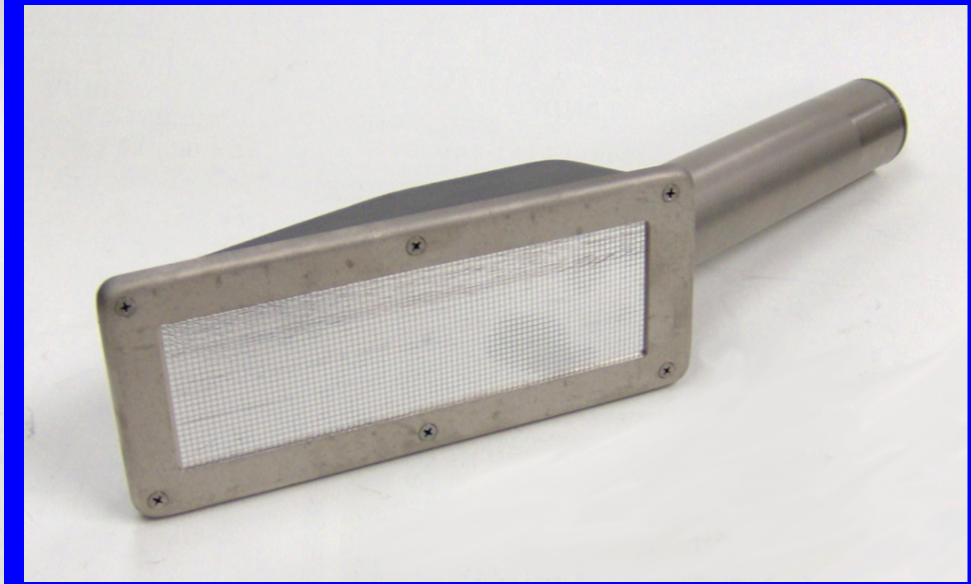
Area: 50 – 126 cm^2 is typical

Background: ca. 100 – 300 cpm, about 20 cpm/uR/hr

Dead Time: ca. 10 us

Beta Scintillator

- Similar in construction to a ZnS alpha scintillator except that the ZnS is replaced with a thin sheet of scintillating plastic
- Susceptible to light leaks (as is any scintillator with an aluminized mylar window)



Approximate Efficiency of Typical Beta Scintillator

	Average Energy (keV)	Maximum Energy (keV)	2π Efficiency (c/b)	4π (total) Efficiency On contact (c/d)
C-14	49	156	0.1	0.05
Tc-99	85	294	0.25	0.15
Tl-204	244	763		0.25
Cl-36	251	710	0.45	0.28
Sr/Y-90	565 (Y-90 and Sr-90)	2280 (Y-90)	0.8	0.65

Dual Phosphor Alpha-Beta Scintillator

Detector: ZnS and 0.25 mm thick plastic scintillator

Radiation detected: operates in alpha only, beta only, or alpha plus beta mode. When responding to betas, there is some response to photons

