The need for an industry-wide, large-area, ultra-low emissivity standard

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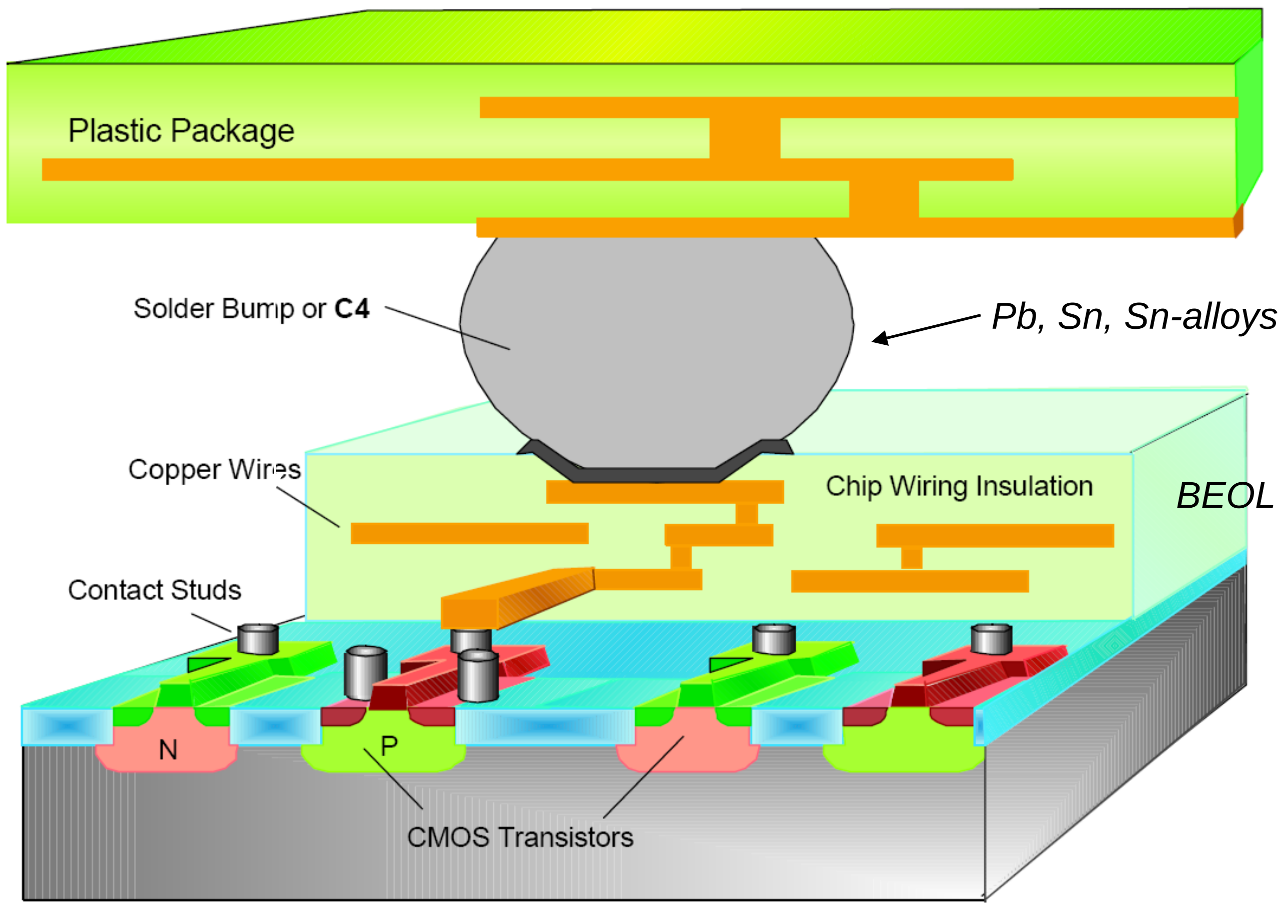
Outline

- Introduction to single event upsets and the need for ultra-low emissivity materials
- Sources of alpha particles in materials used in semiconductors
- Large-area alpha particle detectors in use
- Requirements for industry-wide low-emissivity α-particle standard
- Results from the alpha particle consortium and an XIA study
- Working together on an industry standard
- Summary

Single Event Upsets, Definition and Origin

- *Single Event Upsets*
  - *Errors in computer chips (memory & logic) that don't cause permanent damage*
  - *Created by passage of energetic ionizing radiation through the sensitive volume of chips*
  - *This can be a major reliability problem in servers, laptops, smart phones, pacemakers, electronics near radiation sources*
- *Sources of single event upsets:*
  - *Alpha particles from chip packaging (ceramic, underfill, interconnects, contamination)*
  - *Cosmic rays which create highly ionizing particles when they interact w/ silicon*
  - *Thermal (slow) neutrons from ^{10}B interactions ^{10}B(n,α)*
- *With technology scaling (shrinking dimensions) operational voltages decrease, the critical charge required to flip a bit also decreases, however the size of sensitive area decreases too*

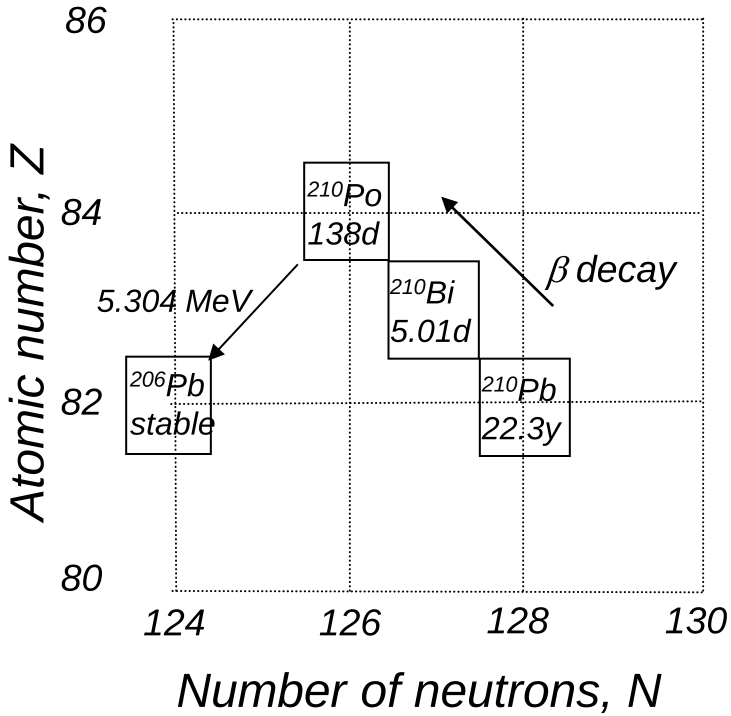
Sources of alpha particles



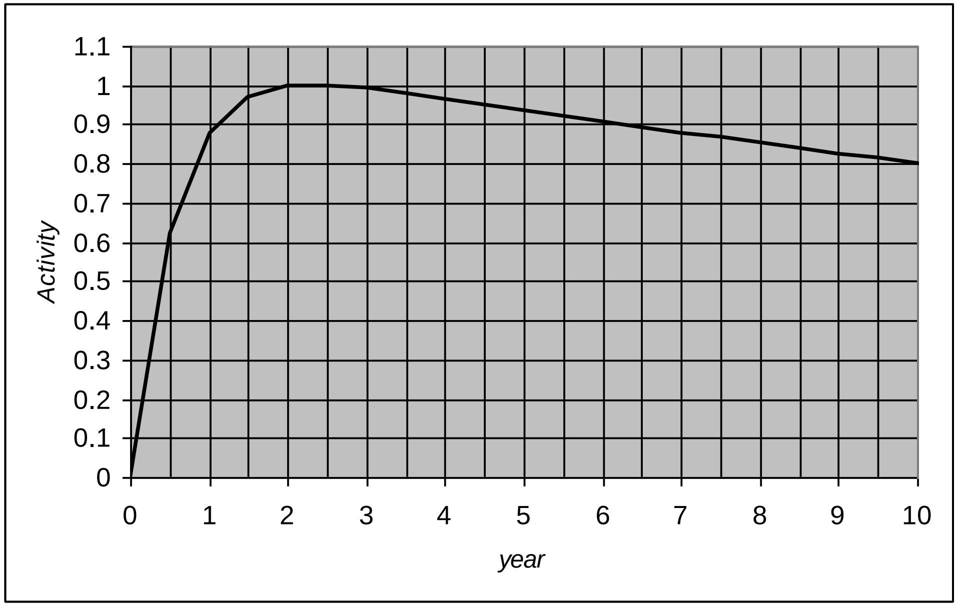
^{210}Pb and ^{210}Po, transition from Pb to Pb-free

