# ENVIRONMENTAL DEFENSE INSTITUTE

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# Review of Ralph Stanton's Radiation Dose from the 2011 Plutonium Inhalation Event at the Idaho National Laboratory - Part 1, Lung Counting


**Environmental Defense Institute**

**By Tami Thatcher, April 2022 update**

# The November 8, 2011 plutonium inhalation event at the Department of Energy's Idaho National Laboratory (INL)

- The accident occurred at the Materials and Fuels Complex (MFC) at the Zero Power Physics Reactor (ZPPR) facility.
- The Department of Energy Accident Investigation found that the accident was preventable and Battelle Energy Alliance failed to put mitigations in place, and ignored multiple warnings of risk to workers concerning plutonium plates.
- Battelle Energy Alliance faced fines if the maximum dose to a worker exceeded 5 rem/yr effective whole body or 50 rem/yr limiting organ or tissue.
- **A 0.1 rem (100 mrem) dose is the level that would indicate to DOE that the accident was of no serious consequence.** Using lung counting, urine and fecal bioassay and conducting a special solubility study, Battelle Energy Alliance estimated Ralph Stanton's dose from the accident as 102.5 millirem, effective whole body and 1166.3 millirem Bone Surface, or **0.1 rem whole-body and 1.2 rem bone.**

# Lung Counting Narrative from the November 8, 2011 plutonium inhalation event

- Lung counting was conducted November 8, the day of the accident at the ZPPR facility. Two workers had americium-241 results exceeding Decision Level.
- Lung counting was conducted again the next day, on November 9. Ralph was the only worker who had two lung counts on November 9.
- Lung counting results were recorded for a November 15 recount.
- The DOE Investigation report would state that “The rapid decreases in results following the initial counts indicates that at least part of the initial positive Am-241 count results could have been due to low-level external contamination…” Yet, DOE-ID has stated no external contamination affected the Day 1 lung count.

# ZPPR Plate Activity Ratio

| Nuclide | Activity Ratio Relative to Am-241 |
|---|---|
| Pu-238 | 0.135 |
| Pu-239 | 1.01 |
| Pu-240 | 0.490 |
| Pu-241 | 4.34 |
| Pu-242 | 0.000144 |
| Am-241 | 1.0 |

From Oak Ridge Bounding Intake and Dose Estimate, December 14, 2011. They used the ratio of Pu/Am of 1.7. [Pu-238 + Pu-239 + Pu-240]/Am-241 ratio of 1.7. The ratio of [Pu-239 + Pu-240]/Am-241 is 1.5.

Oak Ridge left out the Pu-241 ingrowth contribution to Am-241, acceptable for Type M (moderate clearance time) but not for Type S (slow, years of clearance time).

Low Activity Ratios for U-234 (2.65E-5), U-235 (2.63E-7) and U-238 (1.55E-5)

# ZPPR Plate Dose Conversion Factors, Type M

| Nuclide | Half-Life | Percent Mass | Activity Ratio to Am-241 | DCF Effective Whole Body (Sv/Bq) | DCF Bone Surface (Sv/Bq) |
|---|---|---|---|---|---|
| Pu-238 | 87.7 year | 0.0 % | 0.135 | 3.0E-5 | 9.1E-4 |
| Pu-239 | 24,100 year | 25.0 % | 1.01 | 3.2E-5 | 1.0E-3 |
| Pu-240 | 6540 year | 3.3 % | 0.490 | 3.2E-5 | 1.0E-3 |
| Pu-241 | 14.4 year | 0.1 % | 4.34 | 5.8E-7 | 2.0E-5 |
| Pu-242 | 380,000 year | 0.0 % | 1.44E-4 | 3.1E-5 | 9.6E-4 |
| Am-241 | 433 year | 0.4 % | 1.0 | 2.7E-5 | 1.1E-3 |
| U-238 | 4.47 billion year | 70.9 % | 1.55E-5 | 1.6E-6 | (low contribution) |

These DCFs are for 5 micrometer particles.

# Dose Conversion Factors, Inhalation, Effective Whole-body from ICRP 68

| | Pu-239 | Am-241 | |
|---|---|---|---|
| Type M, rem/Ci | 1.20E+8 | 1.00E+8 | Type M gives higher dose |
| Type S, rem/Ci | 3.10E+7 | 3.182E+7 | than Type S |

Alternate units of sievert per becquerel (Sv/Bq):

| | Pu-239 | Am-241 |
|---|---|---|
| Type M, Sv/Bq | 3.20E-5 | 2.70E-5 |
| Type S, Sv/Bq | 8.37E-6 | 8.60E-6 |

- Type M (moderate absorption in the body) predicts a higher dose than Type S (slow absorption in the body and slow clearance). BEA declared the dose to be from Type S but left out Pu-241 ingrowth of Am-241, incorrectly lowering their predicted dose about 10 percent.

# Ralph's Lung Counting for Americium-241

| Day | Am-241 Activity Estimate, nanocuries, based on 59.5 keV |
|---|---|
| Day 1 | 1.285 nCi |
| Day 2, 12:44 | < 0.278 nCi, (reported as Decision Level, DL) |
| Day 2, 15:41 | < 0.256 nCi, (DL) |
| Day 7 | <0.2587 nCi, (DL) |

- Americium-241, with its high abundance gamma emission at the energy of 59.5 keV is typically relied upon, and used to estimate both americium and plutonium in the lungs by knowing ZPPR plate composition.
- The Activity Estimate stated for the lung count is below the "intake" and must take into account the time elapsed between the accident and the lung count. Lung count reports do not include the higher estimated "intake," the Pu-239 also present and do not provide the estimated radiation dose.

