Establishing detection efficiency for surface contamination measurements

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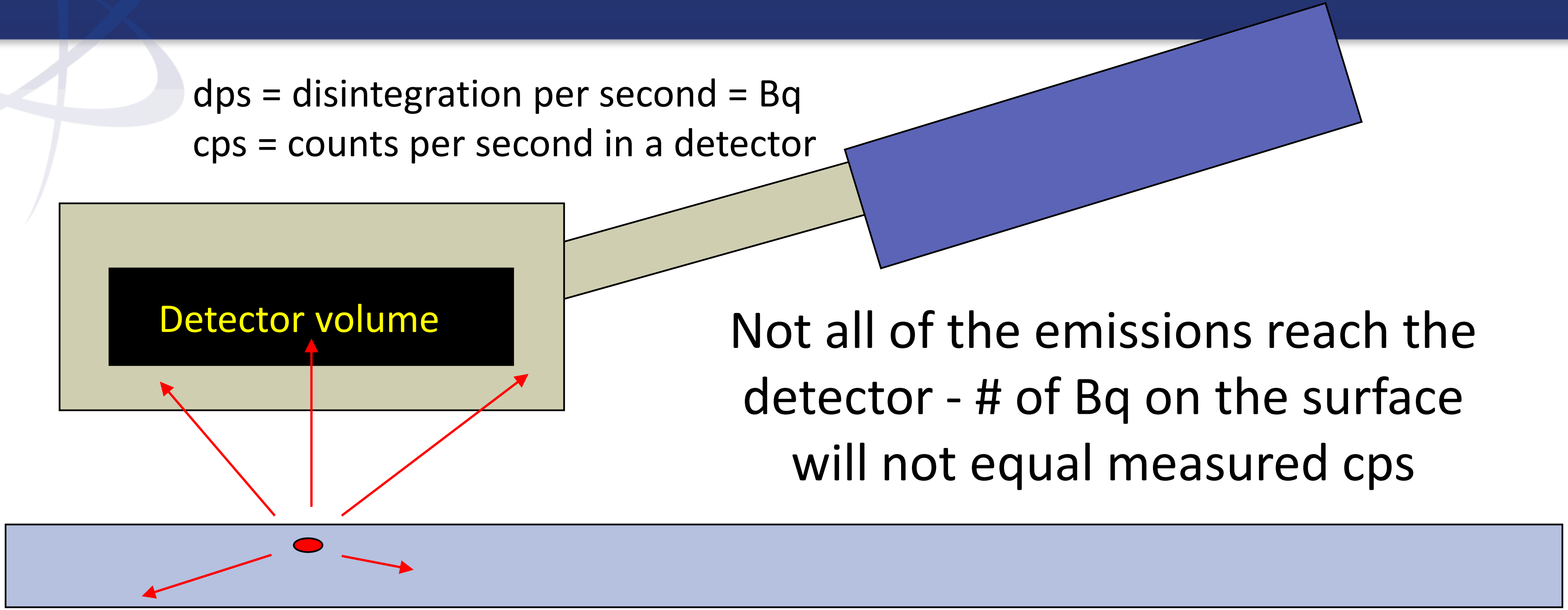
Outline

- Why we need to know detector efficiency?
- Minimum Detectable Activity (MDA)
- Uncertainty
- Using the decommissioning tool to calculate CPM to Bq/cm^2, MDA, and uncertainty
- Methods for measuring/establishing detection efficiency

Instrument Detection Efficiency

dps = disintegration per second = Bq
cps = counts per second in a detector



Not all of the emissions reach the detector - # of Bq on the surface will not equal measured cps

Why do we need to know efficiency?

To convert from cpm to Bq or Bq/cm^2 to compare against regulatory criteria:

- Typical clearance criteria for a Nuclear Substances licence include:
  - 0.3 Bq/cm^2 for all Class A radionuclides;
  - 3 Bq/cm^2 for all Class B radionuclides; or
  - 30 Bq/cm^2 for all Class C radionuclides; averaged over an area <= 100 cm^2
- Transport Criteria:
  - 4 Bq/cm^2 beta/gamma and 0.4 Bq/cm^2 alpha, averaged over an area <= 300 cm^2

Factors affecting detection efficiency

- Distance to source (attenuation of alpha/beta particles in air)
- Detection window to source geometry
- Window thickness/energy cut-off (beta energies are a spectrum)
- Gamma energy (likelihood of interaction with detector)

Typical Detector Types and Instruments

thin window GM “pancake” - αβγ

proprietary thick ZnS scintillator “Berthold LB124” - α/βγ

thin NaI - ↑ energy β, ↓energy γ

thin ZnS sandwiched to plastic scintillator “dual phosphor” - α/βγ

thick NaI - ↑ energy γ

How to establish detection efficiency?

