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MIRION Connect 24

Annual Users' Conference

July 29 - August 2 | Omni Dallas Hotel, Dallas, TX

MIRION TECHNOLOGIES

X-Ray Probes for Defense & Security

The "How and Why"

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Director, PLM: Defense, Security, and…

Mirion Connect | Annual Users' Conference 2024

Dallas, Texas

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X-Ray Probes

Whether used with the RDS-32™ meter, the ADM300A(V1B)™ meter, or the RDS-100/110 (legacy VDR-2 and PDR-77) meters, X-ray/FIDLER probes are often misunderstood. These probes provide information for contamination and directionality whether for searching, reconnaissance or interdiction; particularly for low energy isotopes and transuranic contamination (i.e., Uranium-235 or Plutonium-239). This session will focus on the benefits and real-world challenges of utilizing these probes including the value of using the discriminator and energy selector functionality included with these probes.

Introduction

Typical Defense Kit of Probes

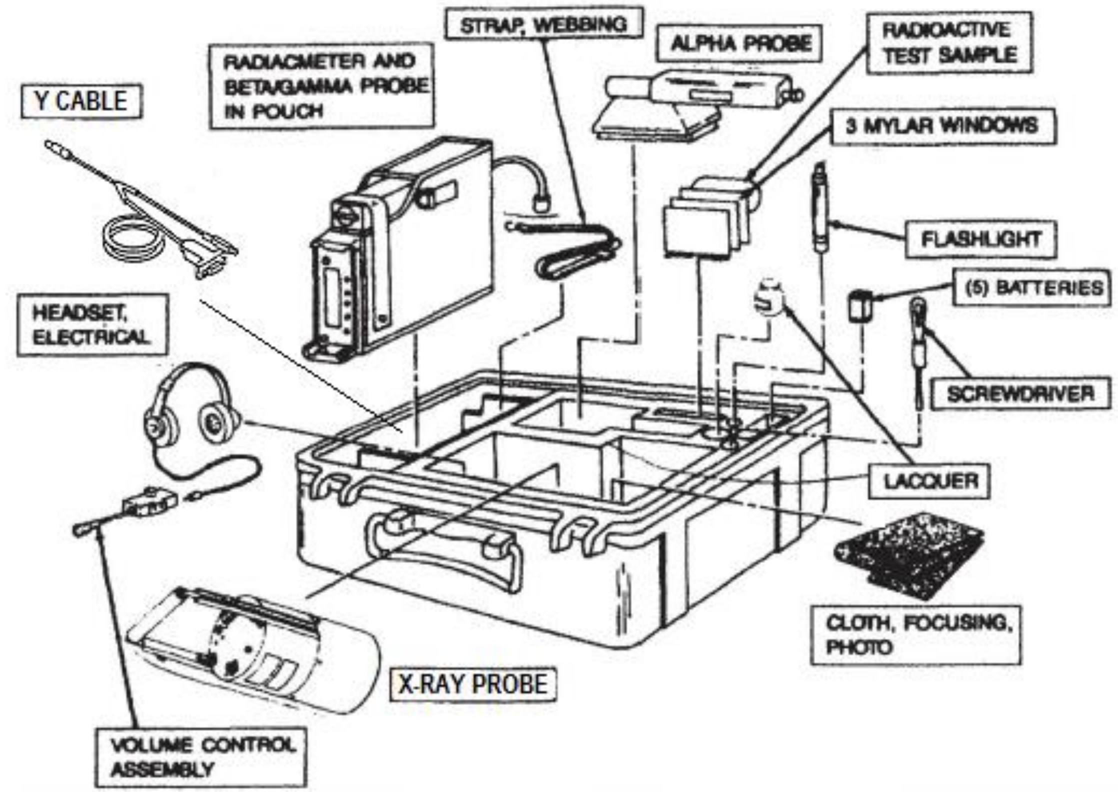
- Base meter
  - May or may not have internal detector(s)
- Alpha probe
- Beta pancake or beta/gamma probe
- X-ray probe
  - Different types for unique applications

- Other probes are often available as “add-on” depending on requirements

Typical Security Kit of Probes

- Base meter
  - May or may not have internal detector(s)
- Alpha probe
- Beta pancake or beta/gamma probe
- X-ray probe
  - Different types for unique applications
- Neutron probe
- Other probes are often available as “add-on” depending on requirements

Why were these probes selected



- Known technology – well characterized
- Robust capability for transport and usage
- Supports major CONOPS
  - Survey (active interrogation) intensity and extent of contamination
  - Area monitoring
  - Personnel, food, and equipment monitoring
  - Ground radiological reconnaissance

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X-Ray Probes

Different X-Ray Probes have sensitivity differences

- XP100 (10cm2 active area)
  - $15x10^3$ cps/Ci/cm^2 Am-241
  - $1.8x10^3$ cps/Ci/cm^2 Pu-239
- XP120
  - 17keV: 1.51cps/kBq +/- 30% (8.1µCi Am-241)
  - 60keV: 2.64 cps/kBq +/- 30% (8.1µCi Am-241)
  - 186keV: 71.79 cps/kBq +/- 30% (200nCi U-235)
  - GROSS: 5.75 cps/kBq +/- 30% (8.1µCi Am-241)
- SX-2R
  - 0.14 cps/Bq (I-129)