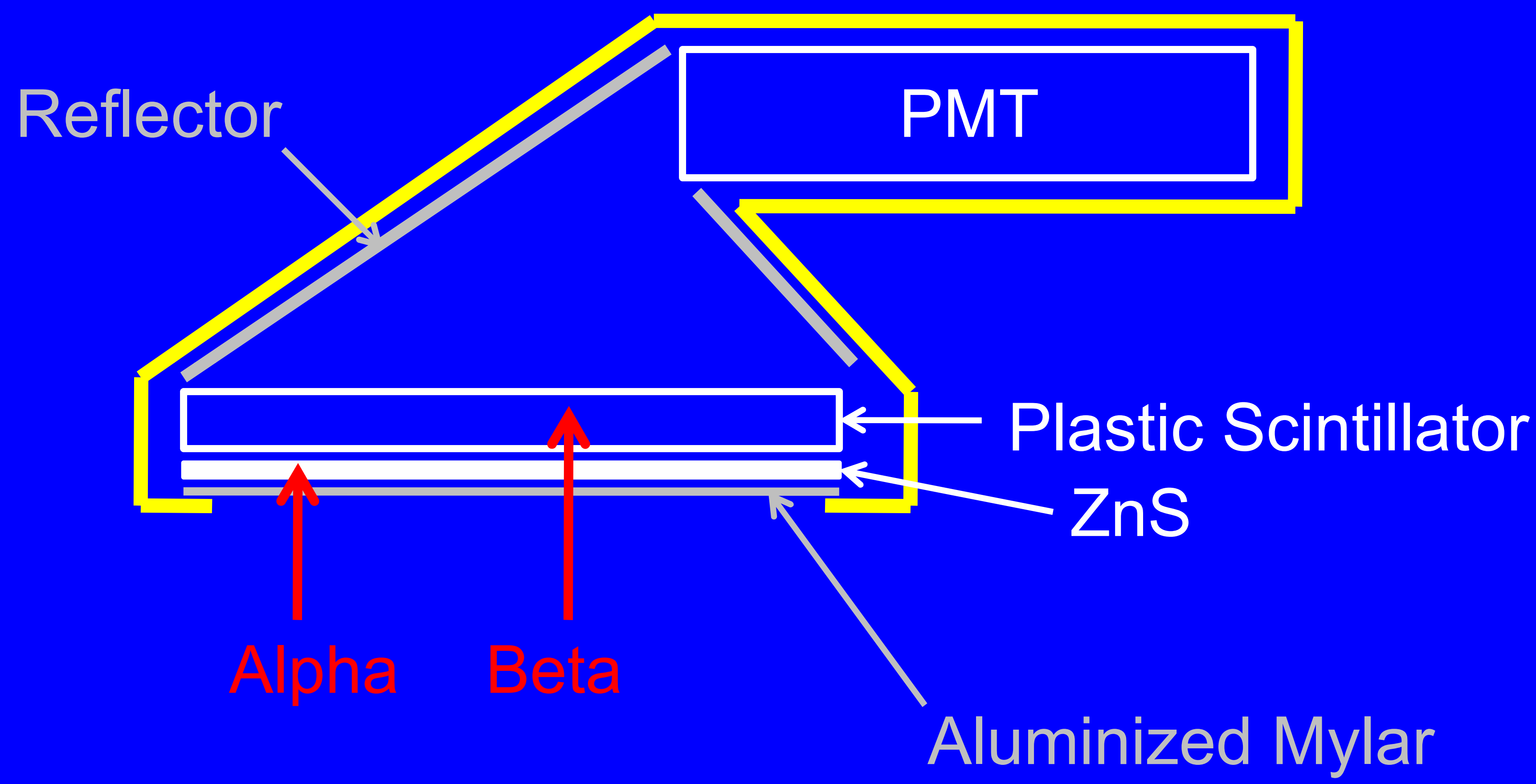
Window: aluminized mylar 0.4 – 0.8 mg/cm^2

Area: 50 to 126 cm^2 is typical

Background: 0 – 2 cpm in alpha mode and 200 – 400 cpm in beta mode

Dual Phosphor Alpha-Beta Scintillator

Construction



Dual Phosphor Alpha-Beta Scintillator

Cross Talk: Alpha pulses can be registered as beta counts and beta pulses registered as alpha counts. Alpha to beta crosstalk might be as high as 10%. Beta to alpha crosstalk only 1% or so. Depends on beta energy.

Susceptible to pinhole light leaks in mylar producing high spurious counts

Pancake GM Detector

Radiation Detected: Primarily used to detect beta particles. Also sensitive to alphas. Responds to gamma rays but not very efficient.

Window: ca. 1.5 mg/cm^2 mica

Area: ca. 15 -20 cm^2

HV: ca. 900 volts

Background: ca. 20 -50 cpm

Dead time: ca 20 usec per count

Alpha Efficiency: ca. 0.15 (15%)

Gamma Efficiency:

ca. 3500 cpm/mR/hr (Cs-137)

Pancake GM Detector

Shielded pancake probes are available that can reduce the background when surveying for surface contamination where gamma sources are nearby.