Alpha activity <u>increases</u> for ~ 2.5 years for newly refined Pb, then decreases

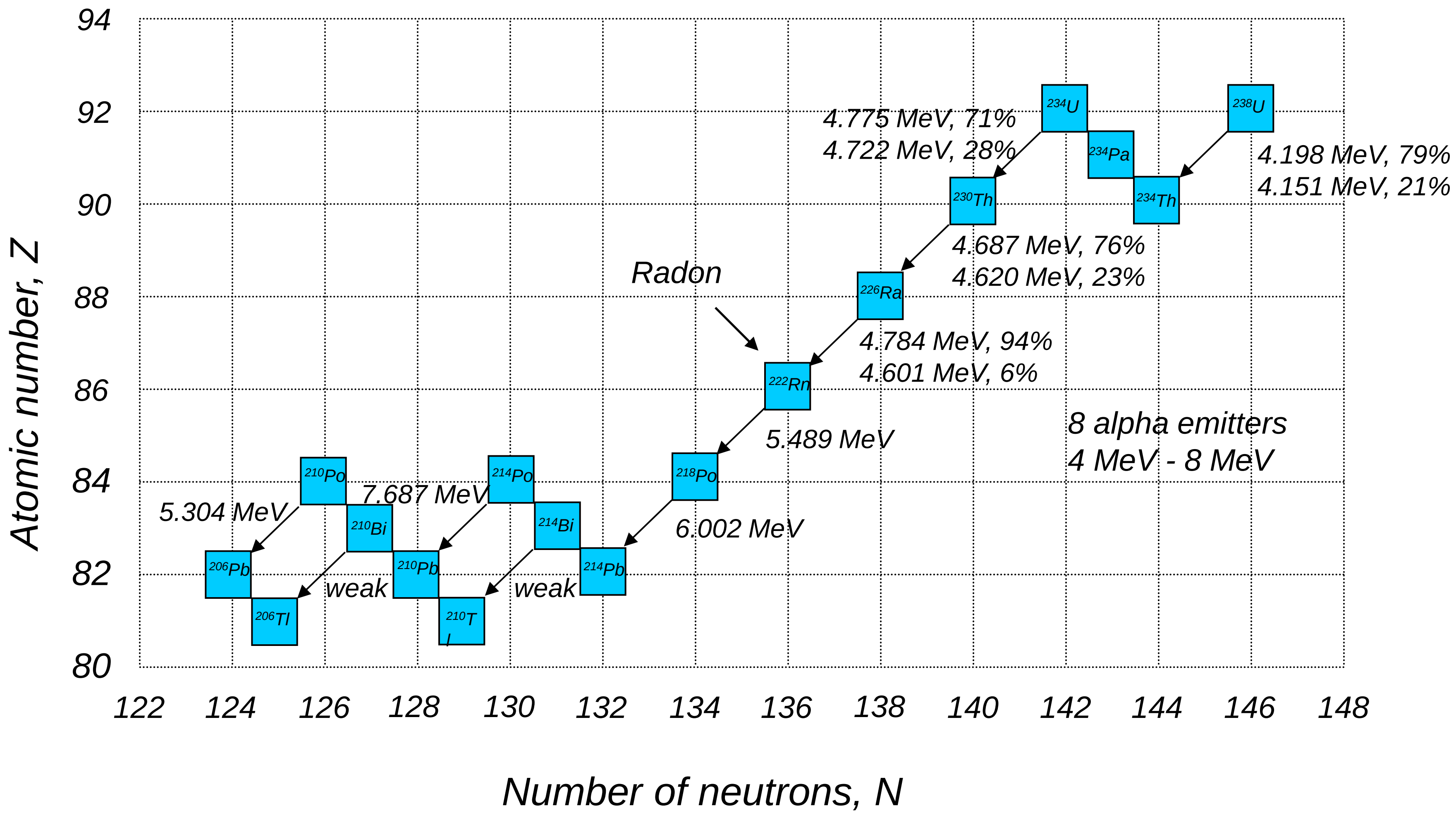
Evidence of Po in some Sn, diffusivity of Po in Sn under study, ^{210}Po in decay chain of ^{238}U



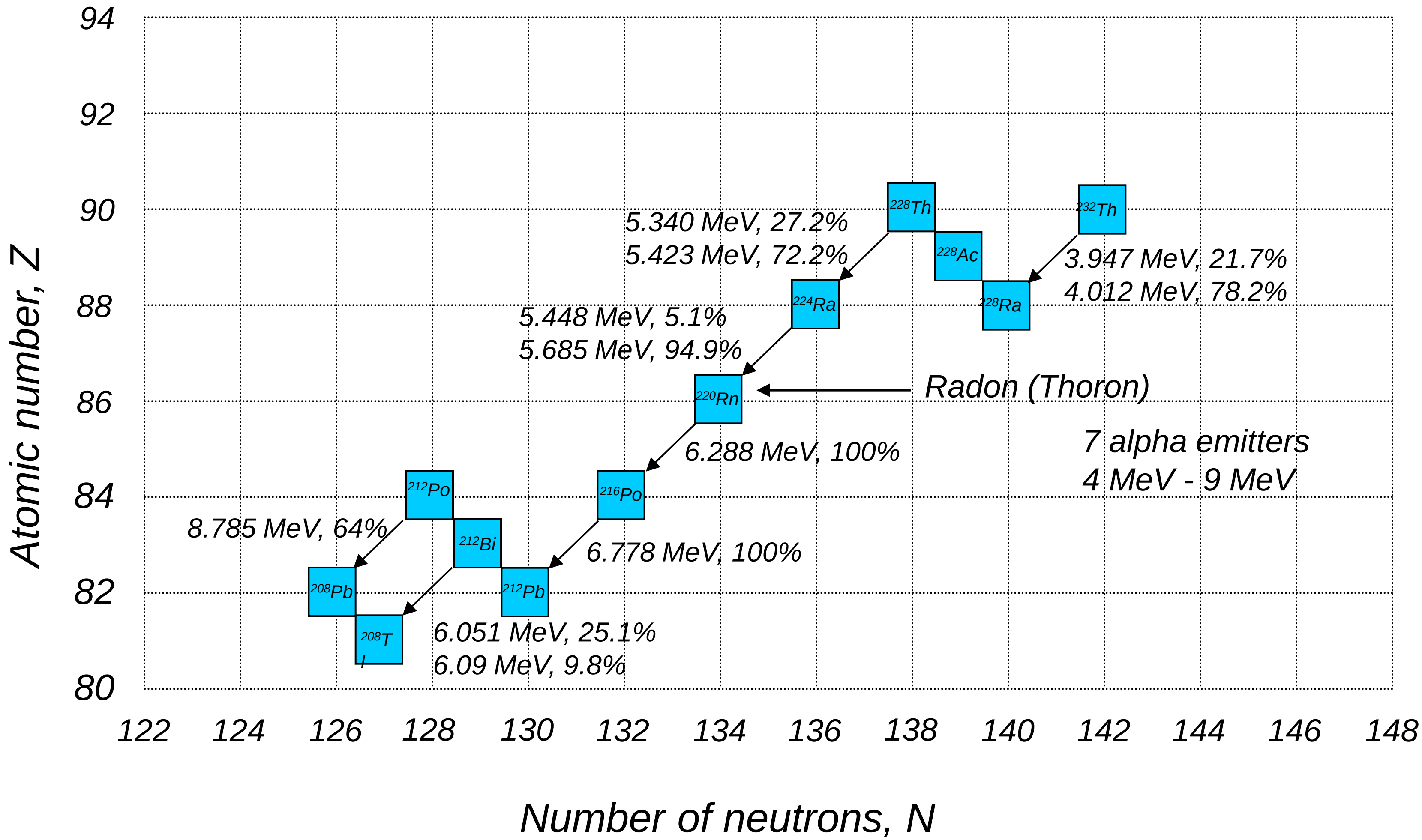
Secular equilibrium from $^{210}Pb \rightarrow ^{210}Po$