We will examine four different methods, in order of regulatory preference:

1. NIST (or equivalent outside USA) traceable planar source where calibration nuclide is the same as target nuclide
2. Traceable planar source where calibration nuclide(s) are suitable surrogate(s) for target nuclide
3. “Homemade” source of known activity (100 Bq to 1 kBq), where calibration nuclide is the same as target nuclide
4. Published or suggested efficiency value (manufacturer or CNSC) for target nuclide

NOTE: efficiency must be verified and documented at minimum annually

Instrument Detection Efficiency

$$Eff\,(\%) = \frac{(cps_{source} - cps_{background})}{source\ activity\,(Bq)} \times 100\%$$

- Convert counts per minute (cpm) to counts per second (cps); i.e., divide by 60
- Use total activity of the calibration source (yields *absolute* 4pi efficiency)
- Do not shield (no plastic bags) the calibration source in any way (unless trying to isolate counts for specific emission type)
- Use consistent and repeatable source-to-detector distance: ~ 1cm
- Measure background in an area devoid of nuclear substances
- Counting time should be the same for source and background
- For nuclides with short-lived progeny (Sr-90/Y-90), consider the activity of the parent only

Converting CPM to activity

CPM to Bq/cm^2 :

Removable surface activity = $\frac{N - NB}{E \times 60 \times A \times F}$

N =	count rate in counts per minute (CPM) measured directly or on the wipe
NB =	background count rate (CPM)
E =	instrument efficiency
60 =	sec/min
A =	area wiped or detector area in cm^2 (for direct measurement)
F =	collection factor if a wipe - if F is not determined experimentally, use 0.1

Minimum Detectable Activity (MDA)

Minimal Detectable Activity (MDA): minimum amount of activity in a sample that can be detected with a 5% probability of erroneously detecting radioactivity when none is present, and a 5% probability of not detecting radioactivity when it is present

Calculating the MDA

Can be expressed in Bq, Bq/cm^2, Bq/m^3 or any other unit of interest

$$\text{MDA (Bq/cm}^2\text{)} = \frac{2.71 + 4.66\sqrt{NB \times [T/60]}}{E \times T \times A \times F}$$

NB = background count rate in CPM and E/A/F = efficiency/surface area/collection factor

T = sample count time and background count time in seconds

- for digital instruments with scaler functions: time is user selected
- for ratemeters: integration time typically 2-7 secs (consult manual)
- for ratemeters: integration time may be variable based on count rate (newer digital meters)
- for ratemeters: some have slow modes for longer integration time (Ludlum Model 14C: 4/22 sec)

Calculating the Uncertainty

$$\sigma(cps) = \sqrt{x} = SD = \sqrt{\frac{counts_{sample}}{(sample\,count\,time(s))^2} + \frac{counts_{background}}{background\,count\,time(s))^2}}$$

- Standard deviation (SD) is expressed in counts but can be converted into cps if divided by time, or Bq/cm^2 if E and A are factored
- If the result + 2xSD (95% confidence interval) is greater than the clearance level, then the measured item should be considered contaminated
- Formula for uncertainty in Bq/cm^2 if counting time is the same for the sample and background:

$$2\sigma \text{ uncertainty (Bq/cm}^2) = \pm 2 \times \frac{\sqrt{N \times [T/60] + NB \times [T/60]}}{E \times T \times A \times F}$$

Is the MDA low enough?