The additional weight can be a disadvantage when scanning for long periods of time and when making long measurements on vertical surfaces.

Approximate Efficiency of Typical Pancake GM Detector

	Average Energy (keV)	Maximum Energy (keV)	2π Efficiency (c/b)	4π (total) Efficiency on contact (c/d)	4π (total) Efficiency At 1 cm (c/d)
Ni-63	17	66		0.0025	
C-14	49	156	0.09	0.05	0.03
Tc-99	85	294	0.2	0.15-0.20	0.12
Tl-204	244	763	0.4	0.25	
Cl-36	251	710			0.26
Sr/Y-90	565 (Y-90 and Sr-90)	2280 (Y-90)	0.66	0.30	0.22
Ru-106 (Rh-106)	1411 (Rh-106)	3541 (Rh-106)		0.55	

Approximate Minimum Detectable Concentration (dpm/100 cm^2)

Radionuclide	Maximum Beta Energy	MDC
Ni-63	66	70,000
C-14	156	3,500
Tc-99	294	1,000
Tl-204	763	670
Sr/Y-90	1415	550

From NUREG-1507. On contact measurements.

Pancake GM Detector

The best general purpose survey meter for routine work.

Side Wall/Window GM Detector

Radiation Detected: Primarily used to measure gamma exposure rates in the mR/hr range.

In the open shield configuration, it is capable of detecting surface contamination emitting betas over 300 keV or so.

Window: ca. 30 mg/cm^2 mica

HV: ca. 800- 900 volts

Background: ca. 20 -50 cpm

Dead time: ca 100- 200 us/count

Side Wall/Window GM Detector

- Rugged, no thin window to damage
- In high intensity radiation fields, will under-respond and even saturate (i.e., read zero)
- Will over-respond (read too high) with low energy (ca. <250 keV) photons when calibrated at higher energies.
- As a rule, the mR/hr scale is used with the shield closed.
- The CPM scale is used when measuring surface beta contamination with the shield open.

Side Wall/Window GM Detector

Energy Compensated GM: By using a bi-metal filter, it selectively attenuates the low energy photons that cause the over-response. This results in a flat energy response.

Gas Flow Proportional Counter

Radiation Detected: Primarily used to detect beta and alpha surface contamination. Responds to gamma rays but not very efficient. Can operate in alpha only, beta only or alpha plus beta modes.

Window: usually 0.8 mg/cm^2 aluminized mylar. Thinner 0.4 mg/cm^2 windows are available as are thicker (beta only) windows

