Review of Plutonium Attribute Measurement Technologies

Neutron Measurements:
Pu Mass & Absence of Oxide

Doug Mayo
Los Alamos National Laboratory
## Attributes: Neutron Measurements

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<td>$^{240}\text{Pu}$-effective + isotopes</td>
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<td>Absence of Oxide</td>
<td>NMC &amp; Pu900</td>
<td>Alpha &gt; 0.5 and 870.8 keV line present</td>
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Attribute: Pu Mass above a Threshold

Combine

High-Resolution Gamma-Ray Isotopic Measurement

$^{240}\text{Pu} / ^{239}\text{Pu}$

with

Neutron Multiplicity Measurement

$^{240}\text{Pu}$-effective mass

to obtain

Pu mass
Three fundamental variables contribute to the neutron emissions from plutonium:

- $^{240}$Pu-effective spontaneous fission rate
- $(\alpha,n)$ neutron rate
- Induced fission rate

In Neutron Multiplicity Counting, these three pieces of measured information are used with a mathematical model to deduce an assay value. Sample-dependent calibration is not required for many categories of materials.
Neutron Multiplicity Counting

Three elements are necessary:

1. an efficient detector (typically 40–55%) with low die-away time and dead-time;
2. electronics to obtain a distribution of multiplicities from the neutron pulse stream—the multiplicity shift register:
   - an MSR4, Canberra 2150,
   - Aquila PSR-B, or Ortec/Antech AMSR; and
3. a mathematical model to relate the measured quantities to the processes that produce the neutron pulse stream—the “point model.”
The Point Model

Singles Rate:

\[ S = F \varepsilon M v_{s1}(1+\alpha) \]

Doubles Rate:

\[ D = F \left( \frac{f_D}{2} \right) (\varepsilon M)^2 \{ v_{s2} + [(M-1)/(v_{i1}-1)] v_{s1}(1+\alpha) v_{i2} \} \]

Triples Rate:

\[ T = F \left( \frac{f_T}{6} \right) (\varepsilon M)^3 \{ v_{s3} + [(M-1)/(v_{i1}-1)][3v_{s2}v_{i2} + v_{s1}(1+\alpha) v_{i3}] \]
\[ + 3[(M-1)/(v_{i1}-1)]^2 v_{s1}(1+\alpha) v_{i2}^2 \} \]
The Point Model

Detector Parameters:
\[ \varepsilon = \text{detection efficiency} \]
\[ f_D = \text{fraction of doubles in the coincidence gate} \]
\[ f_T = \text{fraction of triples in the coincidence gate} \]

Source Parameters:
\[ F = \text{spontaneous fission rate} = 473.5 \text{ fissions/s/g}^{240}\text{Pu}-\text{effective mass} \]
\[ M = \text{fission multiplication} \]
\[ \alpha = \text{ratio of } (\alpha,n) \text{ neutron rate to spontaneous fission rate} \]

Nuclear Parameters:
\[ (n = s \Rightarrow \text{spontaneous fission}, n = i \Rightarrow \text{induced fission}) \]
\[ \nu_{n1} = \text{average number of neutrons produced per fission event} \]
\[ \nu_{n2} = \text{average number of neutron “pairs” per fission event} \]
\[ \nu_{n3} = \text{average number of neutron “triplets” per fission event} \]
To Calibrate a Multiplicity Detector

Use a known $^{252}$Cf source so that

$M = 1$ and $\alpha = 0$. Then,

$S = F \varepsilon \nu_{s1}$

$D = F (f_D / 2) (\varepsilon)^2 \nu_{s2}$

$T = F (f_T / 6) (\varepsilon)^3 \nu_{s3}$

where now

$F$ = spontaneous fission rate for the $^{252}$Cf source

$\nu_{s1} = 3.75$

$\nu_{s2} = 11.96$

$\nu_{s3} = 31.81$

With $F$ known for a given calibration source, can solve for $\varepsilon$, $f_D$, and $f_T$. In principle, if a detector is properly optimized, representative standards are not needed for calibration in multiplicity counting.
Drum Neutron Multiplicity Counter: A Fully Optimized System

- Detector head with junction box
- Computer
- Multiplicity shift register and power supplies
Measurements at Rocky Flats Environmental Technology Sites
Assay results corrected for container effects. $^{240}\text{Pu}$-effective mass converted to Pu mass using reference isotopic ratios.

Average results are within 6% of reference values with a 30-minute count time.
NeutronMultiplicityCounter

• Commercial coincidence counter designed for shipper/receiver measurements.
• Adequate system for proof-of-principle.
• A fully optimized counter would require shorter count times and produce better multiplicity results.
Neutron Multiplicity Counter

- 32 $^3$He tubes, 102-cm active length
- Cavity and exterior are cadmium lined
Absence of Oxide

- Presence of oxygen causes the production of (alpha,n) neutrons.
- Pure metal samples yield zero (alpha,n) neutrons.
- A “non-zero alpha” is a potential indicator of oxide presence.
- However, a non-zero alpha can result from the presence of other low-Z elements such as fluorine, magnesium, aluminum, or beryllium.
- Alpha for pure, freshly separated, low-burn-up plutonium oxide is typically greater than 0.5.
Estimate of Alpha for Pure Pu Oxide

For pure, freshly separated plutonium oxide—assuming only $^{240}\text{Pu}$ and $^{239}\text{Pu}$.

The existence of other isotopes will increase alpha in most cases.
Features of Multiplicity Counting

- Accurate and robust
- Proven technology already in use for international inspections
- Can be authenticated with nonsensitive materials
- Can distinguish plutonium from isotopic neutron sources such as $^{252}$Cf or AmLi
- Requires isotopic ratio information to determine total mass of Pu
NMC System

- Junction Box
- Shielded Cables
- NMC Detector Head
- NMC Analyzer
- Shift Register
- Symmetry Analyzer
- Computational Block
- Shielded Enclosure

Connections:
- Shielded Cables connects to Shift Register
- Shift Register connects to NMC Analyzer
- NMC Analyzer connects to Symmetry Analyzer
- Symmetry Analyzer connects to Computational Block
Portable Shift Register (PSR-B)
IB Considerations for the Detector Head Electronics

Tubes and electronics provide their own radio frequency shielding.
Detector Head Electronics
Detector Electronics
Detector Electronics
NMC Electronics