The need for a large-area low emissivity alpha particle standard

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Outline

- *Introduction to ultra-low alpha particle counting*
- *Level of detection vs counting time as a function of counter background*
- *Fundamentals of alpha particle counting*
- *Radon exposure on samples*
- *Influence of cosmic rays*
- *Static electricity influence on dielectric samples*
- *Efficiency vs sample geometry*
- *Select data from round robin counting*
- *Large area low emissivity alpha particle standard*
- *Summary*

Introduction, why care about alpha particles?

- *Single Event Upsets (SEU)*
  - *Alpha particles in the packaging near the transistors can cause SEU (flipped bits)*
  - *Most materials include trace amounts of Thorium and/or Uranium*

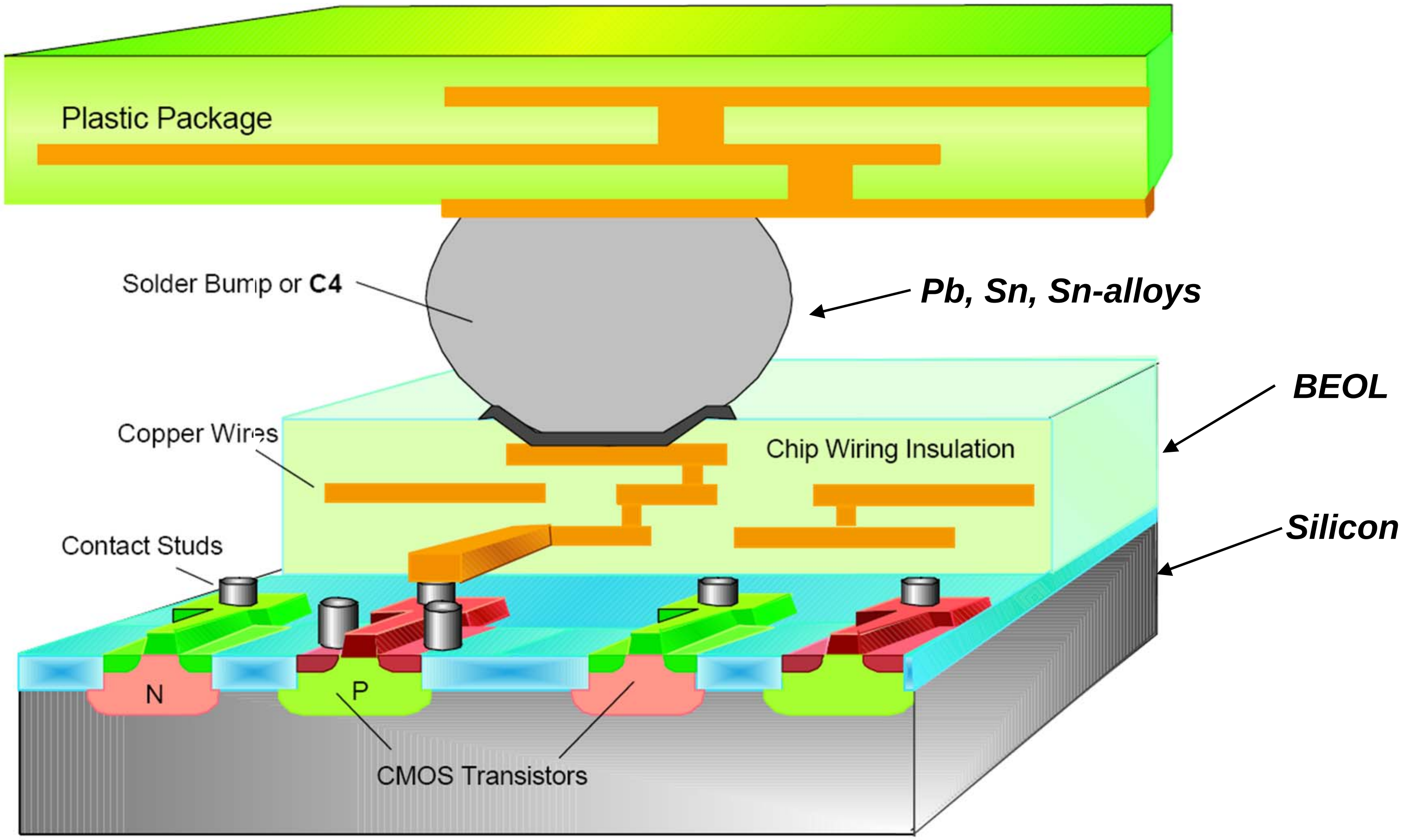
    Sn which has largely replaced Pb has large emission even though no radioactive isotopes
  - *The current specification is $\varepsilon < 2\alpha$/khr-cm^2 (1.4 α/hr on a 300 mm dia. wafer)*

    This is less than the background in most detectors
  - *The detectors can be used to screen materials used to make semiconductors*

    Or to evaluate the contamination during the manufacturing process flow

- *Search for dark matter*
  - *The detectors in use require ultra low backgrounds*
  - *Alpha particle detectors can be used to <u>screen</u> materials used to make DM detectors*