^{238}U decay chain → ^{206}Pb (stable)



^{232}Th decay chain → ^{208}Pb (stable)



^{210}Po: Brett Clark, SCV SER Workshop 2012

Alpha emissivity increases in time from ^{210}Po diffusion (not approach to secular equilibrium)

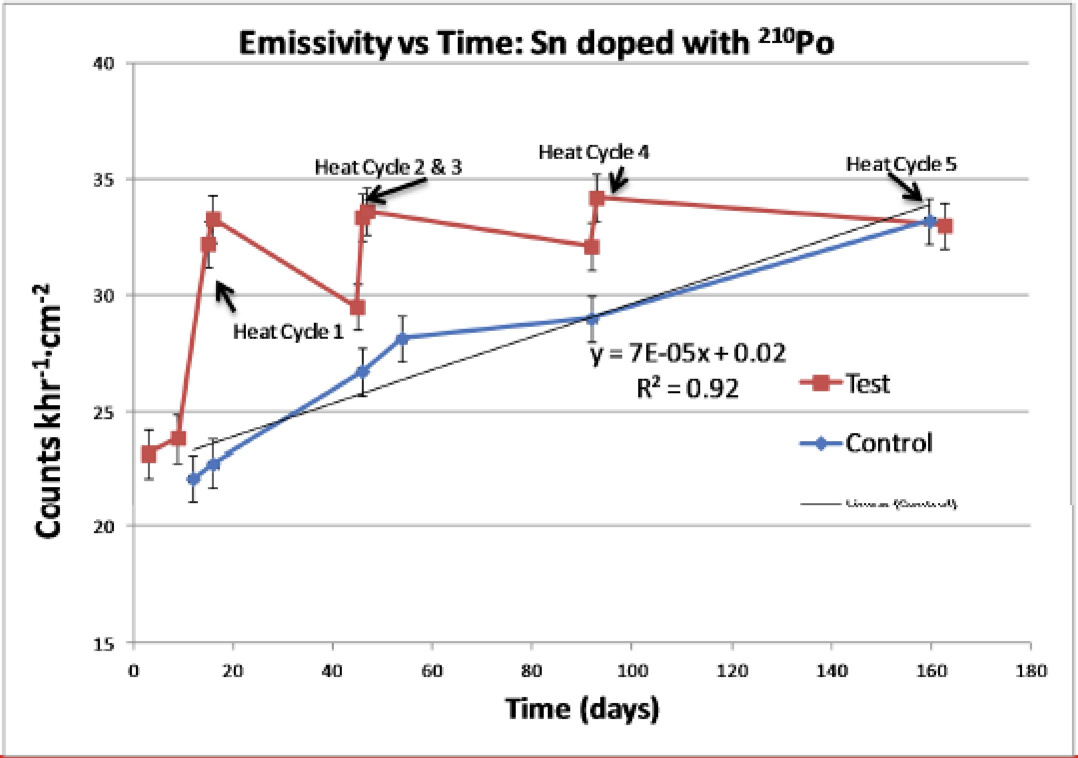
The emissivity increases due to heating

Each heating cycle caused less influence than the previous heating cycle

Emissivity vs. Time: ^{210}Po doped Sn

Po concentration of 1E-4 ppt can cause alpha emissivity of >2α/khr-cm^2

This is not measurable directly.