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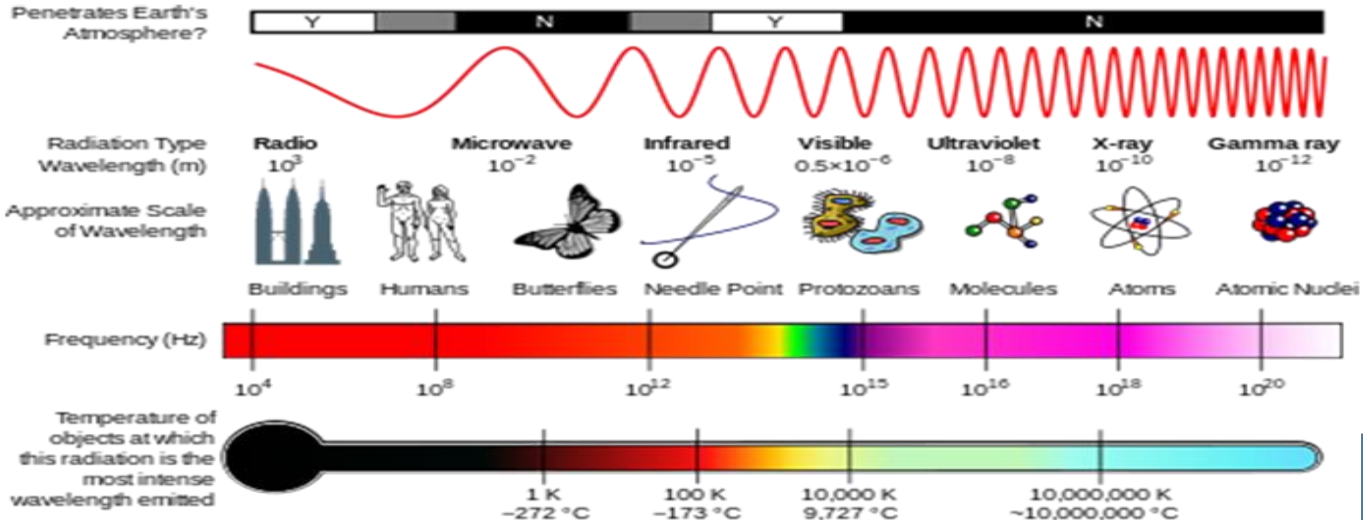
Anatomy of an X-Ray Probe

Brief Discussion on Photons

- The word “Photon” means light
- To an instrument, they are <u>identical</u>
- Ionizing photon radiation is typically divided into gamma rays and x-rays
- The difference between these two is their source of origin:
  - Gamma rays are produced by rearrangement of the nucleus
  - X-rays are produced by rearrangement of electrons
- Photons have no mass and no electrical charge. This means they have high penetrating power



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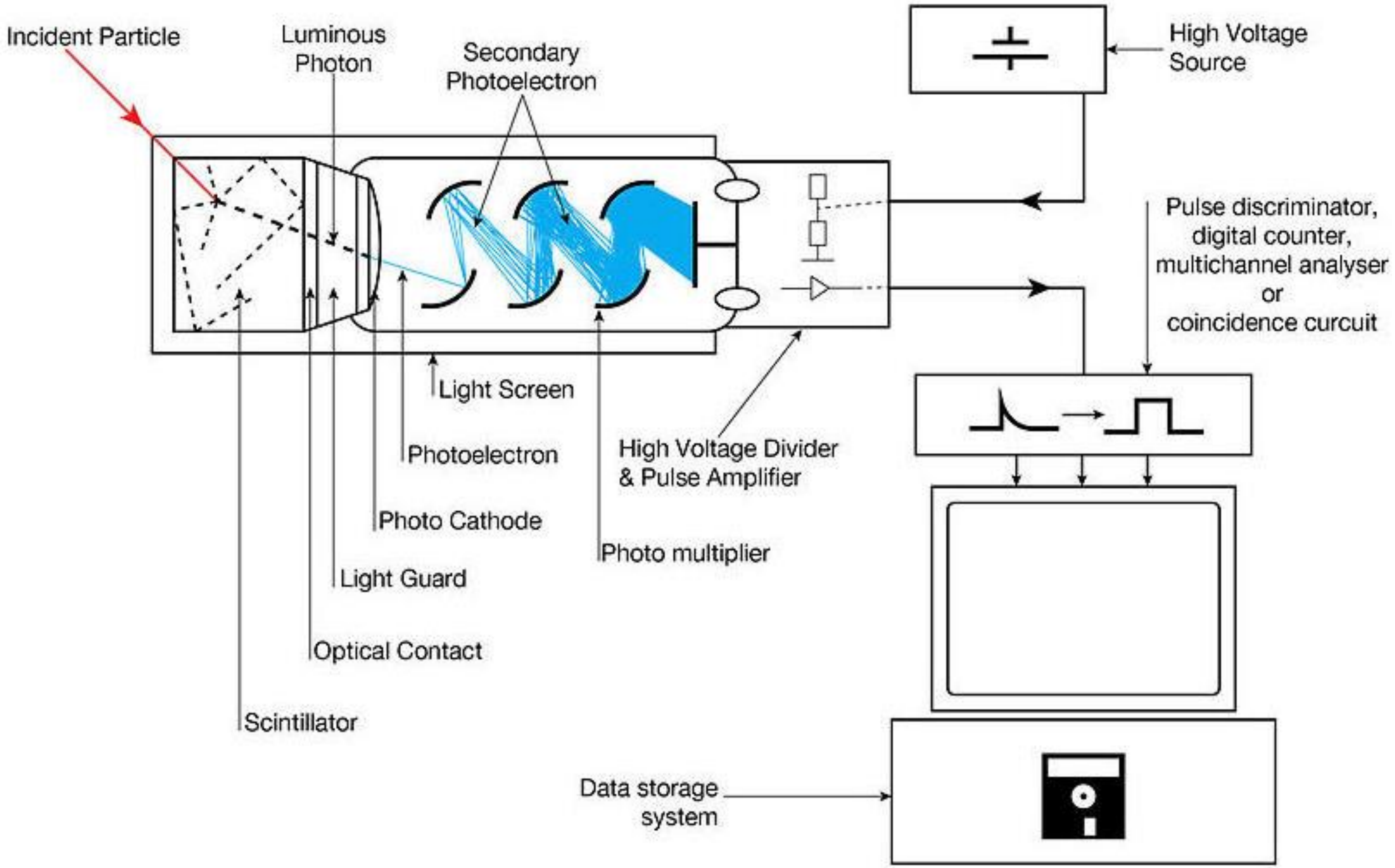
X-Ray Probe Basic Construction