Sources of alpha particles in semiconductor packaging

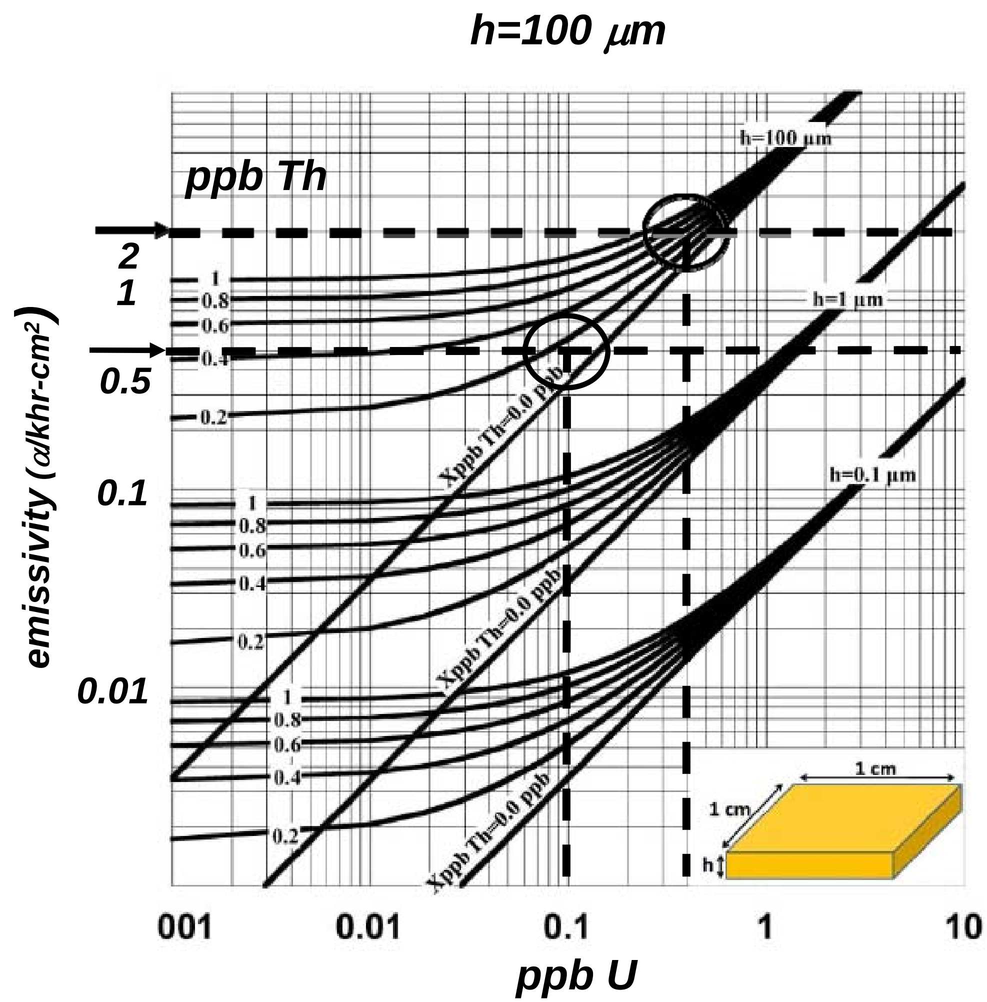


Alpha emissivity, contamination from U, Th on a Silicon Wafer

Particle emissivity of 0.5 α/khr-cm^2 corresponds to ~0.1 ppb U & 0.2 ppb Th in Si

Particle emissivity of 2 α/khr-cm^2 corresponds to ~0.4 ppb U & 0.6 ppb Th in Si

Those small levels are difficult to measure even with ICP-MS



Martinie, IEEE TNS, vol. 58, no. 6, December, 2011, 2798

Level of Detection vs Counting Time:

Level of detection

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

where:

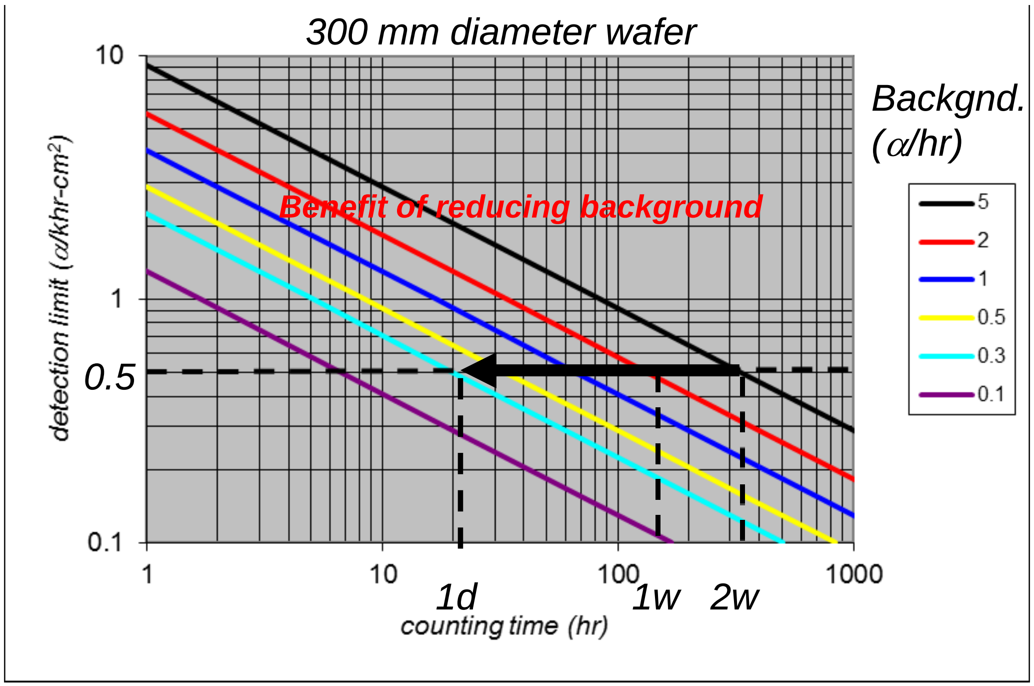
LOD = level of detection

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 detector background

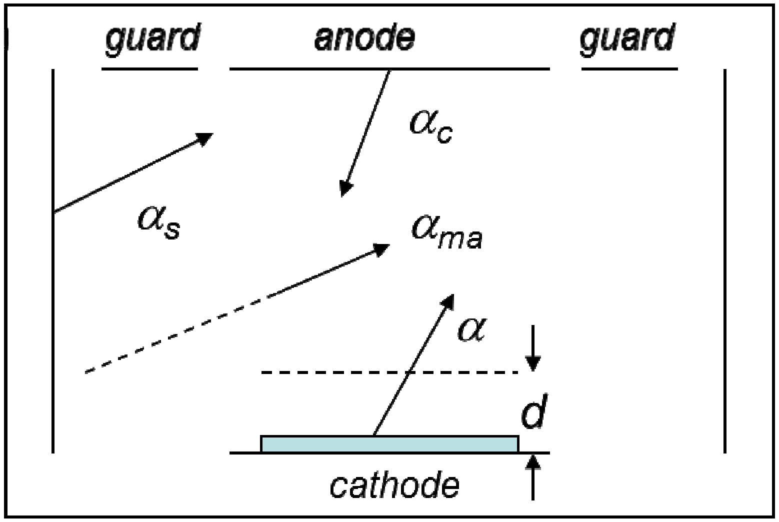
-large counter efficiency

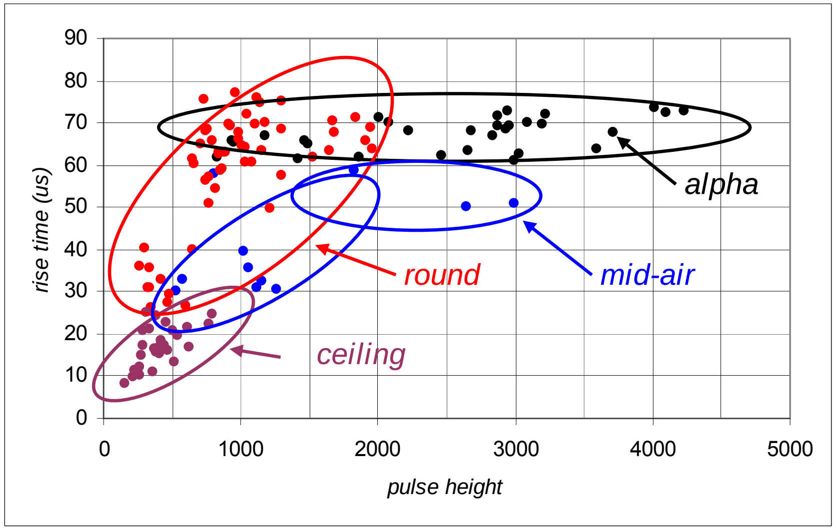
M. Gordon 4th Annual IEEE Santa Clara Valley Soft Error Rate (SER) Workshop, San Jose, Ca. October 25, 2012.

XIA UltraLo-1800: an example of a large-area α-particle detector

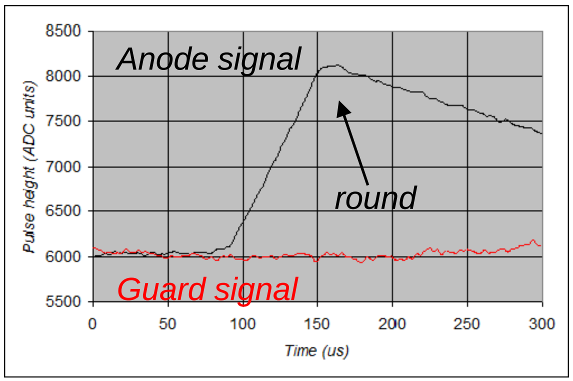
- *Ultra -low background achieved using pulse shape discrimination*
  - *The pulses from the ionization of the counter gas are fit for pulse height, rise time, and "rounding"*
  - *Pulses are further segregated into "alphas," "ceilings, "rounds," and "midair" events depending on the pulse height, rise time, "rounding"*
  - *If the ionization induces a signal on the guard ring it is rejected (events from the side walls)*
  - *The counter needn't be constructed of ultra-low α-particle materials (but it helps)*
  - *The lowest emissivity we have seen is ~ 0.3 α/khr-cm^2 (<u>5 α/day</u> on a 300 mm diameter wafer)- and it was repeatable!*