1. MDA is set at 0.5 times the applicable contamination criterion or limit:

$$\frac{2.71 + 4.66\sqrt{NB \times [^{T}/_{60}]}}{E \times T \times A \times F} \leq 0.5\times\text{contamination limit}$$

2. Assume that a typical measurement near the applicable criterion is twice the background measurement (i.e., N = 2NB) and that the counting time T is identical for both:

$$\frac{2.71+4.66\sqrt{NB\times[^{T}/_{60}]}}{E \times T \times A \times F} + 2 \times \frac{\sqrt{N \times [^{T}/_{60}] + NB \times [^{T}/_{60}]}}{E \times T \times A \times F} \leq \text{contamination limit}$$

$$\frac{2.71+8.12\sqrt{NB\times[^{T}/_{60}]}}{E \times T \times A \times F} \leq \text{contamination limit}$$

Establishing MDA and converting CPM to Bq/cm^2 with uncertainty

Don’t reinvent the wheel - Use the Decommissioning Reporting Tool!

SWIPES - Method of detection		Thermo RadEye B20				*Nuclide with lowest detection efficiency*			Tc-99m		
		Bkgnd CPM	28.6	*Count T (sec)*	120	*Swipe Area (cm2)*	100	*Detector Efficiency (%)*	0.62%	*Swipe Eff (%)*	10.00%
DIRECT - Method of detection		Thermo RadEye B20				*Nuclide with lowest detection efficiency*			Tc-99m		
		Bkgnd CPM	28.6	*Count T (sec)*	120	*Detector area (cm2)*	15.5	*Detector Efficiency (%)*	0.62%		

SURFACE CONTAMINATION RESULTS

ENTER VALUES IN YELLOW CELLS - RED CELLS INDICATE SAMPLE CONTAMINATION + UNCERTAINTY >= REGULATORY CRITERION

SWIPES		MDA (Bq/cm2) =		5.101	Criterion (Bq/cm2)	DIRECT		MDA (Bq/cm2) =		3.291
Sample #	Description	Gross CPM	Bq/cm2	2σ (+/-) Bq/cm2	30	Sample #	Description	Gross CPM	Bq/cm2	2σ (+/-) Bq/cm2
1	Sample 1	100	19.194	4.311		1	Sample 1	65	6.313	2.373
2	Sample 2	100	19.1935	4.311		2	Sample 2	125	16.719	3.040
3	Sample 3	200	46.075	5.748		3	Sample 3	200	29.726	3.708
4						4				
5						5				
6						6				
7						7				
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13						13				
14						14				
15						15				
16						16				

The sheet labelled “Data – User Defined” can be copy/pasted and used for routine contamination measurements, and as an MDA calculator

Establishing Detection Efficiency

Let's examine the methods that can be used to establish detection efficiency.

Method #1 – Traceable planar source

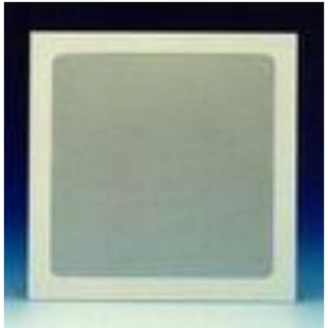
- If source area > detector active area, establish activity under the detector
  - *Source = 100cm^2, detector = 15.5cm^2*
  - *Reference activity = source activity x (15.5/100)*

- Repeatable source to detector distance (~*1 cm, use a jig*)

- Efficiency is:

$$Eff\,(\%) = \frac{(cps_{source} - cps_{background})}{source\ activity\,(Bq)} \times 100\%$$

- Repeat, document and update (if outside +/- 20%) annually for every contamination meter used to quantify surface contamination against regulatory criteria