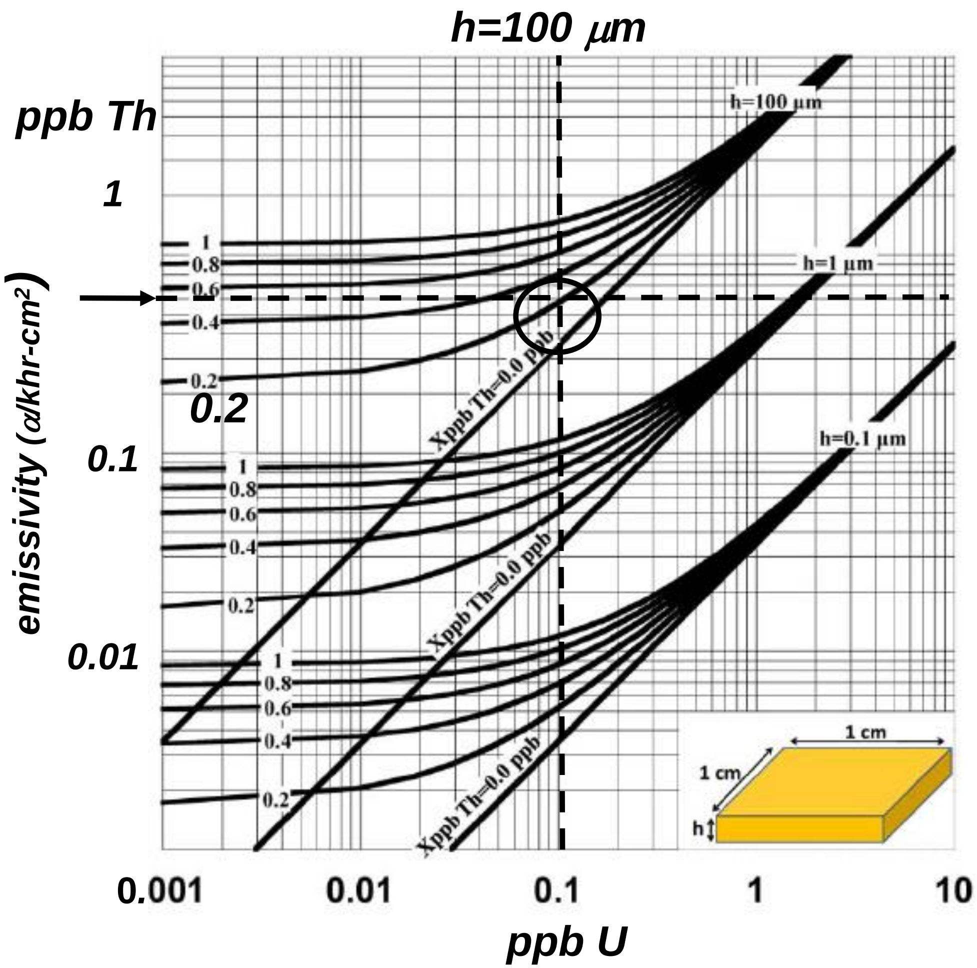
Diffusion accelerated by temperature

2012 IEEE SER Workshop 9

Alpha emissivity, contamination from U, Th on a Silicon Wafer

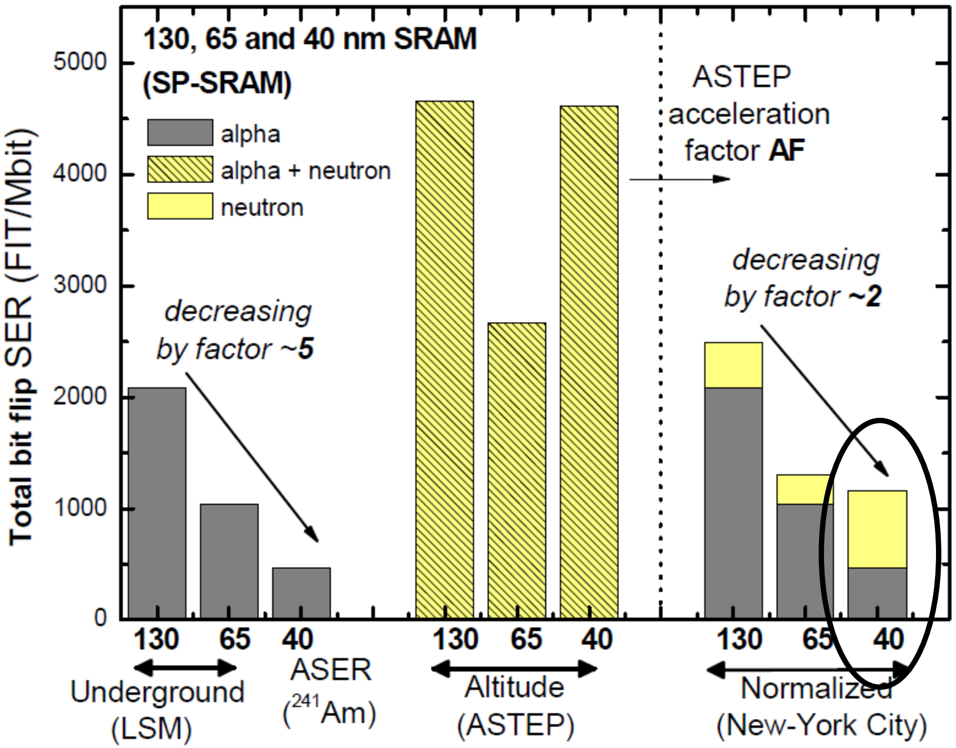
0.1 ppb U and 0.2 ppb Th in a silicon slab causes an alpha particle emissivity of 0.5 α/khr-cm²

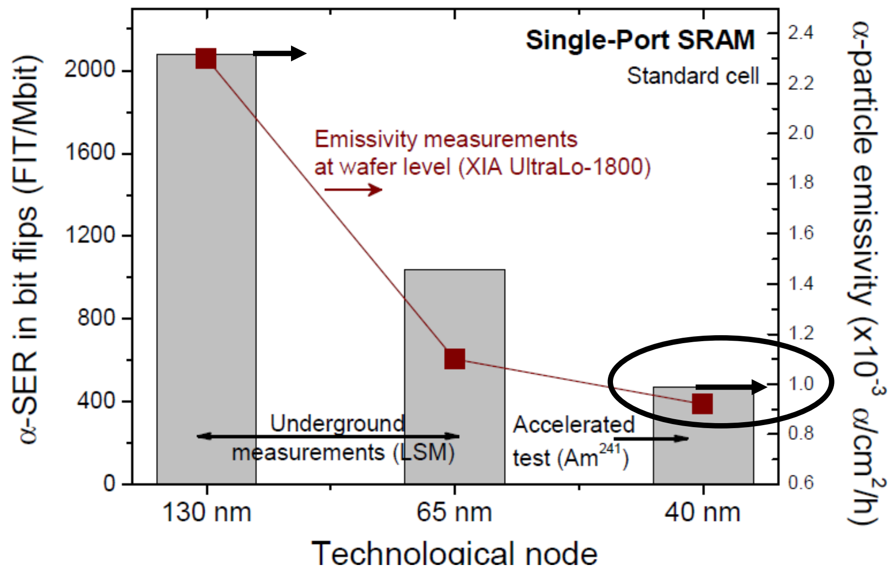
These levels are measurable with neutron activation or special ICP techniques



Martinie, et al., IEEE TNS, vol. 58, no. 6, pp. 2798-2802, (2011)

Alpha component to SEU, scaling data for SRAM





1 FIT = 1 fail in 10^9 years
Alpha component at 40 nm is ~ 40% of total, and emissivity is 0.92 α/khr-cm^2
The alpha component is decreasing due to "stringent material selection"

Autran, 2012 IRPS, p. 3C.5.1-9, submitted for publ. IEEE TNS 2014.

LOD drives need for large area samples, low background detectors

Level of detection

$$LOD = n\sigma = n * \frac{\sqrt{\frac{G}{t_G^{\ 2}} + \frac{B}{t_B^{\ 2}}}}{A * \varepsilon}$$

where:

LOD = level of detection

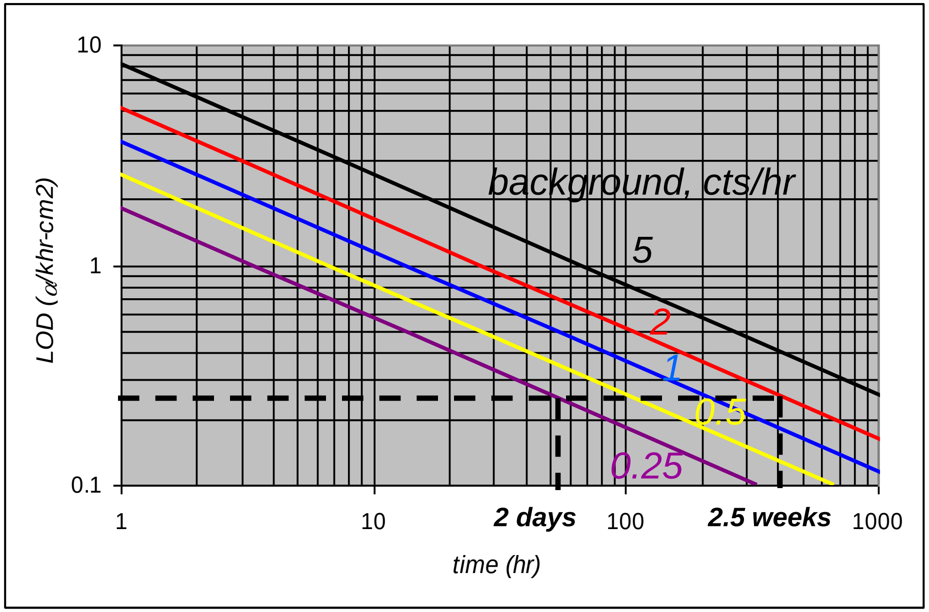
n=1.64 for 90% confidence

G, B, sample and background counts

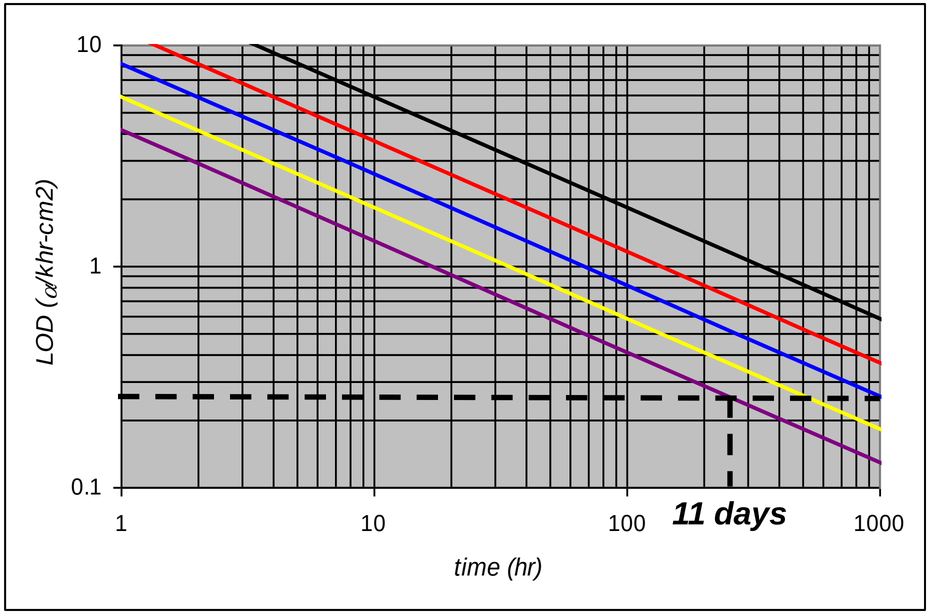
A=sample area

ε=counter efficiency

There is a clear benefit to large-area samples, low background and large detection efficiency



