Challenges in Ultra-low Emissivity Alpha Particle Detection

Michael Gordon

IBM TJ Watson Research Center

Yorktown Heights, NY 10598

gordonm@us.ibm.com

(914) 945-2802

Outline

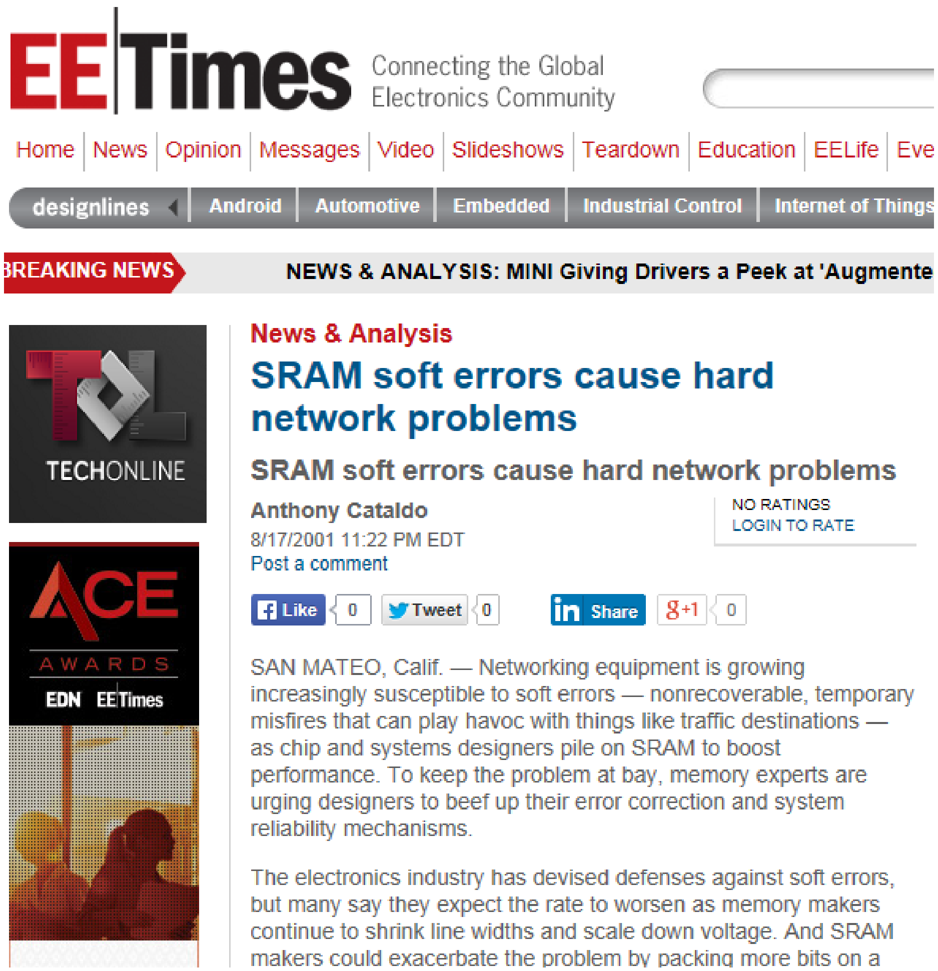
- *Introduction to single event upsets- an example for the need for ultra-low alpha-particle emissivity materials*
- *Sources of alpha particles in materials used in semiconductors*
- *Level of detection vs counting time as a function of counter background*
- *Large-area alpha particle detectors in use*
- *Effect of radon, cosmic rays, and static electricity*
- *Results from several round robin studies*
- *The need for an industry-wide standard*
- *Summary*

Single Event Upsets

- *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 is a major reliability problem in servers, laptops, smart phones, pacemakers, ipads, drones, autonomous vehicles…*

- *Sources of single event upsets:*
  - *Alpha particles from natural radiation in chip packaging (ceramic, underfill, interconnects, wafers, etc)*
    - *current specification is* $\varepsilon < 2\ \alpha$*/khr-cm*^{2}
    - *that's 1.4* α*/hr on a 300 mm diameter wafer*
  - *Cosmic rays which create highly ionizing particles when they interact w/ silicon (spallation)*
  - *Thermal (slow) neutrons from* $^{10}B(n,\alpha)$ *nuclear reaction*

Soft Errors in the News (Sun Microsystems)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News & Analysis

SRAM soft errors cause hard network problems

SRAM soft errors cause hard network problems

Anthony Cataldo
8/17/2001 11:22 PM EDT
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SAN MATEO, Calif. — Networking equipment is growing increasingly susceptible to soft errors — nonrecoverable, temporary misfires that can play havoc with things like traffic destinations — as chip and systems designers pile on SRAM to boost performance. To keep the problem at bay, memory experts are urging designers to beef up their error correction and system reliability mechanisms.