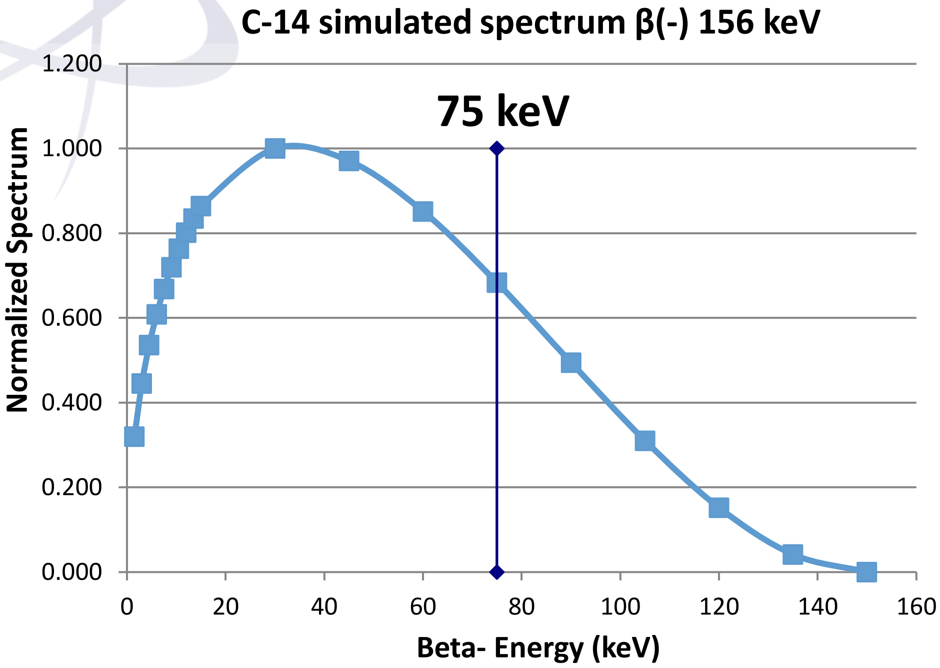
NOTE: This method cannot be used for short-lived medical isotopes due to unavailability of traceable sources

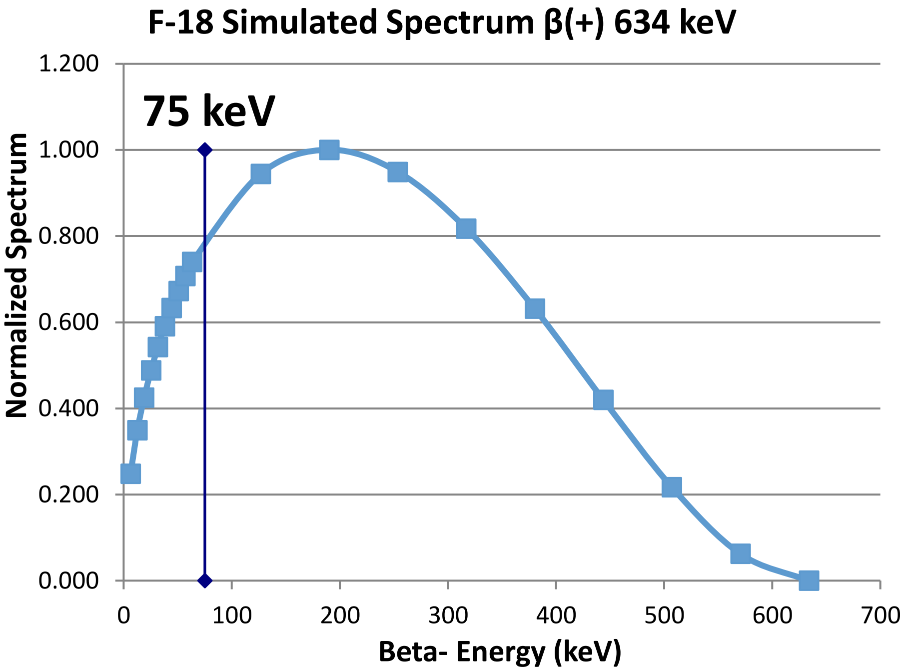
Method #2 - Traceable surrogate planar source

Important that energies are as close as possible, examples:

Isotope to measure	Max beta/electron energy	Gamma energy (branching ratio)
I-131	606 keV (89%)	364 keV (81%)
Cl-36/Ba-133 -- Surrogates	708 keV (100%) -- Cl-36	356 keV (62%) -- Ba-133
Tc-99m	120/138 keV (11%)	141 keV (89%)
Co-57 -- Surrogate	115/129 keV (3.2%)	122 keV (85%)