Examples

NaI

LaBr

Plastic

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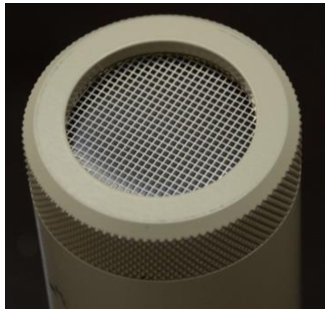
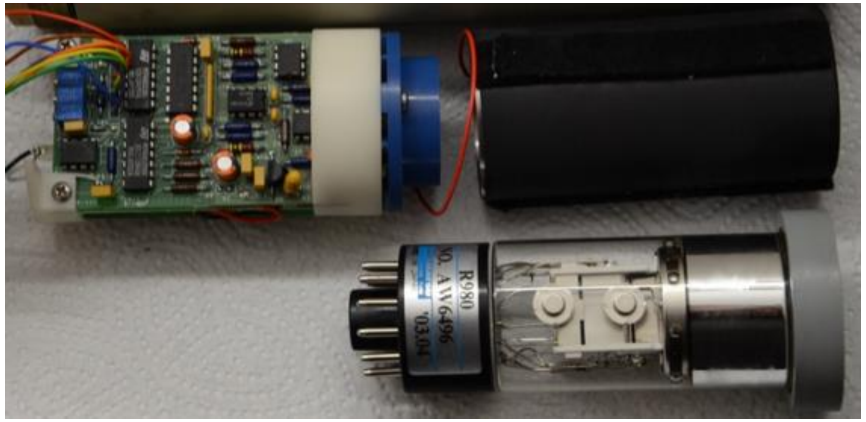
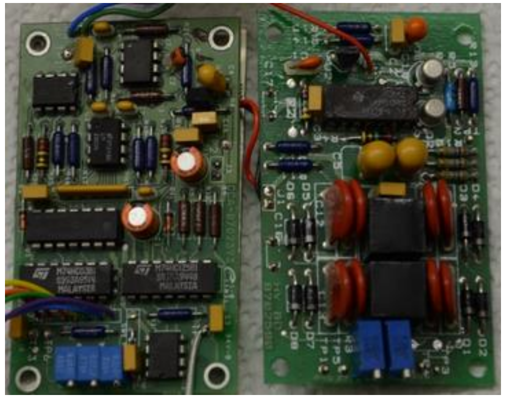
XP-100 X-Ray Probe (L X-Ray with 17keV)





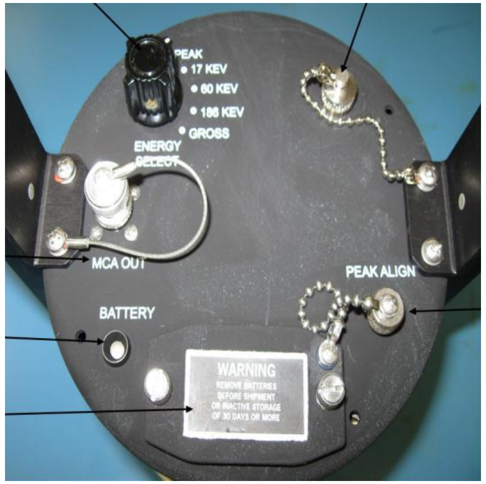


Major Components

- End Cap assembly
- High Voltage Board
- Logic Board (count rates)
- Photomultiplier Tube
- Crystal (CaF^2) 2”/50.8mm x ¼”/6.4mm (Europium activated)
- EEPROM (with calibration coefficients)

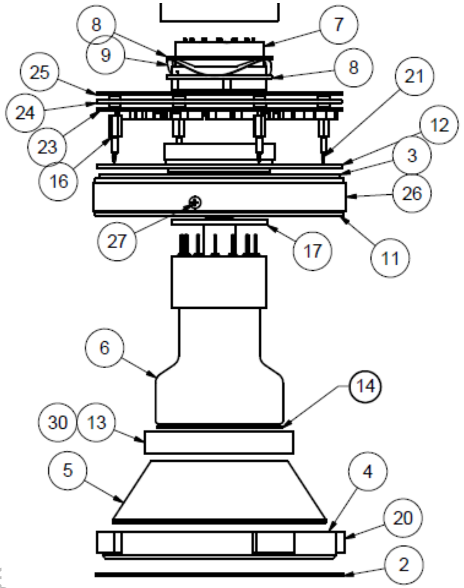
XP-120 X-Ray Probe (discriminator select)

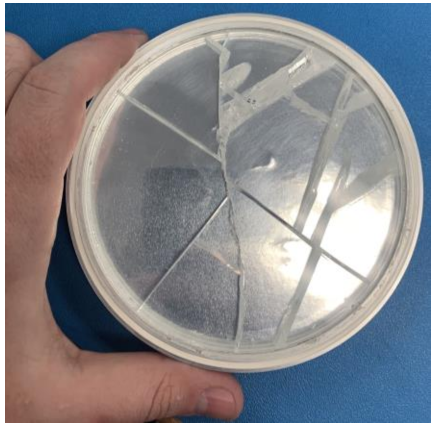
FIDLER: Field Instrument for Detecting Low Energy Radiation (DT-674)



Major Components

- Top Cap Assembly/Handle
- Energy Selection Switch (17keV, 60keV, 186keV, Peak, Gross)
- Bottom Cap assembly
- High Voltage Board
- Digital Board
- Photomultiplier Tube and light reflector
- Crystal (NaI) 5”/126mm x ¼”/6.4mm (Thallium doped)
- EEPROM (with calibration coefficients)





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SX-2R Probe (energy select)

Major Components

- SMART Probe (CSP) family
- Energy Selection push button (limits X-rays below the preset threshold)
- Bottom berrylium window assembly
- Photomultiplier Tube
- Crystal (NaI) 1.5”/38mm x 0.12”/3mm (Thallium doped)
- On-board firmware with USB connection