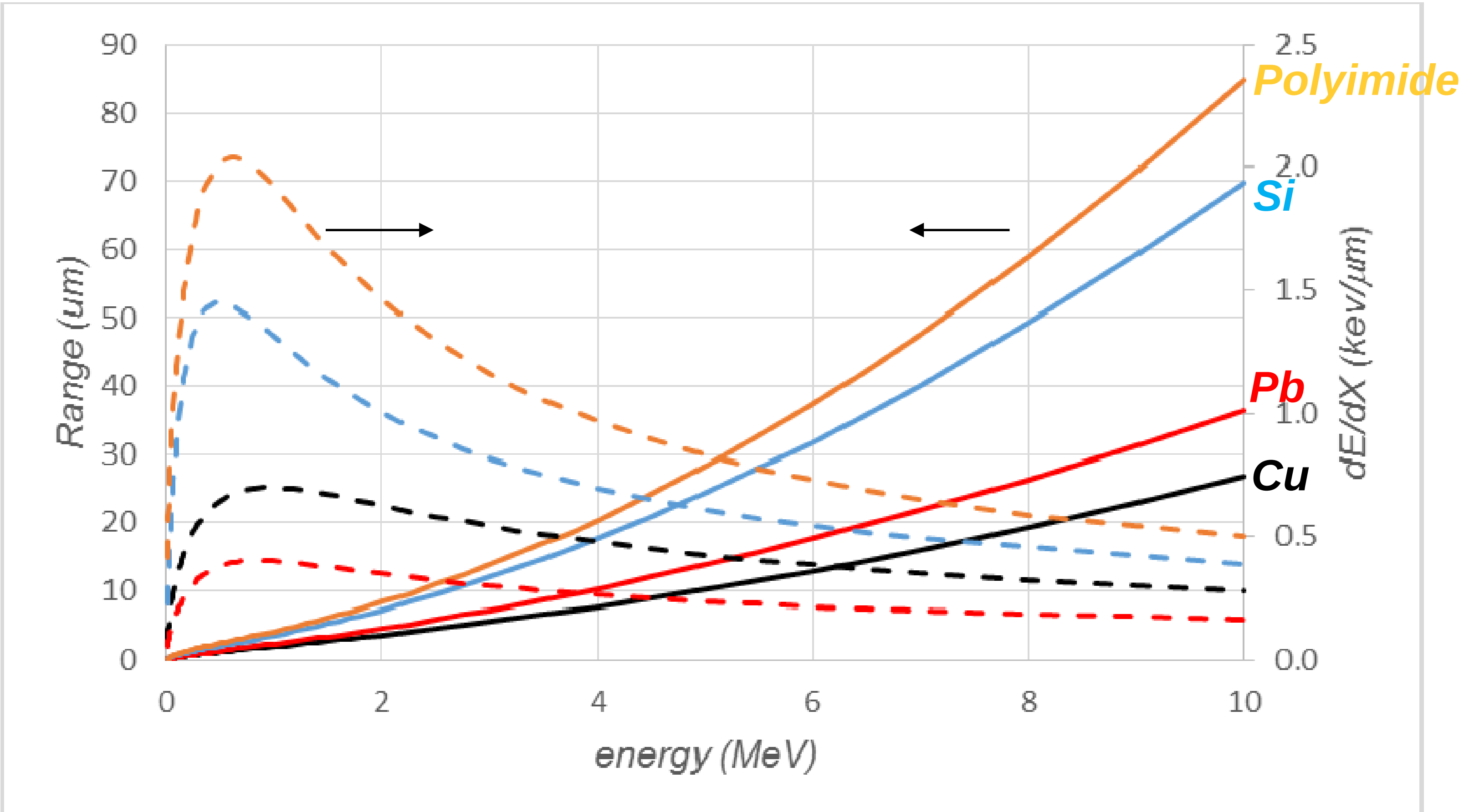
The electronics industry has devised defenses against soft errors, but many say they expect the rate to worsen as memory makers continue to shrink line widths and scale down voltage. And SRAM makers could exacerbate the problem by packing more bits on a

Sun Microsystems learned the hard way several years ago, said David Yen, vice president and general manager of Sun's processor group and former head of its integrated-products group. Sun at times found itself at odds with server customers over problems that it only later learned were attributable to soft errors. "As a vendor we couldn't tell the customer the reason [initially] and everyone would get upset," he said. "It's been a lesson to us all. We have to look at components from the perspective that they're not 100 percent reliable."

Server makers have since made strong error correction part of their designs from the outset. But networking OEMs are just starting to notice the effects of soft errors, observers said. "The awareness has not been very great," said Micron Technology's Pawlowski. "I do technical seminars all over the planet and everywhere I go I always bring up SER."