# Ralph's Lung Counting for Americium-241

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| Day 7 | <0.2587 nCi, (DL) |

- Although these results appear comforting, Ralph's first day result is the highest for the workers. Also, note that a single nasal swipe of 4000 dpm would correspond to 1.8 nanocuries on the swipe.
- Ralph's Day 1 lung count results were not given to Oak Ridge for the initial radiation dose estimation.
- Ralph's Day 1 lung count bounding dose estimate would have exceeded federal limits of 5 rem whole body and 50 rem bone (using Type M and 5 um particles)

# Digging deeper into the Lung Counting reports, Am-241

| Day | Activity Estimate | DL, nCi | Gross, cps | Background, cps |
|---|---|---|---|---|
| Day 1: | 1.285 nCi | "N/R" | 3.23E-2 | 0.0 (DL missing, background=0?) |
| Day 2, 12:44: | 0.227 nCi | < 0.278 nCi | 3.25E-2 | 2.68E-2 (Same gross cps as Day 1) |
| Day 2, 15:41 | 0.227 nCi | < 0.256 nCi | 2.76E-2 | 2.25E-2 |
| Day 7 | -0.178 nCi | <0.2587 nCi | 2.39E-2 | 2.80E-2 (wrong CWT, & Ralph not present) |

- The odd Background of 0.0 for Am-241 is accepted for another worker's results.
- Ralph's and two other DL values are declared "N/R" in lung counting explained in the Oak Ridge report as "not reported." Alternate estimates of DL are made by Oak Ridge.
- DOE denies that there was skin contamination and declares that the Day 1 lung count was properly calibrated and had been properly conducted.
- Why then was Ralph's Day 1 lung count not provided to Oak Ridge? Apparently, it was because the dose estimate by Oak Ridge would have exceeded 5 rem whole body and 50 rem bone.

# *What would 1 nCi Am-241 as a Lung count result mean?*

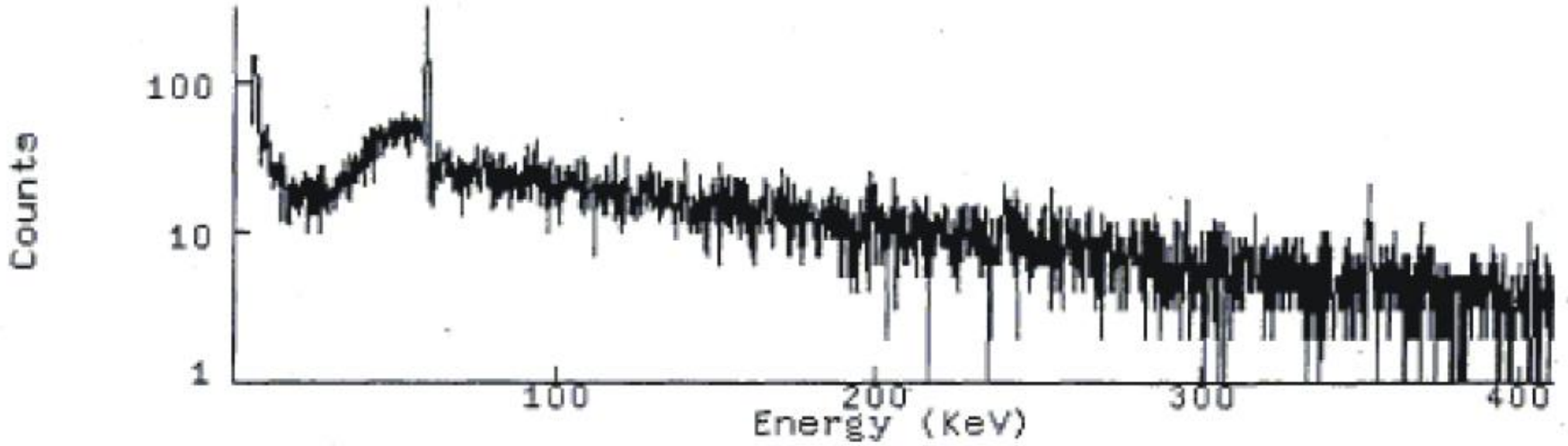
If a lung count found 1 nanocurie of Am-241, for the ZPPR plate, that would mean there was also Pu-239, Pu-240, Pu-241 and Pu-238 present. For simplicity, Oak Ridge multiplied the Am-241 activity by 1.7 to estimate Pu.

But the lung retention for the time between the event and the lung count must be accounted for and gives the estimated intake of Am (and Pu). The Am-241 from a lung count would be divided by 6.33E-2 for Day 1.

15.8 nCi Am-241 * 1.0E8 rem/Ci = 1.58 rem and 26.9 nCi Pu-239 * 1.2E8 rem/Ci = 3.23 rem

| | Am-241, nCi | Pu-239, nCi | Am+Pu, nCi | Am+Pu, dpm |
|---|---|---|---|---|
| Hypothetical lung count "result" finds 1 nCi Am for ZPPR plate | 1 nCi | 1.7 nCi | 2.7 nCi | 5994 dpm |
| Lung burden given elapsed time to lung count on Day 1 | 15.8 nCi | 26.9 nCi | 42.7 nCi | 94,794 dpm |
| Estimated dose for chest wall thickness of 5.36 cm and Type M clearance dose conversion for the 1 nCi Am-241 lung count "result" | 1.58 rem (whole body) | 3.23 rem (whole body) | 4.81 rem (whole body) | 4.81 rem (whole body) |

# Example gamma spectra from a Rocky Flats lung count, ORAUT-TKBS-0011-5




This lung count detected Am-241 at 59.5 keV. The counts, in this case, are in counts per minute but are often reported in counts per second (cps).

