On the Calibration of Alpha Sciences Proportional Counters

Michael Gordon (gordonm@us.ibm.com)

Ken Rodbell

IBM Research
1101 Kitchawan Road
Yorktown Heights, NY 10598
Outline

How is the discriminator set on Alpha Sciences counter and what is the alpha-particle energy associated with the setting? What is the impact of cutting out the low energy alphas from a sample?

– Introduction

– Background

– Overview of the Alpha Sciences proportional counters

– Our low-energy alpha-particle source

– Results

– Conclusion
**Introduction**

- We review a technique for determining the alpha-particle energy associated with a discriminator setting.

- We have a low energy “thick” alpha-particle source that was developed for this work.

- The alpha particles from this source stop in the gas within the active volume of the detector (important for association between pulse-height analysis and alpha-particle energy).

- We compared the count rate of the source vs discriminator setting in the proportional counter, and the count rate of the same source with a silicon surface barrier detector to obtain an energy scale.
Background

- Many labs have Alpha Sciences proportional counters
  - Material labs
  - Semiconductor labs

- Recently, several labs participated in a “round-robin” study of both low and ultra-low emissivity samples, “Multicenter comparison of alpha particle measurements and methods typical of semiconductor processing”*
  - Very few constraints were placed on the measurement
    - No sample preparation or measurement protocol
    - Samples were in many pieces that could be tiled to account for different sizes of the tray/active area of the counter
  - There was a ~ 2X difference between the largest and smallest sample emissivity measured
  - It was proposed that this difference could be due to the discriminator settings on the individual detectors
    - Most people “assume” that the discriminators are set to 1 MeV

* http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5784521
Cutaway section of an old Alpha Sciences counter
SRIM simulations of alpha-particles in Ar gas

The counter gas used is Ar/CH$_4$
SRIM simulations of alpha-particles in Ar gas

\[ \frac{dE}{dx} \text{ (MeV/mm)} \]

\[ \text{Energy (MeV)} \]

\[ \text{Range (mm)} \]

\( \sim 1.1 \text{ MeV } \alpha \)-particles have a 6 mm range

higher-energy alpha particle will not stop in the detector volume
The low-energy $\alpha$-source

- We need a low-energy $\alpha$-source (so that the $\alpha$’s stop in the active volume in the counter)
- We made an alpha-particle source from natural Samarium since it’s one of the lowest energy naturally-occurring $\alpha$-particle emitter
- Sm has 3 naturally-occurring $\alpha$-emitting radioactive isotopes,
  - only $^{147}$Sm is important, due to the shorter $\frac{1}{2}$ life compared to $^{148}$Sm, or $^{149}$Sm

<table>
<thead>
<tr>
<th>Sm Isotope</th>
<th>$\alpha$-energy (MeV)</th>
<th>$\frac{1}{2}$-life (years)</th>
<th>Abundance (%)</th>
<th>Specific activity ($\alpha$/sec-g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{147}$Sm</td>
<td>2.25</td>
<td>1.06E11</td>
<td>15</td>
<td>850</td>
</tr>
<tr>
<td>$^{148}$Sm</td>
<td>1.93</td>
<td>7E15</td>
<td>11.2</td>
<td>0.013</td>
</tr>
<tr>
<td>$^{149}$Sm</td>
<td>1.07</td>
<td>&gt;1E16 (stable?)</td>
<td>13.8</td>
<td></td>
</tr>
</tbody>
</table>

$$SA = \frac{Ln2}{T_{1/2}(sec)} \times \frac{N(atoms / mol)}{A(g / mol)}$$

Chart of the Nuclides, GE, 13th ed.
# Table of natural alpha-particle emitters and their energies