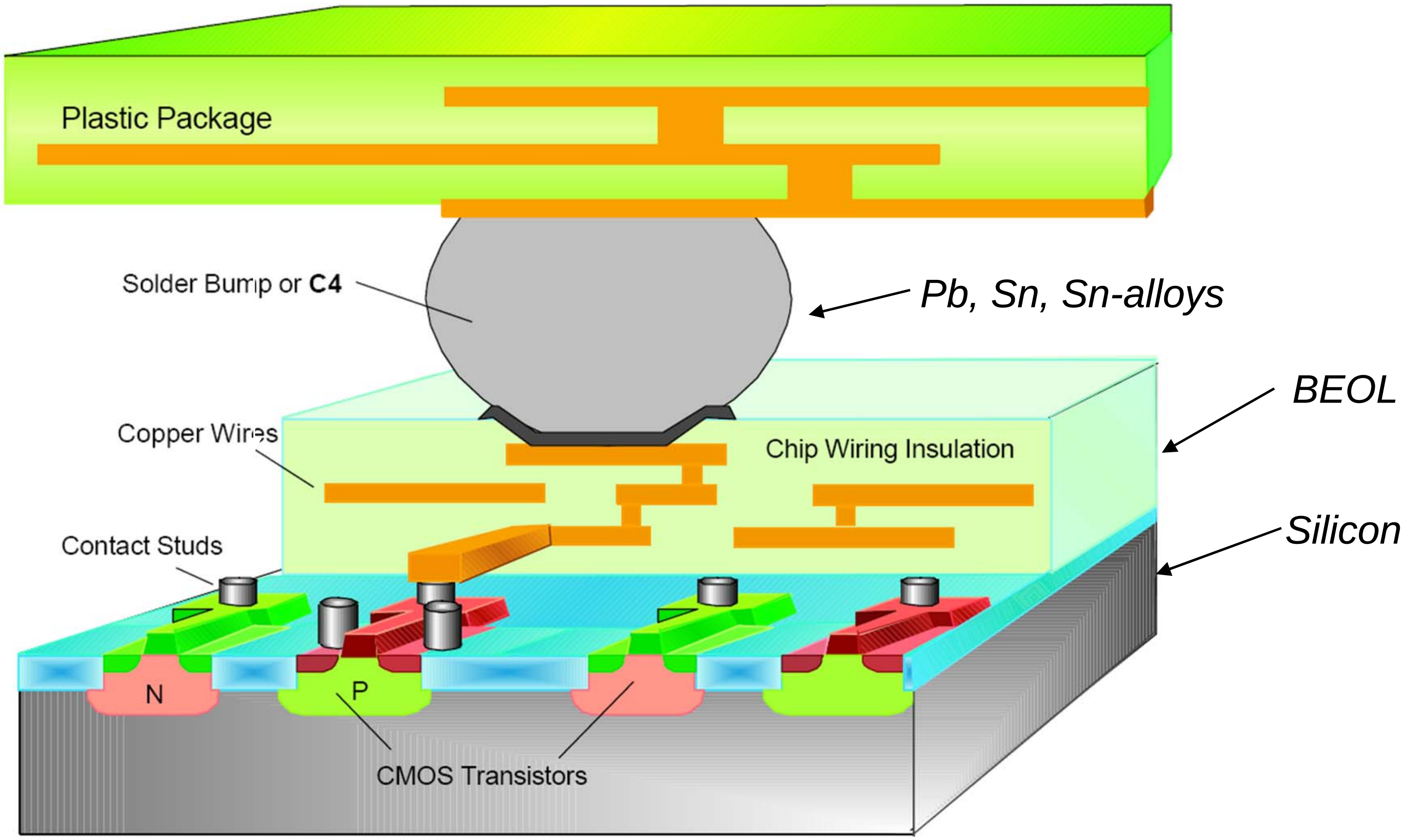
Soft errors occur when charged particles penetrate a memory cell and cross a junction, creating an aberrant charge that changes the state of the bit. Among the most common sources of soft errors are alpha particles emitted by contaminants in memory chip packages or cosmic rays penetrating the earth's atmosphere.