Beta counting efficiency vs energy

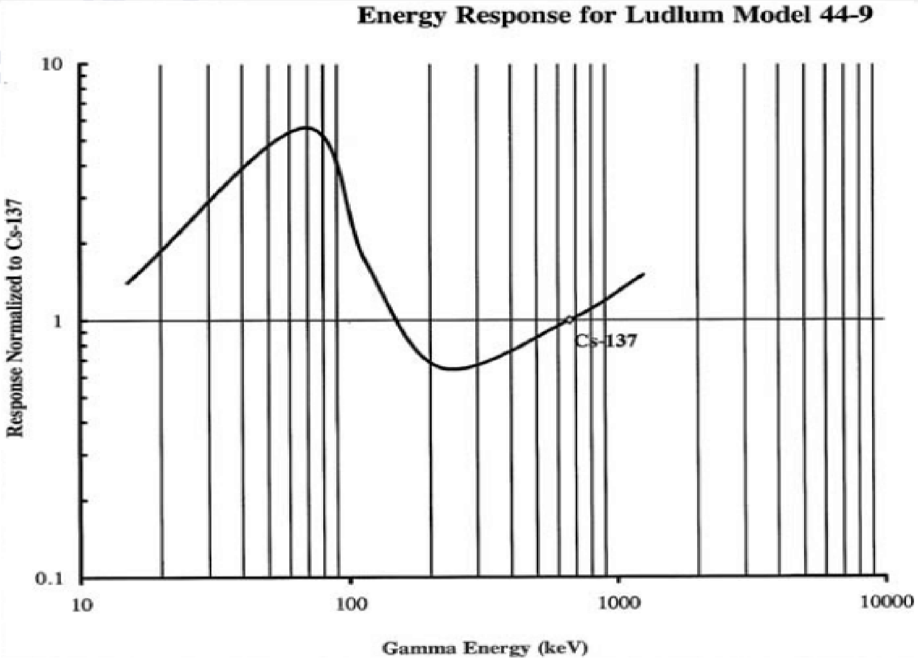




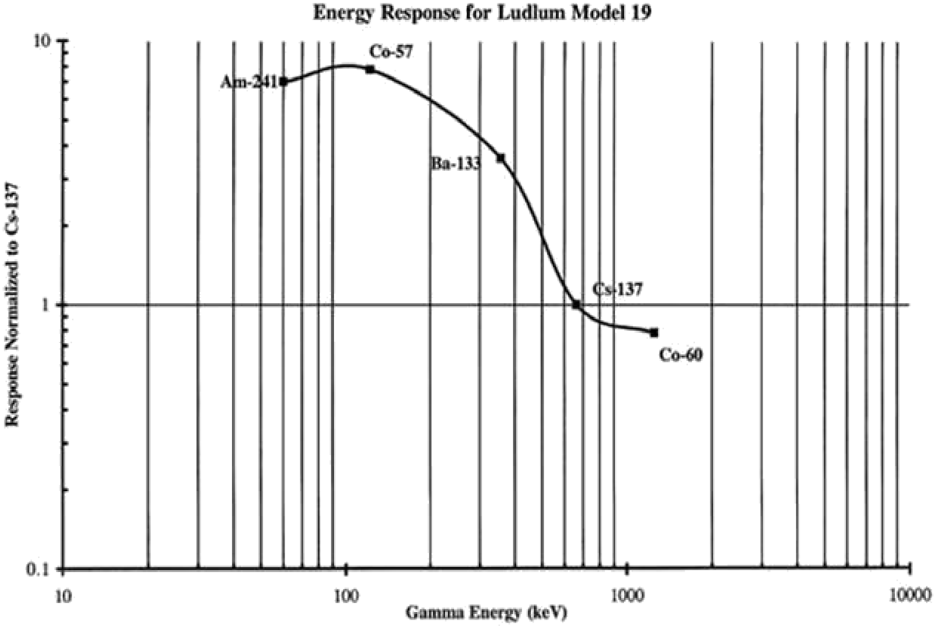
Typical energy cut-off for mylar window on pancake = **~ 75 keV**

Generally, as the beta energy increases, efficiency increases (for detectors sensitive to betas)

Gamma counting efficiency vs energy



GM-pancake



NaI 1” x 1”

Generally, as the gamma energy increases, efficiency decreases

Method #2 - Traceable surrogate sources – Branching Ratios

- Branching ratio corrections between target and surrogate nuclide must be applied when the α/β/γ emissions from the surrogate can be isolated; achieved by:
  - The detector: e.g., thick NaI only sensitive to γ, or a Ludlum 43-93 can discriminate α from βγ (note: a GM pancake does not discriminate α/β/γ)
  - The sources: separate surrogates for one target nuclide (e.g., Co-57(γ) source and C-14(β) source for Tc-99m, example to follow)
  - Shielding the source: verify α/β/γ count rate separately with shielding (e.g., Co-60 (γβ) planar source with/without plastic shield to isolate γ/β counting for Zn-65, example to follow)