Pre-Deployment Checks

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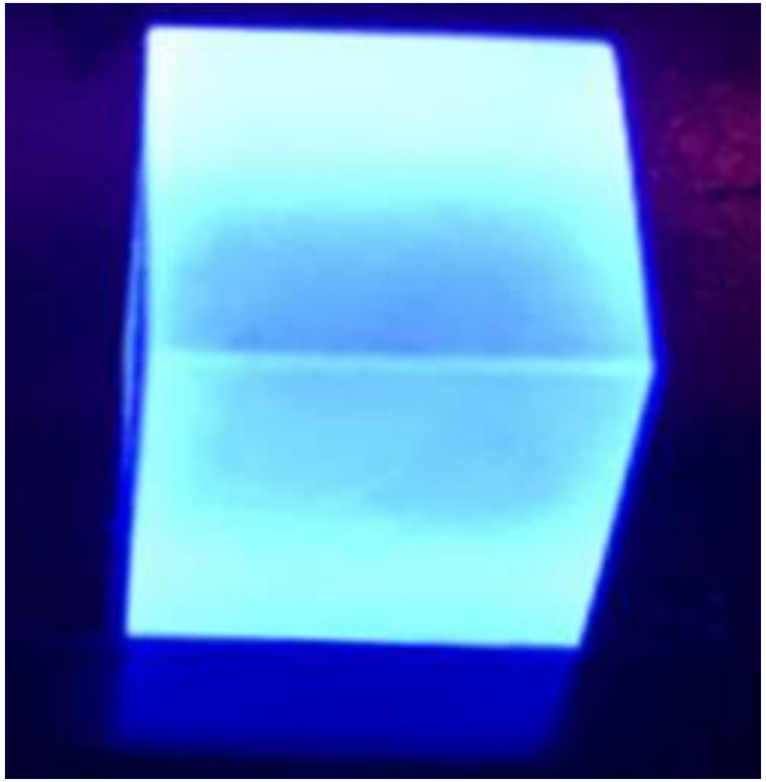
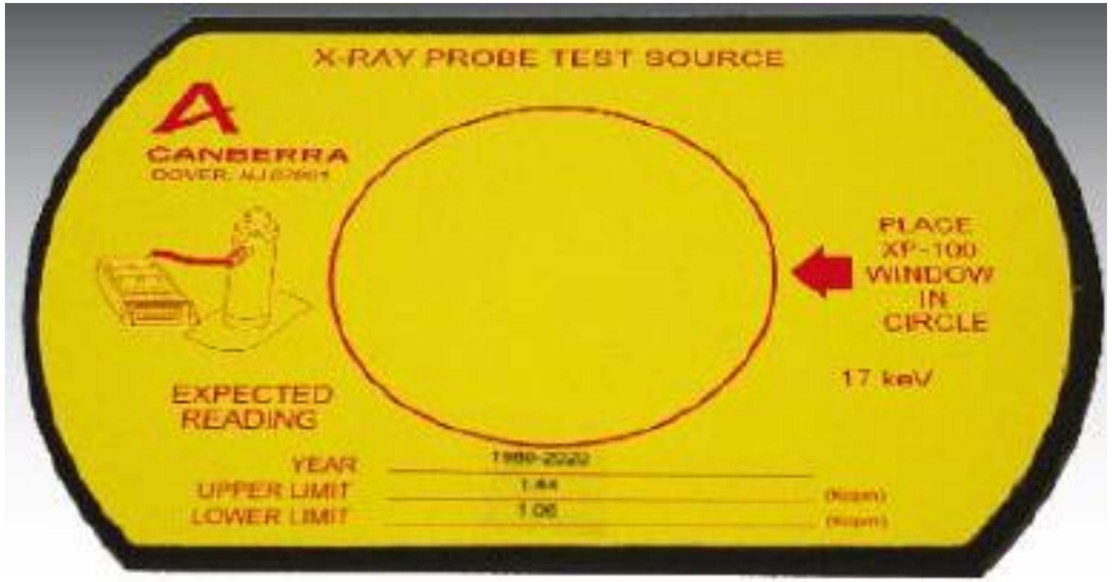
Scintillators

- Scintillator detectors are typically high efficiency resulting in stable readings and reduced uncertainty
- Scintillator materials can be PVT, NaI, CsI, LaBr, and many more
  - Some of these even have capabilities to reliably measure the energy of the radiation
- Calibrated similar to GM tubes
  - Expose to a known reference field
  - Measure count rate as a function of dose rate
  - Verify response is linear across the desired range



Test Sources



Position and orientation are important!

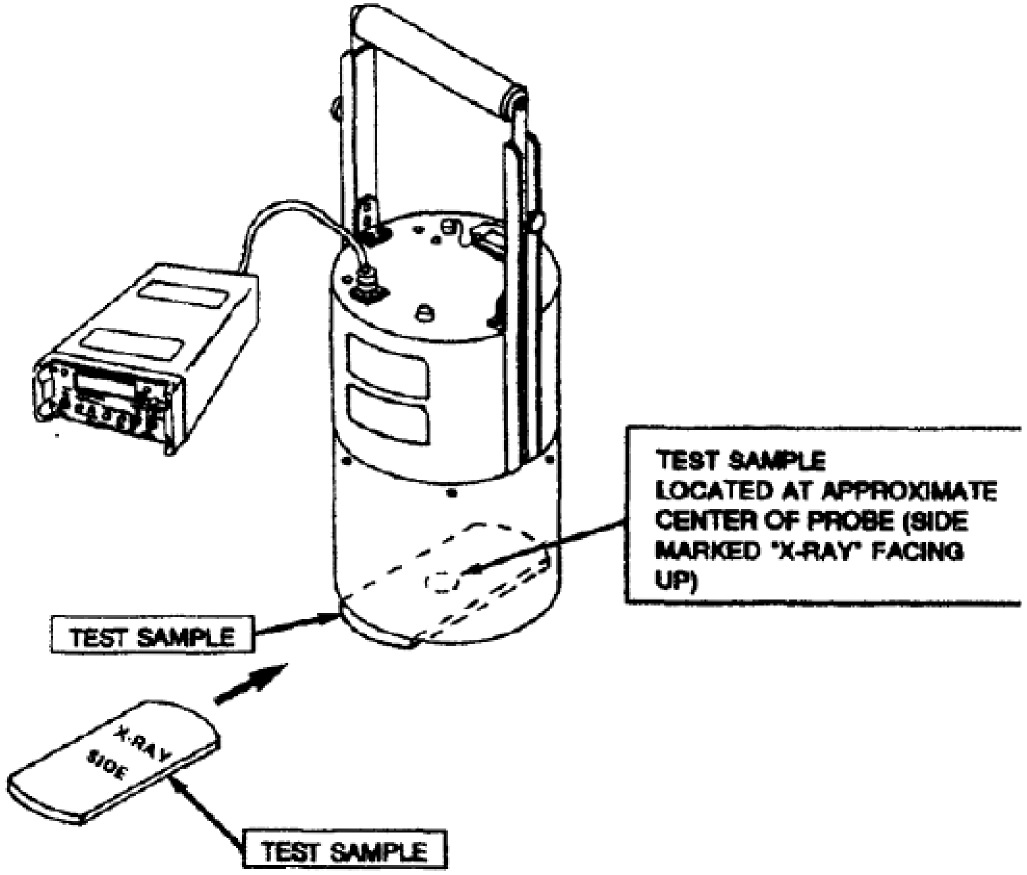
Can confirm activity, but typically not calibrated due to variations in positioning