<table>
<thead>
<tr>
<th>ENERGY (MeV)</th>
<th>MOTHER ISOPOE</th>
<th>HALF-LIFE</th>
<th>EQUILIBRIUM ABUNDANCE</th>
<th>FAMILY CHAIN</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.83</td>
<td>Nd - 144</td>
<td>2.4 E 15 y</td>
<td>24 %</td>
<td>none</td>
<td>Natural part of Nd</td>
</tr>
<tr>
<td>1.50</td>
<td>Ce - 142</td>
<td>5. E 15 y</td>
<td>11 %</td>
<td>none</td>
<td>Natural part of Ce</td>
</tr>
<tr>
<td>2.14</td>
<td>Gd - 152</td>
<td>1.1 E 14 y</td>
<td>21 %</td>
<td>none</td>
<td>Natural part of Gd</td>
</tr>
<tr>
<td>2.23</td>
<td>Sm - 147</td>
<td>1.1 E 14 y</td>
<td>15 %</td>
<td>none</td>
<td>Natural part of Sm</td>
</tr>
<tr>
<td>2.50</td>
<td>Hf - 174</td>
<td>2. E 15 y</td>
<td>0.2%</td>
<td>none</td>
<td>Natural part of Hf</td>
</tr>
<tr>
<td>3.18</td>
<td>Pt - 190</td>
<td>7. E 11 y</td>
<td>0.01%</td>
<td>none</td>
<td>Natural part of Pt</td>
</tr>
<tr>
<td>3.83</td>
<td>Th - 232</td>
<td>1.39 E 10 y</td>
<td>0.2 %</td>
<td>Th - 232</td>
<td>Natural Element</td>
</tr>
<tr>
<td>3.95</td>
<td>Th - 232</td>
<td>1.39 E 10 y</td>
<td>23 %</td>
<td>Th - 232</td>
<td>Natural Element</td>
</tr>
<tr>
<td>4.01</td>
<td>Th - 232</td>
<td>1.29 E 10 y</td>
<td>73 %</td>
<td>Th - 232</td>
<td>Natural Element</td>
</tr>
<tr>
<td>4.15</td>
<td>U - 238</td>
<td>4.50 E 9 y</td>
<td>23 %</td>
<td>U - 238</td>
<td>Natural Element</td>
</tr>
<tr>
<td>4.20</td>
<td>U - 238</td>
<td>4.50 E 9 y</td>
<td>73 %</td>
<td>U - 238</td>
<td>Natural Element</td>
</tr>
<tr>
<td>4.39</td>
<td>U - 235</td>
<td>7.1 E 8 y</td>
<td>100%</td>
<td>U - 235</td>
<td>Natural Element</td>
</tr>
<tr>
<td>4.60</td>
<td>Ra - 226</td>
<td>1.60 E 3 y</td>
<td>6 %</td>
<td>U - 238</td>
<td>Natural Element</td>
</tr>
<tr>
<td>4.62</td>
<td>Th - 230</td>
<td>7.5 E 4 y</td>
<td>24 %</td>
<td>Th - 232</td>
<td>Natural Element</td>
</tr>
<tr>
<td>4.69</td>
<td>Th - 230</td>
<td>7.5 E 4 y</td>
<td>76 %</td>
<td>U - 238</td>
<td>Natural Element</td>
</tr>
<tr>
<td>4.72</td>
<td>Th - 230</td>
<td>7.5 E 5 y</td>
<td>28 %</td>
<td>U - 238</td>
<td>Natural Element</td>
</tr>
<tr>
<td>4.78</td>
<td>U - 234</td>
<td>2.5 E 5 y</td>
<td>72 %</td>
<td>U - 238</td>
<td>Natural Element</td>
</tr>
<tr>
<td>4.78</td>
<td>Ra - 226</td>
<td>1.60 E 3 y</td>
<td>94 %</td>
<td>U - 238</td>
<td>Natural Element</td>
</tr>
<tr>
<td>5.18</td>
<td>Th - 228</td>
<td>1.91 y</td>
<td>0.2 %</td>
<td>Th - 232</td>
<td>(1)</td>
</tr>
<tr>
<td>5.21</td>
<td>Th - 228</td>
<td>1.91 y</td>
<td>0.5 %</td>
<td>Th - 232</td>
<td>(1)</td>
</tr>
<tr>
<td>5.30</td>
<td>Po - 210</td>
<td>1.38 d</td>
<td>100%</td>
<td>U - 238</td>
<td>Daughter of Pb - 210</td>
</tr>
<tr>
<td>5.34</td>
<td>Th - 228</td>
<td>1.91 y</td>
<td>28 %</td>
<td>Th - 232</td>
<td>(1)</td>
</tr>
<tr>
<td>5.42</td>
<td>Th - 228</td>
<td>1.91 y</td>
<td>71 %</td>
<td>Th - 232</td>
<td>(1)</td>
</tr>
<tr>
<td>5.45</td>
<td>Ra - 224</td>
<td>3.64 d</td>
<td>5 %</td>
<td>Th - 232</td>
<td>(1)</td>
</tr>
<tr>
<td>5.49</td>
<td>Ra - 224</td>
<td>3.6 d</td>
<td>100%</td>
<td>U - 238</td>
<td>(2) Seeps from the Earth</td>
</tr>
<tr>
<td>5.61</td>
<td>Bi - 212</td>
<td>60.6 m</td>
<td>0.4%</td>
<td>Th - 232</td>
<td>(1)</td>
</tr>
<tr>
<td>5.68</td>
<td>Ra - 224</td>
<td>3.64 d</td>
<td>95 %</td>
<td>Th - 232</td>
<td>(1)</td>
</tr>
<tr>
<td>5.77</td>
<td>Bi - 212</td>
<td>60.6 m</td>
<td>0.6 %</td>
<td>Th - 232</td>
<td>(1)</td>
</tr>
<tr>
<td>6.00</td>
<td>Po - 218</td>
<td>3.05 m</td>
<td>100 %</td>
<td>U - 238</td>
<td>(2)</td>
</tr>
<tr>
<td>6.05</td>
<td>Bi - 212</td>
<td>60.6 m</td>
<td>25 %</td>
<td>Th - 232</td>
<td>(1)</td>
</tr>
<tr>
<td>6.09</td>
<td>Bi - 212</td>
<td>60.6 m</td>
<td>10 %</td>
<td>Th - 232</td>
<td>(1)</td>
</tr>
<tr>
<td>6.29</td>
<td>Ra - 220</td>
<td>54.5 s</td>
<td>100%</td>
<td>Th - 232</td>
<td>(1)</td>
</tr>
<tr>
<td>6.78</td>
<td>Po - 216</td>
<td>0.15 s</td>
<td>100%</td>
<td>Th - 232</td>
<td>(1)</td>
</tr>
<tr>
<td>7.69</td>
<td>Po - 214</td>
<td>162 us</td>
<td>100%</td>
<td>U - 238</td>
<td>(2)</td>
</tr>
<tr>
<td>8.79</td>
<td>Po - 212</td>
<td>0.3 us</td>
<td>64 %</td>
<td>Th - 232</td>
<td>(1)</td>
</tr>
</tbody>
</table>