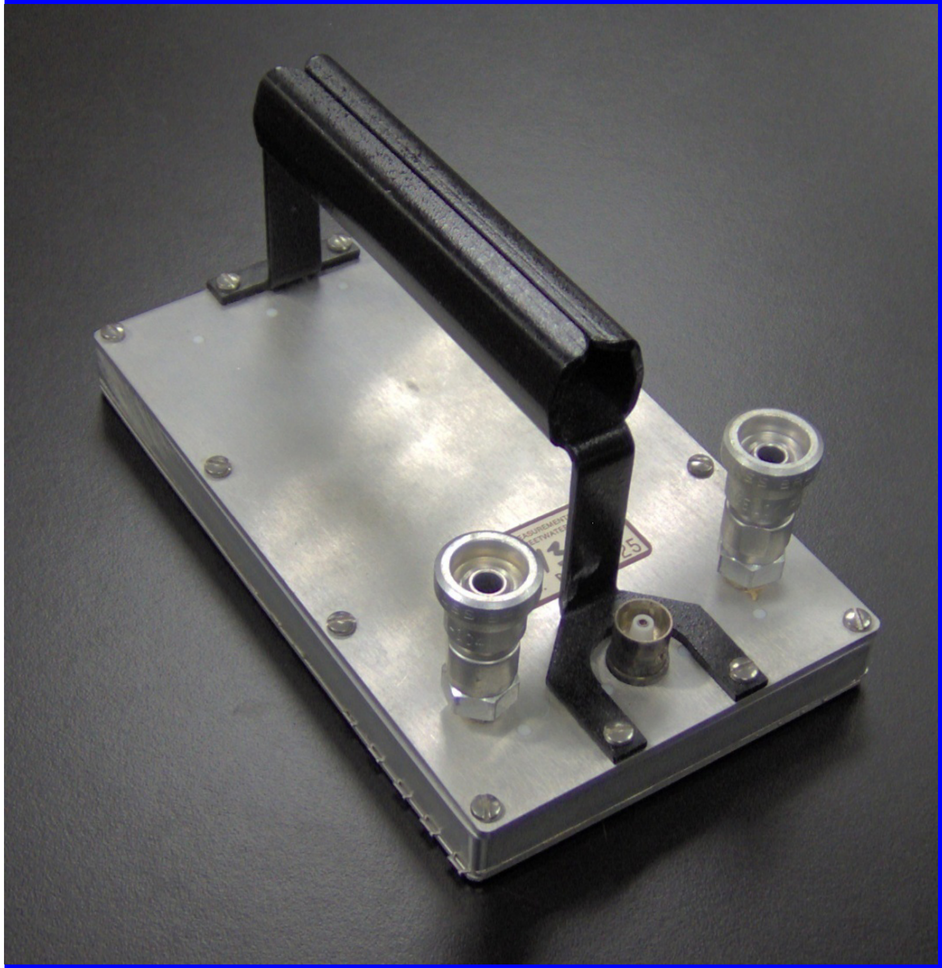
Area: Hand held units ca 100 cm^2

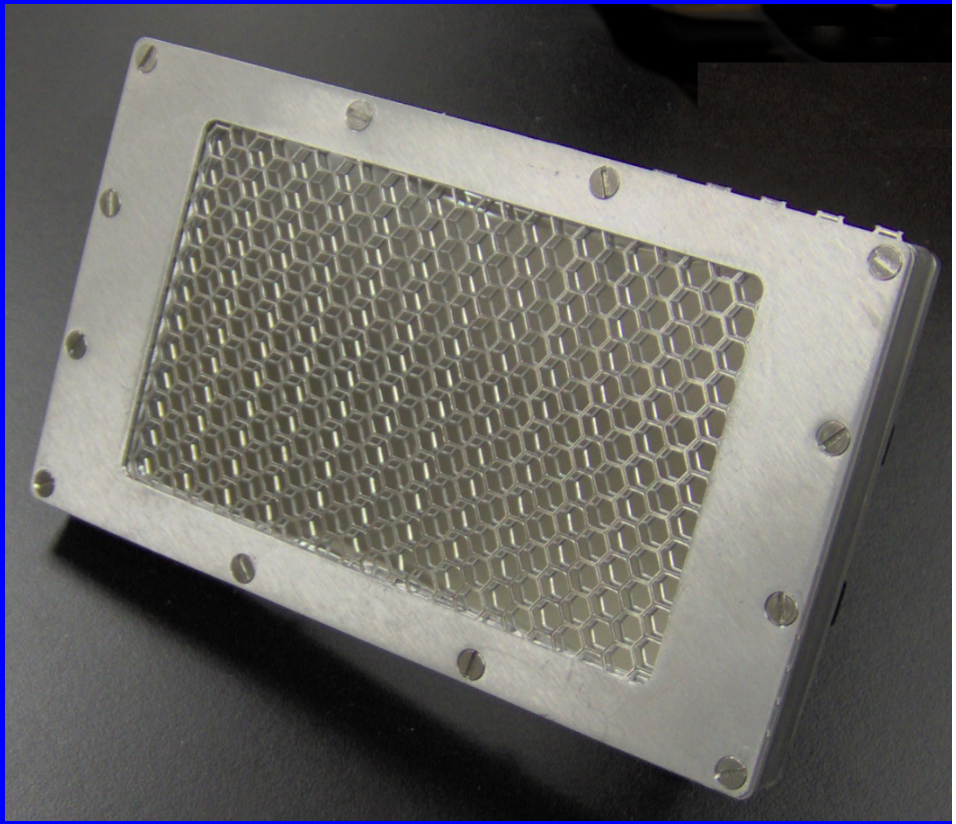
Total Efficiency: Depends on beta energy. Essentially zero for betas below 50 keV.