# Plutonium and americium are known as “alpha” emitters, but a portion of Am-241 decays also produce gamma rays

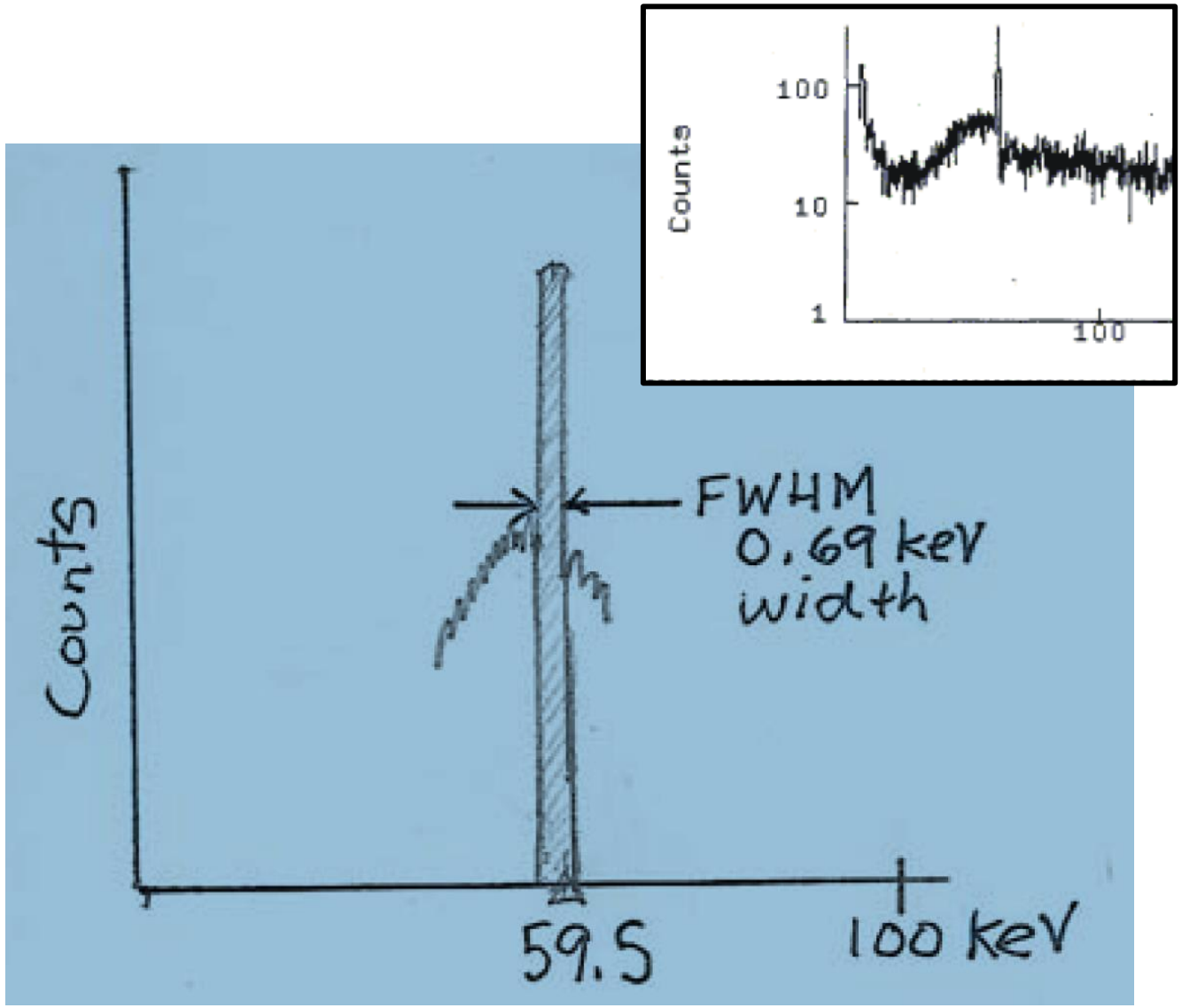
- When Am-241 decays, 36 percent of the alpha decays also emit a gamma ray with the energy level near 59.5 keV. The 36 percent is called “abundance” or “yield.”
- Lower energy gammas (or x-rays) (below 100 keV) are more difficult to detect and therefore have a lower “efficiency” than higher energy gammas.
- A higher chest wall thickness (CWT) means the detector will detect fewer gamma rays.
- The lower number of gross counts detected for a person with a larger chest wall thickness (CWT) will return a higher activity (nanocurie) result [than a person with a lower CWT] after CWT and the detector efficiency are accounted for.
- Gross counts associated with the area of the photopeak minus the “background” counts equals “net” counts. Net counts are converted to activity (nanocurie) and compared to the Decision Level for that lung count.

