

# Calibration of Survey Meters and Measurements of Contamination

# Types of Calibration

# Types of Calibration

A calibration determines the relationship between the instrument response/reading and a quantity of interest.

Instrument Response  $\leftrightarrow$  Quantity of Interest

The three common types of calibration:

- Electronic Calibration
- Energy Calibration
- Radiological (Primary) Calibration
  - Exposure Rate Measurements
  - Counting Efficiency for Activity Measurements

# Electronic Calibration

# Electronic Calibration

## General

Count Rate  $\leftrightarrow$  Pulse Rate

- An electronic calibration determines the relationship between the pulse rate and the count rate. If necessary, the instrument is adjusted so that the count rate exactly matches the pulse rate. In general, electronic calibrations are only performed on instruments that read out in cpm (or cps).
- In the early days, it was common to set the instrument, usually a scaler, into the test mode whereby it would count the cycles in the AC line current. Since the latter's frequency is 60 cycles per second, 3600 counts should be registered over a one-minute count.

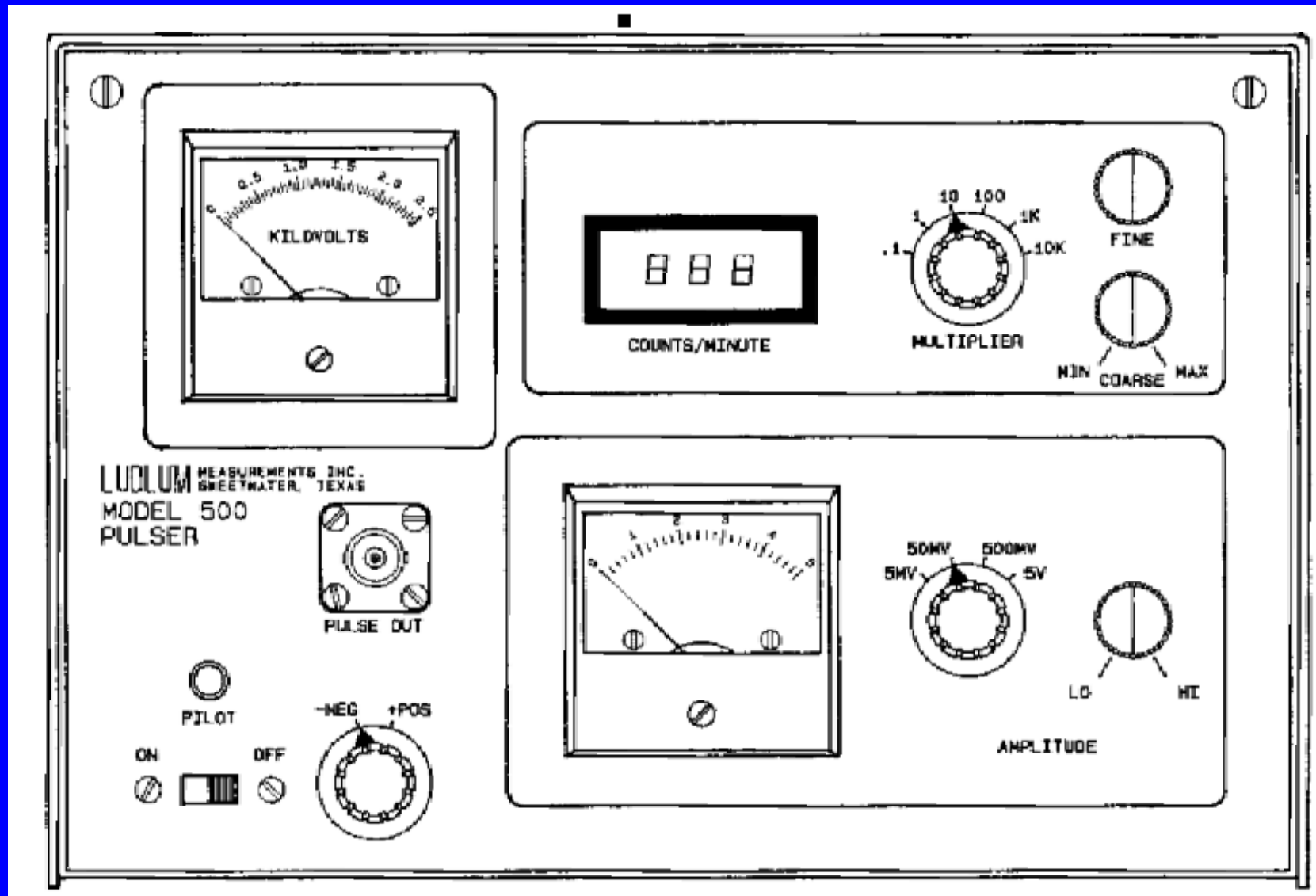
# Electronic Calibration

## General

- Electronic calibrations usually involve connecting a scaler or rate meter to a pulse generator (pulser).
- The generator's pulse rate is variable.
- The amplitude of the pulses can also be adjusted. The pulse amplitude must exceed the meter's threshold setting and should be similar to the size of the pulses produced by the detector.
- If necessary, the meter's threshold setting can be determined by lowering the amplitude of the pulses to the point at which no counts are registered.

# Electronic Calibration

## Pulser



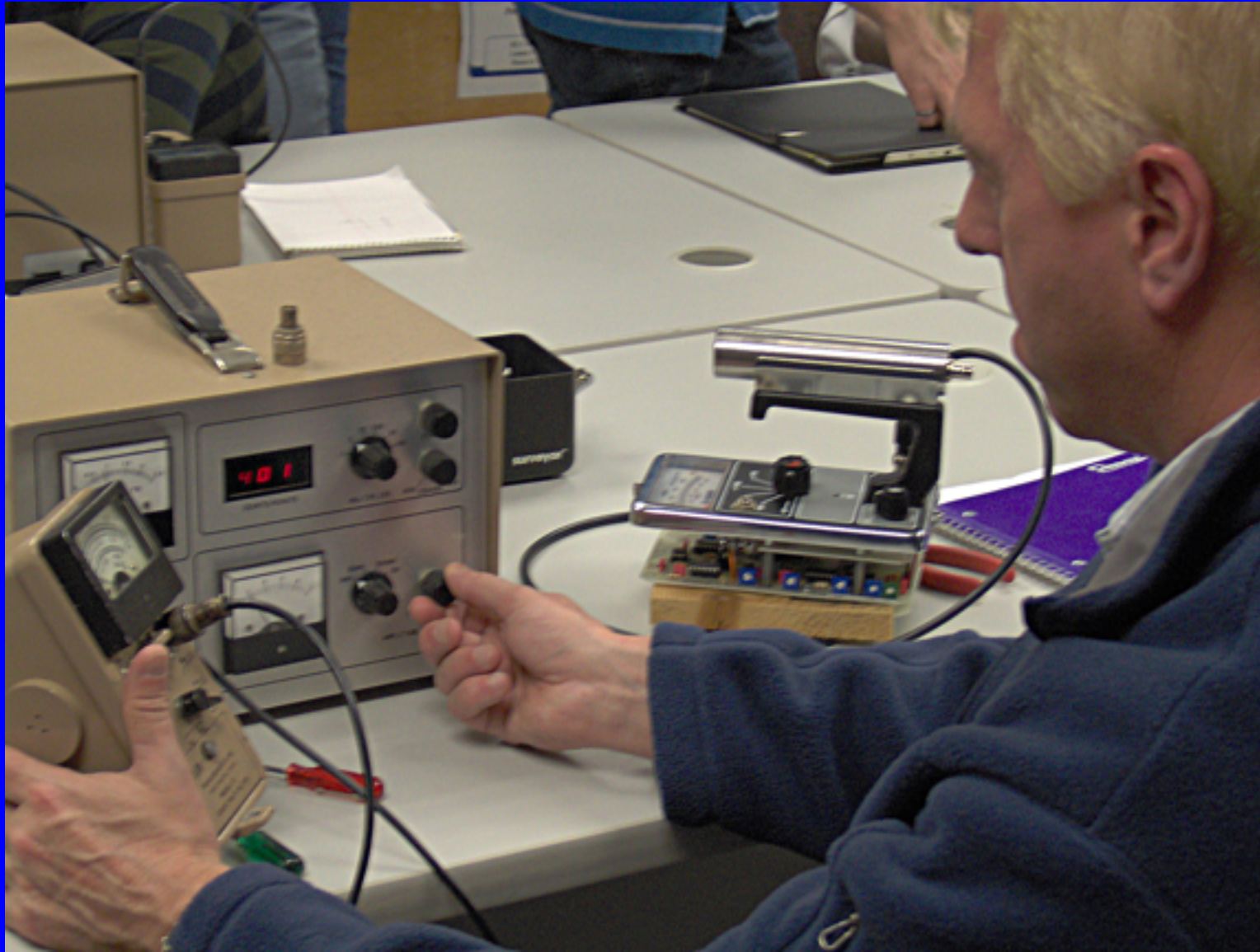
# Electronic Calibration

## General

- Electronic calibrations are generally performed in the middle of each scale.
- For example, if the x1 scale is from 0 to 500 cpm, the pulser would be set to 250 pulses per minute.
- If the meter being calibrated does not register 250 cpm, it would be adjusted to do so.
- The meter would then be switched to the x10 scale and the pulse rate from the pulser would be set at 2500 pulses per minute, etc, etc.



# Electronic Calibration



# Energy Calibration

# Energy Calibration

## General

Measured Pulse Size  $\leftrightarrow$  Energy of Radiation

- In an energy calibration, we determine the relationship between the measured height of the pulses and the energy of the radiation (gamma rays, alpha particles or beta particles).
- The measured height of a pulse is the channel number into which that pulse is sorted.
- The calibration is accomplished by counting a source(s) that emits radiation at known energies and assigning channel numbers to the corresponding "peaks" on the spectrum. Each peak consists of many pulses of similar height.

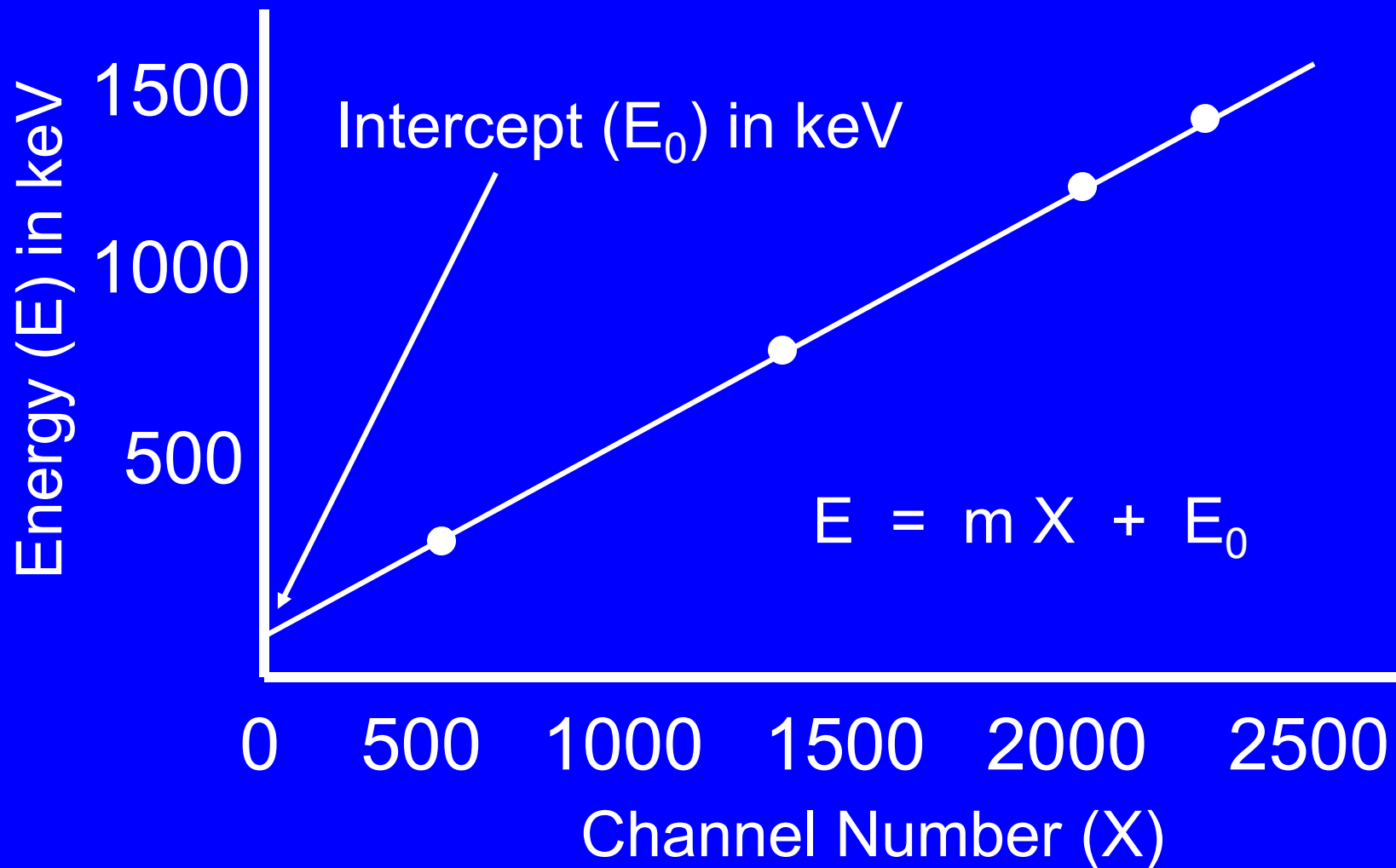
# Energy Calibration

## Factors That Affect the Energy Calibration

- The calibration only applies at a specific high voltage setting and amplifier gain.
- Other factors can affect the calibration, e.g., the energy deposition rate in the detector (sodium iodide detectors are particularly prone to this problem).
- The relationship between radiation energy and the channel assigned to the corresponding peak on the spectrum is usually very close to linear.

# Energy Calibration

## Example Energy Calibration Curve



# Energy Calibration

## Energy Calibration Equation

- Since the relationship between channel number and energy is essentially linear, the following equation is often used to describe the relationship:

$$E = m X + E_0$$

E is the radiation energy (e.g. keV) responsible for the peak

X is the channel assigned to the peak

m is the slope (e.g. keV/channel)

$E_0$  is the energy corresponding to channel zero (e.g. keV)

- Since the relationship between energy and channel number might not be completely linear, a quadratic equation might be used instead.

# Radiological Calibration – Exposure Rate Measurements

# Radiological Calibration – Exposure Rate

## General

Indicated Exposure Rate  $\leftrightarrow$  Actual Exposure Rate

- The relationship between an instrument's indicated exposure rate and the actual exposure rate is determined.
- In other words, we determine the accuracy of the measurements made with the instrument.
- As used here, the term “exposure rate” (e.g., mR/hr) also includes dose rate (e.g., mGy/hr) and dose equivalent rate (e.g., mrem/hr, uSv/hr).
- Instruments that might be calibrated this way include sidewall or side window GMs, uR or uSv meters, ion chambers, etc.