Method #2 – Example using a GM pancake and Tc-99m

Same steps as in Method #1, but a surrogate nuclide is chosen

Isotope to measure	Max beta/electron energy	Gamma energy
Tc-99m	120/138 keV (11 %)	141 keV (89 %)
Co-57 -- Surrogate (gamma)	Source is designed to block electron emissions	122 keV (85 %)
C-14 -- Surrogate (beta)	156 keV (100 %)	None
Results		
Isotope	Measured efficiency	Correction factor applied
Co-57 (gamma)	0.21 %	0.21 % x (89/85) = 0.22 %
C-14 (beta)	5.3 %	5.3 % x (11/100) = 0.58 %

Extrapolated efficiency for Tc-99m: 0.22% + 0.58% = 0.8%

Method #2 – Example using a GM pancake and Zn-65

Same steps as in Method #1, but a surrogate nuclide is chosen

Isotope to measure	Max beta/electron energy	Gamma energy
Zn-65	330 keV (1.4 %)	1116 keV (51 %)
Co-60 -- Surrogate (gamma)	User blocks beta emissions with plastic (result = gamma cpm)	1173/1332 keV (200 %)
Co-60 -- Surrogate (beta)	318 keV (100 %)	Gamma cpm subtracted away by user (unshielded cpm – gamma cpm = beta cpm)
Results		
Isotope	Measured efficiency	Correction factor applied
Co-60 (gamma)	0.39 %	0.39 % x (51/200) = 0.1 %
Co-60 (beta)	16.5 %	16.5 % x (1.4/100) = 0.23 %

Extrapolated efficiency for Zn-65: 0.1% + 0.23% = 0.33%

Method #3 – Example using Tc-99m

- Same steps as in Method #1, but a custom source is produced
- 1 ml of Tc-99m measured at 1 MBq in a dose calibrator (just an example)

- Option A: wait 48 hours
  - Decayed activity = 1E6 Bq x e^((-ln(2)/6.02 hrs)*48 hrs) = 3.94 kBq
  - Extract a known fraction, spread evenly over 15cm^2 swipe
  - Measure the count rate and establish efficiency

- Option B: dilute with known volumes
  - Add known volume of water to achieve ~Bq/µl (may need multiple dilution steps)
  - Extract known activity (0.1 to 1 kBq), spread evenly over 15 cm^2 swipe
  - Measure the count rate and establish efficiency

Method #3 – Example using Tc-99m

- Must be repeated annually, and efficiency established/verified per detector, or
- Efficiency information can be transferred immediately to a long-lived check source (e.g., Cs-137) for every detector; for example:
  - Efficiency of 0.67% established using a decayed or diluted Tc-99m source for detector 1
  - Count rate from Cs-137 check source is measured (use same reference distance), and an efficiency of 0.16% is measured for detector 1
  - Efficiency ratio of 0.67/0.16 = 4.2 used to ***transfer*** the Tc-99m information to the Cs-137 source
  - Detector 1 verified and documented annually with Cs-137 source by multiplying the measured efficiency by 4.2

Method #4 – Example using Tc-99m for a GM pancake

- Contact your licensing specialist (or email me directly) for a reasonable and conservative efficiency to use for the target nuclide, or
- Verify the efficiency suggested or published by the manufacturer for target nuclide

  - For example, for Tc-99m: 0.5% (Ludlum publishes <1%, CNSC suggests 0.5%)

  - Same process seen in Method 3 to transfer efficiency to long-lived check source(s) for every detector and verify/document annually (update efficiency value if outside +/- 20% of initial value)

Method #4 – NOTES

- Method #4 is the least accurate – PLEASE adopt method 1, 2 or 3 if possible
- Transfer check source should ideally have the same emission types (α/β/γ) as target nuclide(s)
- If instrument has dual detector channels (α and β/γ, e.g., Ludlum 43-93 or Thermo AB100), then transfer check source(s) must have α/β/γ emissions to verify and transfer efficiency to both channels
- BE CAREFUL: Some manufacturers overstate their efficiencies
    - Berthold LB124 published efficiency for Tc-99m is 7.9%, experimentally verified to be 1-2%

Questions?

Thank you!