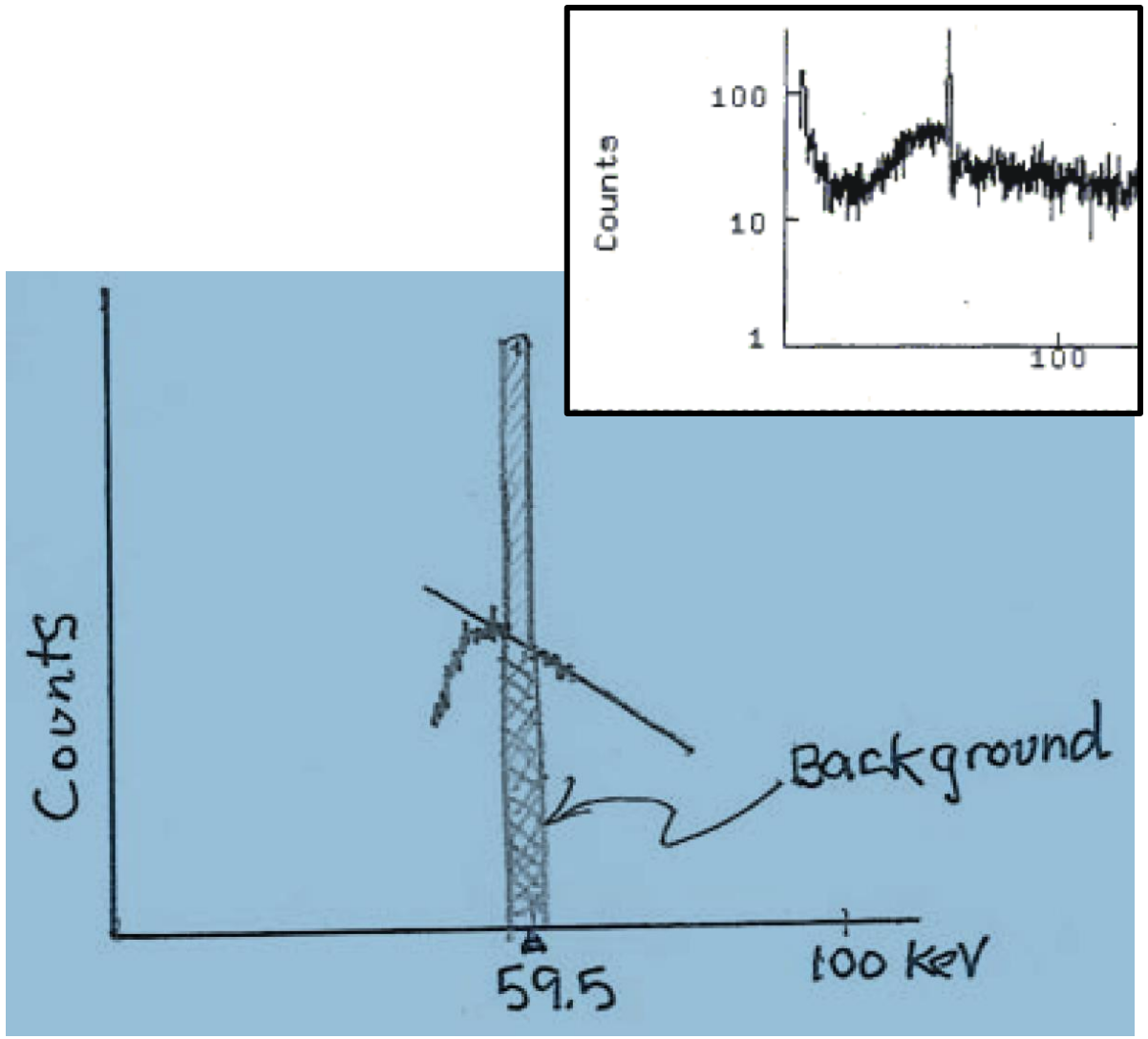
# Americium-241

The expected photo peak for Am-241 for 59.5 keV energy gammas is a narrow peak near 59.5 keV.

The shaded area represents “gross counts.”

The width of the photo peak is fixed at 0.69 keV FWHM value, no matter the actual spread. For a 0.1 keV wide channel, 7 channels would span the FWHM.





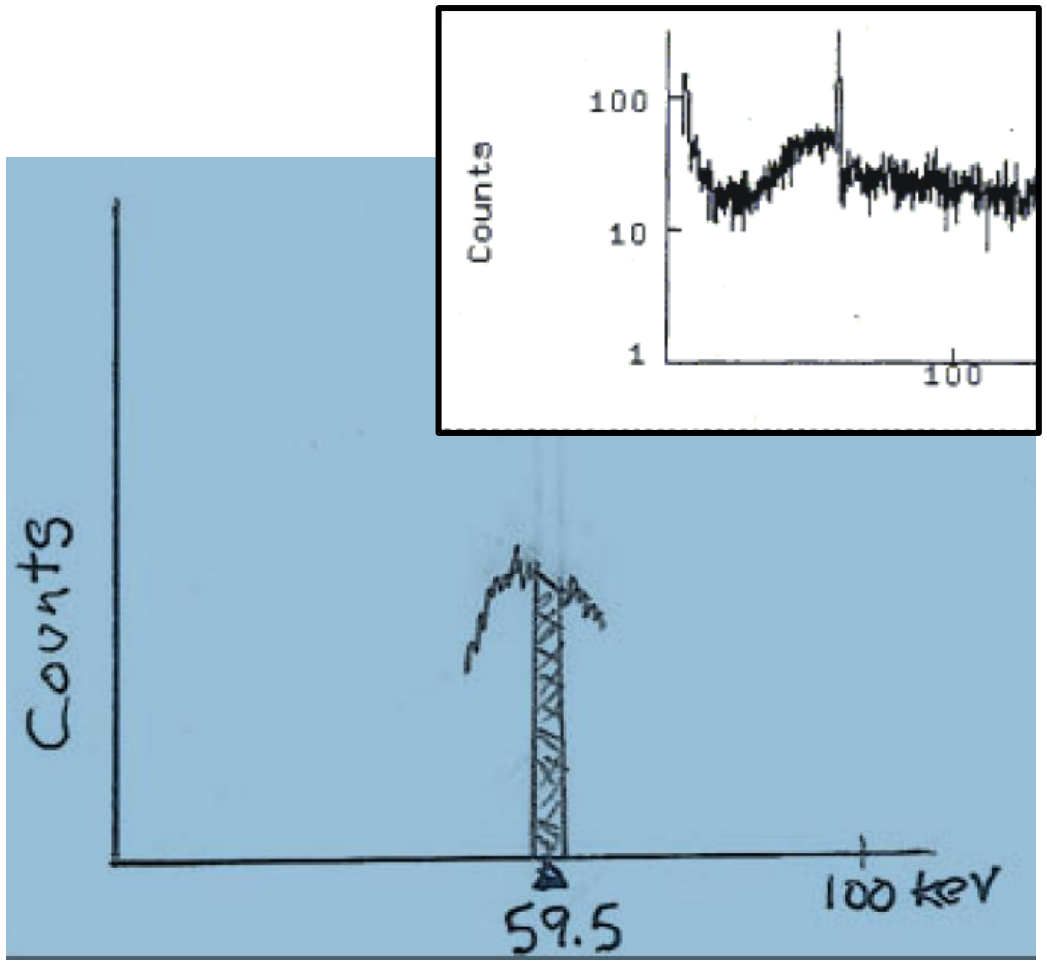

# Photo peak at energy near 59.5 keV

The “base” or “Background” is determined from the heights to the left and right of the photo peak.

The “base” or “Background” is shown in the cross hatch.

Gross counts minus Background counts equal “Net” counts.

Net counts (in counts per second) are converted to activity (nanocuries) using detector efficiency, CWT and gamma ray abundance. Net results are compared to “Decision Level” for the lung count.