General Pre-Deployment Checks

- Physical inspection of instrument
  - Dents, scratches, display
- Operational Test
  - Non-radiological: Battery, mechanical zero, drift, light sensitivity
- Source response:
  - Verify against "Conventionally True Value" of source
- Calibration validity:
  - Within date? Any limits on calibration? Serial numbers match?

Pre-Deployment – FIDLER Example

- Turn power switch to OFF
- Connect the cable from meter to probe
- Confirm cable integrity over full length
- Set ENERGY SELECT to 17KEV setting
- Turn power switch to ON and allow meter to initialize
- Confirm no low battery light/indication on meter or probe
- No source present, should indicate background activity between 50-550CPM
- Set ENERGY SELECT to PEAK/ALIGN setting
- Note background reading and align on check source
- Confirm 8,000-16,000 counts greater than background

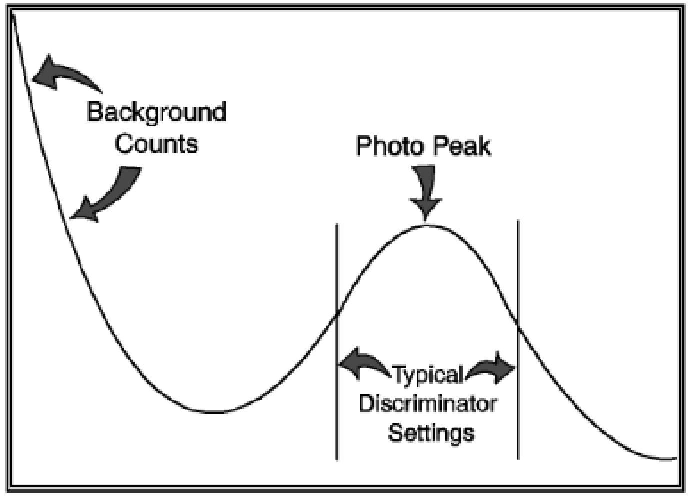


Typical Uses

Typical Uses

- Release/clearance
- Localization of suspected illicit weapons material (primarily Plutonium and Uranium)
- Containment integrity checking
- Ground reconnaissance/field contamination
- Detection of low energy emitters
- Often use in gross/"broad" range for best detection and then limit by discriminator

Overview of Discriminator in X-Ray Probes



Physics

- Size of pulse proportional to energy of X-Ray
- Pulse-height discrimination = “filter”
- High natural background = many moderate to high energy photons
- Complicated detection mechanism results in distribution of about mean pulse size

Probe Electronics

- Need to capture low energy (tens of keV) signal requires very sensitive electronics
- ↑ Susceptibility to electronic noise
- Need to reject high energy photons for high background areas
- Condition/age of detector impacts pulse size distribution