300 mm diameter sample

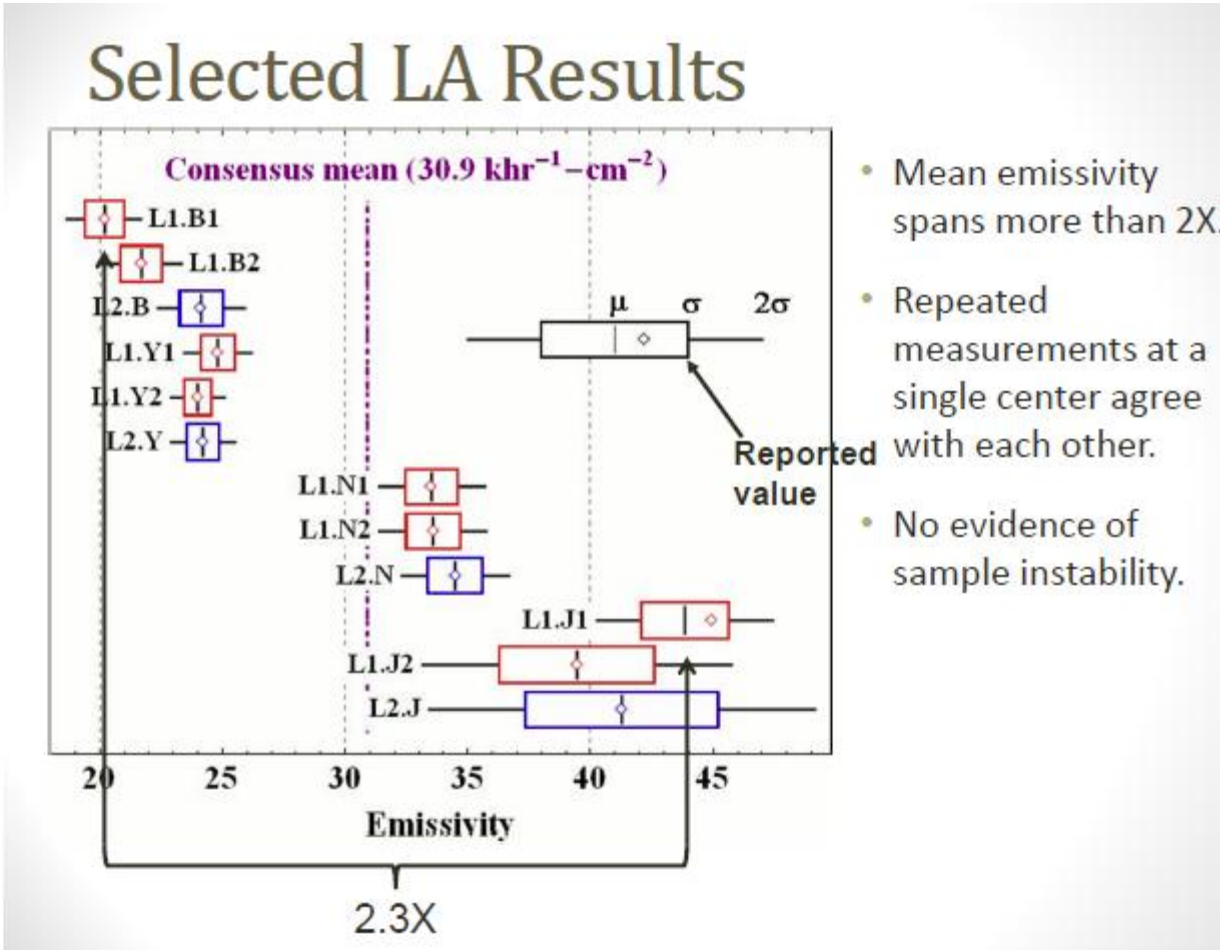


200 mm diameter sample

Large-area alpha particle detectors in use by the Semi industry

	Pros	Cons
Proportional counters *Alpha Sciences* *http://www.alphacounting.com/Model_4950.html* *Ordella* *http://www.ordela.com/PDF/8600A-LB.pdf*	*-Large amplitude signal* *-Relatively inexpensive* *-Simple to operate* *-AS, multiple wafers, < 3600 cm^2*	*-Background controlled by counter materials (ultra-low emissivity materials)* *-Thin, ΔE counter (no energy into)* *-Fragile window (Alpha Sciences)* *-High background (> 2 α/khr-cm^2)* *-Need to measure background often due to fluctuations* *-Sensitive to EMI noise, vibration* *-Poor signal/ noise for ULA samples* *-Single sample (Ordella)*
Ionization counters *XIA LLC* *http://www.xia.com/UltraLo/index.html*	*-Active signal discrimination* *-Very low background (~0.3 α/khr-cm^2)* *-Energy information available* *-Insensitive to noise, vibration* *-Can accommodate large sample (1800 cm^2).*	*-Small amplitude signal* *-Somewhat expensive* *-Single sample*

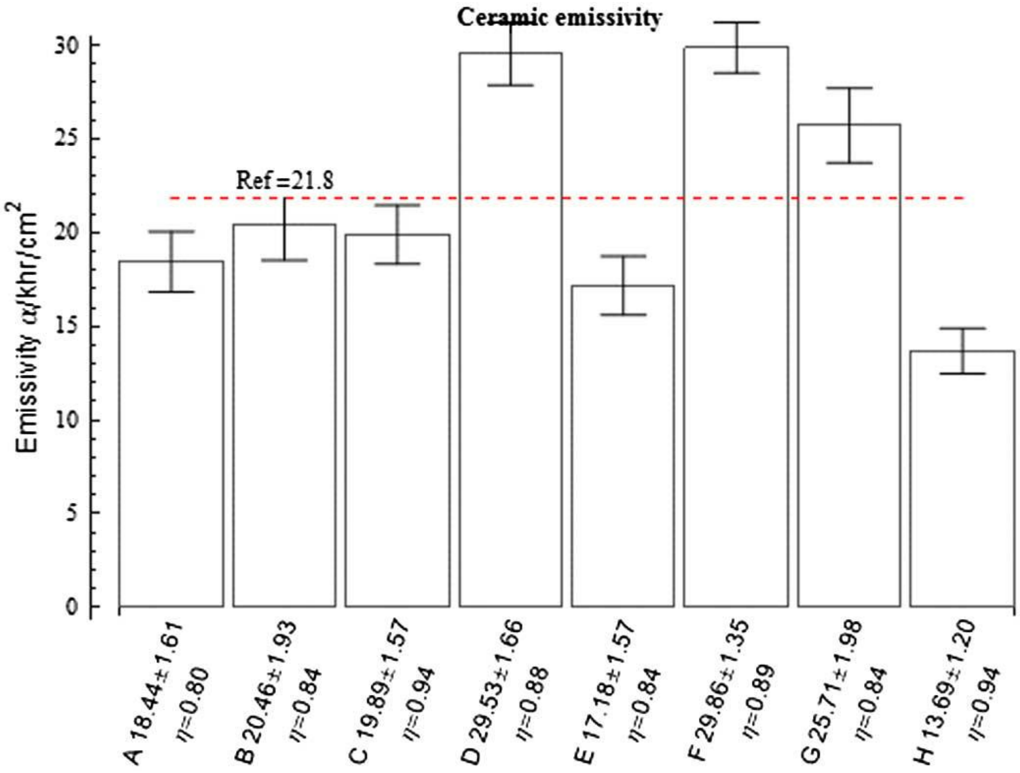
Results from Alpha Consortium, Aluminum alloy, first round



Variability is large, what is the "correct" emissivity?