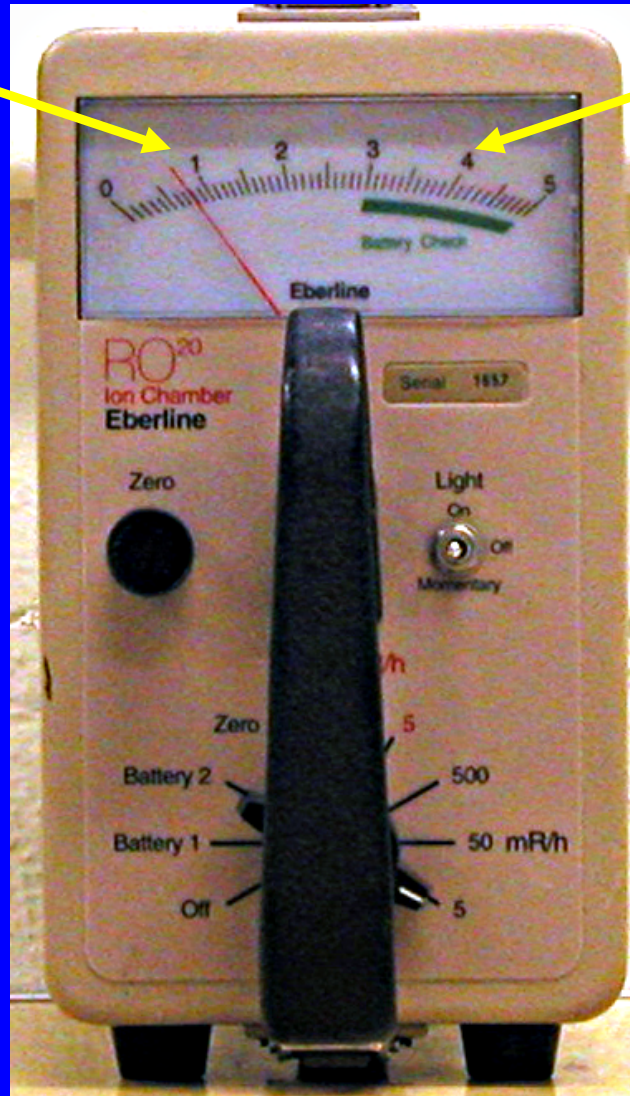
# Radiological Calibration – Exposure Rate

## General

- Survey instrument calibrations for NRC or Agreement State licensees will be performed according to the regulatory and license requirements. At DOE facilities, the calibrations are usually performed according to ANSI N323.
- In either case, the accuracy is determined at a minimum of two points on each scale (usually 20% and 80% of full scale reading) if the instrument has an analog linear readout, or a digital readout with separate scales.
- If the instrument has a logarithmic readout or digital readout without scales and in the middle of each “decade” (5 mR/hr, 50 mR/hr, 500 mR/hr etc).

# Radiological Calibration – Exposure Rate

20% of  
full scale



80% of  
full scale

# Radiological Calibration – Exposure Rate

## Determining the Actual Exposure Rate

The actual exposure rates are:

- Calculated theoretically at various distances from a standard source (usually Cs-137) of known activity. This is the preferred approach. This source must be NIST traceable.
- Measured by a "transfer" instrument, the accuracy of which has been determined by NIST or a secondary NIST laboratory. The transfer instrument should only be used for calibration of other instruments. It is not for "field" use. One concern is that the response of the transfer instrument might change.

# Radiological Calibration – Exposure Rate

## Ways to Vary the Calibration Exposure Rates

Three methods can be employed to produce the various exposure rates required for calibration:

- Use sources of different activities
- Vary the distance between the detector and source
- Employ attenuators between the source and detector.

Attenuators, usually made of lead, are shields that reduce the intensity of the radiation by a specified amount. Unfortunately, attenuators change the energy spectrum.

# Radiological Calibration – Exposure Rate

## Ways to Vary the Calibration Exposure Rates

- The distance required to achieve a desired exposure rate involves the use of the following equation:

$$d = \sqrt{\frac{A \Gamma}{F \dot{X}}}$$

$d$  is the distance between the source and detector (e.g. cm)

$A$  is the activity of the standard source (e.g. mCi)

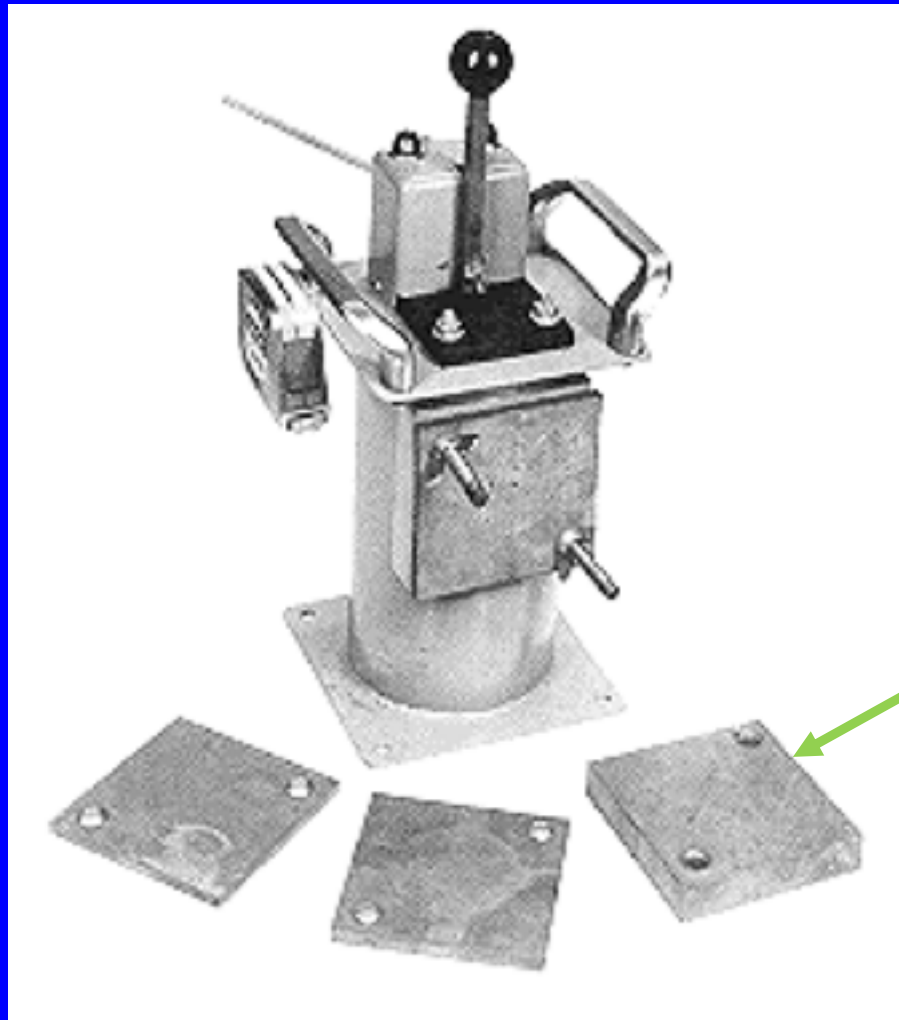
$\Gamma$  is the specific gamma constant (e.g. mR/hr at 1 cm per mCi)

$X$  is the required exposure rate (e.g. mR/hr)

$F$  is the attenuator factor (1 if no attenuator is used)

# Radiological Calibration – Exposure Rate

## Ways to Vary the Calibration Exposure Rates



lead  
attenuator

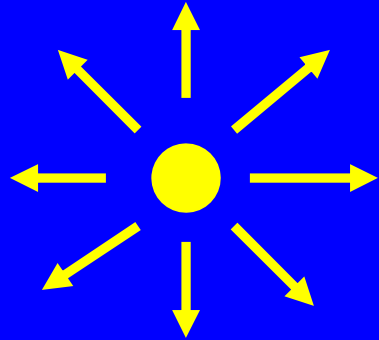
# Radiological Calibration – Exposure Rate

## Common Calibration Set-ups

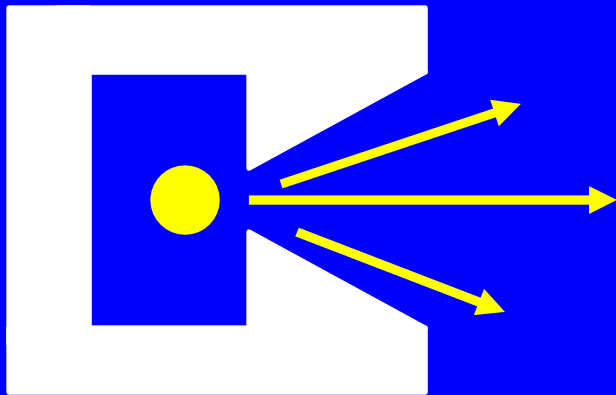
- Free in-air source of known activity
- Collimated source of known activity
- Well calibrator
- Box calibrator

# Radiological Calibration – Exposure Rate

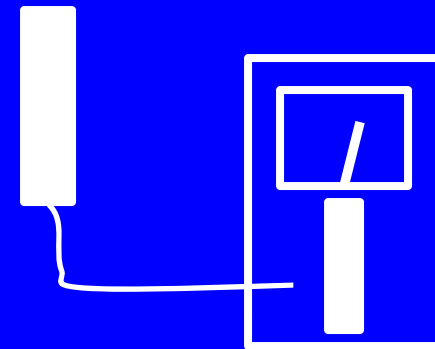
## Standard Source of Known Activity



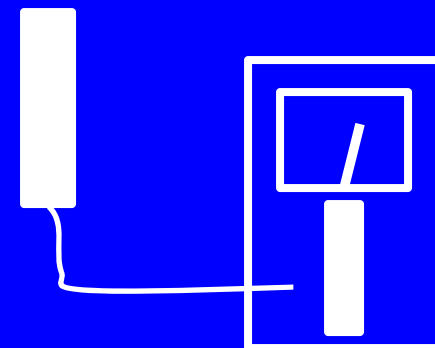
Free In-air Standard Source



Collimated Standard Source



meter





# Radiological Calibration – Exposure Rate

## Free In-air Source of Known Activity

- The standard source is not collimated
- The beam is omnidirectional
- Sometimes performed outdoors

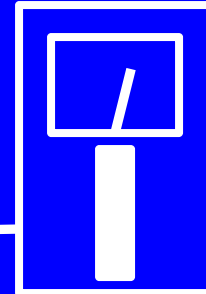
## Collimated Source of Known Activity

- The most common calibration arrangement
- The beam is collimated, usually in the form of a cone
- Scatter is reduced
- Helps minimize worker exposures

# Radiological Calibration – Exposure Rate

Well Calibrator

meter



Standard Source  
(position movable)



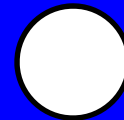
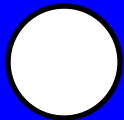
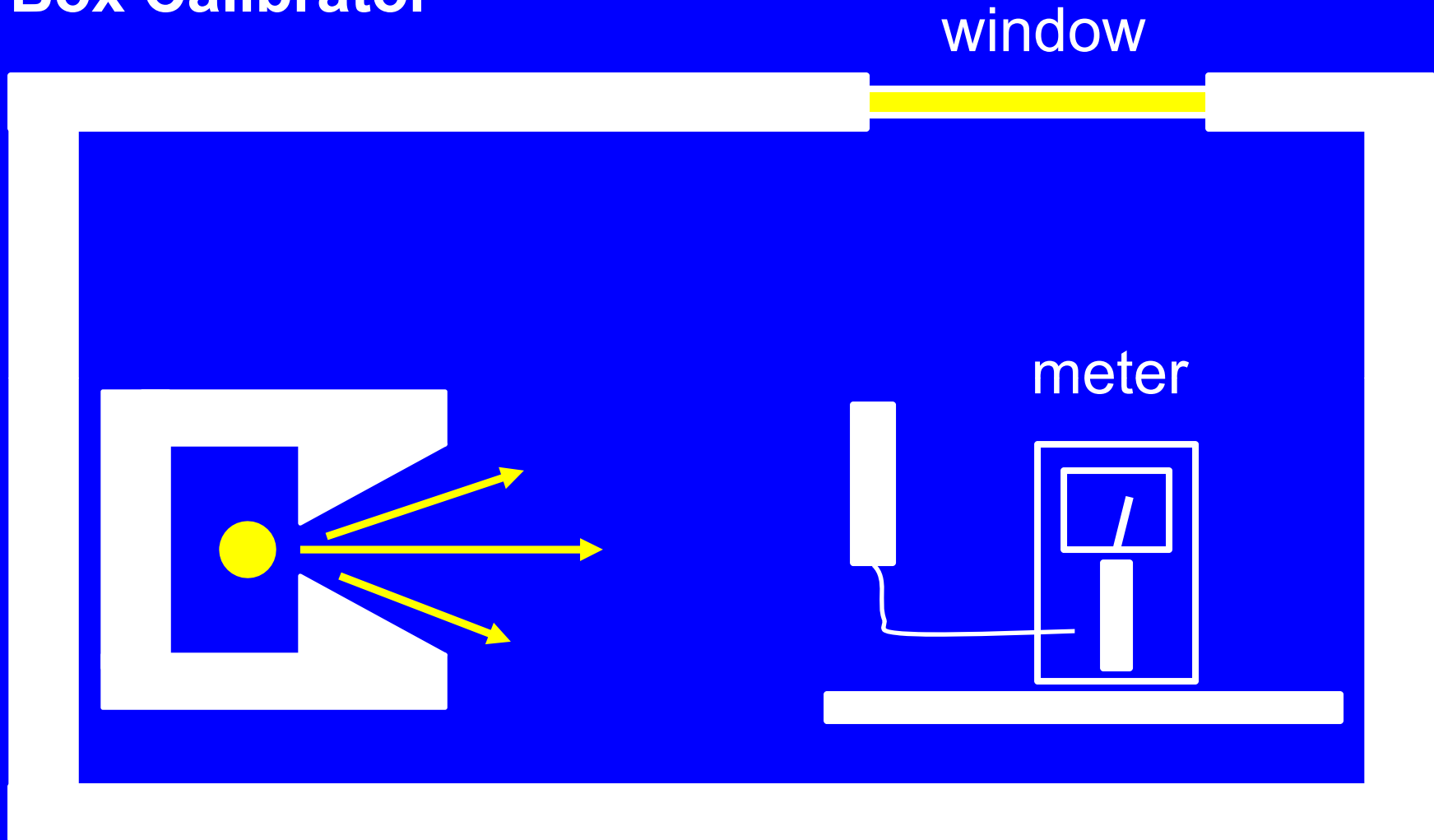
# Radiological Calibration – Exposure Rate

## Well Calibrator

- The detector is in a fixed position at the top of the well
- The source is moved up and down in the well to achieve the desired exposure rate
- The source does not need to be removed from the calibration well
- The actual exposure rates are typically measured with a transfer instrument rather than calculated