Range and dE/dX for alpha particles in materials



Maximum range < 100 μm
Bragg peak, ~0.4 MeV – 1 MeV

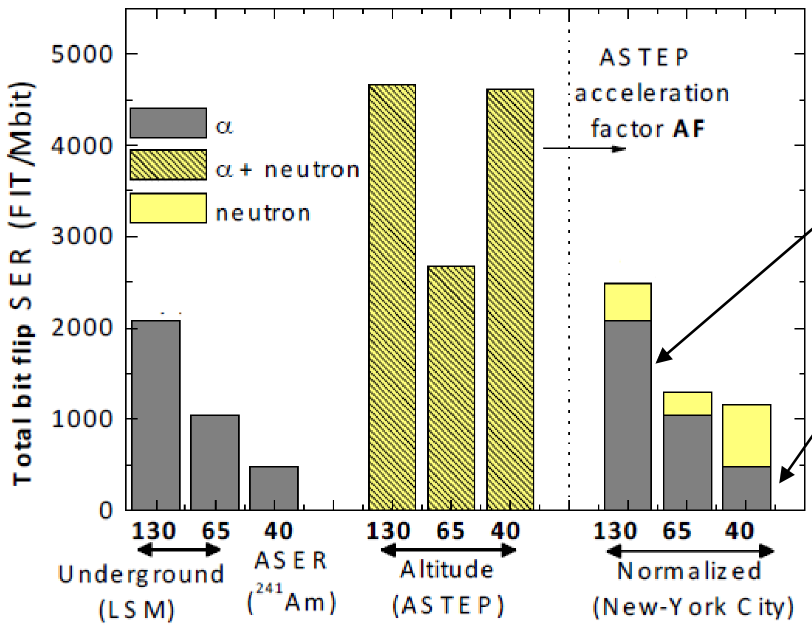
Sources of alpha particles in semiconductor packaging



Failure rate caused by neutrons and alpha particles

Commercial 130 nm, 65 nm and 40 nm SRAM devices
The α-particle component is a substantial fraction of total SRAM error rate

FIT= error in 10^9 hours



2.3 α/khr-cm^2

0.92 α/khr-cm^2

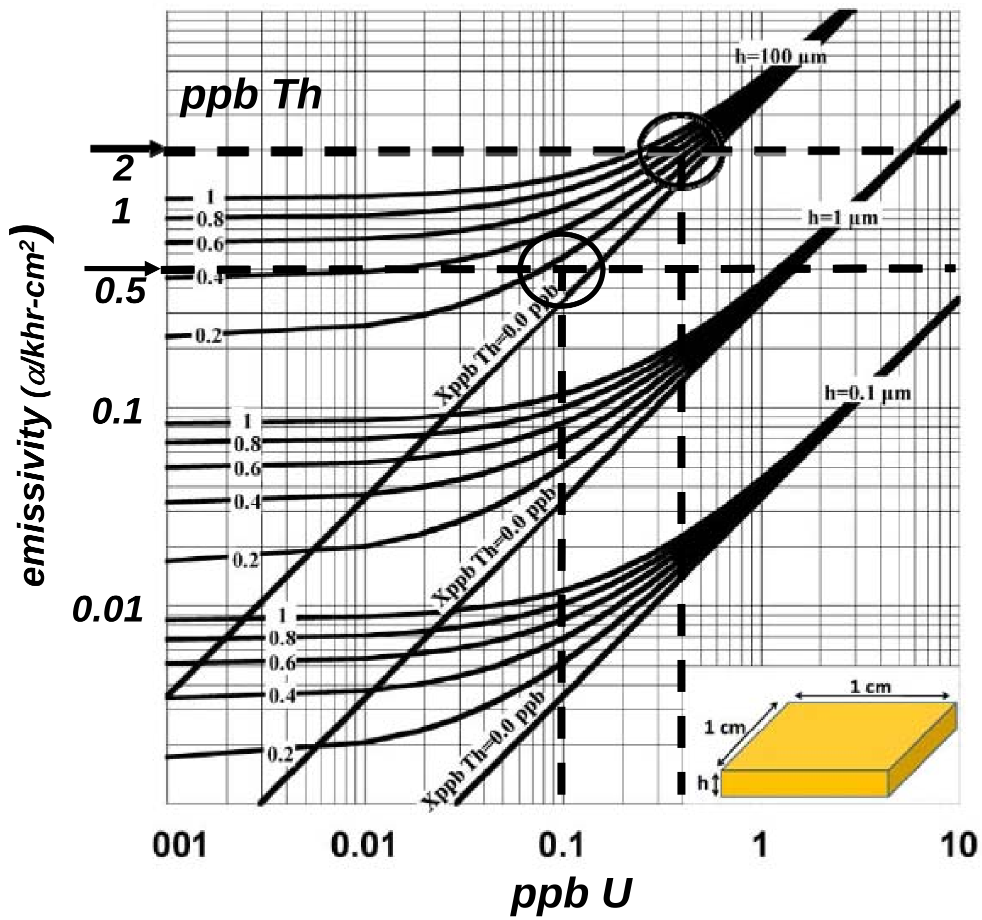
J.L. Autran, et al., Radiation Effects Data Workshop (REDW), RADECS, IEEE, 2014, 1

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

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

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

h=100 μm



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:

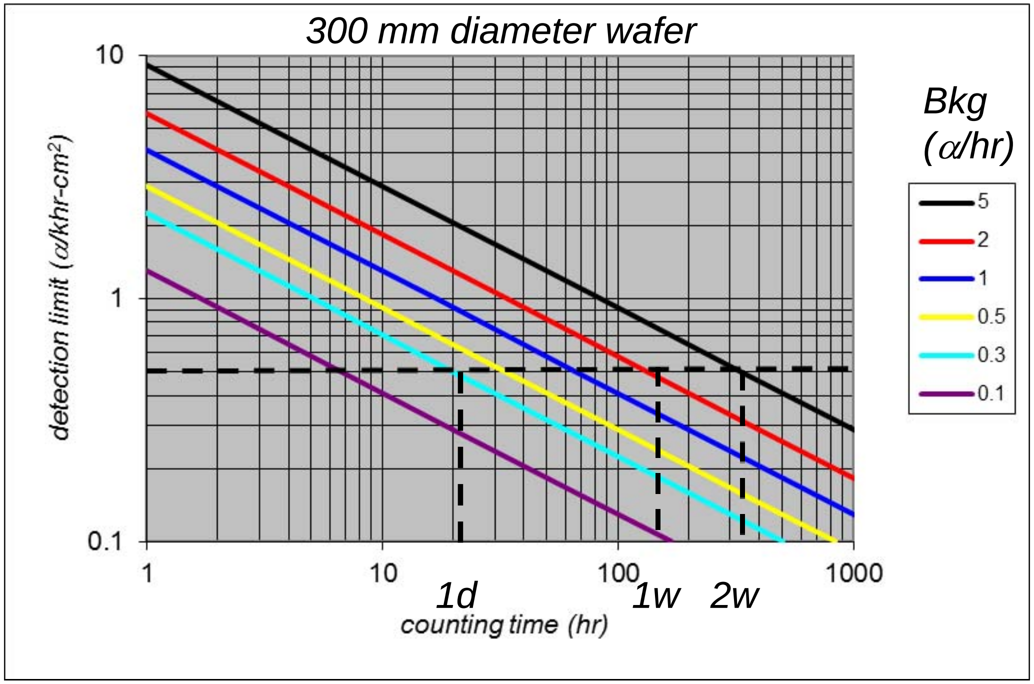
LOD = level of detection

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

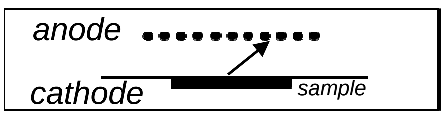
-low counter background

-large counter efficiency

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

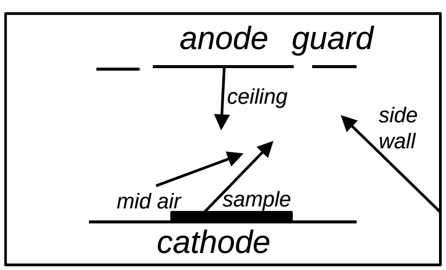
Some large-area alpha-particle detectors in use

Proportional counter
Alpha Sciences



Pros	Cons
-Large amplitude signal	-Counter needs to be constructed of ultra-low emissive materials
-Relatively inexpensive	-ΔE counter (no energy into)
-Simple to operate	-Alphas must pass through window
-Multiple wafers	-High background (> 2 α/khr-cm^2)
-Not sensitive to static charge	-Sensitive to EMI noise, vibration