Alpha Background: ca. 0 - 2 cpm

Beta Background: depends on detector size. Hand held unit might be ca. 300 - 400 cpm

Gas Flow Proportional Counter





During storage, connections to gas line should be capped to prevent dust getting inside

Gas Flow Proportional Counter

Typically uses P-10 gas (90% argon, 10% methane)

Typical flow rate is 40 – 60 mls/min.

Possible to disconnect from gas supply. How long this can be done depends. If the detector is in good condition and is fairly small, an hour or so. If the detector is leaking and is large, a much shorter time. Some people push their luck.

Approximate Efficiency of Typical Gas Flow Proportional Counter (0.8 mg/cm^2)

	Average Energy	Maximum Energy	2π Efficiency	2π Efficiency at 1 cm	4π (total) Efficiency on Contact	4π (total) Efficiency at 1 cm
Alpha	4 – 8 MeV	na	0.35		0.25	0.15
Ni-63	17 keV	66 keV			0.04	0.007
C-14	49 keV	156 keV	0.225	0.28	0.1	0.065
Tc-99	85 keV	294 keV	0.38	0.3	0.25	0.19
Tl-204	244 keV	763 keV	0.55	0.46	0.34	0.28
Sr/Y-90	565 keV (Y-90 and Sr-90)	2280 keV (Y-90)	0.64	0.5	0.64	0.4
Ru-106 (Rh-106)	1411 keV (Rh-106)	3541 (Rh-106)		0.72	0.55	

Approximate Minimum Detectable Concentration (dpm/100 cm^2)

Radionuclide	Maximum Beta Energy	MDC on contact	MDC at 1 cm
Ni-63	66	2,000	10,000
C-14	156	700	1,100
Tc-99	294	300	370
Tl-204	763	200	250
Sr/Y-90	1415	160	180
Alpha	NA	25	40

Based on data from NUREG-1507.
Window thickness of 0.8 mg/cm^2.

Gas Flow Proportional Counter

Must be purged prior to use each day. The larger the detector, the longer the purge. Typically 15 min- 1 hr.

Detector efficiency can vary when a different supplier of gas is used.

Atmospheric pressure (elevation) and temperature can affect the detector response, particularly the beta response.

Gas Flow Proportional Counter

The magnitude of this effect should be assessed if the detector is used at widely varying temperatures and pressures.

It might be determined that it is necessary to employ different beta operating voltages for the different temperatures and pressures.

For example, the typical ORAU beta operating voltage is 1750 volts for temperatures above 35°F and 1775 volts below 35°F

Gas Flow Proportional Counter

The gas flow proportional counter is probably the best instrument for measuring surface contamination over large flat surfaces (i.e., most d and d work)

Floor monitor shown to left. Detector can be disconnected and used to scan vertical or other horizontal surfaces.

Floor monitors generally used for non-quantitative scanning purposes.

Windowless Gas Flow Proportional Counter

In survey instruments, the windowless gas flow proportional counter is marketed as capable of detecting tritium surface contamination.

The betas have no window to penetrate.

Used to perform fixed measurements, not scans

Windowless Gas Flow Proportional Counter

Residual air must be purged before count.

Surface must be flat. A flexible apron sometimes used to provide a better seal between the probe and the surface.

Has a problems with static charges and dust getting inside the detector chamber.