Source: unknown, yellowed sheet in my lab
Energy spectrum from Sm source, in vacuum
Energy spectrum from $^{232}$Th source, in vacuum
Alpha Sciences counter with Ortec discrete electronics

Using off-the-shelf electronics allows for easy adjustment and repair

Analytical form for cylindrical geo.

\[ E(r) = \frac{V}{r \ln(b/a)} \]

For \( r = a \), \( V = 800\text{V} \), \( E \approx 10^6 \text{V/m} \)

Applied Voltage

Pulse Amplitude

1 MeV

2 MeV

Ion saturation

Prop region

Geiger region

From Knoll
**Pulse-height spectrum from sources in the Alpha Sciences counter**

**Sm source**

![Pulse-height spectrum for Sm source](A2110311-2)

**232Th source**

![Pulse-height spectrum for 232Th source](A2110311-1)

**Ultra-low activity sample**

![Pulse-height spectrum for ultra-low activity sample](GC9-111024)
Energy spectrum of Sm source, energy loss from sample through cathode

\[ 2 \text{ mm gap} \]

\[ 2.5 \text{ mm gap} \]

\[ 3 \text{ mm gap} \]

~1 MeV energy loss in air and mylar- before \( \alpha \)'s reach active area

- **vacuum**
- **air**
- **air + mylar**
Energy spectrum of $^{232}$Th source, energy loss from sample through cathode

Passage of the alphas in the gap and mylar causes reduction in maximum energy and in the flux
Results

- Integrate the measured alpha particle energy spectrum from the samarium source, using the silicon detector, above a given threshold (e.g., $E > 0.25$ MeV, $E > 0.5$ MeV, $E > 0.75$ MeV, and $E > 1.0$ MeV).

- Repeat integration for each of the source-to-detector gaps.

- Plot the resulting integrated count rate vs energy.

- Integrate the count rate for the Alpha Sciences counter above a given ADC voltage threshold (e.g., $V > 0.5$ V, $V > 0.9$ V, $V > 1.5$ V, $V > 2.0$ V) using the discrete electronics.

- We can correlate the pulse height with energy—given the MCA spectrum from the Alpha Sciences counter, and the maximum energy in the alpha particle energy spectra.
Results

- data from Si detector “fits” the gas counter data with a ~2.5 mm gap
- 0 count rate with this source is ~1-1.3 MeV
Response of Alpha Sciences counter, original electronics

**Sm source**

Zero count rate corresponds to a total energy loss of 2.25 MeV

**Th source**

Raising the discriminator level lowers the detection efficiency (lowers the count rate) for a thick source

The slope of count rate vs discriminator setting, and the discriminator setting where the count rate goes to zero, will depend on the amplifier gain.
Conclusion

– We have shown the energy spectrum from a low-energy Sm $\alpha$-particle source.

– There is an appreciable energy-loss of low-energy $\alpha$’s before they reach the active gas volume in the Alpha Sciences counters.

– While the discriminator can be set higher to reduce the background count rate, it cuts out the detection of low-energy $\alpha$’s.

– The efficiency of detection in these counters is energy-dependent.

– What energy $\alpha$’s are really important for samples that we measure?

– What is the $\alpha$-particle energy associated with the discriminator setting on your Alpha Sciences counters?