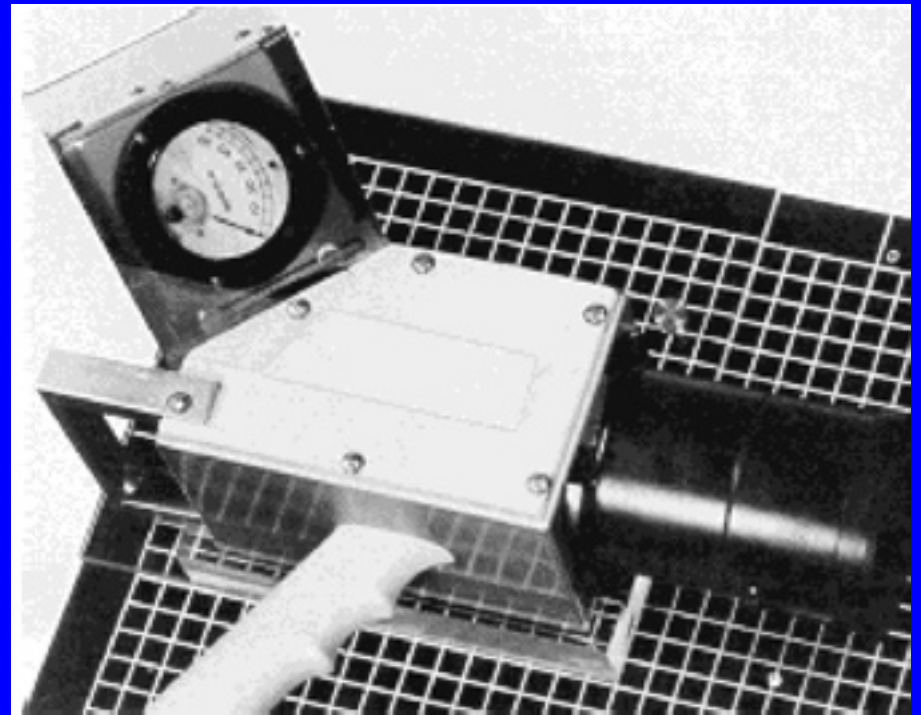
# Radiological Calibration – Exposure Rate

## Box Calibrator



# Radiological Calibration – Exposure Rate

## Box Calibrator



# Radiological Calibration – Exposure Rate

## Box Calibrator

- The calibration is performed with the sources and detector inside a shielded box. The box is usually on wheels
- A lead glass window is on the top of the box so that the instrument can be read
- Box calibrators are very convenient when space is limited
- The actual exposure rates are measured with a transfer instrument because of the potential for scatter in the box
- The source to detector distance is not very adjustable
- The primary ways to adjust the exposure rates are to use multiple sources and collimators

# Radiological Calibration – Exposure Rate

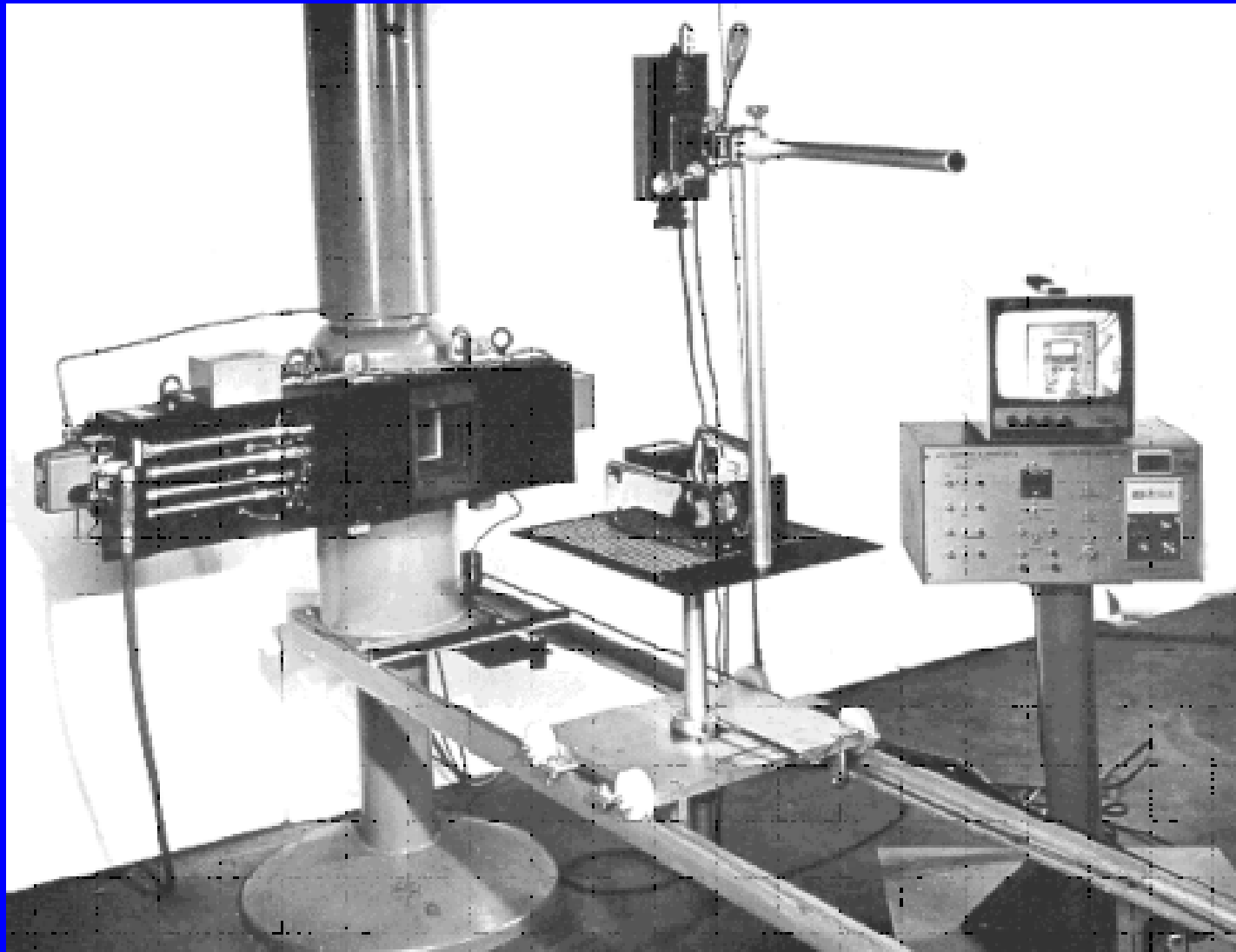
## Reading the Meter During Calibration

To minimize exposures to the calibration personnel, the meter might be read remotely. This might be accomplished by:

- Viewing the meter on a remote monitor - a video camera is aimed at the meter display
- Viewing the meter reading (or its reflection in a mirror) through a telescopic lens or a pair of binoculars
- Coupling the meter to a computer so that the instrument response is indicated on the computer monitor. This might be a hard-wired or blue tooth connection

# Radiological Calibration – Exposure Rate

## Reading the Meter During Calibration





# Radiological Calibration – Exposure Rate

## Example Calibration

Prior to the calibration, the instrument was adjusted to be as accurate as possible at the midpoint on each scale.

Calibration source nuclide: Cs-137

Specific gamma ray constant:  $0.32 \text{ R m}^2 \text{ h}^{-1} \text{ Ci}^{-1}$

Decay corrected activity of calibration source 1: 25 Ci

Decay corrected activity of calibration source 2: 100 Ci

Attenuator factor: 8.56

# Radiological Calibration – Exposure Rate

## Example Calibration

Source Activity (A)	Source to Detector Distance (d)	Attenuator Factor (F)	Actual Exposure Rate ( $\dot{X}_t$ )	Meter Scale	Indicated exposure Rate ( $\dot{X}_i$ )	Calibration Factor $\left(\frac{\dot{X}_t}{\dot{X}_i}\right)$
25 Ci	2.16 m	8.56	0.2 R/hr	0 – 1 R/hr	0.18	1.11
25 Ci	3.16 m	1	0.8 R/hr	0 – 1 R/hr	0.74	1.08
25 Ci	2.0 m	1	2.0 R/hr	0 – 10 R/hr	1.97	1.02
100 Ci	2.0 m	1	8.0 R/hr	0 – 10 R/hr	8.10	0.99
100 Ci	1.26 m	1	20 R/hr	0 – 100 R/hr	17.6	1.14
100 Ci	0.63 m	1	80 R/hr	0 – 100 R/hr	76.0	1.05
Average Calibration Factor						1.07

Depending on the regulatory/license requirements, no adjustments (e.g., using a calibration factor) are necessary if the indicated exposure rate is within 10 to 20% of the actual exposure rate.

# Radiological Calibration – Exposure Rate

## Traceability of the Standard Source

- The standard source should be traceable to the National Institute of Standards and Technology (NIST). This usually means that the source activity was determined with an instrument whose efficiency was determined with a source that came from NIST or a secondary laboratory.
- National standard: the primary standard source maintained by NIST to which other standard sources should be traceable.
- Secondary standard: a source whose activity has been determined by direct comparison with the national standard.
- Tertiary standard: a source whose activity was determined by comparison with a secondary standard.

# Radiological Calibration – Exposure Rate

## Traceability of the Standard Source

- The standard used by a given laboratory might be a secondary or tertiary standard.
- A standard produced at NIST for the purpose of shipment to another laboratory might be referred to as a transfer standard.
- See ANSI N42.22-1995 *Traceability of Radioactive Sources to the National Institute of Standards and Technology (NIST) and Associated Instrument Quality Control*.
- As a rule of thumb, a source should be recertified every two to three half-lives or 8 to ten years, whichever comes first. This is particularly important for unsealed plated sources.

# Radiological Calibration – Exposure Rate

## Energy Dependence

- Calibrations demonstrate that the measurement accuracy is acceptable at the calibration energy (usually 662 keV). Nevertheless, measurements of exposure rates at other photon energies might not be so accurate.
- Fortunately, this effect is rarely an issue above 300 keV or so. Almost any instrument calibrated at 662 keV can be expected to make accurate measurements above 300 keV.
- However, below 300 keV, many detectors over respond. Such instruments, if calibrated at 662 keV, would indicate an exposure rate higher than actually existed due to 100 keV photons.

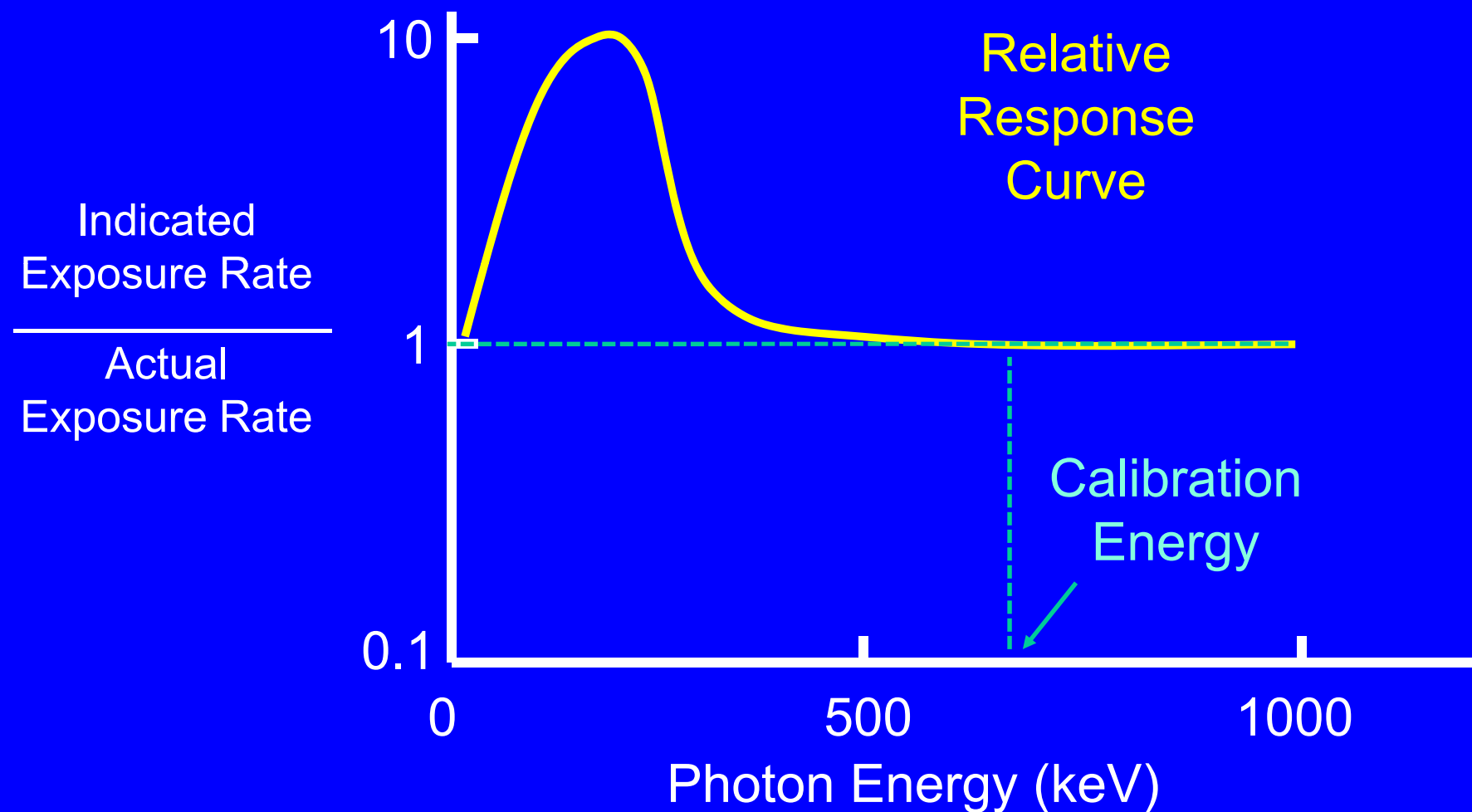
# Radiological Calibration – Exposure Rate

## Energy Dependence

- Characteristics of instruments that over-respond at low energies:
  - they operate in the pulse mode
  - the photon interactions in the detector are with a material whose atomic number is greater than 7 to 8 (the atomic number of air, water, human tissue)
- Instruments that over-respond at low energies: most GMs, NaI detectors (e.g., uR meter),  $\text{CaF}_2$ ,  $\text{CaSO}_4$
- Energy independent instruments: energy compensated GM, ion chambers, plastic scintillators (micro rem meter), LiF

# Radiological Calibration – Exposure Rate

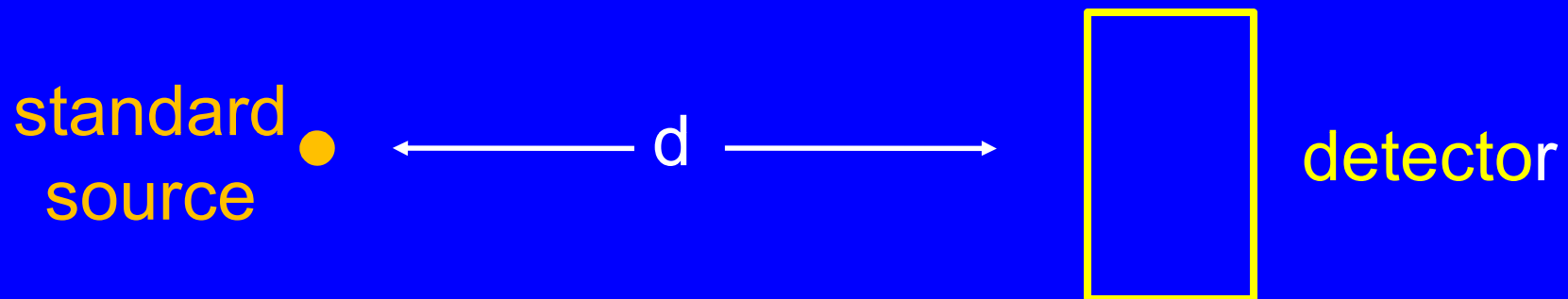
## Energy Dependence



# Radiological Calibration – Exposure Rate

## Effective Detector Chamber Center

The exposure rate (radiation intensity) sometimes varies throughout the detector volume, e.g., it might be higher on the side of the detector chamber closest to the source.