Jeff Wilkinson, SCV SER Workshop 2012, Wilkinson, et al. IRPS, 2011, pp. 5B3.1-5B3.10

Results from Alpha Consortium, ceramic, second round



Still see the same 2.3X range between labs

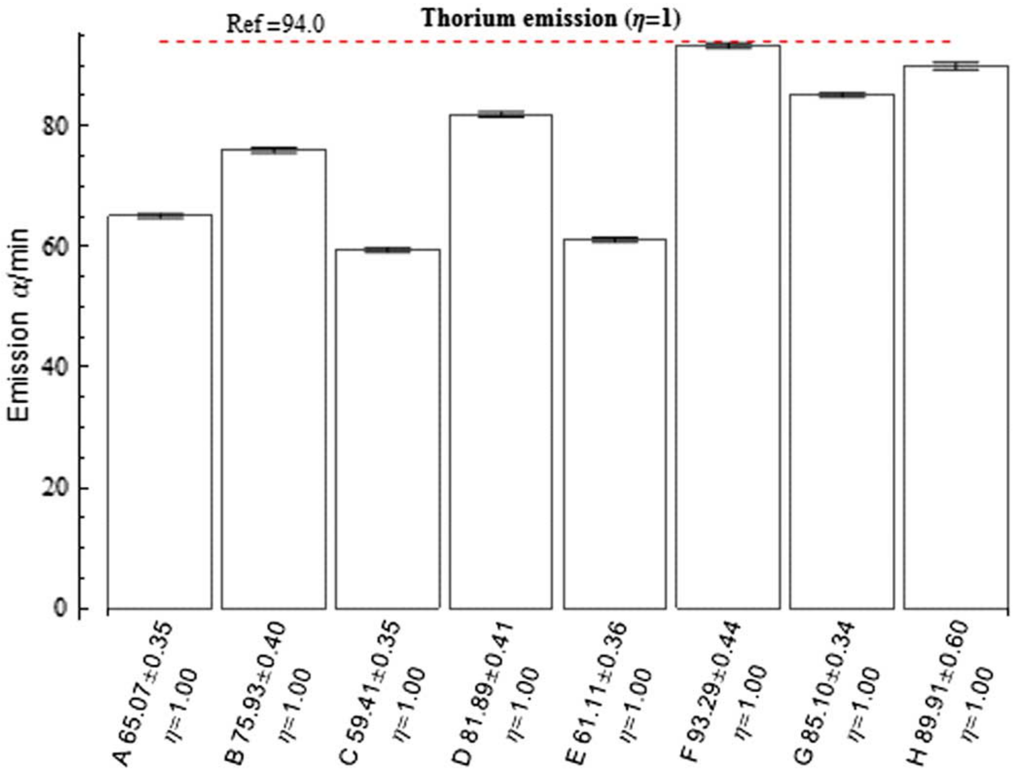
Variation is not due to the energy discriminator settings on the counters

Energy range	*alphas*
E > 1 MeV	*100%*
E > 2 MeV	*90%*
E > 3 MeV	*71%*

Variability is large, what is the "correct" emissivity?

Wilkinson, et al. IEEE TNS, Vol. 61, No. 4, 1516, (2014)

Results from Alpha Consortium, ^{230}Th point source, second round



Detector efficiency set to 1

NIST-traceable source

α - emission rate 94 α/min

Still very large variation between labs (confirmation that differences have nothing to do with energy threshold)

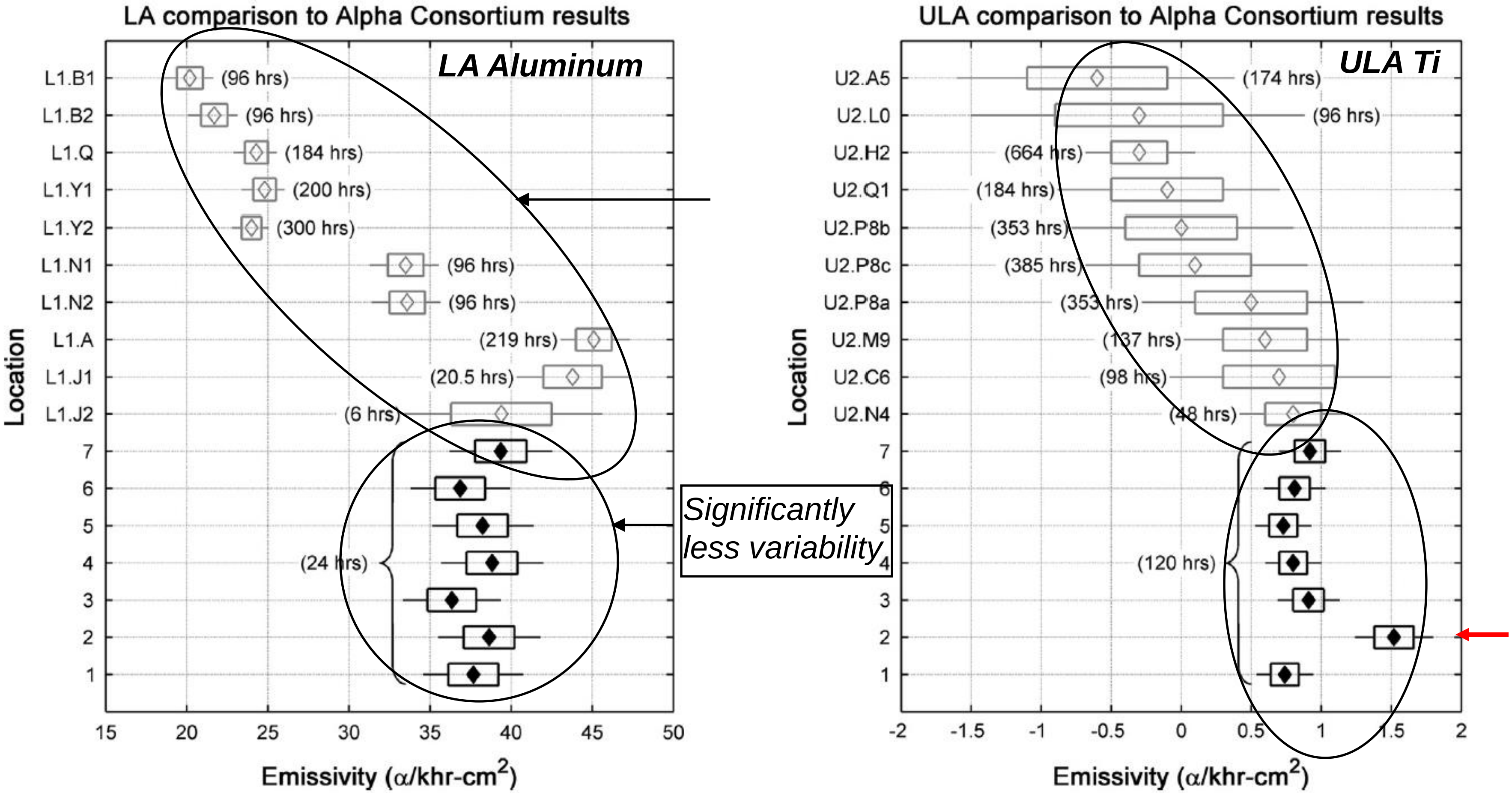
Alpha emission rate is orders of magnitude greater than ULA

Variability is large, this time we know the "correct" emissivity for this source

Wilkinson, et al. IEEE TNS, Vol. 61, No. 4, 1516, (2014)