XIA UltraLo-1800: large-area α-particle detector

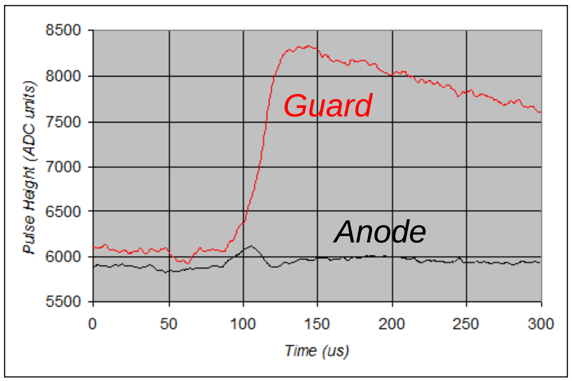




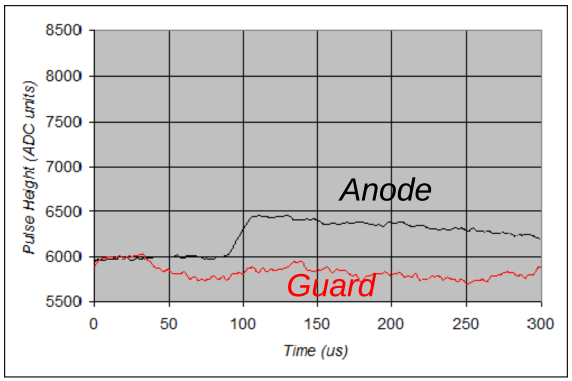
Source on cathode



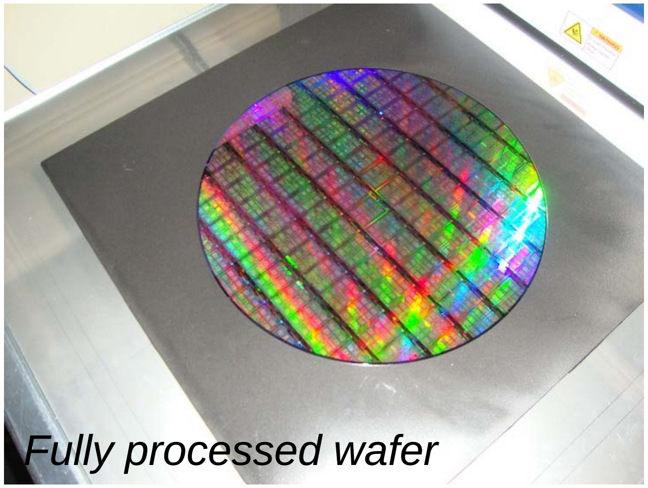
Source on sidewall



Source on anode

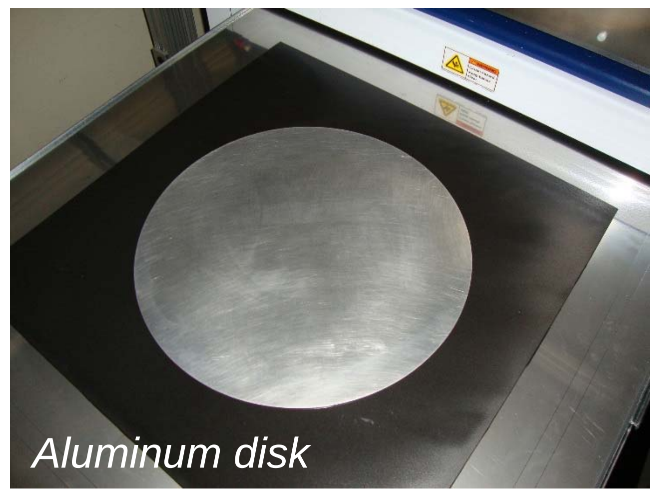


Some samples for alpha particle measurement


Fully processed wafer

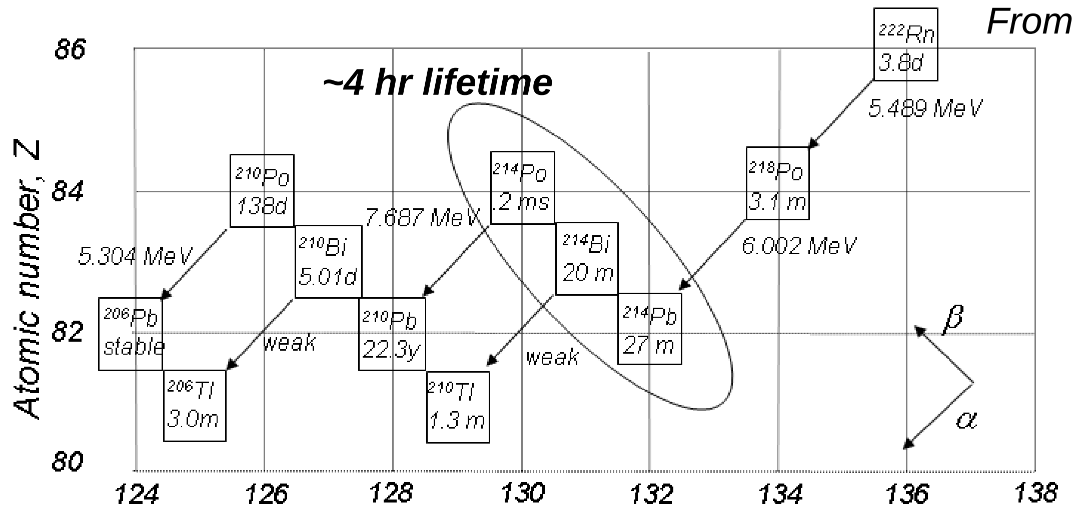

Tin raw material


Wafer ‘carcass” with solder balls