- In practice, the distance ( $d$ ) between the source and detector that we use is the distance from the center of the source to the physical center of the detector.
- Sometimes, the required distance is specified from the center of the source to the “effective” center of the detector.



# Radiological Calibration – Exposure Rate

## Effective Detector Chamber Center

- The effective chamber center is the point at which the average overall exposure rate within the chamber can be found.
- At large source to detector distances, the exposure rate doesn't change very much across the chamber and the effective chamber center is close to the physical center of the chamber. No problem here.
- However, at small source to detector distances, the exposure rate can decrease very quickly as we move from the side of the chamber closest to the source to the far side of the chamber. In this case, the effective chamber center is shifted forward. Not good.

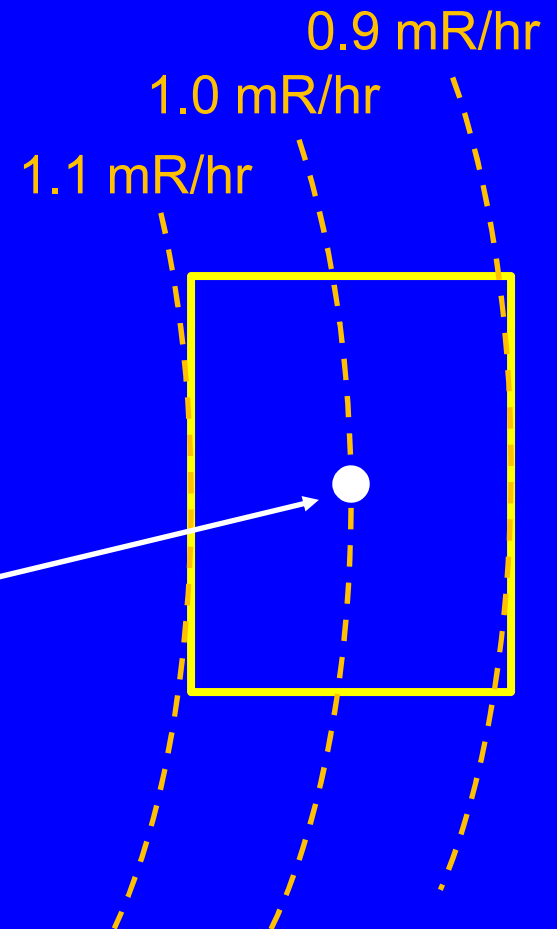
# Radiological Calibration – Exposure Rate

## Effective Detector Chamber Center

Large source to detector distance. Good.

●  
source

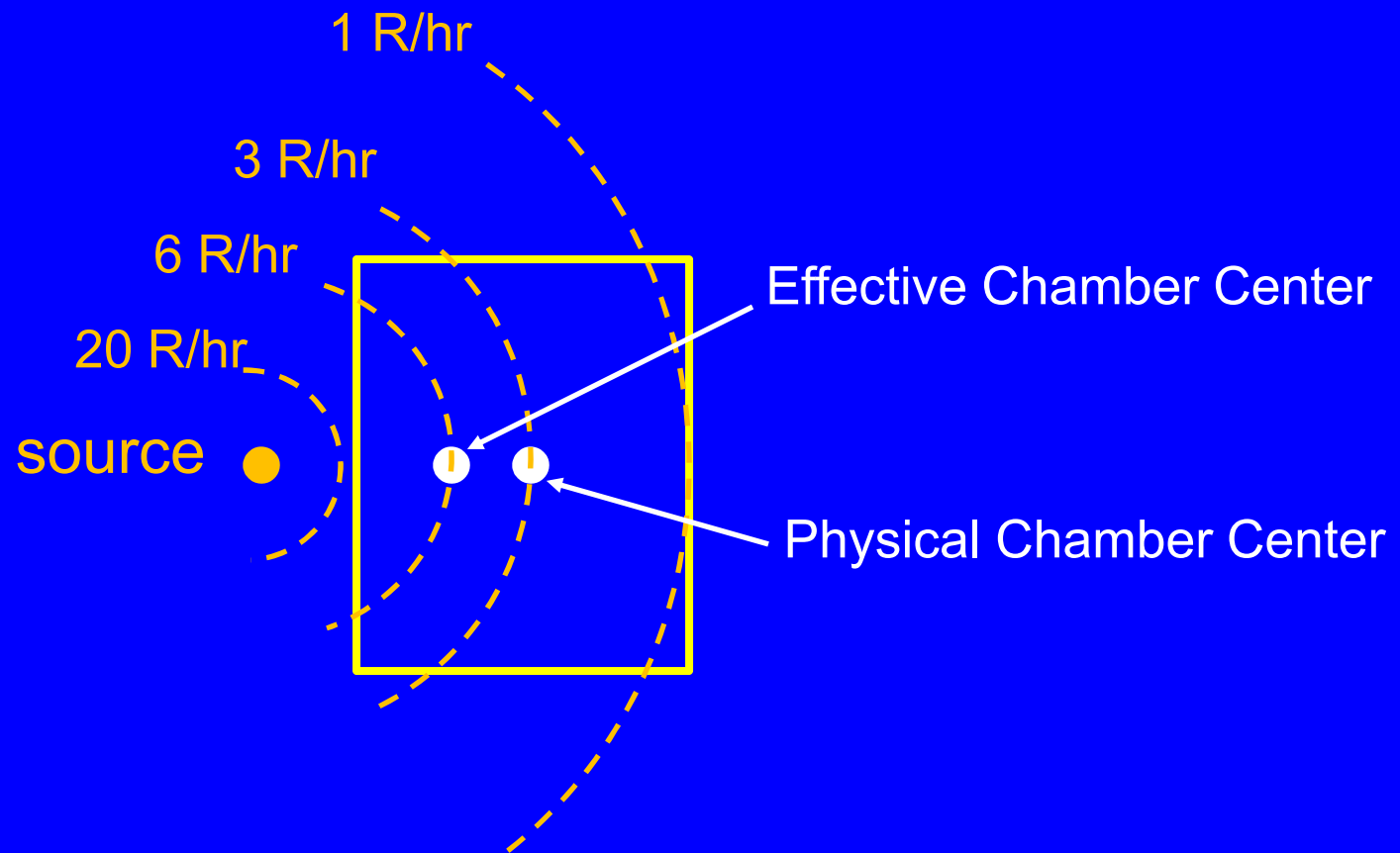
Physical and Effective  
Chamber Center



# Radiological Calibration – Exposure Rate

## Effective Detector Chamber Center

Small source to detector distance. Bad.



# Radiological Calibration – Exposure Rate

## Effective Detector Chamber Center

- The goal is to calibrate (and make measurements) far enough away from a source so that the intensity of the radiation is as uniform throughout the detector chamber as possible.
- A rule of thumb used in ANSI N323 is to keep the source to detector distance at least five times the maximum chamber dimension.
- The source to detector distance is particularly important when using ion chambers which tend to have large detector volumes (e.g., 7 – 8 cm across).

# Radiological Calibration – Exposure Rate

## Effective Detector Chamber Center

- If the detector is elongate (e.g., a side window GM), the long axis of the detector should be at right angles to the source. This helps ensure a uniform radiation intensity within the detector chamber.



Detector axis at right angle to source

# Radiological Calibration – Exposure Rate

## Scatter

- During calibration, we must know the actual exposure rate that the instrument is responding to.
- The following equation, used during calibration to calculate the actual exposure rate at a specific distance from the source, calculates the exposure rate from the direct beam.

$$\dot{X} = \frac{A \Gamma}{d^2}$$

# Radiological Calibration – Exposure Rate

## Scatter

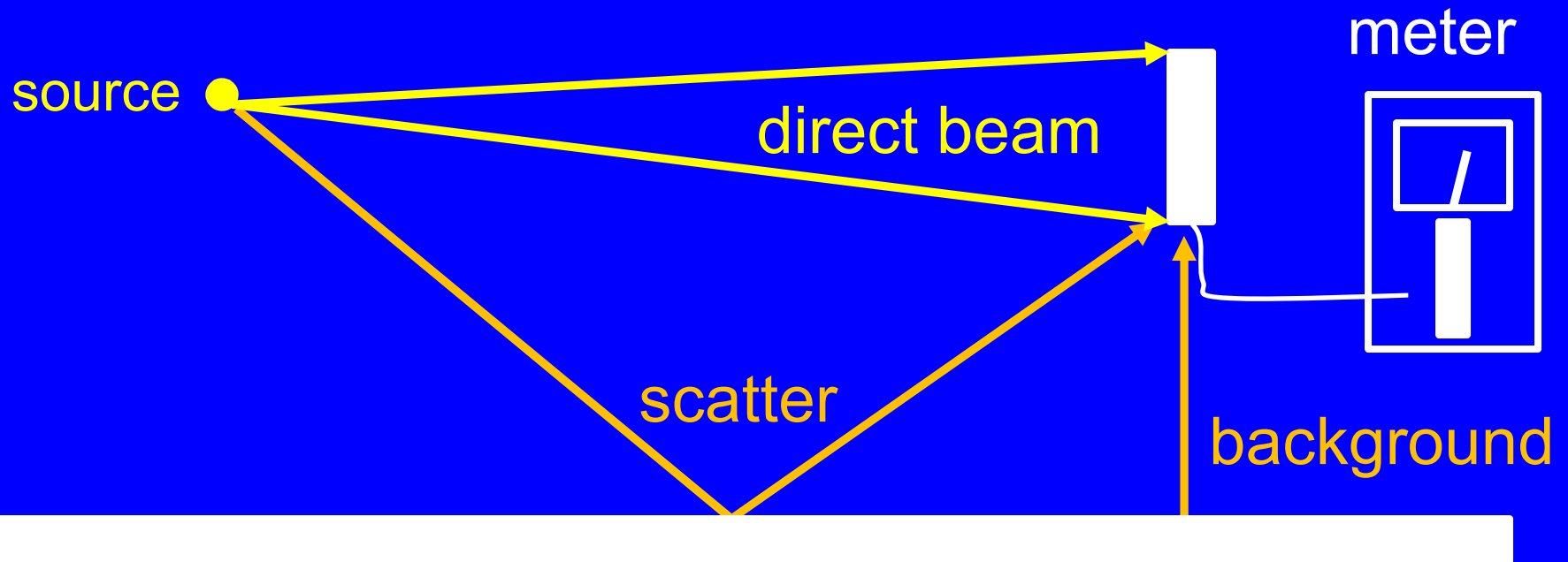
- However, the actual exposure rate that the instrument responds to is due to:
  - the direct beam from the source
  - background
  - scatter
- The contribution from the direct beam can be calculated.
- The contribution from background can be measured in the absence of the source.
- Determining the contribution from scattered radiation is a problem.

# Radiological Calibration – Exposure Rate

## Scatter

$$\dot{X} = \frac{A \Gamma}{d^2}$$

Exposure rate due to direct beam only





# Radiological Calibration – Exposure Rate

## Scatter

How the problem of scatter might be handled:

1. Scatter is sometimes ignored. This leads to an error in the calibration so that a perfectly accurate instrument would appear to over-respond.
2. The calibration is performed in a scatter free facility.
3. A shadow shield is employed to account for scatter and background.

# Radiological Calibration – Exposure Rate

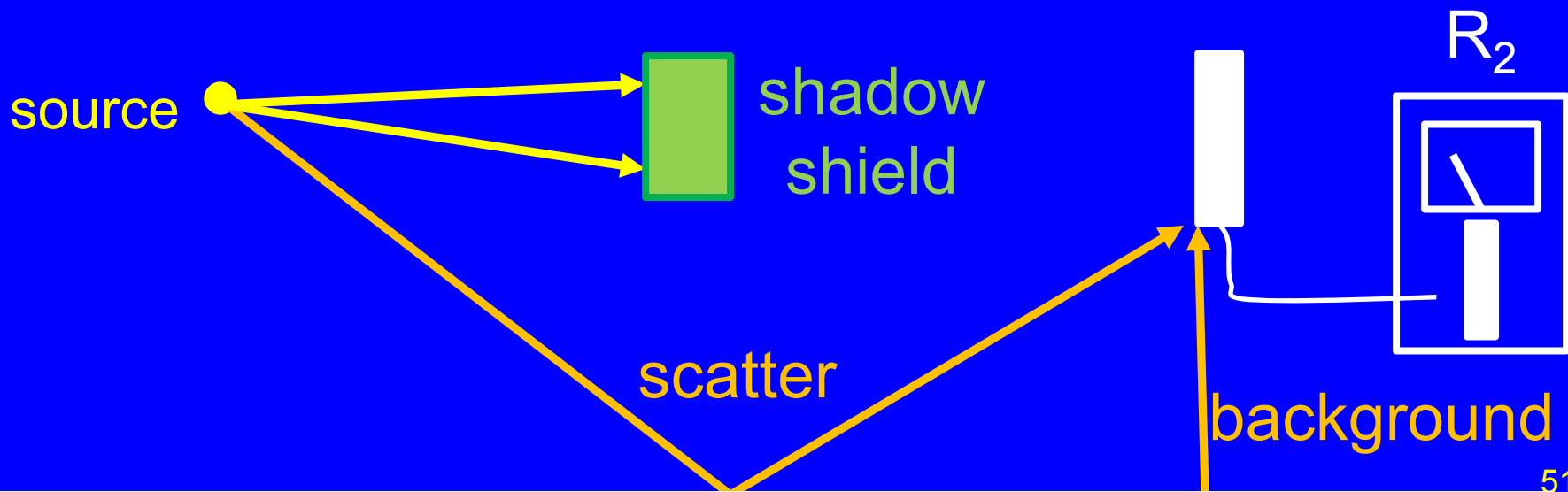
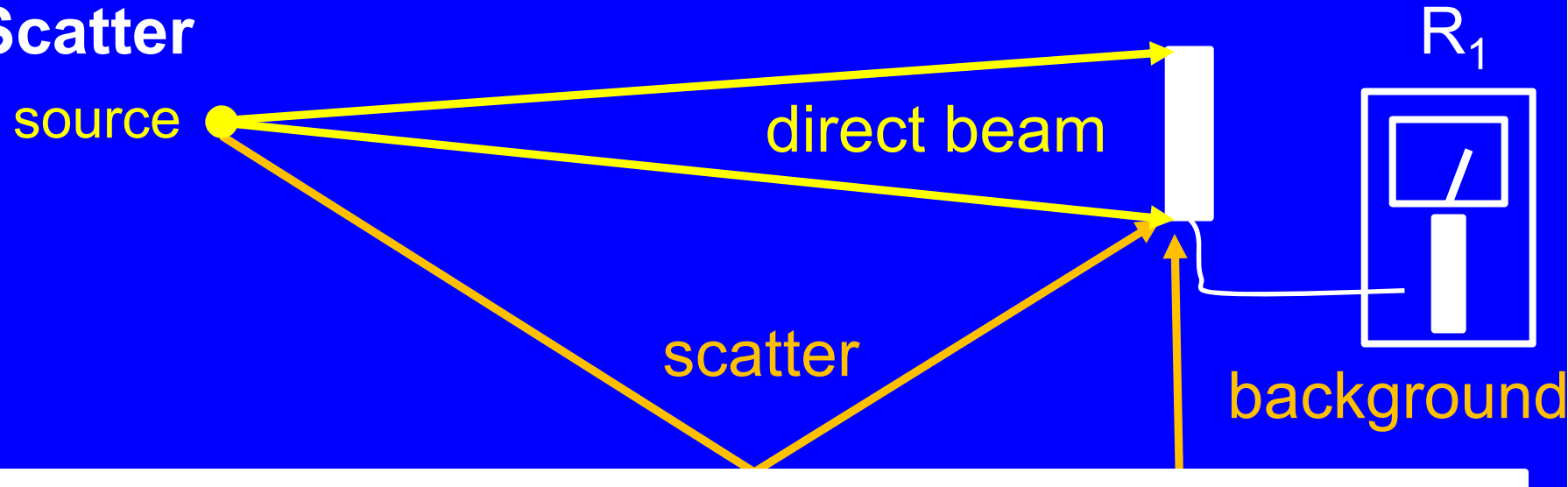
## Scatter

Use of a shadow shield:

- The instrument response ( $R_1$ ) to the direct beam, background and scatter is recorded.
- A lead shadow shield is placed between the source and detector (e.g., midway). It must not be so close to the source or detector that it blocks scatter, and it must be thick enough to completely stop the direct beam.
- The instrument response ( $R_2$ ) to background and scatter is recorded.
- The difference between the two readings ( $R_1 - R_2$ ) represents the instrument response to the direct beam only.