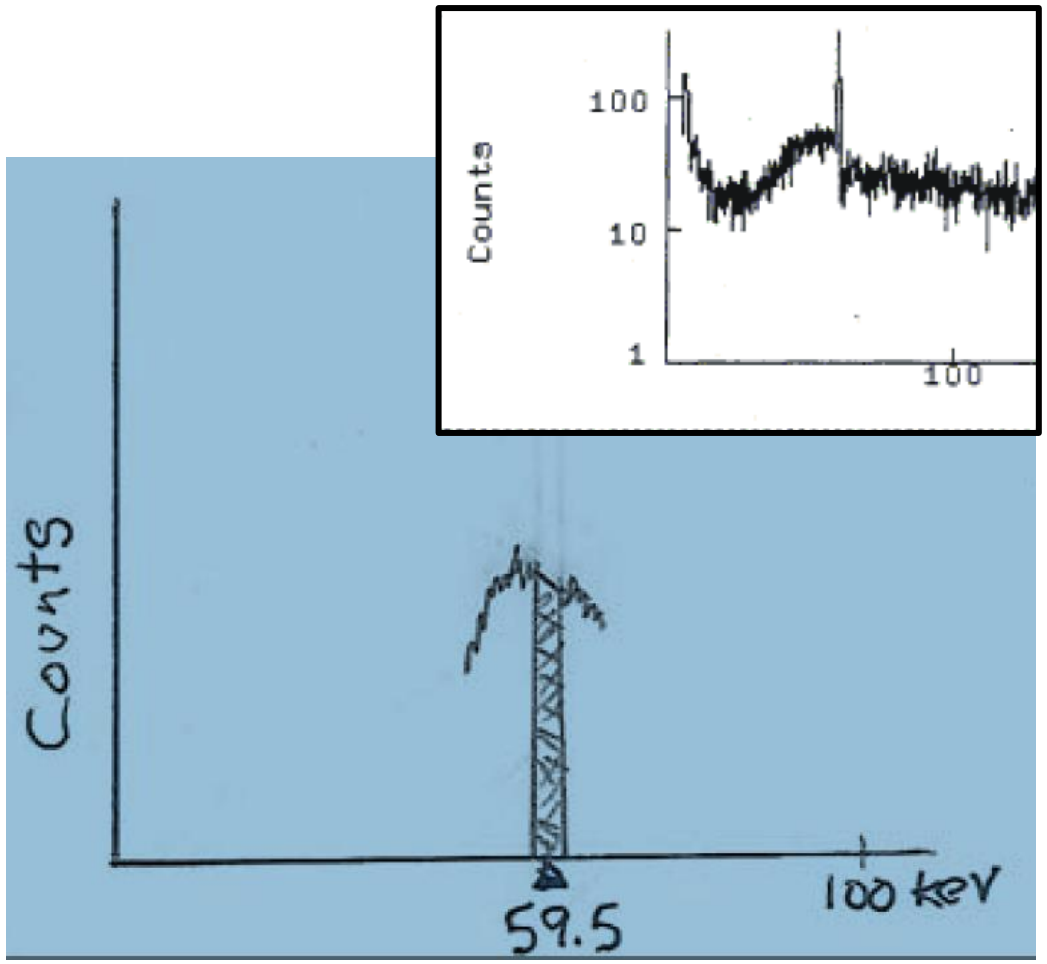

# The Missing Photo Peak ?

In several cases, BEA's Lung Counting software issues a message that "peak search" was not sure which radionuclide was associated with the expected energy (59.5 keV here). No peak was found in the center but to the left and right, peak values were found, outside of the 0.69 FWHM keV range.

The software cannot determine the "Background" and sets the background counts equal to 0.0.

The missing peak not only shifted left and spread across more energy channels, there is not a way to determine the original height of the missing photo peak from the lung count report.

If Ralph's lung counting actually found no Am-241, why were Ralph's urine and fecal bioassay results still detecting americium and plutonium even 224 days after the accident and preventing his return to radiation work?




# The Missing Photo Peak ?

The software could not determine the “Background” and sets the background counts equal to 0.0.

The gross counts for Am-241 on Day 1 and Day 2 (12:44) are nearly identical. No clearance from the lungs is indicated.

The Am-241 result is lowered only because background was subtracted on Day 2 (12:44) count. The sides around 59.5 keV were lowered on Day 2 (12:44) – but why?

# Gamma Spectrometry Analysis

- The gamma spec equipment counts the gamma events and keeps track of how many decays occurred and at what energy level (in kiloelectron volts, keV).
- Many radionuclides emit gamma rays of several energy levels.
- Software is used to evaluate the counts associated with each energy level, and hopefully, identify and quantify the radionuclides present from the jungle of gamma ray energies. Unusual proportions of radionuclides complicate gamma spectrometry.
- Not all radionuclides emit gamma rays. Strontium-90, and other pure “beta” emitters cannot be directly estimated from gamma spec.

# Gamma energy levels, examples

| Radionuclide | Gamma Ray Energy (keV) | Gamma Ray Abundance per decay, percent |
|---|---|---|
| Thorium-234 | 63.3 keV | 3.81 % |
| | 92.4 keV | 2.73 % |
| | 92.8 keV | 2.69 % |
| Uranium-235 | 143.8 keV | 10.5 % |
| | 185.7 keV | 54.0 % |
| Americium-241 | 17.5 keV | 19.5 % |
| | 59.5 keV | 36.0 % |

# Actinide Radioactive Decay Series

- Uranium-238, uranium-235, thorium-232 are naturally occurring radionuclides that decay through a long series of decay progeny.

U-238

↓

Th-234 → Pa-234 → U-234

. ↓

. Th-230 → Ra-226 → Rn-222 → Po-218 → Pb-214

. ↓

. and more

# Actinide Radioactive Decay Series

- Note that plutonium-238 ties into the uranium-238 decay series.