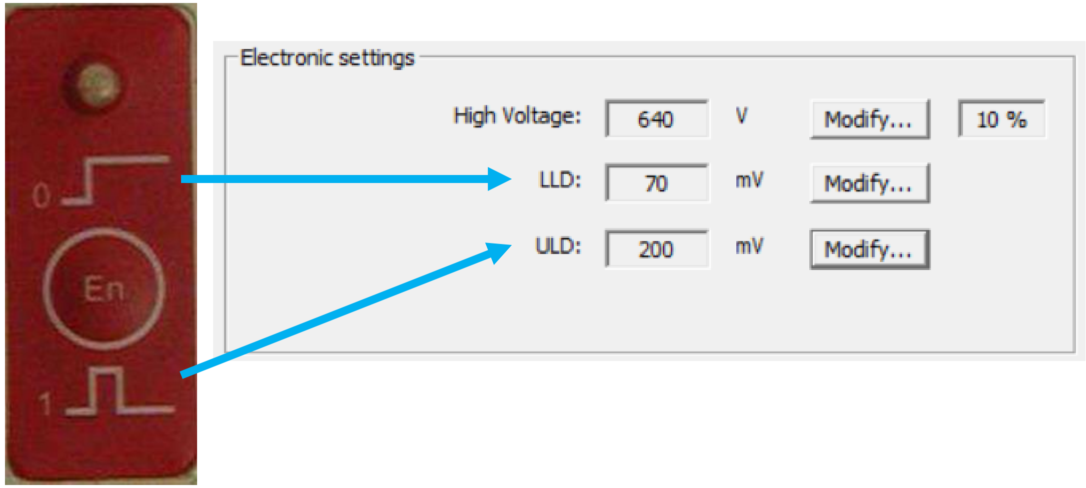
Radiation Detection and Measurement

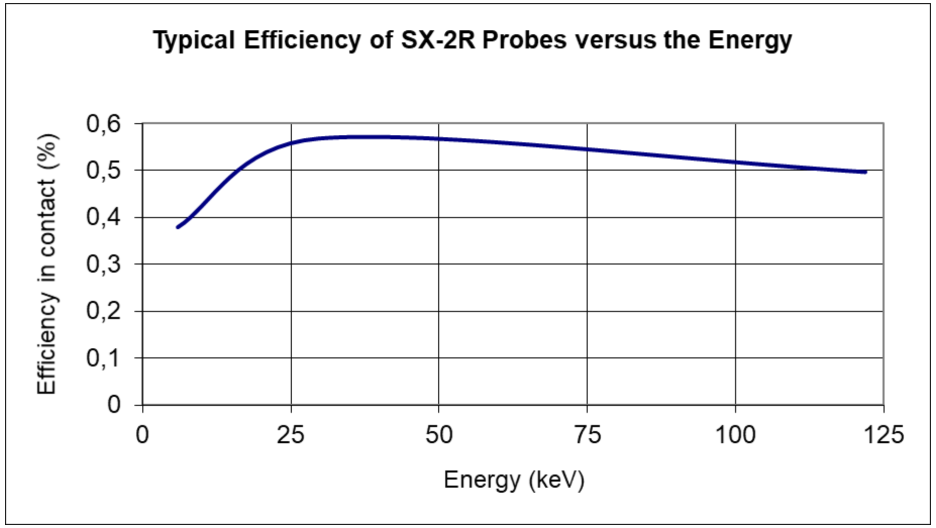
Common Energies of Interest

- Tritium (maximum energy): 18.6keV beta
- Plutonium-239 (progeny): 17keV X-Ray
- Americium-241 (Pu progeny): 60keV gamma
- Uranium-235 (HEU): 185.7keV X-Ray
- Uranium-235 (progeny): 80keV X-Ray

	Alpha	Beta	Photons
Am-241	X		X
H-3		X	
Pu-239	X		X
Thorium Alloys	X	X	X
U-Natural	X	X	X
U-Depleted	X	X	X
U-Highly Enriched	X	X	X

SX-2R Probe Discriminator Example





Energy Range: 5-200keV

- Looking at low energy X-Ray leak
  - High energy may hide the leak
- Using the High Energy (ULD) cut-off button
  - Set by default to 200mV (22keV) Cadmium-109
  - Press/hold, LED on, measure counts <u>below</u> set threshold only

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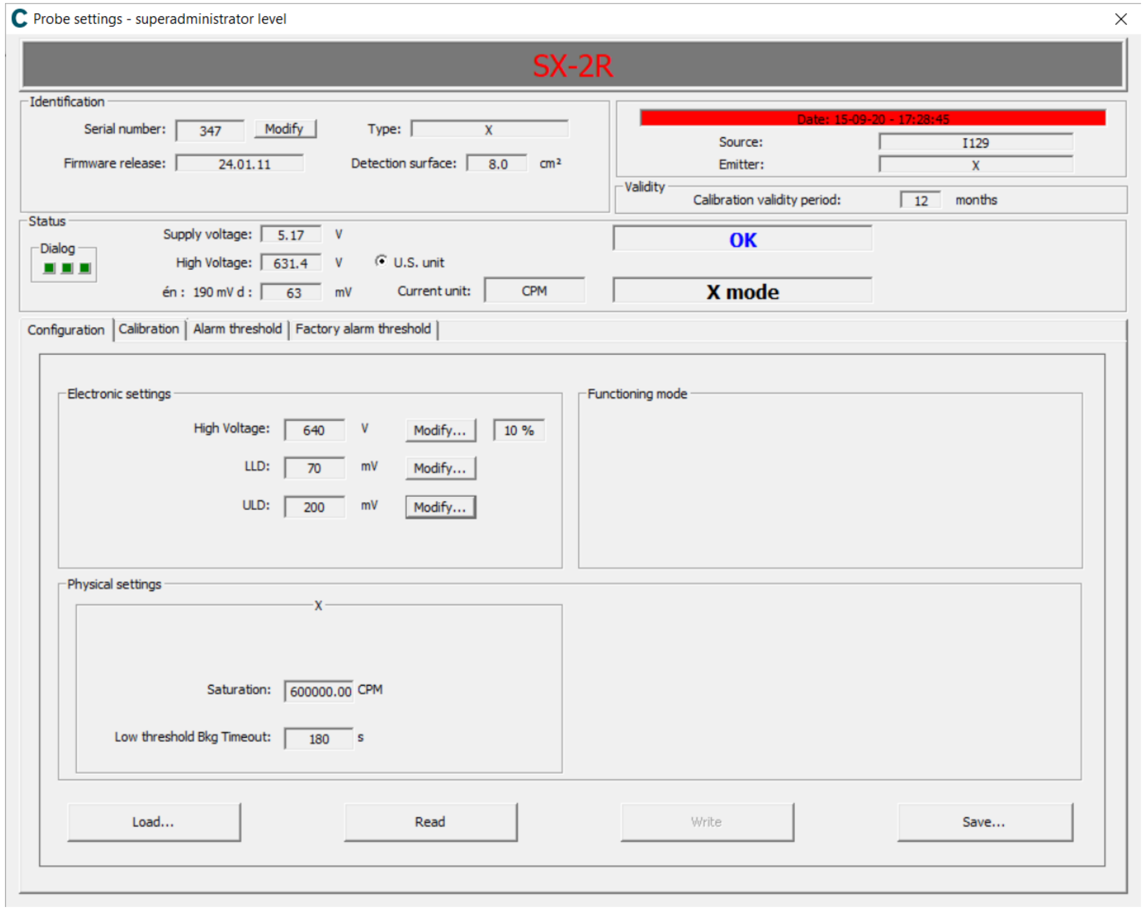
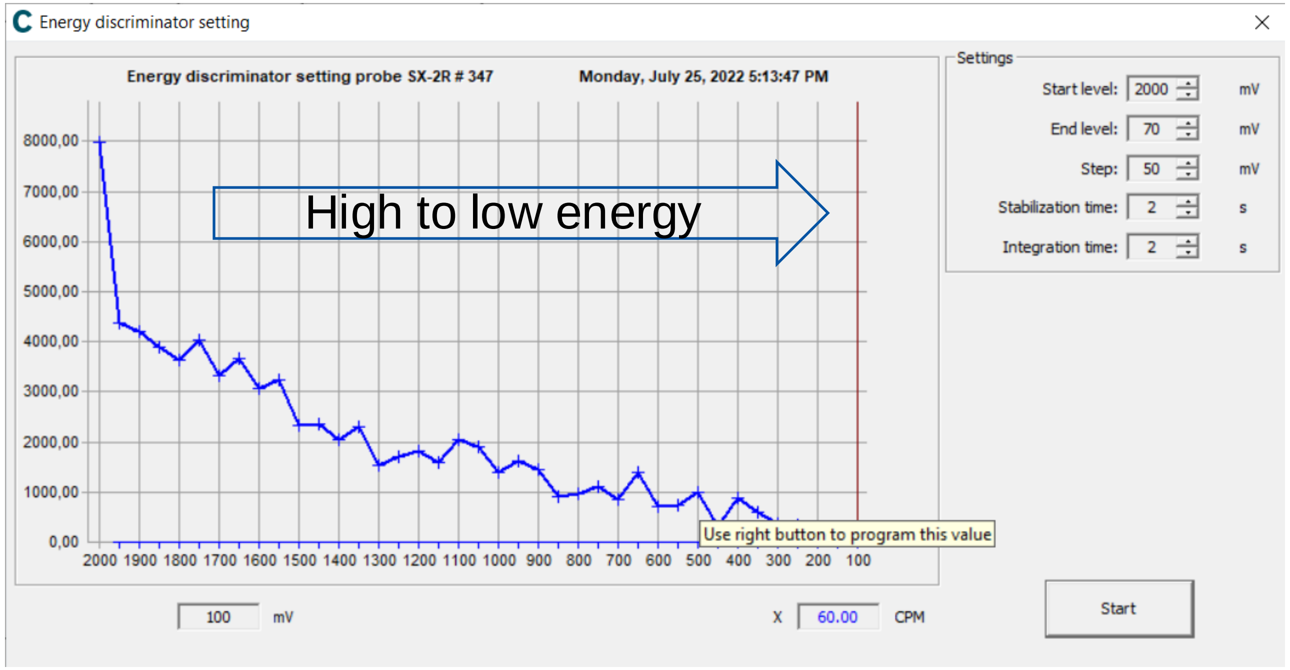
SX-2R Probe Discriminator Example