# Radiological Calibration – Exposure Rate

## Scatter



# Radiological Calibration – Determining the Counting Efficiency for Activity Measurements

# Radiological Calibration – Counting Efficiency

## General

Count Rate  $\leftrightarrow$  Activity

- This involves determining the relationship between an instrument's count rate and activity.
- In other words, we determine the detector efficiency for a particular source.
- In this discussion we only consider the measurement of alpha and beta activity. The activity is usually expressed in dpm or Bq.
- Instruments that might be calibrated this way include pancake GMs, proportional counters, beta scintillators, ZnS scintillators.

# Radiological Calibration – Counting Efficiency

## General

- The detector is placed above a plated standard source of known activity and the gross count rate ( $R_g$ ) is recorded.
- The ambient background count rate ( $R_b$ ) is subtracted to calculate the net count rate.
- The detector efficiency is calculated:

$$E = \frac{R_g - R_b}{A} = \frac{R_n}{A}$$

$E$  is the detector efficiency (e.g., cpm/dpm, cps/Bq)

$R_n$  is the net count rate (e.g., cpm, cps)

$A$  is the standard source activity (e.g., dpm, Bq)

# Radiological Calibration – Counting Efficiency

## Two Types of Activity

- There are two types of activities:
  - $2\pi$  activity (aka. the surface emission rate)
  - $4\pi$  activity (aka. the total activity)
- Since either activity can be used to calculate the detector efficiency, there are two types of detector efficiency:

$$E_{2\pi} = \frac{R_n}{A_{2\pi}}$$

$2\pi$  efficiency

$$E_{4\pi} = \frac{R_n}{A_{4\pi}}$$

$4\pi$  efficiency

# Radiological Calibration – Counting Efficiency

## $2\pi$ Activity (surface emission rate)

- This refers to the number of alpha or beta particles leaving the surface of the source per unit time.
- The  $2\pi$  activity of the standard source is usually the only activity that is NIST traceable. In most cases, the  $4\pi$  activity is not truly NIST traceable since it is calculated.
- The manufacturer typically measures the  $2\pi$  activity with a windowless gas flow proportional counter. With this instrument, any charged particle that leaves the surface produces a count.
- The manufacturer often specifies the  $2\pi$  activity as cps or cpm rather than Bq or dpm.



# Radiological Calibration – Counting Efficiency

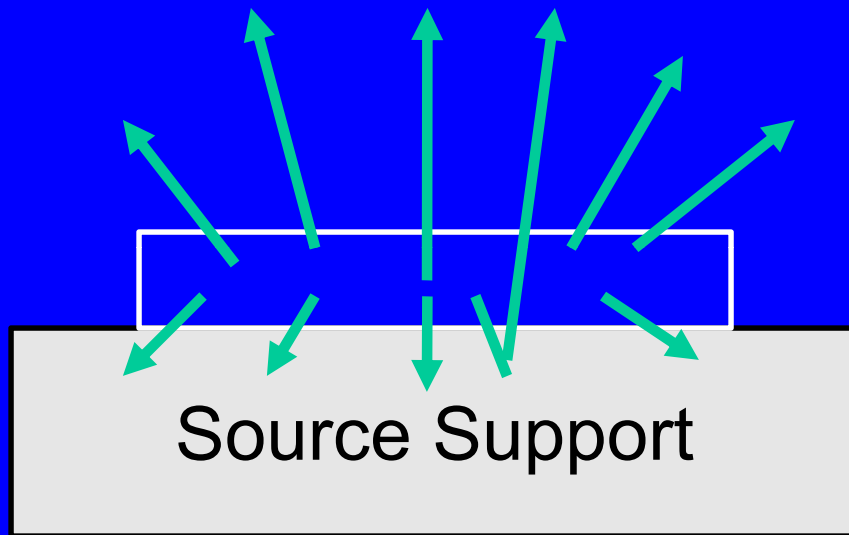
## $4\pi$ Activity (total activity)

- This refers to the number of decays per unit time. In most cases this is the same as the number of alpha or beta particles emitted by the source per unit time.
- To calculate the reported  $4\pi$  activity, the manufacturer usually multiplies the measured  $2\pi$  activity by a factor that accounts for backscatter in the source.
- For alpha sources which experience very little backscatter, the  $2\pi$  activity might be multiplied by a number like 1.97 to calculate the  $4\pi$  activity.
- For beta sources which experience considerable backscatter, the  $2\pi$  activity might be multiplied by a number similar to 1.60

# Radiological Calibration – Counting Efficiency

## $2\pi$ and $4\pi$ Activity

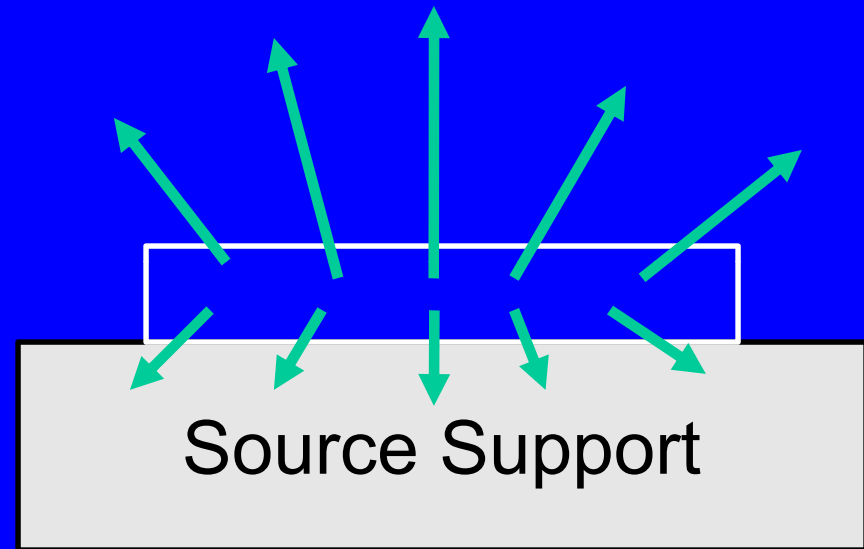
### Beta Source



$2\pi$  Activity = 6 cpm

$4\pi$  Activity = 10 dpm

### Alpha Source



$2\pi$  Activity = 5 cpm

$4\pi$  Activity = 10 dpm

# Radiological Calibration – Counting Efficiency

## Standard Sources

- The standard source consists of a very thin deposit of an alpha or beta emitter on a smooth supporting surface.
- The radioactive material might, or might not, have some type of thin protective covering.
- The radioactive deposit is usually circular and smaller than the detector area. In some cases, “extended” sources whose areas are larger than the detector are used.
- The radioactive material should be a pure alpha or beta emitter (i.e., no gammas).
- Preferably, the source is a long-lived radionuclide so that decay corrections are unnecessary.

# Radiological Calibration – Counting Efficiency

## Standard Sources

- The source support is typically a smooth metal surface (e.g., stainless steel, nickel).
- Some supports are flexible in order to mimic curved surfaces such as pipes.

# Radiological Calibration – Counting Efficiency

## Factors Affecting Efficiency - Distance

- Because it has a significant affect on detector efficiency, the source to detector distance during calibration should be identical to that employed when measurements of activity are performed.
- At facilities where there is a potential for removable contamination, the standard counting distance might be 0.5 or 1.0 cm above the surface.
- At facilities where there is little to no removable activity, the measurements and calibration might be performed “on contact.”

# Radiological Calibration – Counting Efficiency

## Factors Affecting Efficiency - Energy

### Alpha Emitters:

- The counting efficiency for alpha emitters is generally assumed to be independent of the alpha particle energy. This assumption might not be true, but given the uncertainties associated with measuring alpha activity (e.g., self-absorption), it is a reasonable approach.

### Beta Emitters:

- The counting efficiency for beta particles is definitely affected by the beta particle energy. The higher the beta energy, the higher the counting efficiency.
- How this is dealt with is situation dependent.

# Radiological Calibration – Counting Efficiency

## Factors Affecting Efficiency - Energy

Beta Emitters cont:

- Ideally, the energy of the betas emitted by the standard is the same as the energy of the betas that will be measured.
- If that is not possible, it is better to calibrate with lower energy beta particles than will be measured. Then, when measurements of activity are performed, the efficiency will be low (i.e., conservative).
- If the gross activity of multiple nuclides will be measured, and an acceptable ratio between these nuclides can be established, a weighted efficiency might be used.

# Radiological Calibration – Counting Efficiency

## Factors Affecting Efficiency - Energy

$$\textit{Weighted Efficiency} = f_1 E_1 + f_2 E_2 + \dots f_n E_n$$

$f_1$  is the fraction of the total activity expected to be contributed by radionuclide 1

$E_1$  is the detector efficiency for radionuclide 1

$f_2$  is the fraction of the total activity expected to be contributed by radionuclide 2

$E_2$  is the detector efficiency for radionuclide 2



# Radiological Calibration – Counting Efficiency

## Example Calibration

Source Number	$2\pi$ Activity (cpm)	$4\pi$ Activity (dpm)	Meter Scale	Net Count Rate (cpm)	$2\pi$ Efficiency (c/d)	$4\pi$ Efficiency (c/d)
8410	155	258	x 1	52.5	0.34	0.20
8411	2,210	3,540	x 10	672	0.30	0.19
8412	22,730	36,370	x 100	7,075	0.31	0.19
				Average Efficiency	0.32	0.19

Detector type: Pancake GM

Probe window physical area: 20 cm<sup>2</sup>

Source: Tc-99 beta source (294 keV max). Circular disk 0.75” in diameter, nickel source support

# Measuring Alpha and Beta Activity

# Measuring Alpha and Beta Activity

## General

- Once the detector efficiency has been determined during the calibration, it becomes possible to measure the activity of radioactive material.
- Either of the following might be measured:
  - Activity under the detector (e.g., dpm, Bq)
  - Activity per unit area (e.g., dpm/100 cm<sup>2</sup>, Bq/cm<sup>2</sup>)
- Activity per unit area (concentration) is usually more important because contamination limits specified in the regulations or facility license are typically in dpm/100 cm<sup>2</sup>.

# Measuring Alpha and Beta Activity

## Activity Measurements

- The detector is positioned on the source (e.g., bench top) and the gross count rate is recorded.
- An appropriate background count rate (see App. C) is subtracted to calculate the net count rate.
- The source activity under the detector is calculated:

$$A = \frac{R_n}{E}$$

A is the measured source activity (e.g., dpm, Bq)

$R_n$  is the net count rate (e.g., cpm, cps)

E is the detector efficiency (e.g., cpm/dpm, cps/Bq)

# Measuring Alpha and Beta Activity

## Activity Measurements

- If we use a  $4\pi$  efficiency in the equation, we calculate the  $4\pi$  activity:

$$A_{4\pi} = \frac{R_n}{E_{4\pi}} \leftarrow \text{generally what we want}$$

- If we use a  $2\pi$  efficiency in the equation, we calculate the  $2\pi$  activity:

$$A_{2\pi} = \frac{R_n}{E_{2\pi}} \leftarrow \text{rarely of interest}$$

# Measuring Alpha and Beta Activity

## Activity per Unit Area Measurements

- The concentration of the radioactive material (activity per unit area) is of more importance than the activity under the detector. It is calculated as follows:

$$C = \frac{R_n}{E_{4\pi} \frac{A_p}{100}}$$

$C$  is the measured  $4\pi$  concentration (e.g., dpm/100 cm<sup>2</sup>)

$R_n$  is the net count rate (e.g., cpm)

$E_{4\pi}$  is the detector  $4\pi$  efficiency (e.g., cpm/dpm)

$A_p$  is the detector probe area (e.g., cm<sup>2</sup>)

# Measuring Alpha and Beta Activity

## Activity per Unit Area Measurements

- While the probe area ( $A_p$ ) used in the calculation should be the area of the surface that the detector responds to, in practice we use the physical area of the probe window. The probe's "effective area" should not be used.
- There are two other approaches that are used to calculate the activity per unit area:
  - use of an extended source during calibration (see App. A)
  - use of ISO-7503-1 methodology (see App. B)

# Measuring Alpha and Beta Activity

## Example Calculation of Activity

A pancake GM is used to measure a spot of Tc-99 beta (294 keV maximum energy) contamination on a Formica bench top.

Calculate the total  $4\pi$  activity in dpm.

Gross count rate: 75 cpm

Detector background for Formica (and linoleum): 40 cpm

$2\pi$  counting efficiency: 32 % (0.32 c/beta)

$4\pi$  counting efficiency: 19 % (0.19 c/d)

$$A_{4\pi} = \frac{R_n}{E_{4\pi}} = \frac{75 - 40}{0.19} = 184 \text{ dpm}$$



# Measuring Alpha and Beta Activity

## Example Calculation of Concentration

Assume that the area of the contamination extends over an area larger than the detector and calculate the concentration in dpm/100 cm<sup>2</sup>.

$$\begin{aligned} C &= \frac{R_n}{E_{4\pi} \left( \frac{A_p}{100} \right)} \\ &= \frac{75 - 40}{0.19 \left( \frac{20}{100} \right)} \\ &= 921 \text{ dpm} / 100 \text{ cm}^2 \end{aligned}$$

# Regulations Pertaining to Survey Instrument Calibration

# Regulations

## **NRC: Part 20--Standards for Protection Against Radiation**

Subpart F--Surveys and Monitoring Sec. 20.1501 General.

“(a) Each licensee shall make or cause to be made, surveys that—

(1) May be necessary for the licensee to comply with the regulations in this part; and

(2) Are reasonable under the circumstances to evaluate-- (i) The magnitude and extent of radiation levels; and (ii) Concentrations or quantities of radioactive material; and (iii) The potential radiological hazards.