U-238 **Pu-238**

↓ ↓

Th-234 → Pa-234 → U-234

. ↓

. Th-230 → Ra-226 → Rn-222 → Po-218 → Pb-214

. ↓

. *Pu-238 can add to decay progeny such as the Pb-214* and more

# Actinide Radioactive Decay Series

Lead-214 (Pb-214) can result from the decay of naturally-occurring uranium-238 ----and also from unnatural levels of uranium-238, or the decay of plutonium-238. **Detecting the presence of Pb-214 does not ensure that the source was low or naturally-occurring.**

Manmade plutonium-239 decays to “naturally occurring” uranium-235.

Manmade uranium-236, U-232 and plutonium-240 decay into the “naturally occurring” thorium-232 series.

Plutonium-241 (half-life of 14.35 years) decays to americium-241.

Having a greater variety of radionuclides present complicates gamma spec and may invalidate assumptions built into the libraries used to identify radionuclides and estimate radionuclide quantities.

# Actinide Radioactive Decay Series

Plutonium-241 (half-life of 14.35 years) decays to americium-241 which decays to neptunium-237 and through the “neptunium” series. Americium-241 ingrowth from Pu-241 increases significantly in just a few years.

| | beta | | alpha | | alpha | |
|---|---|---|---|---|---|---|
| Pu-241 | → | Am-241 | → | Np-237 | → | Pa-233 → more |
| (14 year) | | (433 year) | | (2,200,000 year) | | |

The decay of Pu-241 to Am-241 causes Am-241 to buildup in a few years time. Pu-241’s beta emission has a low dose, but Am-241 gives a large dose.

# Department of Energy Lung Count Reports historically incomplete and unreliable

- Printed lung count reports do not explain what the results mean in terms of radiation dose.
- Printed lung count reports do not reveal all important sources of uncertainty such more shielding from higher ratio of muscle to fat or errors in general chest wall thickness estimates.
- Gamma spec software allow **unrecorded manipulations** to reduce gross counts, increase background counts (to decrease net counts), and even remove peaks.
- The methods and software currently used have been used since about 1999 and peak search problems should not have occurred if gamma spectra were normal. Reviews inadequately documented.

# Ralph's Lung Count Reports contain numerous irregularities

- Numerous software peak search program problems occur. This can happen when the photo peaks are not where they are expected and for other mismatches between the gamma spectrum and libraries used by the software.
- The photo peak search problems cause background to be set to 0.0. This problem occurs only for the next most contaminated worker, yet those lung count results were accepted.
- While the 59.5 keV Am-241 gamma is the primary focus of BEA's lung counting, U-238, U-235, Pu-239, Pu-238 and U-238's Th-234 are reported.
- If the lung count results found only normal background spectra, why did various peak search problems occur among Ralph's lung counts? (Am-241, Pb-214, Th-234?)

# Ralph's Lung Count Reports contain numerous irregularities (Continued)

- There are also unusual trends and disproportional changes across the results.
- For example, Ralph's lung count Am-241 gross counts from Day 1 are similar to the first lung count on Day 2 (12:44). But the second count on Day 2 (15:41), the gross count drops substantially from the first Day 2 count.
- Thorium-234 results on Day 7 drop by **a very large amount** yet the error in the Chest Wall Thickness should have increased the estimated activity as it did for other radionuclides as would be expected for that error.
- The numerous irregularities in Ralph's lung count reports appear to have been missed by various reviewers.

# Lung Counting reporting for the 17.5 keV Americium peak

| Day | Activity Estimate | DL, cps | Gross, cps | Bkg, cps |
|---|---|---|---|---|
| **Day 1:** | **55.5 nCi** | **7.57E-3** | **1.90E-2** | **1.40E-2** |
| Day 2, 12:44 | -19.2 nCi | 4.79E-3 | 1.52E-2 | 1.69E-2 |
| Day 2, 15:41 | 6.61 nCi | 4.88E-3 | 1.58E-2 | 1.52E-2 |
| Day 7 | -52.0 nCi | 4.99E-3 | 1.65E-2 | 2.04E-2*wrong CWT |

- The Am-241 abundance at 17.5 keV is 19.5 percent, the efficiency (for the detector and CWT) is 1.26E-3 percent. The 17.5 keV Am-241 photo peak estimate yields a much higher estimate of Am-241 lung burden than the 59.5 keV peak, in Ralph's lung counts.

# Lung Counting reporting for the 17.5 keV Americium peak

| Day | Activity Estimate | DL, cps | Gross, cps | Bkg, cps |
|---|---|---|---|---|
| **Day 1:** | **55.5 nCi** | **DL = 7.57E-3 cps** | **1.90E-2** | **1.40E-2** |
| **(Note: Day 1 DL = 83.27 nCi by converting cps using CWT and detector eff)** | | | | |
| Day 2, 12:44 | -19.2 nCi | 4.79E-3 | 1.52E-2 | 1.69E-2 |
| Day 2, 15:41 | 6.61 nCi | 4.88E-3 | 1.58E-2 | 1.52E-2 |
| Day 7 | -52.0 nCi | 4.99E-3 | 1.65E-2 | 2.04E-2*wrong CWT |

- Day 1 result appears the most reliable and I use it without averaging the other counts. While the Net counts, (Gross minus Background = Net) are below DL, the activity estimate is within a factor of 2 of the DL. It need not be discarded.
- Day 7's background counts are inexplicably high, lowering the result.

# Examples of Lung burden to estimate "Intake"

| Lung Count "Result" for Am-241 | Lung Burden, nCi, for Am-241 | Estimated Intake of Am-241 | Bounding Intake of Am-241 | Bounding Intake of Pu-239 |
|---|---|---|---|---|
| 0.227 nCi (from 59.5 keV, first Day 2 lung count) | 0.278 nCi DL (result below DL so DL was the assumed lung burden) | 4.83 nCi (5.76E-2 lung retention based on time elapsed since event for Day 2) | 4.8 nCi | 8.2 nCi |
| 1.29 nCi (from 59.5 keV, Day 1 lung count) | 1.29 nCi | 20.4 nCi (6.33E-2 lung retention for Day 1 count) | 20.4 nCi | 34.68 nCi |
| 55.5 nCi (from 17.5 keV, Day 1 lung count) | 83.27 nCi, DL | 877 nCi, (I chose 55.5 nCi as a less conservative estimate than DL and 6.33E-2 lung retention for Day 1) | 877 nCi | 1491 nCi |

*Estimated based on Oak Ridge Bounding Dose Estimate of December 14, 2011 or scaling to their estimates for the same CWT & time of count.