Sodium Iodide (NaI) Gamma Scintillator

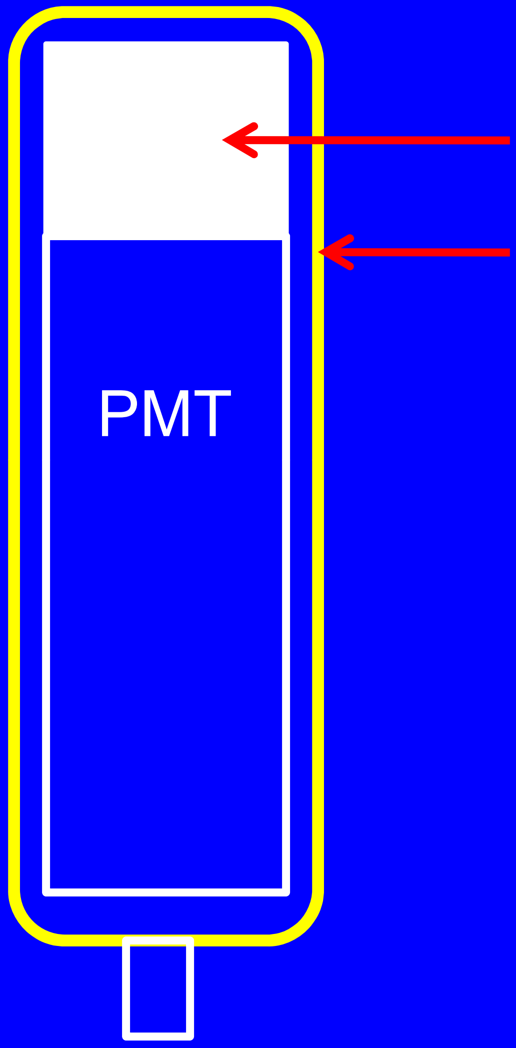
Radiation Detected: Exclusively used to detect gamma rays (and x-rays).

Typical Crystal Size: 1 – 2 inch diameter

The crystal is housed in a hermetically sealed metal container with a quartz/glass window at one end. The window is in contact with the photocathode of a photomultiplier tube. The photons produce flashes of light (scintillations) from the crystal that are converted into electronic pulses by the photomultiplier tube.

Background: There is substantial variation in background. For a given location, the background increases with crystal size. Typically 800 – 4000 cpm

Sodium Iodide (NaI) Gamma Scintillator



Sodium Iodide (NaI) Gamma Scintillator

Pulse Height Analysis: Since pulse size is directly related to the photon energy deposited in the NaI crystal, the latter can, and are, used to measure gamma ray energy. Most hand-held gamma spectroscopy systems used to identify radioactive material employ NaI or LaBr detectors.

However, NaI survey meters are usually employed to detect gamma rays, not measure their energy.

To the left: display on hand-held gamma spectroscopy system (IndentiFINDER)

Pulse Height Analysis: With some meters, it is possible to set a "window" so that they only respond to pulses in a specified size range, e.g., in a situation where there is both Cs-137 and Co-60, a window could be set up about the Co-60 pulses reducing the interference from the Cs-137 and other nuclides contributing to background.

In this instrument, Channels 1 and 2 are preset windows. When switched to ch 1, the meter only responds to small pulses. When set to ch 2, it only responds to the large pulses.

Micro R Meter

Radiation Detected: Photons (gamma rays, x-rays, bremsstrahlung, etc.)

Detector: Sodium iodide scintillator inside case.

Typical Lowest Scale: 0 – 3 uR/hr or 0 – 25 uR/hr

Typical Highest Scale: 0 – 3,000 or 0 – 5,000 uR/hr

Micro R Meter

- Convenient to carry since no cable to deal with
- Over-responds (reads too high) when used to measure exposure rates due to low energy (< 250 keV) photons if it was calibrated at a higher energy
- Like all NaI detectors, the crystal can crack due to thermal stress. Avoid rapid and dramatic changes in temperature
- Audio output standard

Micro Rem Meter (or Micro Sv)

Radiation Detected: Photons (gamma rays, x-rays, bremsstrahlung, etc.)