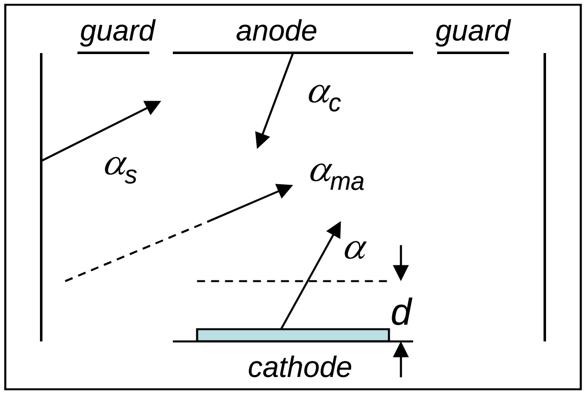
Ionization counter
XIA LLC



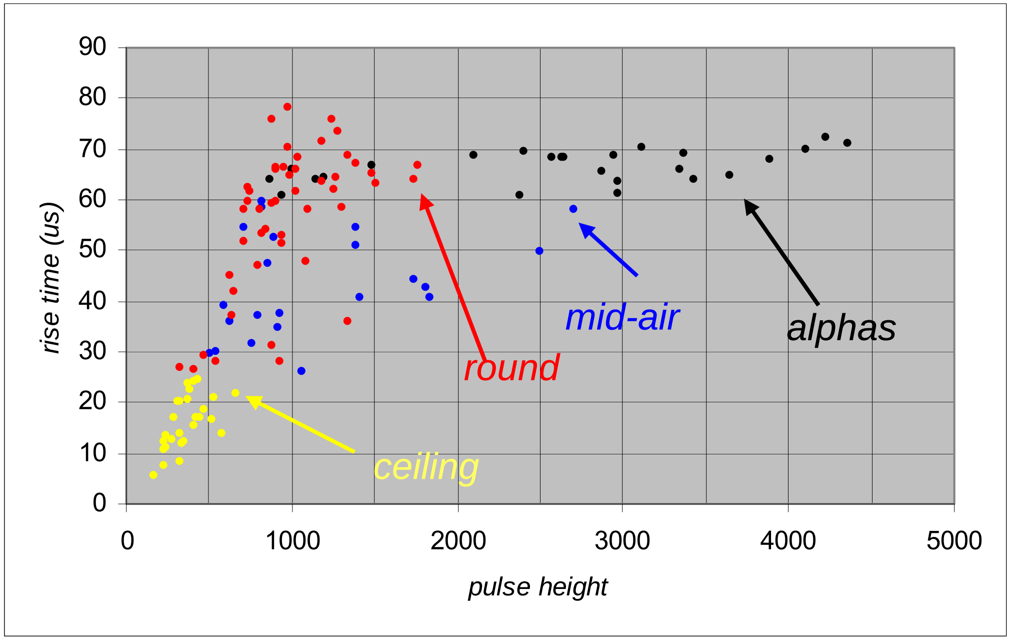
Pros	Cons
-<u>Active signal discrimination</u> (rise time, amplitude and veto)	-Small amplitude signal
-Very low background (~0.3 α/khr-cm^2)	-Somewhat expensive
-Energy information	-Single wafer
-Insensitive to noise, vibration	-Sensitive to static charge on sample

Operating principles of the XIA ionization detector

- Sample sits on cathode, 300 mm ϕ or 1800 cm^2 operating mode



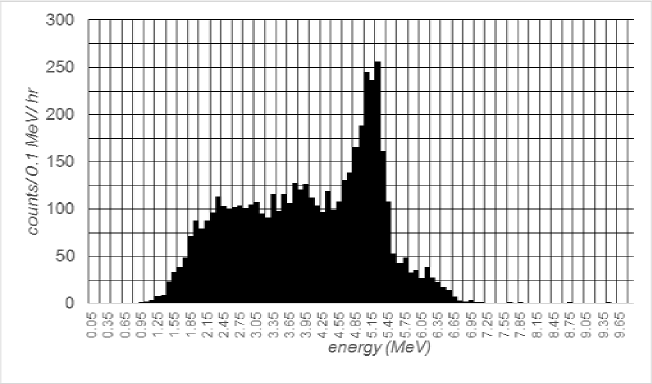
- Counter is filled with Argon (boil-off) from dewar
- Each signal induced on anode is digitized and fit for amplitude and rise time
- Ceiling events have small amplitude and rise time
- Events from the side induce a signal on the guard ring and are rejected
- Mid air events have rise times that are too small (< 60 μs)
- Round events are those where the parabolic shape of the signal is too large (unphysical for alpha events)
- 1 MeV α-particle threshold



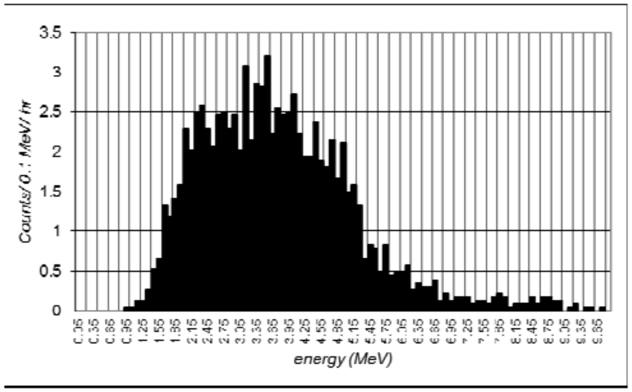
Gordon, et al., IEEE TNS, Vol 59, No 6, Dec. 2012, 3101