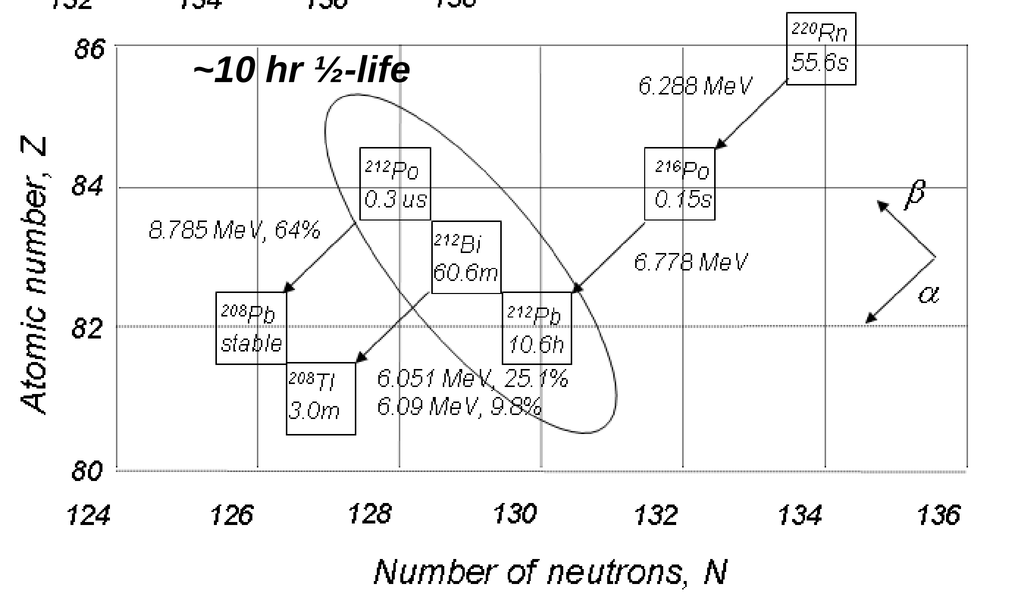

Aluminum disk

Radon daughters plate out on samples exposed to air

From ^{238}U decay chain



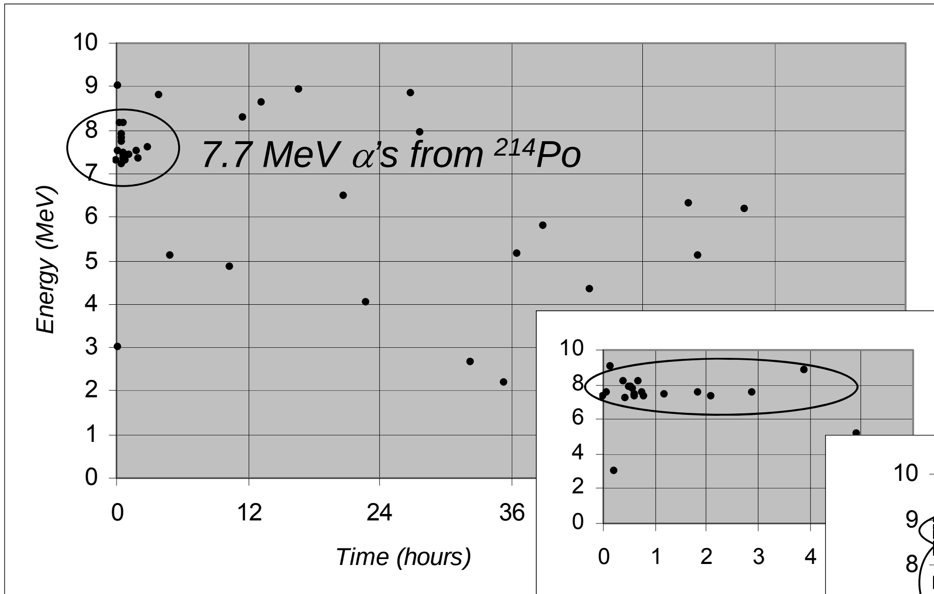
From ^{232}Th decay chain



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

Radon Issues- sample in dry box vs exposed to air

Sample stored in dry N_2

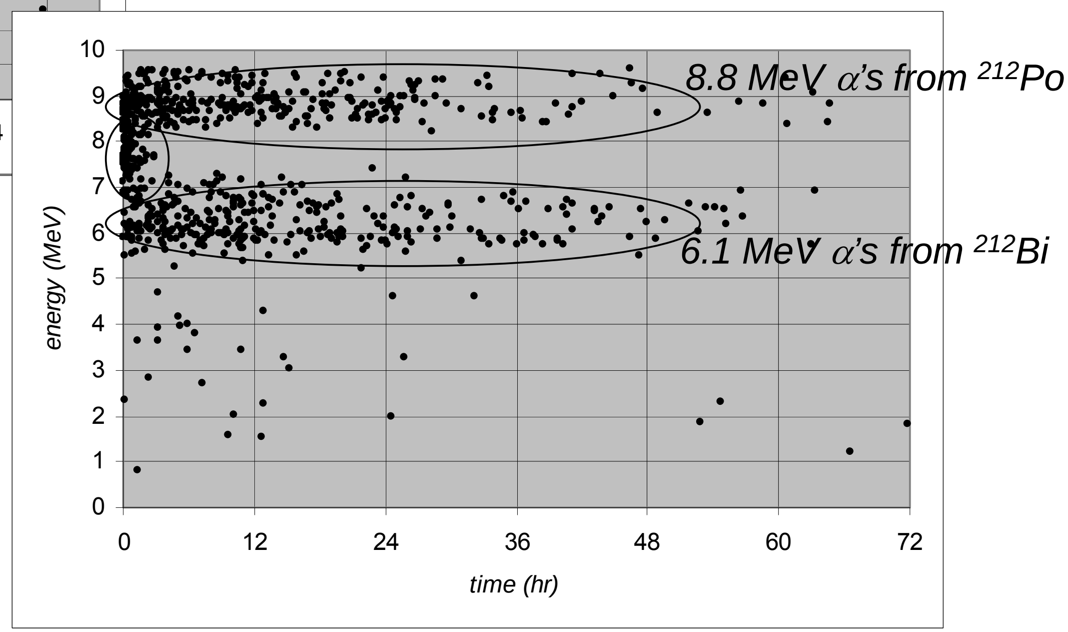


1st 4 hours wasted

Alpha counting can only occur after the radon dies off

-hours to days!