Detector: Plastic scintillator inside case.

Typical Lowest Scale: 0 – 20 urem/hr

Typical Highest Scale: 0 – 200,000 urem/hr (0 – 200 mrem/hr)

Micro Rem Meter (or Micro Sv)

- Convenient to carry since no cable to deal with
- Somewhat lighter and more rugged than Micro R meter
- Flat energy response. Unlike the Micro R meter, it reads accurately at low energies even if calibrated at high energy
- Might or might not have audio output
- One version comes with thin window to improve its response to low energy x-rays

Sodium Iodide (NaI) Gamma Scintillator

Fairly fragile. Subject to mechanical shock and thermal shock (rapid large changes in temperature can crack the crystal).

If the hermetically sealed container is compromised, the NaI crystal can absorb moisture (and turn yellow). In some cases, the damage surface layer of the crystal can be removed and the crystal continue to be used.

Sodium Iodide (NaI) Gamma Scintillator

Damaged crystals can still produce a signal, but the performance deteriorates. In many cases, the damage is not recognized and the detector is still used.

The image to the left shows a collimated NaI detector on a cart. In this case, the detector “sees” a one square foot area of soil.

FIDLER

Field Instrument for the Detection of Low Energy Radiation.

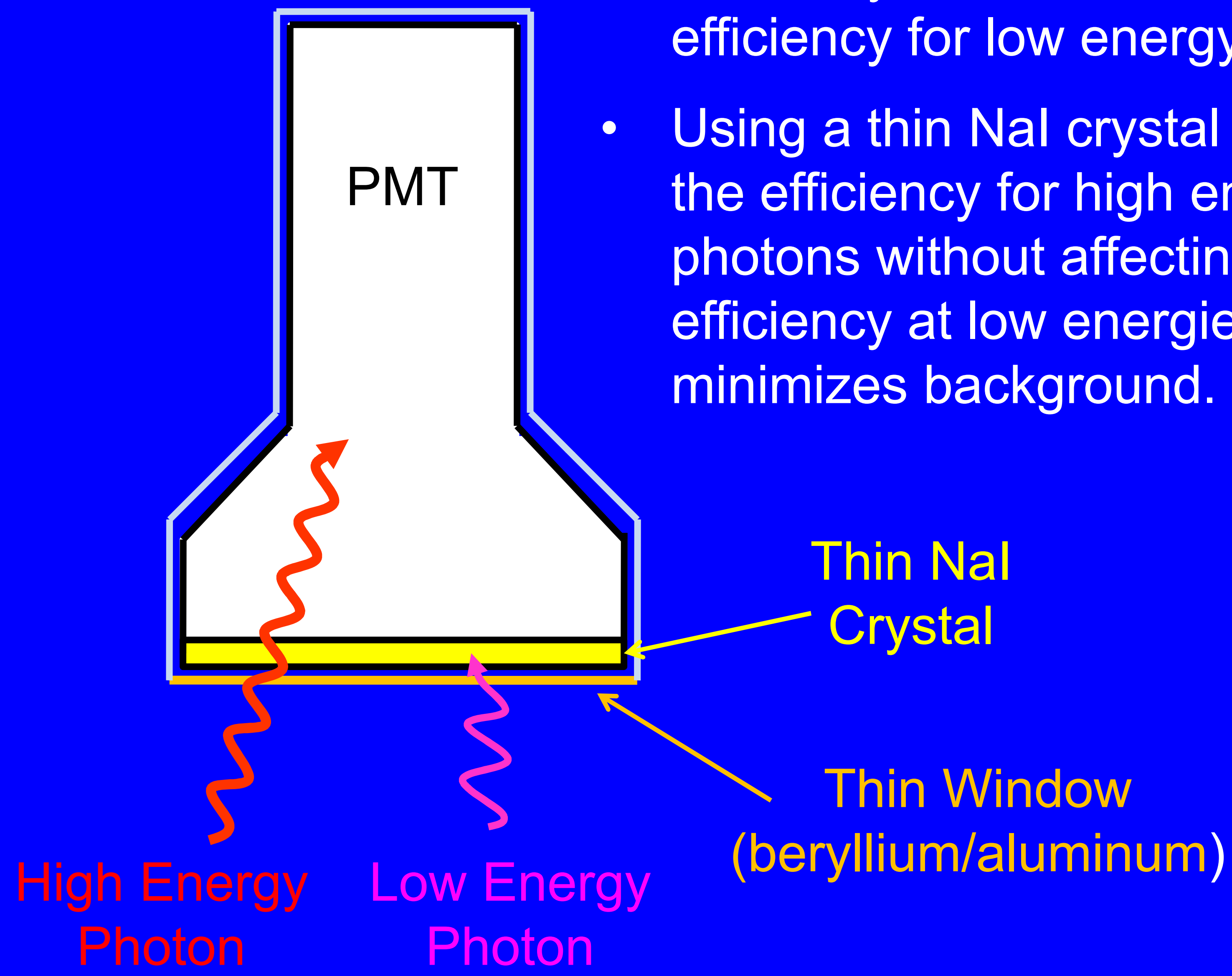
Radiation Detected: Used to detect low energy gamma rays and x-rays. Most commonly employed to detect the 59.5 keV gamma rays of Am-241. Sometimes used to detect U-238 via the low energy photons emitted by its decay products Th-230 and/or Th-234