(b) The licensee shall ensure that instruments and equipment used for quantitative radiation measurements (e.g., dose rate and effluent monitoring) are calibrated periodically for the radiation measured.”

# Regulations

## NRC: Part 34 - Industrial Radiography

### Subpart C: 34.25 Radiation survey instruments

(a) The licensee shall keep sufficient calibrated and operable radiation survey instruments at each location where radioactive material is present to make the radiation surveys required by this part and by 10 CFR part 20 of this chapter. Instrumentation required by this section must be capable of measuring a range from 0.02 millisieverts (2 millirems) per hour through 0.01 sievert (1 rem) per hour.

# Regulations

## NRC: Part 34 - Industrial Radiography

### Subpart C: 34.25 Radiation survey instruments

(b) The licensee shall have each radiation survey instrument required under paragraph (a) of this section calibrated—

- (1) At intervals not to exceed 6 months and after instrument servicing, except for battery changes;
- (2) For linear scale instruments, at two points located approximately one third and two-thirds of full-scale on each scale; for logarithmic scale instruments, at mid-range of each decade, and at two points of at least one decade; and for digital instruments, at 3 points between 0.02 and 10 millisieverts (2 and 1000 millirems) per hour; and

# Regulations

## NRC: Part 34 - Industrial Radiography

### Subpart C: 34.25 Radiation survey instruments

(3) So that an accuracy within plus or minus 20 percent of the calibration source can be demonstrated at each point checked.

(c) The licensee shall maintain records of the results of the instrument calibrations in accordance with § 34.65..”

# Regulations

## NRC: Part 35 - Medical

### Subpart C: 35.61 Calibration of Survey Instruments

(a) A licensee shall calibrate the survey instruments used to show compliance with this part and 10 CFR Part 20 before first use, annually, and following a repair that affects the calibration. A licensee shall—

- (1) Calibrate all scales with readings up to 10 mSv (1000 mrem) per hour with a radiation source;
- (2) Calibrate two separated readings on each scale or decade that will be used to show compliance; and
- (3) Conspicuously note on the instrument the date of calibration.

# Regulations

## **NRC: Part 35 - Medical**

### Subpart C: 35.61 Calibration of survey instruments

(b) A licensee may not use survey instruments if the difference between the indicated exposure rate and the calculated exposure rate is more than 20 percent.

(c) A licensee shall retain a record of each survey instrument calibration in accordance with § 35.2061.



# Regulations

## NRC: Part 36 - Irradiators

### Subpart D: 36.57 Radiation Surveys

(c) Portable radiation survey meters must be calibrated at least annually to an accuracy of  $\pm 20$  percent for the gamma energy of the sources in use. The calibration must be done at two points on each scale or, for digital instruments, at one point per decade over the range that will be used. Portable radiation survey meters must be of a type that does not saturate and read zero at high radiation dose rates.

# Regulations

## NRC: Part 39 – Well Logging

### Subpart C: 39.33 Radiation detection Instruments

(c) The licensee shall have each radiation survey instrument required under paragraph (a) of this section calibrated—

- (1) At intervals not to exceed 6 months and after instrument servicing;
- (2) For linear scale instruments, at two points located approximately  $1/3$  and  $2/3$  of full-scale on each scale; for logarithmic scale instruments, at midrange of each decade, and at two points of at least one decade; and for digital instruments, at appropriate points; and
- (3) So that an accuracy within plus or minus 20 percent of the calibration standard can be demonstrated on each scale.

# Regulations

## NRC: Part 39 – Well Logging

### Subpart C: 39.33 Radiation detection Instruments

(d) The licensee shall retain calibration records for a period of 3 years after the date of calibration for inspection by the Commission.

# Regulations

## DOE: Part 835 – Occupational Radiation Protection

### Subpart E: 835.401 General Requirements

- (b) Instruments and equipment used for monitoring shall be:
- (1) Periodically maintained and calibrated on an established frequency;
  - (2) Appropriate for the type(s), levels, and energies of the radiation(s) encountered;
  - (3) Appropriate for existing environmental conditions; and
  - (4) Routinely tested for operability.

# Calibration Frequency

# Calibration Frequency

## NRC 10 CFR

10 CFR 20.1501. General Requirements. “periodically for the radiation measured.”

10 CFR 34.25 . Industrial radiography. “At intervals not to exceed 6 months and after instrument servicing, except for battery changes”

10 CFR 35.61. Medical. “before first use, annually, and following a repair that affects the calibration.”

10 CFR 36.57. Irradiators. “at least annually”

10 CFR 39.33. Well Logging. “At intervals not to exceed 6 months and after instrument servicing”

# Calibration Frequency

***Regulatory Guide 8.21 Health Physics Surveys for Byproduct Material at NRC-Licensed Processing and Manufacturing Plants (1979) and Regulatory Guide 8.24 Health Physics Surveys During Enriched Uranium-235 Processing and Fuel Fabrication (1979)***

“Portable survey instruments should be placed on a routine maintenance and calibration program that will ensure that properly calibrated and operable survey instruments are available at all times for use by the health physics staff.”

# Calibration Frequency

## **Regulatory Guide 8.23 *Radiation Safety Surveys at Medical Institutions* (1981)**

“at least every 12 months . . . after repair or maintenance that may affect the calibration of the instrument.”

## **Regulatory Guide 8.30. *Health Physics Surveys in Uranium Recovery Facilities* (2002)**

“calibrations at 12-month intervals or at the manufacturer’s suggested interval, whichever is shorter”



# Calibration Frequency

**NUREG-1556, Vol. 9. *Consolidated Guidance About Materials Licenses: Program-Specific Guidance About Medical Use Licenses.***

“Survey meters must be calibrated at least annually, before first use, and after servicing. (Battery changes are not considered "servicing.")”

## **DOE 10 CFR**

10 CFR 835.401. General Requirements.

“Periodically maintained and calibrated on an established frequency”

# Calibration Frequency

## RADIATION PROTECTION PROGRAMS GUIDE

*for Use with* Title 10, Code of Federal Regulations, Part 835, Occupational Radiation Protection. DOE G 441.1-1C

“ANSI N323A establishes an annual calibration frequency for portable monitoring instruments. The calibration frequency should be determined and the calibration should be performed according to the details presented in the above referenced consensus standards. If routine checks (e.g., routine operability tests and as-found tests) indicate that the response of an instrument (or type of instrument) remains stable over a long period of time, then the calibration frequency may be extended. Conversely, if routine checks indicate that an instrument (or type of instrument) fails to provide a stable response over the prescribed calibration interval, then the calibration interval should be shortened.”

# Calibration Frequency

## ANSI N323 (1997)

Each instrument shall be calibrated at least annually. More frequent calibration is recommended if the instrument is used in extreme environmental conditions, or is subject to particularly heavy usage (e.g., industrial radiography or well logging).

The calibration frequency should also be increased if greater than 10% of “as-found” readings indicate out-of-calibration instruments.

Calibration is also required by the standard after any maintenance or adjustment is performed that might affect the instrument response. This would not normally include a battery change out (see ANSI N323-1978).

# Calibration Points and Accuracy

## NRC Requirements

# Calibration Points and Accuracy - NRC Requirements

## NRC: Part 34 - Industrial Radiography

### Subpart C: 34.25 Radiation survey instruments

- (2) For linear scale instruments, at two points located approximately one third and two-thirds of full-scale on each scale; for logarithmic scale instruments, at mid-range of each decade, and at two points of at least one decade; and for digital instruments, at 3 points between 0.02 and 10 millisieverts (2 and 1000 millirems) per hour; and
- (3) So that an accuracy within plus or minus 20 percent of the calibration source can be demonstrated at each point checked.

# Calibration Points and Accuracy - NRC Requirements

## NRC: Part 35 - Medical

### Subpart C: 35.61 Calibration of Survey Instruments

- (1) Calibrate all scales with readings up to 10 mSv (1000 mrem) per hour with a radiation source;
  - (2) Calibrate two separated readings on each scale or decade that will be used to show compliance; and
  - (3) Conspicuously note on the instrument the date of calibration.
- (b) A licensee may not use survey instruments if the difference between the indicated exposure rate and the calculated exposure rate is more than 20 percent.

# Calibration Points and Accuracy - NRC Requirements

## NRC: Part 36 - Irradiators

### Subpart D: 36.57 Radiation Surveys

(c) Portable radiation survey meters must be calibrated at least annually to an accuracy of  $\pm 20$  percent for the gamma energy of the sources in use. The calibration must be done at two points on each scale or, for digital instruments, at one point per decade over the range that will be used.

# Calibration Points and Accuracy - NRC Requirements

## NRC: Part 39 – Well Logging

### Subpart C: 39.33 Radiation detection Instruments

- (2) For linear scale instruments, at two points located approximately  $1/3$  and  $2/3$  of full-scale on each scale; for logarithmic scale instruments, at midrange of each decade, and at two points of at least one decade; and for digital instruments, at appropriate points; and
- (3) So that an accuracy within plus or minus 20 percent of the calibration standard can be demonstrated on each scale.



# Calibration Points and Accuracy - NRC Requirements

## Regulatory Guide 8.30. *Health Physics Surveys in Uranium Recovery Facilities.*

“Each instrument should be calibrated at two points at about one-third and two-thirds of each linear scale routinely used or with a calibration at one point near the midpoint of each decade on logarithmic scales that are routinely used. Digital readout instruments with either manual or automatic scale switching should be calibrated in the same manner as are meter-dial instruments. Digital readout instruments without scale switching should be calibrated in the same manner as are logarithmic readout instruments.

. . . A survey instrument may be considered properly calibrated when the instrument readings are within  $\pm 20\%$  of the calculated or known values for each point checked”

# Calibration Points and Accuracy - NRC Requirements

**NUREG-SR1556, Vol. 2. *Consolidated Guidance About Materials Licenses: Program-Specific Guidance About Industrial Radiography Licenses***

“A single point on a survey meter scale can be considered satisfactorily calibrated if the indicated exposure rate differs from the calculated exposure rate by less than 10%.”

“Linear Scale: Meters on which the user selects a linear scale must be calibrated at no less than two points on each scale. . . at approximately 1/3 and 2/3 of the decade.”

“Multidecade Logarithmic Scale: a multidecade logarithmic scale must be calibrated at no less than one point on each decade and no less than two points on one of the decades . . . approximately 1/3 and 2/3 of the decade.”

# Calibration Points and Accuracy - NRC Requirements

## *NUREG-SR1556, Vol. 2 Consolidated Guidance About Materials Licenses: Program-Specific Guidance About Industrial Radiography Licenses*

“Automatically Ranging Digital Display: Meters . . . indicating rates must be calibrated at no less than one point on each decade and at no less than two points on one of the decades. . . at approximately 1/3 and 2/3 of the decade.”

“Scales in excess of 10 mSv/hr (1,000 mrem/hr) need not be calibrated. However, such scales should be checked for operation and approximately correct response.”

# Calibration Points and Accuracy - NRC Requirements

***NUREG-SR1556, Vol. 7 Consolidated Guidance About Materials Licenses: Program-Specific Guidance About Academic, Research and Development, and Other Licenses of Limited Scope***

“Linear readout instruments with a single calibration control for all scales shall be adjusted at the point recommended by the manufacturer or at a point within the normal range of use. Instruments with calibration controls for each scale shall be adjusted on each scale. After adjustment, the response of the instrument shall be checked at approximately 20% and 80% of full scale. The instrument's readings shall be within +/- 15% of the conventionally true values for the lower point and +/- 10% for the upper point.” This follows the recommendations of ANSI N323A-1997.

# Calibration Points and Accuracy - NRC Requirements

**NUREG-SR1556, Vol. 7 *Consolidated Guidance About Materials Licenses: Program-Specific Guidance About Academic, Research and Development, and Other Licenses of Limited Scope***

“Logarithmic readout instruments, which commonly have a single readout scale spanning several decades, normally have two or more adjustments. The instrument shall be adjusted for each scale according to site specifications or the manufacturer's specifications. After adjustment, calibration shall be checked at a minimum of one point on each decade. Instrument readings shall have a maximum deviation from the conventionally true value of no more than 10% of the full decade value.”

# Calibration Points and Accuracy - NRC Requirements

*NUREG-SR1556, Vol. 7 Consolidated Guidance About Materials Licenses: Program-Specific Guidance About Academic, Research and Development, and Other Licenses of Limited Scope*

“Meters with a digital display device shall be calibrated the same as meters with a linear scale.”

“Readings above  $2.58 \times 10^{-4}$  coulomb/kilogram/hour (1 R/hr) need not be calibrated, but such scales should be checked for operation and response to radiation.”

# Calibration Points and Accuracy - NRC Requirements

*NUREG-SR1556, Vol. 7 Consolidated Guidance About Materials Licenses: Program-Specific Guidance About Academic, Research and Development, and Other Licenses of Limited Scope*

“Surface Contamination Measurement Instruments

If each scale has a calibration potentiometer, the reading shall be adjusted to read the conventionally true value at approximately 80% of full scale, and the reading at approximately 20% of full scale shall be observed. If only one calibration potentiometer is available, the reading shall be adjusted at mid-scale on one of the scales, and readings on the other scales shall be observed. Readings shall be within 20% of the conventionally true value.”

# Calibration Points and Accuracy

## - NRC Requirements

### *NUREG-SR1556, Vol. 9 Consolidated Guidance About Materials Licenses: Program-Specific Guidance About Medical Use Licenses*

“Instrument readings should be within  $\pm 10\%$  of known radiation values at calibration points; however, readings within  $\pm 20\%$  are acceptable if a calibration chart or graph is prepared and made available with the instrument.”

“Calibrate Linear-Readout Instruments at no fewer than two points on each scale. . . (at approximately 20% and 80%)”

“Calibrate Logarithmic-Readout Instruments at two points on each decade.”

“Readings above 1000 mR/hr . . . need not be calibrated; however, such scales may be checked for operation and approximately correct response.”



# Calibration Points and Accuracy - NRC Requirements

**NUREG-SR1556, Vol. 9 *Consolidated Guidance About Materials Licenses: Program-Specific Guidance About Medical Use Licenses***

“Calibrate Digital-Readout Instruments with either manual or automatic scale switching for indicating exposure rates at no fewer than two points on each scale. Check calibrations near the ends of each scale (at approximately 20% and 80% of each scale).”

“Calibrate Digital-Readout Instruments without scale switching for indicating exposure rates at two points on each decade.”

“Calibrate Integrating instruments at two dose rates (at approximately 20% and 80% of the dose rate range).”

# Calibration Points and Accuracy

## ANSI N323 Requirements

# Calibration Points and Accuracy – ANSI N323 Requirements

## General

DOE Implementation Guide DOE G 441.1-7 (1999) *Portable Monitoring Instrument Calibration Guide* states that the calibration should be performed according the details presented in ANSI N323A-1997.

The ANSI standard considers two categories of instruments:

1. Instruments for Measuring Exposure Rate, Dose Rate, or Dose Equivalent Rate
2. Instruments for Measuring Surface Contamination

# Calibration Points and Accuracy – ANSI N323 Requirements

## 1. Instruments for Measuring Exposure Rate, Dose Rate, or Dose Equivalent Rate

e.g., ion chamber, uR meter, urem meter, side window GM

### 4.2.1.1 Linear readout instruments

“Linear readout instruments with a single calibration control for all scales shall be adjusted either at the point recommended by the manufacturer or at a point within the normal range of use. Instruments with calibration controls for each scale shall be adjusted on each scale.”