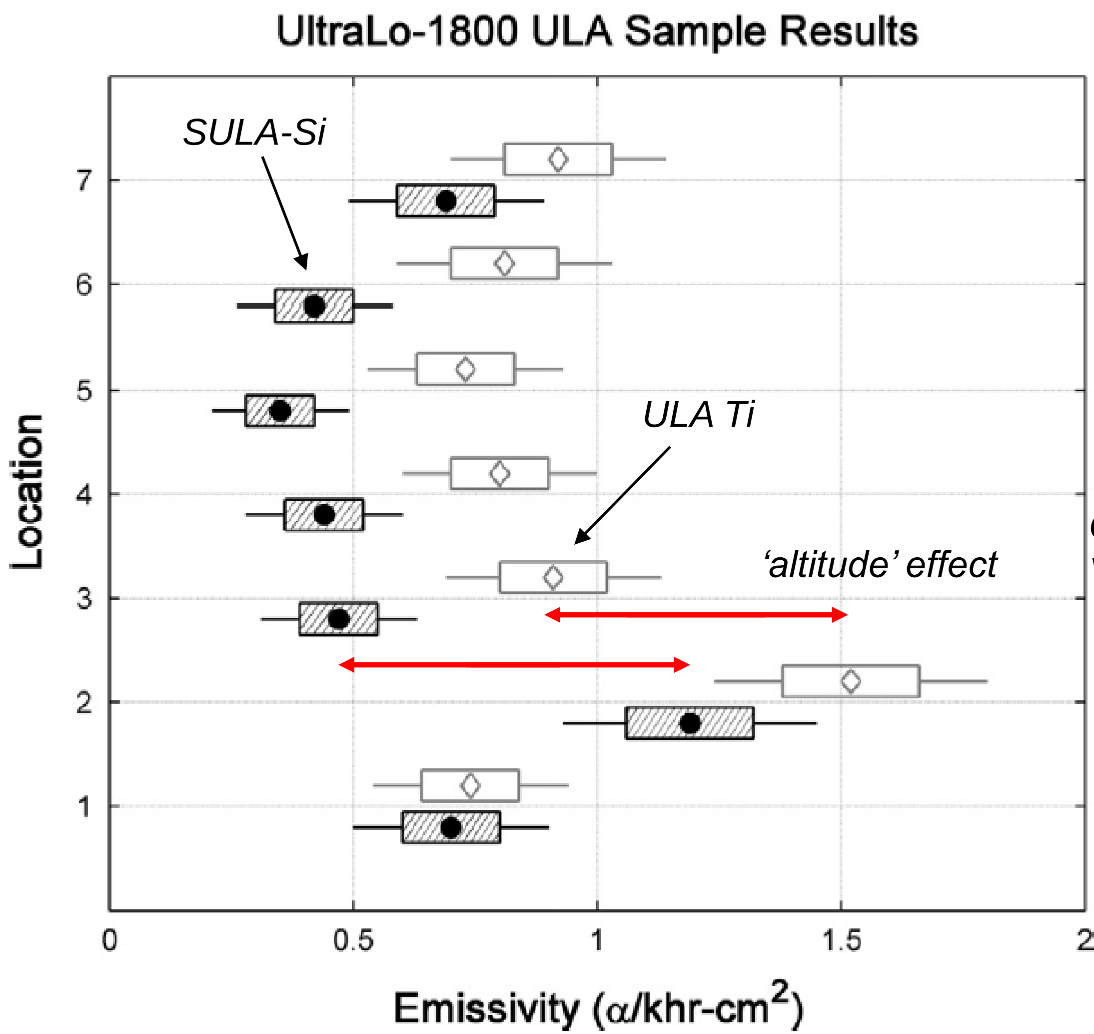
Results from XIA controlled study

Huge variation and "negative" emissivities



McNally, et al., Nucl. Instr. Meth. A, 750, 96, (2014)

Results from XIA controlled study



Gordon, et al., IEEE TNS Vol. 59, No. 6, 3101, (2012).

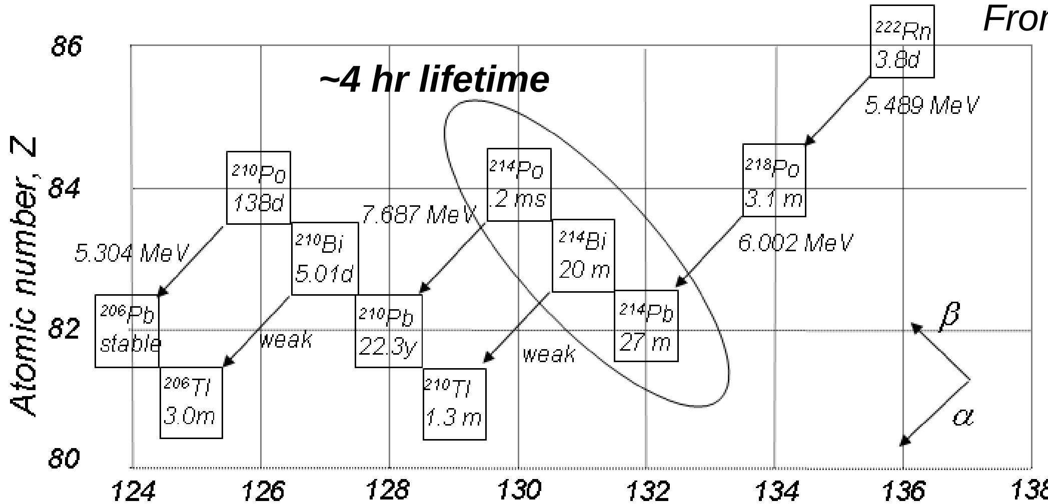
McNally, et al., Nucl. Instr. Meth. A, 750, 96, (2014)

Requirements for an industry-wide standard

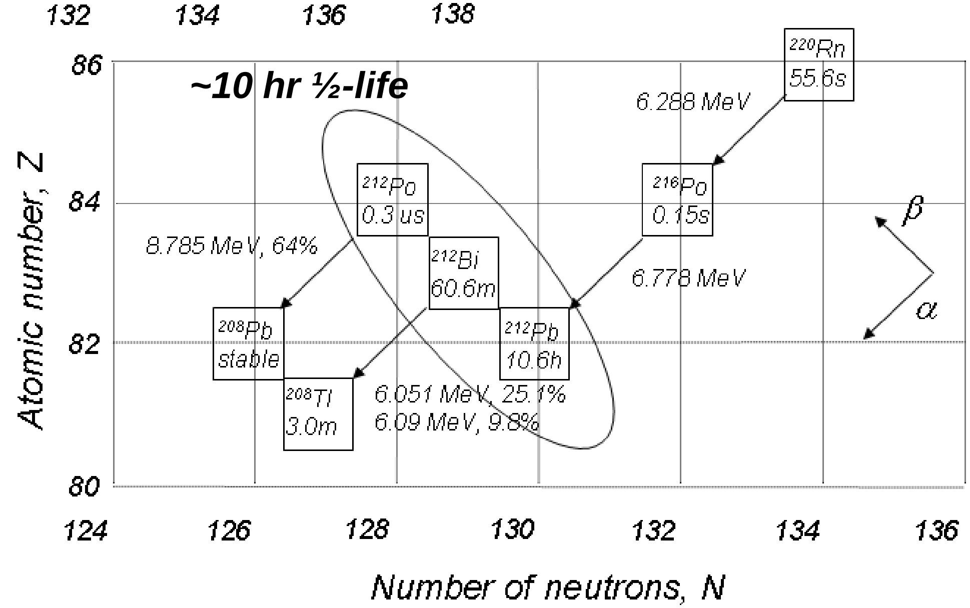
- In the first alpha-particle consortium, the lab to lab variability was larger than the current alpha-particle specification
- JEDEC 221 standard
  - Describes best practices for accurate low level measurements
  - Lacks standard for inter- or intra-lab comparison
- Large-area source requirements
  - Thick source (to mimic most samples with Th & U), 4 MeV < E_α < 8.8 MeV
  - Emissivity ~2 α/khr-cm^2 up to ~20 α/khr-cm^2
  - "Known" emission rate (hard to know)
  - Stable emission with respect to time, energy
  - Robust for shipping/ handling
  - Material should be difficult to contaminate
  - Emissivity should be uniform within ~ 1 cm^2 area
  - Ideally we would have several NIST-traceable standards available
  - Minimize contamination by radon (or handling)
- Concerns
  - 'altitude' effect- results from SULA and some ULA samples will depend on altitude/ shielding