Sample exposed to air 24 hrs



1st 3 days wasted

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

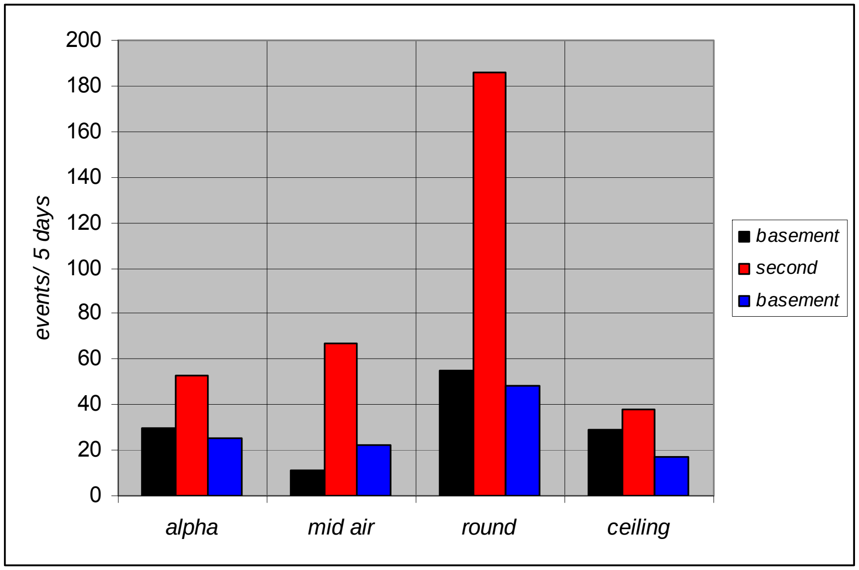
α-particle emissivity depends on neutron flux

- Same detector: 2 locations in the <u>same building</u> (basement & second floor near picture windows)
- Same bare wafer sample, radon excluded
- The number of all classes of events > on 2nd floor
- Modeled the ^{28}Si(n,α) and ^{40}Ar(n,α) nuclear reactions: $\varepsilon \sim 0.3\ \alpha$/khr-cm^2 (for no α in samples)
- The neutron flux is ~2X lower in the basement due to shielding

Events that are discriminated out
radon cosmic rays anode

Location	Alpha	Mid-air	Round	Ceiling
Basement	30	11	55	29
2nd floor	53	67	186	38
Basement	25	22	48	27
Ratio	1.9	4.1	3.6	1.4

Gordon, et al., IEEE Trans. Nucl. Sci., vol. 59, No 6, Dec. 2012, 3101



The effect of static on electrically insulating samples

From the triboelectric series, glass can charge to + HV (and Teflon to – HV)

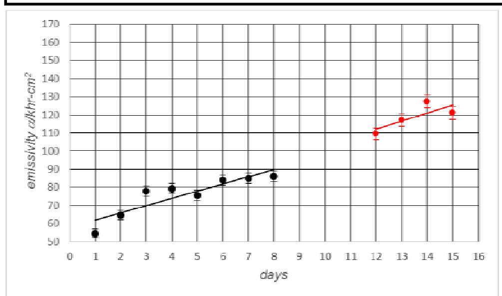
Static electricity of either polarity will perturb the originally homogeneous electric field within an ionization counter. Both polarities have the effect of reducing the count rate

We used the natural radioactivity from a glass wafer that had been charged & measured the natural discharge rate and ways to force discharge

Measured glass for 8 days

Put low activity ~85 pCi ^{230}Th source on top w/HV off, 3days

Removed source and continued counting

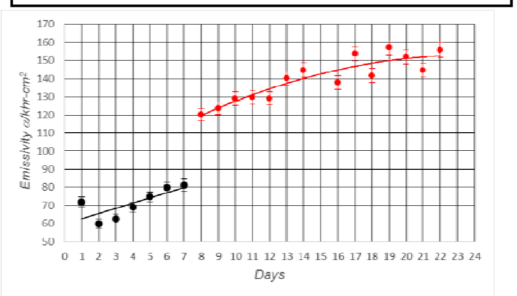


Source not effective

Measured glass for 7 days

Used 0.1μCi ^{241}Am source close to glass, 3X3 pattern 5 minutes each position

Continued counting

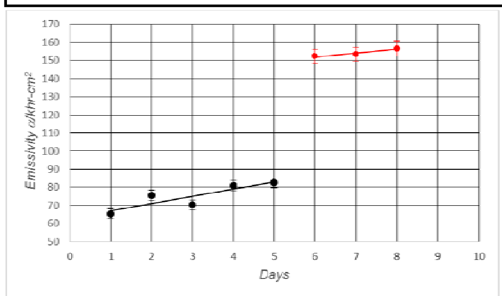


Source partially effective

Measured glass for 5 days

Used antistatic tool on four corners of the glass

Continued counting



Antistatic tool effective

Gordon, et al., IEEE Trans. Nucl. Sci., vol. 62, No 6, Dec. 2015, 3020

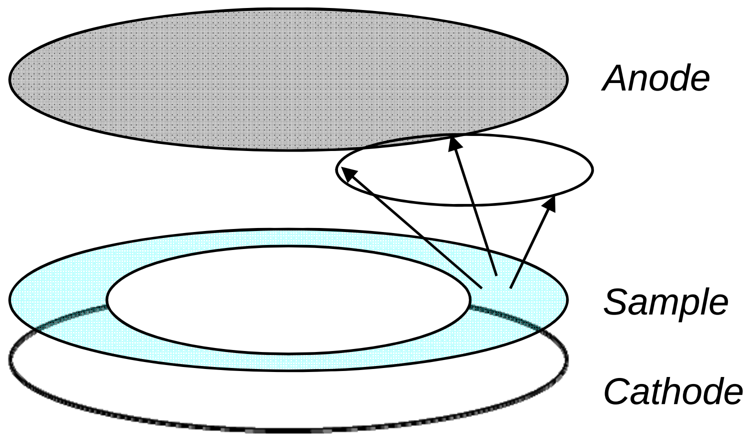
natural discharge time ~ 3 weeks

The effect of geometry on the detection efficiency

Alpha particles emitted near the edge of the detector have a 50% chance of detection (and 1/2 will be vetoed due to charge collected on guard electode)

All alpha particles for small samples will be collected

Need to model the detection efficiency as a function of sample geometry and correct the alpha particle count with 1/eff.