“After adjustment, the response of the instrument shall be checked near the end points of each scale (approximately 20% and 80% of full scale).”

# Calibration Points and Accuracy – ANSI N323 Requirements

## 1. Instruments for Measuring Exposure Rate, Dose Rate, or Dose Equivalent Rate

### 4.2.1.1 Linear readout instruments

“Note - For microprocessor-based instruments that have been proven linear through type testing and/or acceptance testing, only one point on each scale or decade is required.”

“Instrument readings shall be within  $\pm 15\%$  of conventionally true values (CTV) for the lower point and  $\pm 10\%$  of CTV for the upper point. Readings within  $\pm 20\%$  shall be acceptable if a calibration chart or graph is prepared and provided with the instrument.”

# Calibration Points and Accuracy – ANSI N323 Requirements

## 1. Instruments for Measuring Exposure Rate, Dose Rate, or Dose Equivalent Rate

### 4.2.1.2 Logarithmic readout instruments

“Logarithmic readout instruments, which commonly have a single readout scale spanning several decades, normally have two or more adjustments. The instrument shall be adjusted for each scale according to the site specifications or the manufacturer’s specifications. Alternatively, it shall be permissible to calibrate at points of particular importance to the user if the reasons for the change and impact on accuracy are documented and justified.”

# Calibration Points and Accuracy – ANSI N323 Requirements

## 1. Instruments for Measuring Exposure Rate, Dose Rate, or Dose Equivalent Rate

### 4.2.1.2 Logarithmic readout instruments

“After adjustment, calibration shall be checked at a minimum of one point on each decade. Instrument readings shall have a maximum deviation from the CTV of no more than 10% of the full decade value. If the display is not marked at intervals corresponding to  $\pm 10\%$  of the point (i.e., a calibration at a mark frequently does not have graduations to  $\pm 10\%$  in the next decade), it is permissible to use the spacing on the low side of the calibration point to estimate the calibration limit on the high side of the calibration point.”

# Calibration Points and Accuracy – ANSI N323 Requirements

## 1. Instruments for Measuring Exposure Rate, Dose Rate, or Dose Equivalent Rate

### 4.2.1.3 Digital readout instruments

“Digital instruments shall be calibrated as in 4.2.1.1”

“Note - For microprocessor-based instruments that have been proven linear through type testing and/or acceptance testing, only one point on each scale or decade is required.”

“If the instrument is designed to auto scale, the calibration point should be selected far enough from the autoscaling point that auto scaling will not affect the reading. Instruments should be cycled through a complete test of all display segments or indicators, either electronically or radiologically.” 112



# Calibration Points and Accuracy – ANSI N323 Requirements

## 1. Instruments for Measuring Exposure Rate, Dose Rate, or Dose Equivalent Rate

### 4.2.1.4 Integrating instruments

“Instruments that integrate dose shall be checked at a minimum of two dose rates at approximately 20% and 80% of the stated dose rate range or as recommended by the manufacturer.”

“NOTE - If the full instrument dose rate range is not intended for use, then the range acceptable for use shall be noted on the instrument.”

# Calibration Points and Accuracy – ANSI N323 Requirements

## 1. Instruments for Measuring Exposure Rate, Dose Rate, or Dose Equivalent Rate

### 4.2.1.4 Integrating instruments

“The integrations shall continue to a value sufficient to ensure a statistically valid reading that shall be within 15% of the CTV. For digital instrumentation, integration should be checked to the maximum reading obtainable on the display. If it is not practical to accomplish the full-scale radiological integration, the electronics and display may be checked electronically at the maximum integration point, with the radiological integration being performed at a lower point that is achievable.”

# Calibration Points and Accuracy – ANSI N323 Requirements

## 1. Instruments for Measuring Exposure Rate, Dose Rate, or Dose Equivalent Rate

### 4.2.1.5 Neutron dose equivalent instruments

Corrections to mistakes in the standard are noted in brackets.

“shall be calibrated as in 4.2.1.1 through 4.2.1.4; except that the calibration accuracy for ranges from 0-100 Sv/h [this should read 0-100 microSv/hr] or 0-100 Sv [this should read 0-100 microSv] (0-10 mrem/h or 0-10 mrem) shall be  $\pm 30\%$  and the calibration accuracy for ranges from 100 Sv/h [this should read 100 microSv/hr] or 100 Sv [this should read 100 microSv] (10 mrem/h or 10 mrem) and above shall be  $\pm 20\%$ .”

# Calibration Points and Accuracy – ANSI N323 Requirements

## 2. Instruments for Measuring Surface Contamination

### 4.2.2 Surface contamination measurement instruments

“Where the instrument is calibrated as an integral unit, a minimum of one point on each scale shall be calibrated up to  $10^3$  Bq/100 cm<sup>2</sup> ( $\sim 6 \times 10^4$  dpm/100 cm<sup>2</sup>). If each scale has a calibration potentiometer, the reading shall be adjusted to read the CTV at approximately 80% of full scale, and the reading at approximately 20% of full scale shall be observed. If only one calibration potentiometer is available, the reading shall be adjusted at mid-scale on one of the scales, and readings on the other scales shall be observed. Readings shall be within 20% of the CTV.”

# Calibration Points and Accuracy – ANSI N323 Requirements

## 2. Instruments for Measuring Surface Contamination

### 4.2.2.1 Beta-gamma contamination measurement instruments

“Counting efficiencies should be determined for the type of activity expected to be measured. Where mixed or unknown contamination is to be measured, a number of different radionuclides with different energies, including low energy photons, should be utilized.. The distance from the source to the face of the detector shall be included with the recorded counting efficiencies.”

# Calibration Points and Accuracy – ANSI N323 Requirements

## 2. Instruments for Measuring Surface Contamination

### 4.2.2.1 Beta-gamma contamination measurement instruments

“Where GM tubes are used as detectors, the unit shall be tested to ensure that saturation does not occur unless the maximum indicated value of the instrument is exceeded by at least a factor of two. The instrument shall continue to indicate a full-scale reading until the radiation field is reduced to less than the maximum display value. Digital readouts shall convey that the radiation level present exceeds the upper measurement level of the instrument in a manner described by the instrument manufacturer.”

# Calibration Points and Accuracy – ANSI N323 Requirements

## 2. Instruments for Measuring Surface Contamination

### 4.2.2.2 Alpha contamination measurement instruments

“All scintillation and air or gas proportional detectors shall be checked for light leaks or holes in the window material before calibration is initiated. A maximum acceptable background count rate shall be determined, documented, and used to test instruments prior to calibration.”

“Counting efficiencies shall be determined with the radionuclide to be detected, if possible, or with a radionuclide with similar energy.”

# **Electronic Calibrations as a Substitute for a Radiological Calibration**



# Substituting an Electronic Calibration

## General

In some cases, an electronic calibration can be performed on all the scales of an instrument (e.g., x1, x10, x100, x1000) while the primary radiological calibration can only be performed on selected scales (e.g., x1, x10, x100).

The electronic calibration ties the readings on the scales that were not calibrated in a radiation field (e.g., x1000) to the readings on the scales that were calibrated in a radiation field.

ANSI N323A-1997: “Electronic calibration shall be acceptable for some instrument ranges where calibration with a source is impractical, provided the electronic calibration is related to actual exposure data at one or more points.”

# Substituting an Electronic Calibration

## General

Regulatory Guide 8.21 *Health Physics Surveys for Byproduct Material at NRC-Licensed Processing and Manufacturing Plants (1979)*: “An adequate calibration of survey instruments cannot be performed solely with built-in check sources.

Electronic calibrations that do not involve a source of radiation also do not determine the proper functioning and response of all components of an instrument. However, an initial calibration with a radiation source and periodic tests using electronic input signals may be considered adequate for high ranges that are not used routinely.”

Regulatory Guide 8.30 *Health Physics Surveys in Uranium Recovery Facilities* and Regulatory Guide 8.24 *Health Physics Surveys During Enriched Uranium-235 Processing and Fuel Fabrication* use almost identical wording.

# Substituting an Electronic Calibration

## General

NUREG CR-6062 *Performance of Portable Radiation Survey Instruments* noted that many NRC licensees calibrated their survey instruments at a single point and relied on electronic calibrations for the other scales or decades. This, the NUREG commented, was a completely unacceptable practice.

# Substituting an Electronic Calibration

## Difficulty Calibrating on all Scales

- It is always desirable to perform a radiological calibration on each scale by exposing the detector to a radiation field of known intensity.
- However, it might be impossible or inappropriate to calibrate certain scales (usually the highest or lowest scales).

# Substituting an Electronic Calibration

## Difficulty Calibrating the Highest Scales

- Calibrating the highest scale of an ion chamber (e.g., by exposing it to over 100 R/hr) might not be consistent with keeping worker exposures ALARA.
- It might also be difficult to obtain a source of sufficient strength to calibrate the highest scale.
- Moving the detector very close to the source to increase the exposure rate might be inappropriate : according to ANSI N323A-1997: “A separation between the calibration source and the detector should exceed five times the maximum dimensions of the larger of the source or the detector.”

# Substituting an Electronic Calibration

## Difficulty Calibrating the Lowest Scales

- The lowest scales on some instruments such as NaI detectors can measure small fractions of background (e.g., 0 – 3  $\mu\text{R/hr}$ ).
- Moving the detector very far enough away from the source to produce the necessary low exposure rate can lead to problems because the scattered radiation from the source, which is hard to quantify, will become a major contributor to the radiation field (NRC Health Physics Position Statement HPPOS-279 *Technical Assistance Request Regarding Electronic Calibration of Survey Instruments*)
- It can be difficult to obtain NIST traceable sources of sufficiently low activity.

# Cable Changeouts

# Cable Changeouts

## General

- The probe, meter, and cable are sometimes calibrated as a package. Replacing a bad cable requires that the new combination of probe, meter and cable be calibrated.
- Some facilities do not require recalibration following cable changeouts if the system passes the constancy test.
- Replacement cables should be identical to the cable being replaced in terms of cable length, cable type and connector type.
- It is best, at the time of calibration, to document that the replacement cables do not affect the instrument response.



# Cable Changeouts

## General

- ANSI N323A-1997:

“It shall be permissible for the probe and count rate meters to be calibrated separately. The exchange of probes shall be permitted if the variations between combinations of units provided to a given location has been documented to be within 20% of the CTV [conventionally true value]. This shall be documented for all combinations of probe and count rate meter models and ranges. The range of acceptable count rates for a specific check source shall be documented. If the exchange of probes is permitted, the new detector shall respond within the same range of acceptable count rates as the previous probe using the same check source as used with the original probe.”

# Instrument Labeling

# Instrument Labeling

**ANSI N323A-1997.**

Each survey instrument should be labeled with the following:

- Most recent calibration date
- Initials or name of calibration personnel
- Date for next calibration
- Serial number or equipment identifier e.g., barcode
- If the instrument is for special use, or if the calibration is limited in some way (e.g., the instrument is not calibrated on the high or low scale), a special label should be employed.

# Instrument Labeling

## NUREG-SR1556, Vol. 2.

“The following information should be attached to the instrument as a calibration sticker or tag:”

- Source that was used to calibrate the instrument
- A calibration chart or graph for each scale or decade of a survey meter that is greater than  $\pm 20\%$  of the actual values identifying the average correction factor, or a note indicating that scale was checked only for function or is inoperative.
- Date of calibration
- Date survey instrument is due calibration
- Name or initials of individual calibrating instrument.

# Instrument Labeling

NUREG-SR1556, Vol. 7 and Vol. 11.

- “For exposure rate meters, the source isotope used to calibrate the instrument (with correction factors) for each scale
- The efficiency of the instrument, for each isotope the instrument will be used to measure (if efficiency is not calculated before each use)
- For each scale or decade not calibrated, an indication that the scale or decade was checked only for function but not calibrated
- The date of calibration and the next calibration due date
- The apparent exposure rate or count rate from the check source, if used”

# Functional (Operability) Test

# Functional (Operability) Test

## General

- Each day prior to use, every survey instrument should be tested to identify any changes in its response that have occurred since its last calibration. This test might also be performed in the middle and/or end of the day.
- The results of this test check should be documented along with the detector and probe serial numbers.
- Unless a failure of the QC check is known to be due to a specific incident, all the data collected since the previous check will be of questionable validity. A documented decision is then made as to whether this data will be used or discarded.

# Functional (Operability) Test

## Typical Components of a Functional Test

When applicable, the following items should be included:

- Battery condition
- High voltage setting.
- Threshold, discriminator and/or window settings.
- Zero adjustment
- The background. Whenever possible, this should be performed in the same area.
- Light leaks for scintillators with thin windows.
- Instrument response to a check source (constancy check)



# Functional (Operability) Test

## Instrument Response to Check Source (constancy)

- The check source activity does not have to be known
- The check source must emit radiation that the instrument is designed to detect.
- There should be a specific and reproducible geometry between the source and detector. A jig might be used to ensure reproducible positioning of the source and detector.
- If the check source is placed directly against the detector small variations in the source position can have big effects on the count rate. e.g., the readings of a plastic check source can differ by 10% or more depending on which of the two sides of the source is against the detector.

# Functional (Operability) Test

## Instrument Response to Check Source (constancy)

- Ideally, a response check is done on each meter scale normally used - therefore several check sources of different activities might be required.
- Backup check sources are a good idea. If a check source is lost or unavailable and there is no backup, the instrument should not be used.
- The instrument response to the check source(s) should be determined at, or immediately after, the instrument calibration.

# Functional (Operability) Test

## NRC 10 CFR 35.80 Mobile Medical Service

“(2) Check instruments used to measure the activity of unsealed byproduct material for proper function before medical use at each client’s address or on each day of use, whichever is more frequent. At a minimum, the check for proper function required by this paragraph must include a constancy check;

(3) Check survey instruments for proper operation with a dedicated check source before use at each client’s address;”

# Functional (Operability) Test

## **Regulatory Guide 8.23 *Radiation Safety Surveys at Medical Institutions (1981)***

“Daily constancy checks of survey instruments should be made before and after each use.”;

## **Regulatory Guide 8.30. *Health Physics Surveys in Uranium Recovery Facilities.***

“Survey instruments should be checked for constancy of operation with a radiation check source prior to each usage. If the instrument response to the radiation check source differs from the reference reading by more than 20%, the instrument should be repaired if necessary and recalibrated (Ref. 27, paragraph 4.6). This constancy check should be supplemented by calibrations at 12-month intervals or at the manufacturer’s suggested interval, whichever is shorter”

# Functional (Operability) Test

## RADIATION PROTECTION PROGRAMS GUIDE

*for Use with* Title 10, Code of Federal Regulations, Part 835, Occupational Radiation Protection. DOE G 441.1-1C

“Functional tests should be performed prior to initial use of an instrument in the field. Functional tests should be detailed in the instrument-use procedures and should include, as a minimum: general condition; battery condition; verification of current calibration (i.e., check to see that the date due for calibration has not passed); background readings; and other tests (high voltage, zero setting, alarm functions, etc.) as applicable to the instrument. Functional tests should also include a source response check (i.e., observing the instrument response to a check source) before initial operation.”