Selected examples, uncontrolled material, vs ULA

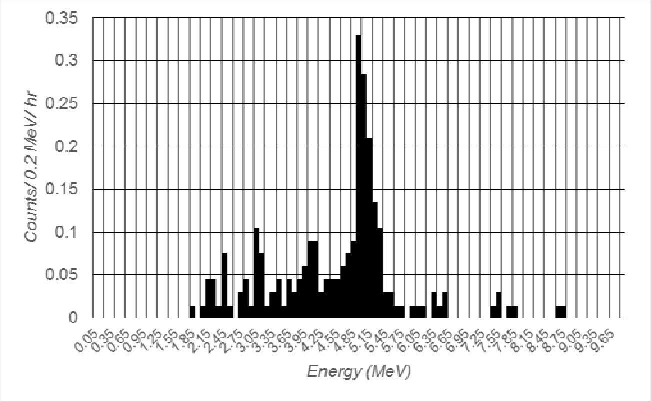
Sn, ε = 7895 +/- 111 α/khr-cm^2



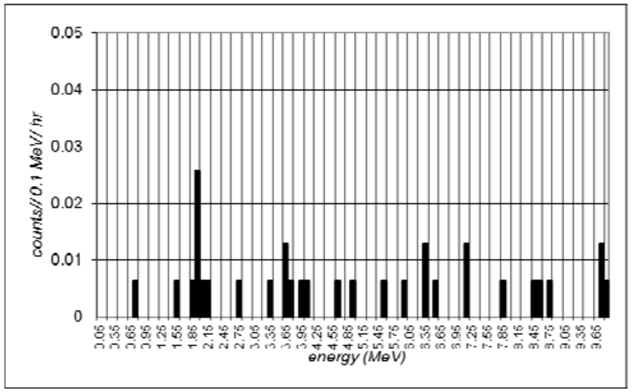
300 mm Al disk, ε = 143 +/- 3 α/kr-cm^2



LAL, ε = 9.9 +/- 0.8 α/lkhr-cm^2

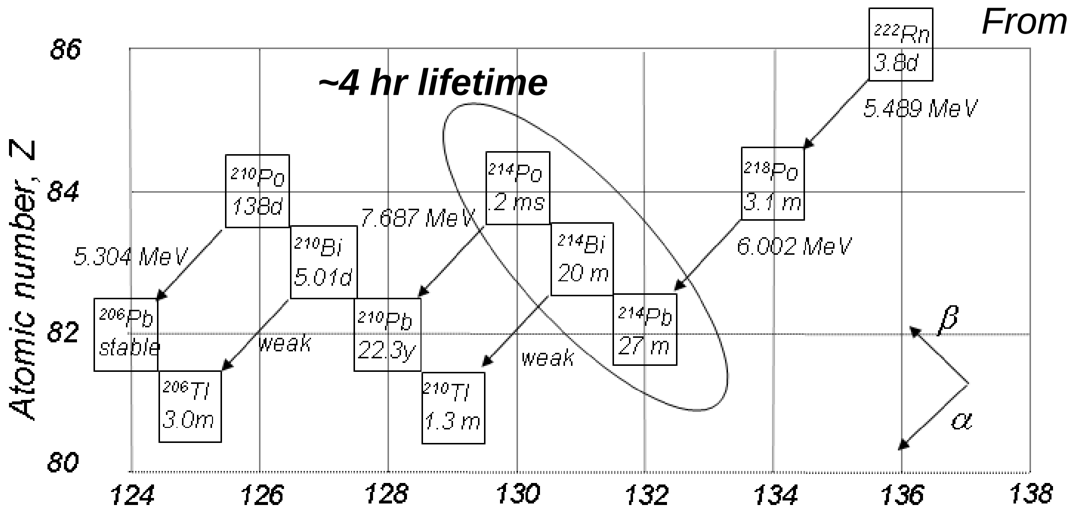


Sn, ε = 0.33 +/- 0.06 α/khr-cm^2

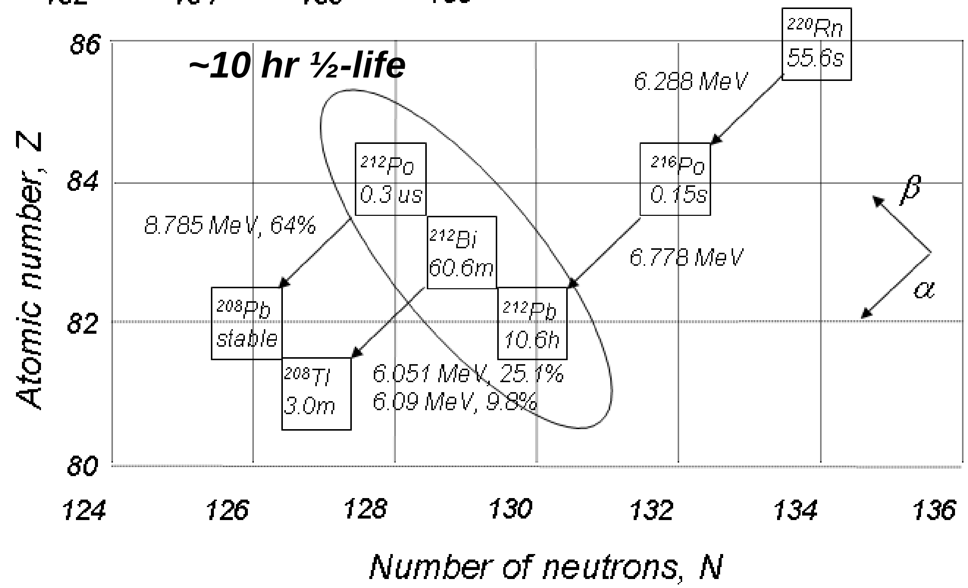