Vector represents α-particle track length in counter gas (function of gas pressure and alpha particle energy)

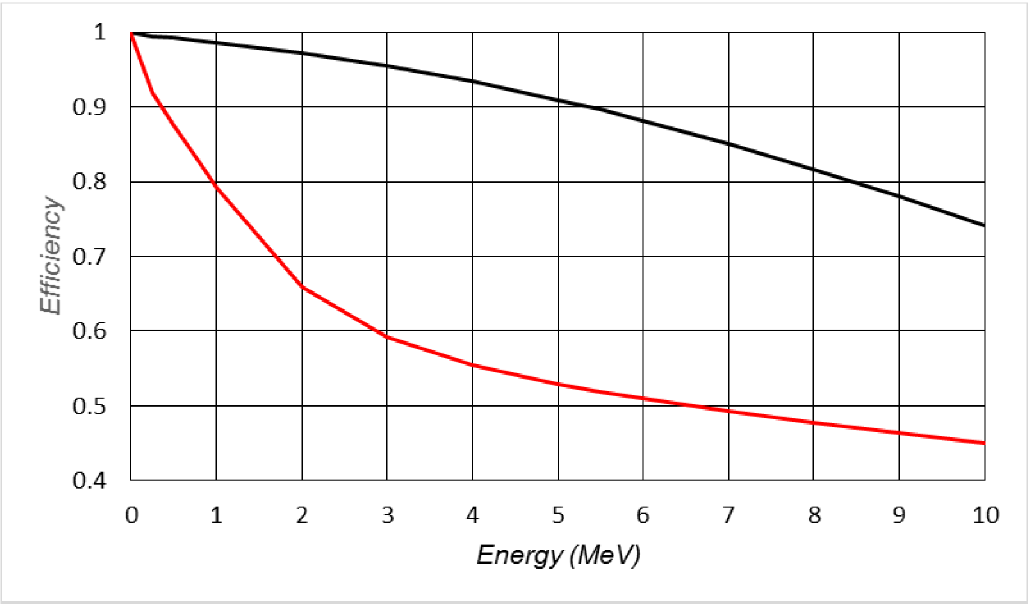
Particles are not counted if trajectory causes ionization which leaves charge in the guard ring

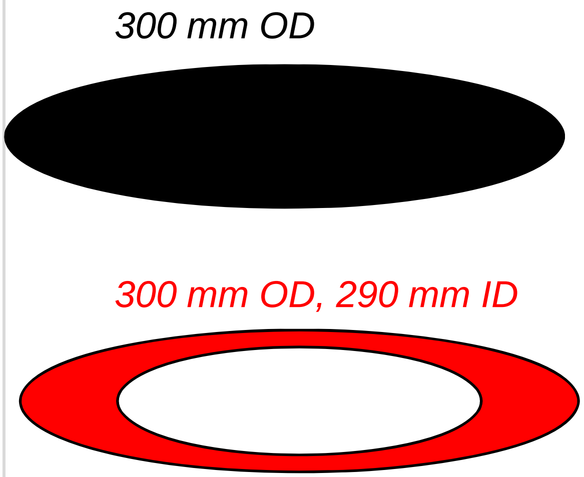
The effect of geometry on the emissivity