# Functional (Operability) Test

## RADIATION PROTECTION PROGRAMS GUIDE

*for Use with* Title 10, Code of Federal Regulations, Part 835, Occupational Radiation Protection. DOE G 441.1-1C

“During use in the field, instruments should be tested with a check source to ensure that the readings remain within prescribed limits. This should be done as prescribed in ANSI N323A. The performance of functional tests during use in the field should be appropriately documented. This may be as simple as a check-list on the survey sheet.”

# Functional (Operability) Test

## ANSI N323 (1997)

"If at any time the instrument response to the source differs from the reference reading by  $\pm 20\%$  (for any photon instrument the reading should be at least ten times background), the instrument shall be returned to the calibration facility for calibration or for maintenance, repair and recalibration as required. Reference readings shall be obtained for each instrument when exposed to a source in a constant and reproducible manner, either at the time that the instrument is received in the field or before its first use."

# Functional (Operability) Test

## ANSI N323 (1997)

"Check sources should provide radiation of the same type or types as provided by those sources used in instrument calibration (as described in 5.1). However, check sources may provide radiation different than that used for calibration if

- a) The source/instrument geometry is well understood and easily reproduced
- b) The instrument response to this radiation is well understood and is not critically dependent on instrument adjustment (e.g., the use of a beta source to check instruments sensitive to photon radiation may be acceptable while the use of a photon source to check a detector utilizing a BF3 tube is not acceptable). A reproducible source/detector geometry shall be established and used for all source response checks."



# Functional (Operability) Test

## ANSI N323 (1997)

"a source response check may not be practicable for some instruments, such as high range instruments and neutron exposure rate instruments. In these cases, the facility should develop compensatory methods to demonstrate that the instrument is operable before use."

# Appendix A

## Glossary

# Glossary

**Acceptance Testing:** Evaluation or measurement of performance characteristics to verify that certain stated specifications and contractual requirements are met.

**Accuracy:** The degree of agreement between the observed value (meter reading) and the actual value of the quantity being measured (e.g., exposure rate or activity).

**Calibrate:** To adjust or determine the instrument response to known values of the quantity being measured.

**Check Source:** A radioactive source, not necessarily calibrated, that is used to confirm the continuing satisfactory operation of an instrument.

**Coefficient of Variation:** The standard deviation expressed as a percentage of the mean (average).

**Correction (calibration) Factor:** A factor that the instrument reading is multiplied to obtain the actual value of the quantity being measured.

# Glossary

**Energy Dependence:** Variation in the instrument response as a function of radiation energy for a constant radiation type and intensity, i.e., the effect of radiation energy on the instrument accuracy.

**Extracameral:** Components of the instrument other than the detector proper. Exposure of extracameral components in a radiation field might affect the instrument reading.

**Functional Tests:** Tests (aka operability or performance test) to determine that an instrument is operational and capable of performing its intended function. Such tests may include, for example, battery check, zero setting, or source response checks.

**Geotropism:** A change in an instrument's reading as its orientation changes, due to gravitational effects.

**National (primary) Standard:** An instrument or source maintained and promulgated by the National Institute of Standards and Technology.

# Glossary

**Overload Response:** The response of an instrument to radiation intensities greater than the upper measurement level.

**Reference Orientation:** The orientation in which the instrument is normally intended to be operated, as stated by the manufacturer.

**Reference Point:** Markings on the instrument used to identify the center of the detector.

**Reproducibility (precision):** The degree of agreement between repeated measurements of the same radiation field intensity. Expressed as a standard deviation computed from a series of measurements.

**Response Time:** The time it takes for the instrument reading to change from 10% to 90% of the final reading.

**Secondary Standard:** A source or instrument that has been compared directly with the national standard.

# Glossary

**Source Response Check:** A functional test that includes the observation of the response of an instrument to a check source.

**Tertiary Standard:** A source or instrument that has been compared directly with a secondary standard - often used as the laboratory standard.

**Transfer Standard:** A source or instrument compared directly or indirectly with a National Standard that is designed for transport to a laboratory to serve as a laboratory standard. Usually a detector.

**Traceability:** The ability to show, through documentation, that a particular instrument or radiation source has been calibrated using either the national standard or a transfer standard in a chain or echelon of calibrations, ultimately leading to a comparison with the national standard.

# Appendix B

## Detector Efficiency Determinations with Extended Sources

# Counting Efficiency for Extended Source

## General

- There is a trend towards using calibration sources that are larger than the areas of the detectors being calibrated.
- Such sources are often referred to as extended sources.
- The manufacturer typically reports the source activity per unit area (e.g. dpm/cm<sup>2</sup>) as well as its total activity (dpm).



# Counting Efficiency for Extended Source

## Advantages

- Extended sources closely mimic large areas of contamination.
- The efficiencies determined using large area sources can account for the detector window area. The latter does not have to be determined separately.

## Disadvantages

- Extended sources are considerably more expensive than small area sources.
- The range of activities is more limited.

# Counting Efficiency for Extended Source

## Example Calibration

Detector type: Pancake GM with 20 cm<sup>2</sup> window area

Source: Tc-99 extended NIST traceable source

Source Number	2 $\pi$ Concentration (cpm/100 cm <sup>2</sup> )	4 $\pi$ Concentration (dpm/100 cm <sup>2</sup> )	Meter Scale	Net Count Rate (cpm)	2 $\pi$ Efficiency (c/d/100 cm <sup>2</sup> )	4 $\pi$ Efficiency (c/d/100 cm <sup>2</sup> )
8410x	1,550	2,580	x 1	87.9	0.057	0.034
8411x	20,160	33,556	x 10	1,220	0.061	0.036
8412x	202,083	336,370	x 100	11,860	0.059	0.035
				Average Efficiency	0.060	0.035

Note the units for efficiency!

# Counting Efficiency for Extended Source

## Example Calculation of Concentration

A pancake GM is used to measure Tc-99 beta (294 keV maximum energy) contamination on a Formica bench top.

Calculate the total  $4\pi$  activity in dpm/100 cm<sup>2</sup>.

Gross count rate: 75 cpm

Detector background for Formica (and linoleum): 40 cpm.

$2\pi$  counting efficiency: (0.060 c/beta/100 cm<sup>2</sup>)

$4\pi$  counting efficiency: (0.035 c/d/100 cm<sup>2</sup>)

$$C_{4\pi} = \frac{R_n}{E_{4\pi}} = \frac{75 - 40}{0.035} = 1,000 \text{ dpm} / 100 \text{ cm}^2$$

# Appendix C

## Concentration Calculations Using ISO 7503-1

# Concentration Calculations Using ISO 7503-1

## General

- The conditions under which alpha or beta counting efficiencies are determined are ideal:
  - The source is an uncovered very thin deposit. This eliminates attenuation of the emitted alphas or beta particles in the source.
  - The source support is a very smooth high Z material. This maximizes backscatter of beta particles.
- As such, the efficiencies determined in the calibration room are higher than will be experienced in the “real world” where the emitted particles are often attenuated in the source and backscatter is at a minimum.

# Concentration Calculations Using ISO 7503-1

## General

- ISO-7503-1 *Evaluation of Surface Contamination - Part 1: Beta Emitters and Alpha Emitters* attempts to partially correct this overestimation of the detector efficiencies.
- Within the United States, the ISO methodology has found its greatest acceptance in decommissioning. The ISO approach is recommended by MARSSIM (NUREG 1575) which provides guidance for Final Status Surveys at sites undergoing decommissioning. NUREG 1507, *Minimum Detectable Concentrations with Typical Radiation Survey Instruments for Various Contaminants and Field Conditions* provides considerable information relevant to the application of this international standard.

# Concentration Calculations Using ISO 7503-1

## The ISO-7503-1 Equation

- The ISO equation used to calculate the concentration of alpha and beta surface contamination:

$$C = \frac{R_n}{\varepsilon_i \varepsilon_s \frac{A_p}{100}}$$

$C$  is the measured concentration (e.g., dpm/100 cm<sup>2</sup>)

$R_n$  is the net count rate (e.g., cpm)

$\varepsilon_i$  is the instrument efficiency (e.g., c/beta)

$\varepsilon_s$  is the source efficiency

$A_p$  is the detector probe area (e.g., cm<sup>2</sup>)

# Concentration Calculations Using ISO 7503-1

## Instrument Efficiency ( $\epsilon_i$ )

- Better known as the  $2\pi$  efficiency, this is the fraction of the particles leaving the surface that produce a count.

## Source Efficiency ( $\epsilon_s$ )

- The fraction of decays that result in a particle leaving the surface. ISO 7503-1 recommends the following defaults:

### Beta Emitters

maximum energy above 0.4 MeV	$\epsilon_s = 0.5$
maximum energy from 150 – 400 keV	$\epsilon_s = 0.25$

### Alpha Emitters

all energies  $\epsilon_s = 0.25$



# Concentration Calculations Using ISO 7503-1

## Example Calculation

A pancake GM is used to measure Tc-99 beta (294 keV maximum energy) contamination on a Formica bench top.

Calculate the concentration in dpm/100 cm<sup>2</sup>.

Detector window area: 20 cm<sup>2</sup>

Gross count rate: 75 cpm

Detector background for Formica (and linoleum): 40 cpm

2 $\pi$  counting efficiency: 32 % (0.32 c/beta)

4 $\pi$  counting efficiency: 19 % (0.19 c/d)

# Concentration Calculations Using ISO 7503-1

## Example Calculation

Since the beta maximum energy is between 150 and 400 keV, we will use a source efficiency of 0.25.

$$\begin{aligned} C &= \frac{R_n}{\epsilon_i \epsilon_s \frac{A_p}{100}} \\ &= \frac{75 - 40}{0.32 \times 0.25 \left( \frac{20}{100} \right)} \\ &= 2,188 \text{ dpm} / 100 \text{ cm}^2 \end{aligned}$$

## Appendix D

# Assessing the Survey Instrument Background Count Rate

# Background Count Rate

## Introduction

- With one minor exception, ZnS alpha scintillators and proportional counters (operated in the alpha only mode) are unresponsive to anything but alpha particles, i.e., their background count rate should be close to 0 to 1 cpm.
- Higher backgrounds typically mean that the detector is contaminated, or in the case of a ZnS alpha scintillator, that the detector has a light leak. ZnS detectors can respond to fast neutrons, but neutrons are rarely a significant contributor to background.
- Detectors that respond to beta particles (e.g., GM detectors, beta scintillators, proportional counters) also respond to photons and cosmic rays. The larger the detector, the greater the background count rate.

# Background Count Rate

## Assessing Background Count Rate for Beta Detectors

- Different approaches can and are employed for determining the background count rate of a beta detector.
  1. General ambient background
  2. Location specific ambient background
  3. Material specific background
  4. Location specific ambient and material specific background

# Background Count Rate

## 1. General Ambient Background

- The detector background is determined in a low background area, or an area typical of the facility. It is determined by holding the detector in the air and recording the instrument reading.
- The background count rate is primarily due to photons (gamma rays and x-rays), to a lesser extent cosmic rays, and to a very minor extent, radioactive contaminants in the detector.

# Background Count Rate

## 2. Location Specific Ambient Background

- A potential problem with the previous approach: it doesn't account for spatial variability in background. If background variability is small, this approach is acceptable.
- Where background variability is large (e.g., in facilities with high activity gamma emitters), it might be better to determine a background for each measurement location.
- This can be done by holding the probe far enough above the surface where the measurement is performed that the detector cannot respond to surface contamination. Another method would be to make the background measurement with a plastic shield between the surface and the detector.

# Background Count Rate

## 3. Material Specific Background

- A gross beta or alpha measurement on an uncontaminated ceramic tile surface can be very different from a measurement on uncontaminated drywall or wood.
- This reflects the differences in the concentrations of naturally occurring radionuclides in different the materials.
- To account for this, some facilities assign a unique background count rate to each material type. In some cases, the same background count rate might be employed for a group of materials (e.g., wood and drywall).
- The table on the following slide(after NUREG 1507) illustrates some of these different backgrounds.



# Background Count Rate

## 3. Material Specific Background

Surface Material	Background Count Rate (cpm) <sup>a</sup>					
	Gas Proportional			GM	ZnS	NaI
	$\alpha$ Only	$\beta$ Only	$\alpha + \beta$			
Ambient <sup>b</sup>	$1.00 \pm 0.45^c$	$349 \pm 12$	$331.6 \pm 6.0$	$47.6 \pm 2.6$	$1.00 \pm 0.32$	$4702 \pm 16$
Brick	$6.00 \pm 0.84$	$567.2 \pm 7.0$	$573.2 \pm 6.4$	$81.8 \pm 2.3$	$1.80 \pm 0.73$	$5167 \pm 23$
Ceramic Block	$15.0 \pm 1.1$	$792 \pm 11$	$770.2 \pm 6.4$	$107.6 \pm 3.8$	$8.0 \pm 1.1$	$5657 \pm 38$
Ceramic Tile	$12.6 \pm 0.24$	$647 \pm 14$	$648 \pm 16$	$100.8 \pm 2.7$	$7.20 \pm 0.66$	$4649 \pm 37$
Concrete Block	$2.60 \pm 0.81$	$344.0 \pm 6.2$	$325.0 \pm 6.0$	$52.0 \pm 2.5$	$1.80 \pm 0.49$	$4733 \pm 27$
Drywall	$2.60 \pm 0.75$	$325.2 \pm 8.0$	$301.8 \pm 7.0$	$40.4 \pm 3.0$	$2.40 \pm 0.24$	$4436 \pm 38$
Floor Tile	$4.00 \pm 0.71$	$308.4 \pm 6.2$	$296.6 \pm 6.4$	$43.2 \pm 3.6$	$2.20 \pm 0.58$	$4710 \pm 13$
Linoleum	$2.60 \pm 0.98$	$346.0 \pm 8.3$	$335.4 \pm 7.5$	$51.2 \pm 2.8$	$1.00 \pm 0.45$	$4751 \pm 27$
Carbon Steel	$2.40 \pm 0.68$	$322.6 \pm 8.7$	$303.4 \pm 3.4$	$47.2 \pm 3.3$	$1.00 \pm 0.54$	$4248 \pm 38$
Treated Wood	$0.80 \pm 0.37$	$319.4 \pm 8.7$	$295.2 \pm 7.9$	$37.6 \pm 1.7$	$1.20 \pm 0.20$	$4714 \pm 40$
Untreated Wood	$1.20 \pm 0.37$	$338.6 \pm 9.4$	$279.0 \pm 5.7$	$44.6 \pm 2.9$	$1.40 \pm 0.51$	$4623 \pm 34$

# Background Count Rate

## 4. Location Specific Ambient and Material Specific Backgrounds

At each measurement location two counts are performed:

$R_G$  is the gross count rate with the detector on a contaminated surface. This is the detector response to betas and photons from the contamination, betas and photons from the material (e.g., ceramic tile), and background photons.

$R_S$  is the shielded count rate with a plastic shield between the detector and the surface. This is the detector response to photons from the contamination and background photons.

# Background Count Rate

## 4. Location Specific Ambient and Material Specific Backgrounds

$R_M$ , the material specific background (e.g., for ceramic tile) is subtracted from the gross count rate.

$$R_{N1} = R_G - R_M$$

$R_{N1}$  is the net instrument response to the betas and photons emitted by the contamination and to background photons.

The shielded count rate is subtracted from  $R_{N1}$  to give  $R_{N2}$ , the instrument's response to the betas from the contamination.

$$R_{N2} = R_{N1} - R_S$$