# Bounding “Intake” to estimate Dose, Type M

| Bounding Intake of Am-241 | Bounding Intake of Pu-239 | Effective Whole-Body Dose, rem | Bone Surface, Committed Equivalent Dose, Rem |
|---|---|---|---|
| 4.8 nCi | 8.2 nCi | 1.45 rem<br>This ignored Day 1 lung count | 49.7 rem |
| 20.4 nCi | 34.68 nCi | 6.0 rem<br>This reflects Day 1 lung count for 59.5 keV | 204 rem |
| 877 nCi | 1491 nCi | 265 rem<br>This reflects Day 1, 17.5 keV Am-241 lung count | 9081 rem |

In contrast, BEA’s dose estimate was 1.1 nCi Am-241 and 1.9 nCi Pu, for **0.1 rem whole-body and 1.2 rem bone, Type S.**

# Method for Estimation of Inhalation from CAM Derived Air Concentration (DAC)

- This example uses 791 DAC measured by CAM
- DAC for Pu-239 from 10 CFR 835 is 5E-12 microcurie/milliliter, uCi/mL (assumes all Pu-239)
- 5 minutes of breathing time during accident
- Breathing rate, 1.5 cubic meter/hr (m3), *average person*
- 791 DAC*5E-12 uCi/mL = 4E-9 uCi/mL

4E-9 uCi/mL * 5 min * (1hr/60 min) *1.5 m3/hr * E6mL/m3 =

= 5.0E-4 uCi = 0.5 nanocuries = 1110 disintegrations per minute

# Inhalation estimate based on contamination levels (not lung counts)

| Inhaled Am Pu mixture, Activity | Inhaled Am Pu mixture, dpm | Basis |
|---|---|---|
| 0.5 nCi | 1110 dpm | 791 DAC, CAM 15 ft away from breathing space (assumes all Pu-239) |
| 2.94 nCi | 6535 dpm | 4657 DAC, CAM 15 ft away maximum reading (assumes all Pu-239) |
| 450 nCi | 1 million dpm | Assumed possible 1 million dpm |
| 2250 nCi | 5 million dpm | Based on 5.5 million dpm swipe (rounded low)<br>Corresponds to:<br>833 nCi Am-241 and 1417 nCi Pu-239 |

The 5 million dpm contamination is similar to Bounding Intake from lung count's 17.5 keV intake. This is also more consistent with long term urine and fecal excretion of Pu and Am, the symptoms after the event and blood changes than BEA's estimate. The higher estimates of plutonium and americium intake are credible.

# Nasal smear results

| Pu-239 Activity, nCi | Am-241, nCi | Both nostrils, Pu+Am dpm | Intake, Pu+Am dpm | Basis |
|---|---|---|---|---|
| 0.181 nCi | 0.107 nCi | 401 + 238 dpm | 12,780 dpm | BEA's stated nasal results, max. 284 dpm one nasal swab, Pu-239/240. Total 639 dpm for left and right nostril Pu-239/240 and Am-241 |
| 4.17 nCi | 2.78 nCi | 9250 dpm + 6167 dpm | 185,000 + 123,333 dpm | For 4625 dpm one nasal swab, Pu-239/240 (missing logbook). Total 15,417 for left and right nostril Pu-239/240 and Am-241. The Pu-239 alone yields 10 rem (Type M, 5 um) For both Pu and Am, 60 rem (Type M, 1 um) |

- Left and right nostrils added together are divided by 0.05 to estimate intake.
- 4625 dpm x 2 = 9250 dpm for left and right nostrils, only Pu-239/240.

# BEA Underestimated Ralph's Radiation Intake and Dose

- BEA's estimated dose was **0.1 rem whole-body and 1.2 rem bone** and an inhalation intake of 2.99 nCi (Pu + Am) with some ingestion and used Type S dose conversion factors. This low dose is incongruent with the evidence.
- A more realistic dose estimate reasonably involves an inhalation intake of no less than 55 nCi and as high as 2250 nCi (Pu + Am). Using Type M dose conversion factors, the dose would be from **6 rem to 265 rem**, effective whole body dose. **The long-lasting blood changes mean the dose was higher than 6 rem, effective whole body.**
- These estimates would be reduced if Type S dose conversion factors are used, but **Pu-241 ingrowth must be included**. And the possibility of Super S Class for more highly insoluble material was not investigated, which could increase the lung dose estimate above Type S.

# Effective Whole-Body and Bone Dose Estimates

| Am-241 Activity, nCi | Pu-239, Activity, nCi | Intake Pu+Am dpm | Effective Whole-Body Dose, rem | Bone Surface, Committed Equivalent Dose, Rem | Basis |
|---|---|---|---|---|---|
| 1.09 nCi | 1.9 nCi | 6646 dpm | 0.1 rem | 1.2 rem bone | BEA's low dose is not credible. (Type S, 5um) |
| 20.4 nCi | 34.68 nCi | 122,278 dpm | 6 rem | 204 rem bone | Based on Day 1 59.5 keV Am-241 lung count, also too low to be credible. (Type M, 5 um) |