(*) LLD is set to cut electronic "noise"



Fiesta Plate acquisition for example only

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Typical Use Cases

- From US Defense Health Agency
- Covers alpha, beta, and gamma emitters
- Higher sensitivity than Pancake Probes
- Discriminator/energy limit to discern isotope
- Typical Energy ranges:
  - 17keV typical of Transuranic Radioactive Waste
  - 60keV typical of Americium-241
  - 186keV typical of Uranium-235

		Probe Type				
		β/γ Probe	α Probe	X-ray Probe	Pancake Probe	micro-R Probe
		Alpha Emitters				
Measuring Objective	Detection or Measurement[1]	C (Open Window)	A	b[4]	A	C
	Locate Missing Source[2]	C (Open Window)	C	A	A	C
		Beta Emitters				
	All Types	B (Open Window)	U	b[4]	A	C
		Gamma Emitters				
	Detection or Measurement	A	U	A	A	A
	Locate Missing Source	A	U	A	A	A
	Basic External Radiation Dose Measurement Survey[3]	A	U	U	U	b[4]
		Unknown sources				
	Detection or Measurement	B	U	b[4]	A	b[4]

A = First Choice; B = Second Choice; C = Use If No Other Probes Are Available; U = Unacceptable

1. Determine the presence or intensity of radiation.

2. Find a radioactive source.

3. Determine ambient radiation doses and dose rates in a given area.

4. Most alpha and beta emitters have associated gamma rays and/or x rays. Therefore, these probes can be used to detect the presence of many alpha and beta emitters. If there are no associated gamma rays or x rays emitted, then these probes will not detect the radioactive material.

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Plutonium Soil Contamination – FIDLER

- Extend handle (based on operator height) for survey approximately 12” above ground
- Plutonium-239 suspected only (we look for Plutonium-241 → Americium-241 = 60keV)
- Adjust discriminator for 60keV to limit interference and focus on expected material only
- Obtain an average background reading for at least 2 minutes in un-contaminated area
- Recommend meter in audio/click mode
- Determine a search grid and walk slowly
- Stop when increase in count rate detected for at least 5-10 seconds and mark appropriately

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Contamination Limits - USA

	DOT*	DOE†	NRC‡
Alpha Emitter - Transuranics	220 dpm/100 cm^2	20 dpm/100 cm^2	20 dpm/100 cm^2
Alpha Emitter - Uranium	2200 dpm/100 cm^2	1000 dpm/100 cm^2	1000 dpm/100 cm^2
Beta Emitter - Sr-90, Others	2200 dpm/100 cm^2	200 dpm/100 cm^2	200 dpm/100 cm^2
Beta Emitter - Fission Products	2200 dpm/100 cm^2	1000 dpm/100 cm^2	1000 dpm/100 cm^2

- Typical X-Ray probes provide counts per second and/or counts per minute
- An indication of expected contamination can be derived from known efficiencies
- Due to variability in field conditions and equipment this should only be considered as a rough guide
- Laboratory methods (portable or fixed) are required to provide absolute contamination determination

* 49 CFR 173.443, “Contamination Control”

† 10 CFR 835, Appendix D, “Surface Contamination Values”

‡ NRC Regulatory Guide 1.86, “Termination of Operating Licenses for Nuclear Reactors”