Window: Typically beryllium (0.25 mm thick). Sometimes aluminum or other material.

FIDLER

- Heavy
- Expensive
- Typically used to make fixed measurements (facing down and 30 cm above the ground)
- Scanning is tedious because of the weight
- To reduce background and increase sensitivity, it is common to set up a window about the pulse sizes of interest

FIDLER



- Thin beryllium window increases efficiency for low energy photons
- Using a thin NaI crystal reduces the efficiency for high energy photons without affecting efficiency at low energies. This minimizes background.

Ion Chamber

Radiation Detected: primarily used to measure exposure rates due to photons (e.g., gamma rays and x-rays). Most ion chambers come with a thin window that permits the detection of alphas and/or betas in the uncovered configuration.

Chamber Volume: Typically 200 – 300 cm^3

Chamber Gas: Typically air. Possibly nitrogen or argon.Some are open to the atmosphere, some are sealed. If sealed, the gas might or might not be pressurized, e.g., the Victoreen 451P is sealed and pressurized with air to 6 atmospheres.

Window (if present)Thickness: either 1.5 or 7 mg/cm^2

Lowest Scale: might be 0 – 0.5 (pressurized), 5.0, or 25 mR/hr

Highest Scale: might be o to 5, 50, 500 or 1000 R/hr

Ion Chamber

- Appearance can vary quite a bit
- Operate in current mode
- No audio
- Slow to respond. Might need 1 – 2 minutes for reading to stabilize

Ion Chamber

- The response of ion chambers open to the atmosphere (e.g., RO-2) is affected by temperature and pressure. Corrections might be necessary.
- If the chamber is open to the atmosphere, the air passes through a desiccant (typically indicating silica gel) prior to entering chamber.
- When dry, silica gel is deep rich blue. When it has absorbed too much moisture to be useful, it turns pink and must be replaced

Ion Chamber

- Exposure rate measurements are usually made with the window closed because exposure rate (in mR or R/hr) is only defined for photons (not betas).
- It is sometimes possible to estimate the beta dose rate with the difference between the open and closed readings made on an ion chamber. The difference reflects the instrument response to the betas.
- The difference in mR/hr is multiplied by a factor derived from measurements on a uranium slab to get the beta dose rate in mrad/hr. Typical factors are in the 4 to 5 range.