**BEA's low dose estimate of 102.5 millirem is not credible. And 5 rem whole-body was substantially exceeded.**

**The Day 1 lung count is also too low to be credible compared to nasal swab and bioassay results.**

# Effective Whole-Body and Bone Dose Estimates

| Am-241 Activity, nCi | Pu-239, Activity, nCi | Pu+Am dpm | Effective Whole-Body Dose, rem | Bone Surface, Committed Equivalent Dose, Rem | Basis |
|---|---|---|---|---|---|
| 55.55 nCi | 83.33 nCi | 308,333 dpm | 15.6 rem (5 um)<br>60 rem (1 um) | 534 rem (5 um)<br>1096 rem bone (1 um) | Based on nasal swab result of 4625 dpm per nostril Pu-239/240 |
| 877 nCi | 1491 nCi | 5 million dpm | 265 rem | 9081 rem bone | Upper bound, based on Day 1 17.5 keV Am-241 lung count; and consistent with 5 million dpm contamination level. (Type M, 5 um) |

**BEA's low dose estimate of 102.5 millirem is not credible. And 5 rem whole-body was substantially exceeded.**

# Smaller particle size increases dose

- Particle size not known
- Bioassay points to small particle size
- Particle size not investigated
- Type M solubility and 1 micrometer diameter particle size yields over 4 times higher whole-body dose than 5 micrometer diameter particle size.

# Whole-Body Dose Conversion Factors

| Particle Size and Solubility Type | Effective Whole-Body DCF, rem/Ci (Bone Surface DCF, rem/Ci) | |
|---|---|---|
| | Am-241 | Pu-239/240 |
| 5 um, Type M | 1.0E8 rem/Ci WB (40.7E8 rem/Ci Bone) | 1.2E8 rem/Ci WB (37.0E8 rem/Ci Bone) |
| 1 um, Type M | 4.44E8 rem/Ci WB (80.3E8 rem/Ci Bone) | 4.29E8 rem/Ci WB (78.07E8 rem/Ci Bone) |

- FGR 11, 1 um, Type M. Smaller particle size delivers higher dose.
- ICRP 68, (1994) 5 um, Type M.
- Intake multiplied by DCF equals radiation dose.

# Effective Whole-Body and Bone Dose Estimates

| Am-241 Activity, nCi | Pu-239, Activity, nCi | Pu+Am dpm | Effective Whole-Body Dose, rem | Bone Surface, Committed Equivalent Dose, Rem | Basis |
|---|---|---|---|---|---|
| 55.55 nCi | 83.33 nCi | 308,333 dpm | 60 rem (1 um) | 1096 rem bone (1 um) | Based on nasal swab result of 4625 dpm per nostril Pu-239/240 |
| 1.09 nCi | 1.9 nCi | 6646 dpm | 0.1 rem | 1.2 rem bone | BEA's Final Dose Estimate, Type S, 5 um particle size. Dose estimate not credible. |

**BEA's low dose estimate of 102.5 millirem is not credible. And 5 rem whole-body was substantially exceeded.**

# Thank you

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# Key References


- U.S. Department of Energy Office of Health, Safety and Security Accident Investigation Report, *Plutonium Contamination in the Zero Power Physics Reactor Facility at the Idaho National Laboratory, November 8, 2011*, January 2012.
- Oak Ridge National Laboratory, UT-Battelle, *Independent Review, Bounding Intake and Dose Estimates Associated with the November 8, 2011 Airborne Release at the INL Zero Power Physics Reactor*, December 14, 2011.
- Battelle Energy Alliance, Dose Assessments for November 8, 2011 ZPPR Event, INL/INT-12-12-27269, September 2012. Partial report, Redacted.
- Lung count reports issued by Battelle Energy Alliance for Ralph Stanton for November 8, 9 (12:44), 9 (15:41) and November 15.

# Acronyms

- Bkg – background or base
- cps – counts per second
- CWT Chest Wall Thickness estimated from height and weight
- DAC – derived air concentration
- DL – Decision Level, based on decay counting statistics
- dpm – disintegrations per minute
- FWHM – full width half maximum is the width of the photopeak at half its height, or the assumed width for that region of the spectrum in gamma spectrometry
- keV – kiloelectron volt, energy level unit for measuring gamma ray energy
- nCi – nanocurie or 1.0E-9 curie
- Rem - a doubly-diluted measure of radiation health harm based on expected cancer fatality risk, only loosely related to absorbed dose. 100 rem equals 1 Sievert.

# Helpful conversions

- 1000 nanocurie (nCi) is equal to 1 microcurie (uCi)
- 1 disintegration per minute (dpm) is divided by 60 to obtain 0.0167 disintegrations per second (dps)
- 1 disintegration per second equals 1 becquerel (Bq)
- 1 curie equals 37 E+9 Bq
- 1 dpm/2220 equals the result in nCi
- Derived Air Concentration (DAC) requires the radionuclide's 10 CFR 835 radioisotope's Appendix A concentration
- Converting Decision Level in counts per second to activity requires the detector and chest wall thickness efficiency and the gamma ray's abundance.
- DL (nCi) = $\frac{\text{DL (cps)} * 1E+9 \text{ nCi} * 100 * 100}{37 \text{ E9 dps} * \text{Efficiency in percent} * \text{Abundance in percent}}$
- For example, $\frac{9.56E\text{-}3 \text{ cps} * 1E+9 \text{ nCi} * 100 * 100}{37 \text{ E9 dps} * 0.189 * 36.0}$ = 0.3797 nCi, Am-241 DL for CWT 5.36 cm

# Helpful conversions (continued)

- A High Purity Germanium (HPGe) detector is used for lung counting and could have 4096 to 16,000 channels.
- A Full-Width-Half-Maximum (FWHM) width of 0.69 keV could span seven 0.1 keV channels.
- Gamma spectroscopy uses energy levels of gamma rays to identify radionuclides; gamma spectrometry quantifies the activity of the radionuclides using the number of emitted gamma rays.

- February 23, 2022, *224 days corrected March 19, 2022. Minor edits March 20, 2022.
- April 22, 2022 revised nasal swab for 4625 dpm Pu-239/240 each nostril and added Am-241 based on ratio of Pu-239/240 to Am-241 of 1.5. Dose using 1 micrometer diameter FGR 11 rather than 5 um dose conversion factors.