Radon daughters plate out on samples exposed to air

From ^{238}U decay chain



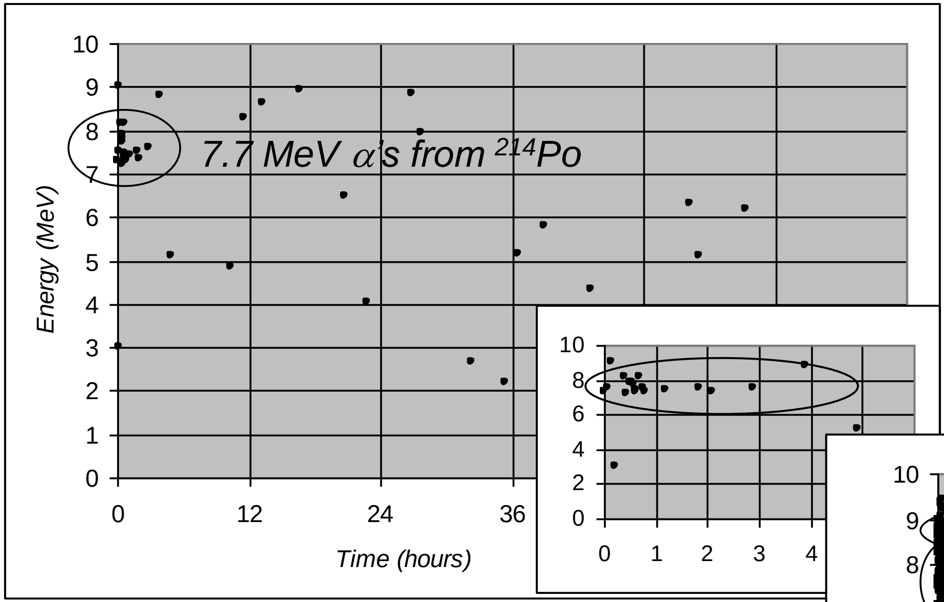
From ^{232}Th decay chain



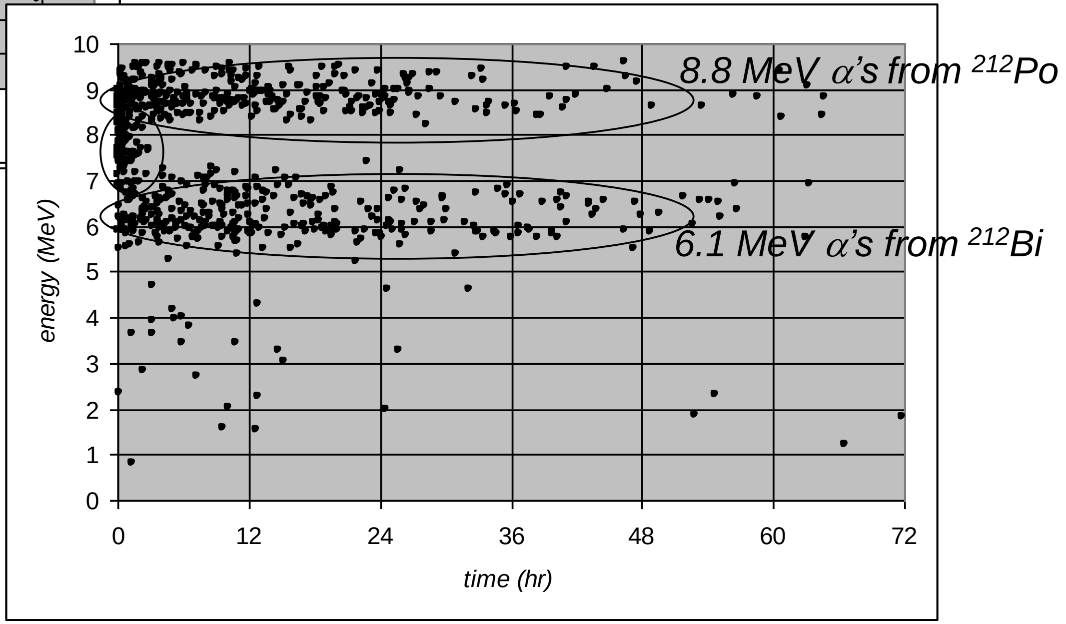
Gordon, et al., IEEE TNS, Vol 59, No 6, 3101, (2012)

Radon Issues- data

Sample stored in dry N_2



Sample exposed to air 24 hrs



Gordon, et al., IEEE TNS, Vol 59, No 6, 3101, (2012)

Possible material for a large-area, ultra-low emissivity standards

- *Titanium sheet (from consortia measurements)*
- *Oxygen free copper sheet*
- *Sn sheet*
- *Electrically-conductive material on substrate*

"low-alpha particle emission electrically conductive coating"

US Patent 8815725, Gaynes, Gordon, Lewandski

- *Si wafer*
- *Point sources, ^{230}Th,^{147}Sm*

^{147}Sm, a low-energy α-source

$T_{1/2}$=1.06E11 years

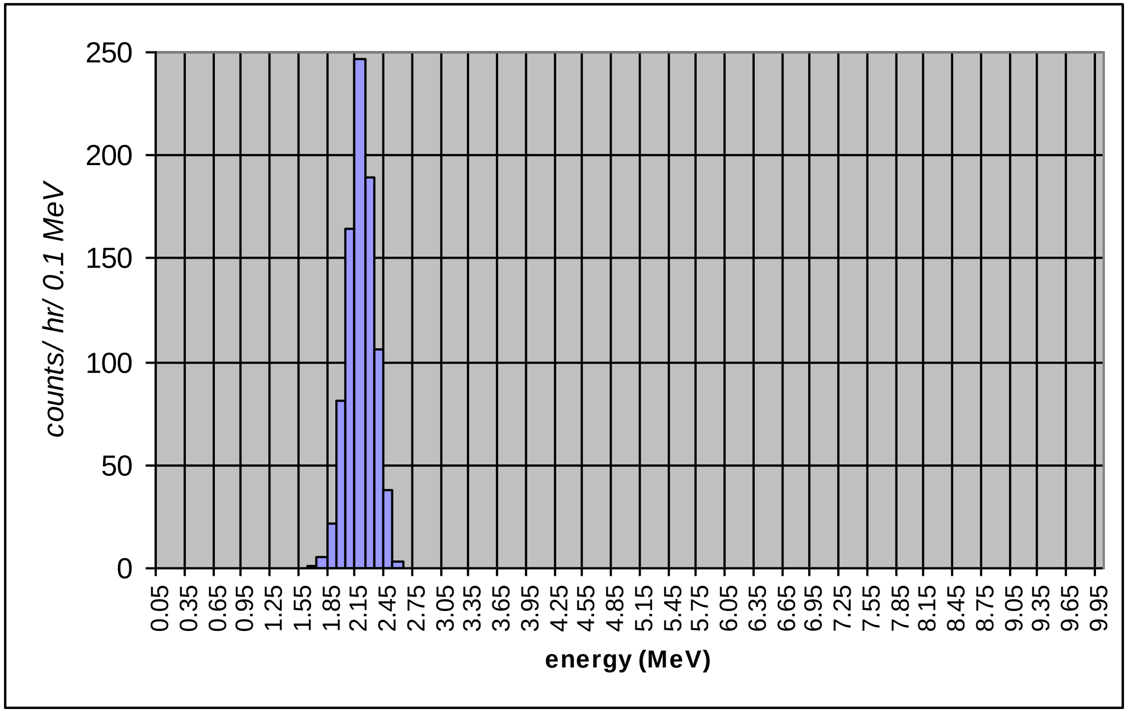
15% abundant

$E\alpha$ = 2.25 MeV

Specific activity = 127 α/g-sec

$$SA = \frac{Ln2}{T_{1/2}(\text{sec})} \, x \, \frac{N_a(atoms/mol)}{A(g/mol)}$$

Energy spectrum of ^{nat}Sm sputtered on 200 mm wafer



http://www.nndc.bnl.gov/chart/
Chart of the Nuclides, GE, 13th ed.

Summary

- *The semiconductor industry needs material certified at the ULA (2α/khr-cm^2) level, with lower levels in the foreseeable future, to ensure proper operation of alpha particle detectors.*
- *A new class of detectors is capable of making measurements of ULA materials reliably.*
- *We need a stable calibration source to routinely assess the performance and repeatability of measurements of our alpha particle detectors and to compare samples measured at different sites.*
- *We have requested the help from NIST to add creditability to this work, and to provide certification/ calibration.*
- *We have several possible candidates for standards.*

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