Measurement Challenges

Radiation Detection and Measurement

Detection v. Measurement

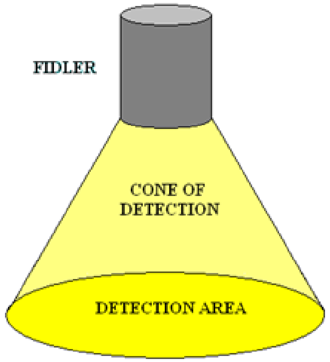
- Quantitative measurements in the field are difficult (isotopic and geometric response functions may be needed)
- Significantly affected by minutes amount of overburden
  - Dust
  - Humidity
  - Snow/precipitation
  - Dew

Uranium and Plutonium Field Survey

- Both alpha emitters
- Uranium best accomplished by beta emissions
  - Thorium and Proactinium progeny
- Plutonium we tend to look for accompanying contaminant
  - Americium-241 (60keV gamma ray)
  - Impacted by age of weapon/material

Geometric Example – FIDLER Probe

Detection Areas for a 4.75 inch diameter FIDLER		
Detector height		**Detection Area**
(inches)	(cm)	(cm^2)
1	2.54	177
4	10.16	445
5	12.70	562
8	20.32	993
10	25.40	1348
11	27.94	1546
12	30.48	1757
13	33.02	1982
14	35.56	2220
15	38.10	2472
16	40.64	2738
17	43.18	3017
18	45.72	3310
19	48.26	3616
20	50.80	3936
21	53.34	4269
22	55.88	4616
23	58.42	4976
24	60.96	5350



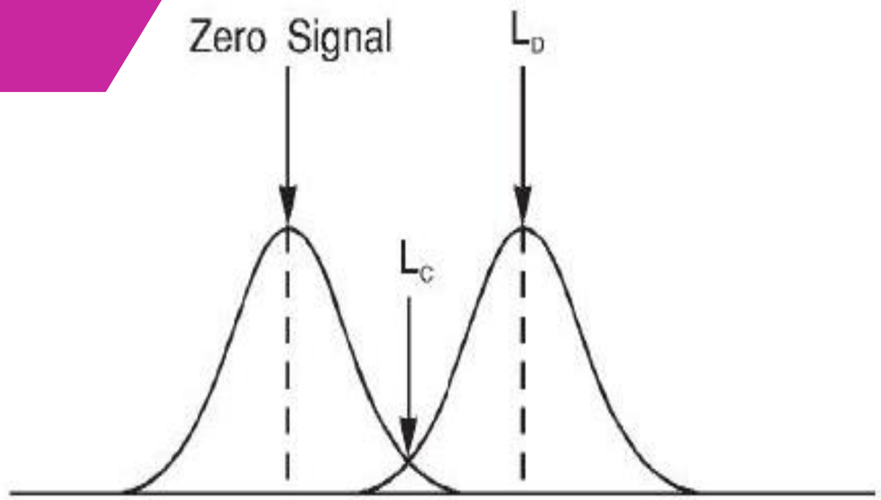
CAUTION: The same detector height used in the field must be the same as the height used for calculating efficiency.

- Detection height has a significant impact on the detection area
- Efficiency must be confirmed/calculated at the same height
- Actual device must be characterized
- Guidance supports a 50% conservative factor if operating at 12 inches

Minimum Dectable Activity (MDA)

What goes into the calculation…

- **You can never prove "zero radiation"**
- You can prove "no more than ___ radiation
- Typical scan speed (25 inches per second)
- Desired MDA can't be too close to background
  - Ideally at least 2-3x background
- Cannot measure activities below what statistics dictates
- Dependent on energy resolution, efficiency, shielding, and background



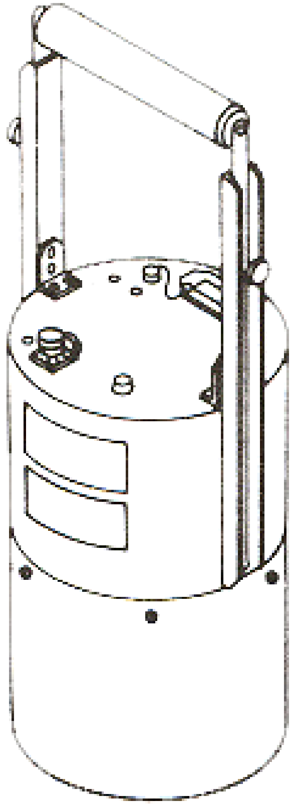
More shielding=lower MDA (More sensitive measurement)
Better energy resolution=lower MDA

$$MDC = \left(\frac{K^2 + 2K\sqrt{2\dot{B} \times T}}{M \times \varepsilon \times Y \times T} \right)$$

K=confidence factor (0=50%, 1.645=95%)
B=background rate
T=time
M=mass of sample
ε=Efficiency
Y=branching ratio

Tradeoffs

X-Ray Scintillator Tradeoffs



DETECTOR, RADIAC
DT-674/PDR-77
(X-RAY PROBE)

- Window mass 7mg/cm^2 or more limits low energy level of probe
- Sensitive to beta, photon, neutron
- Requires more advanced operator understanding of benefits and tradeoffs
- Tend to be larger/heavier than other probe types
- Requires peak adjustment in very cold temperatures for reliable results
- Thin mylar film damaged from setting down without protection/consideration

X-Ray Scintillator Tradeoffs

- ~10% energy attenuation of low energy alpha (not as problematic for gamma/x-ray)
- Susceptible to damage (ambient light signal)
- Can include a protective covering = attenuation
- Sudden/extreme temperature change impacts
- Contact of front face with contaminated material can cause erroneous readings
- Alpha particle in air ~4cm
- Environmental considerations – particularly for alpha particles

X-Ray Scintillator Tradeoffs

- BUT – Use the right tool for the right job!

Thank you

Who I am: David Stewart

- With Mirion for 20+ years
- Various leadership, technical, and product roles
- Field time
  - Site-based system design
  - Reactor outage support
  - Installation oversight
- Director, PLM: Defense, Security, and Imaging
- New transplant to Tennessee – same temperatures as Upstate New York – go figure ☺