Analytic model used to calculate the efficiency for the detector in 300 mm mode

Black line: 300 mm disk, efficiency > 85% up to ~ 7 MeV

Red line: 300 mm OD, 290 mm ID ring, efficiency > 50% up to 7 MeV

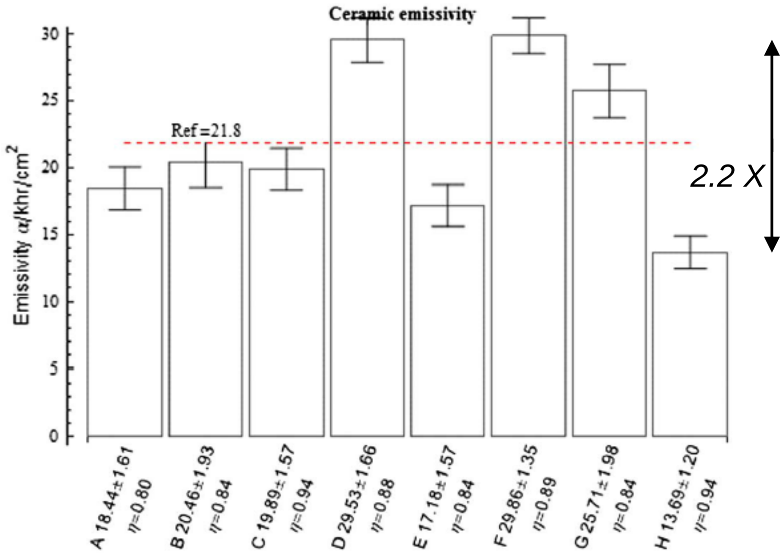




Alpha Measurements, select results of round robin studies

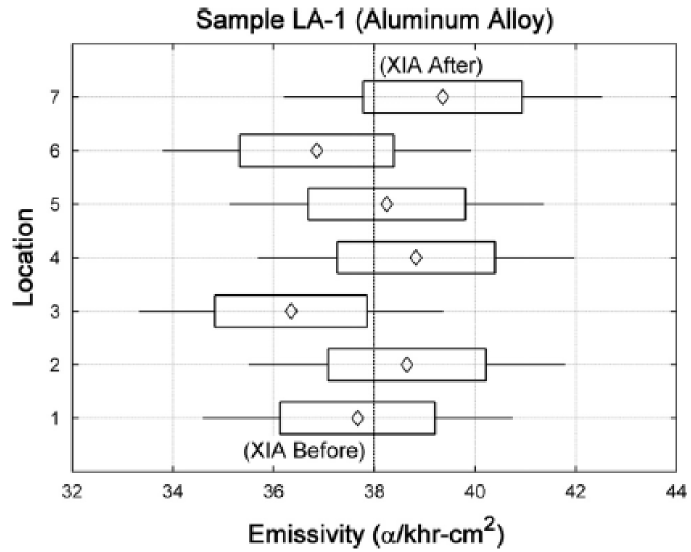
Two round robins- similar results

Low Alpha Ceramic Sample



Alpha Sciences Proportional, Ordella Proportional and XIA Ionization Counter

All participants used new XIA counters



Only new XIA ionization counters

Huge variation on LA samples *Probably due to source to cathode height variation*	*Excellent consistency*

Jeff Wilkinson, et al., IEEE TNS, vol. 61, No. 4, Aug. 2014, 1516

B.D. McNally et al., NIM Phys. Res. A 750, 2014, 96

Alpha Measurements, select results of round robin studies

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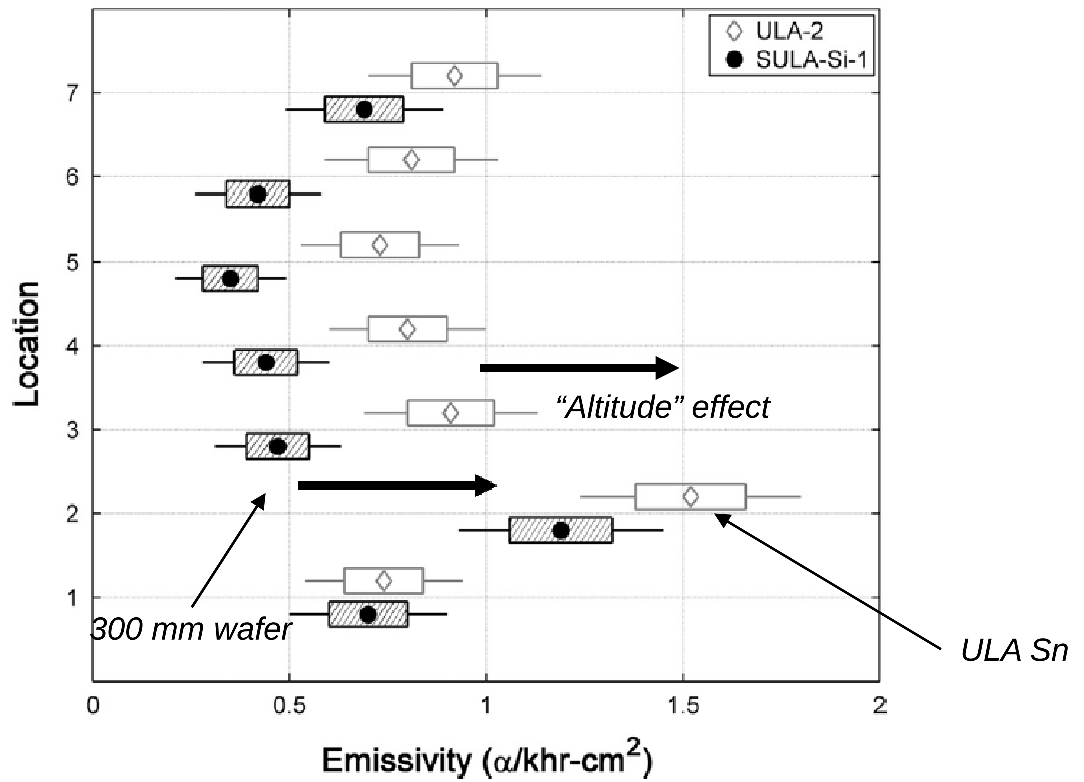

Excellent consistency, altitude dependence (neutrons)

B.D. McNally et al., NIM Phys. Res. A 750, 2014, 96

Requirements for an industry-wide standard

- *Lab to lab variability (in the first consortium) 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*
- *Source requirements*
  - *Thick source, not monoenergetic (like emission from most samples), 1MeV < $E\alpha$ < 8.8 MeV*
  - *Emissivity ~2 α/khr-cm^2 up to ~20 α/khr-cm^2*
  - *Stable emission with respect to time, energy*
  - *Robust for shipping/ handling*
  - *Material should be difficult to contaminate*
  - *Material should probably be electrically-conductive*
  - *Emissivity should be uniform within ~ 1 cm^2 area*
  - *Ideally we would have several “identical” standards available*
  - *Need to ensure that the sample isn’t contamined by radon*

Summary

- *Detecting low levels of alpha particles in materials is challenging*

- *Radon, cosmic rays, static electricity, and sample geometry can affect the results*

- *Users of low-background alpha particle detectors need NIST-traceable standards to ensure proper operation of their detectors*

  – *Preferably the standard would have an emissivity near the level of the samples to be measured*