Radon daughters plate out on samples exposed to air

From ^{238}U decay chain



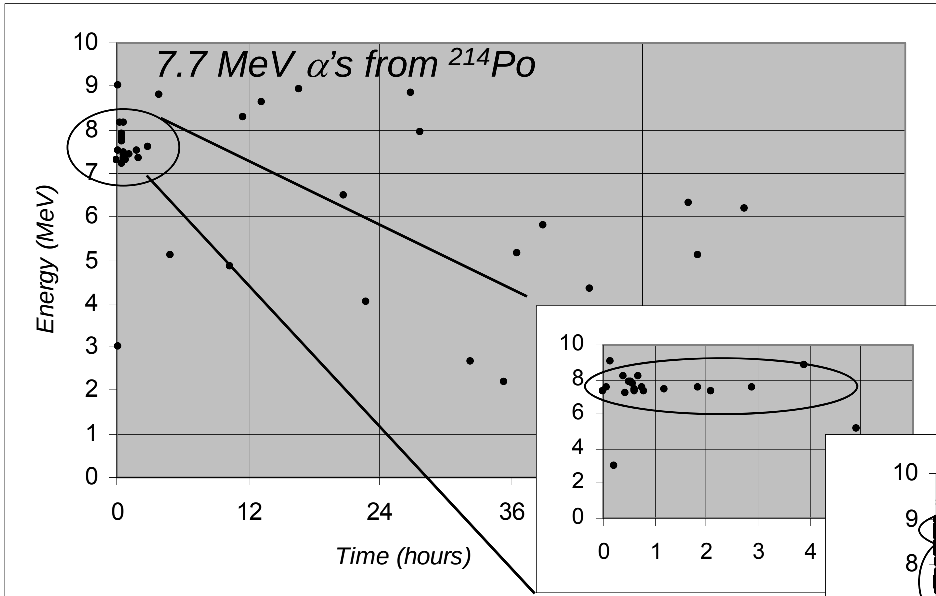
From ^{232}Th decay chain



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

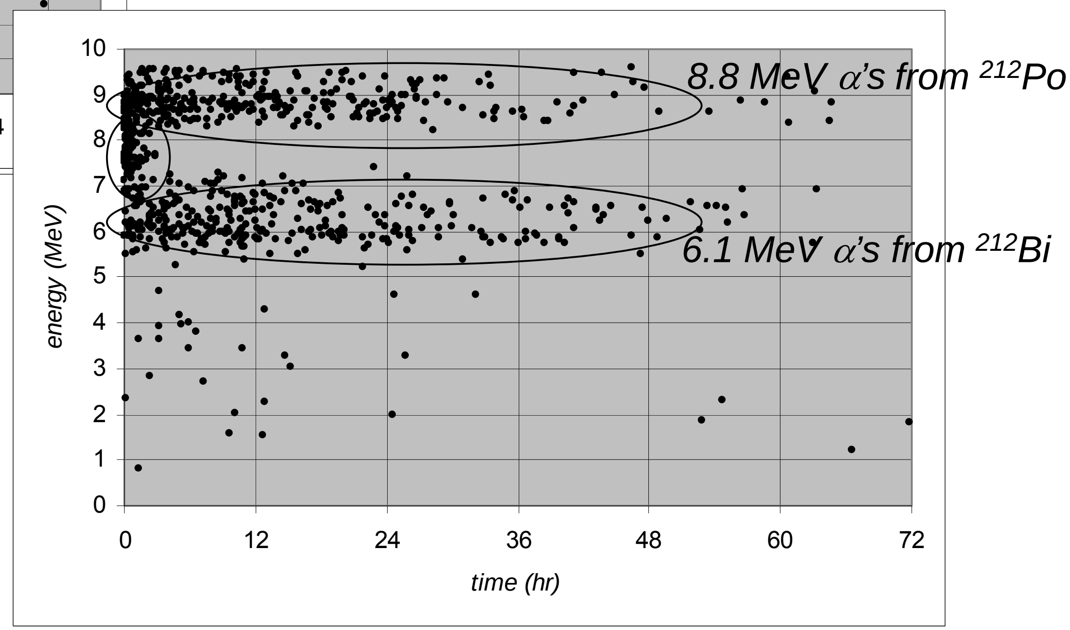
Examples of effects of radon adsorption

Sample stored in dry N_2



Sample storage and handling is critical

Sample exposed to air 24 hrs



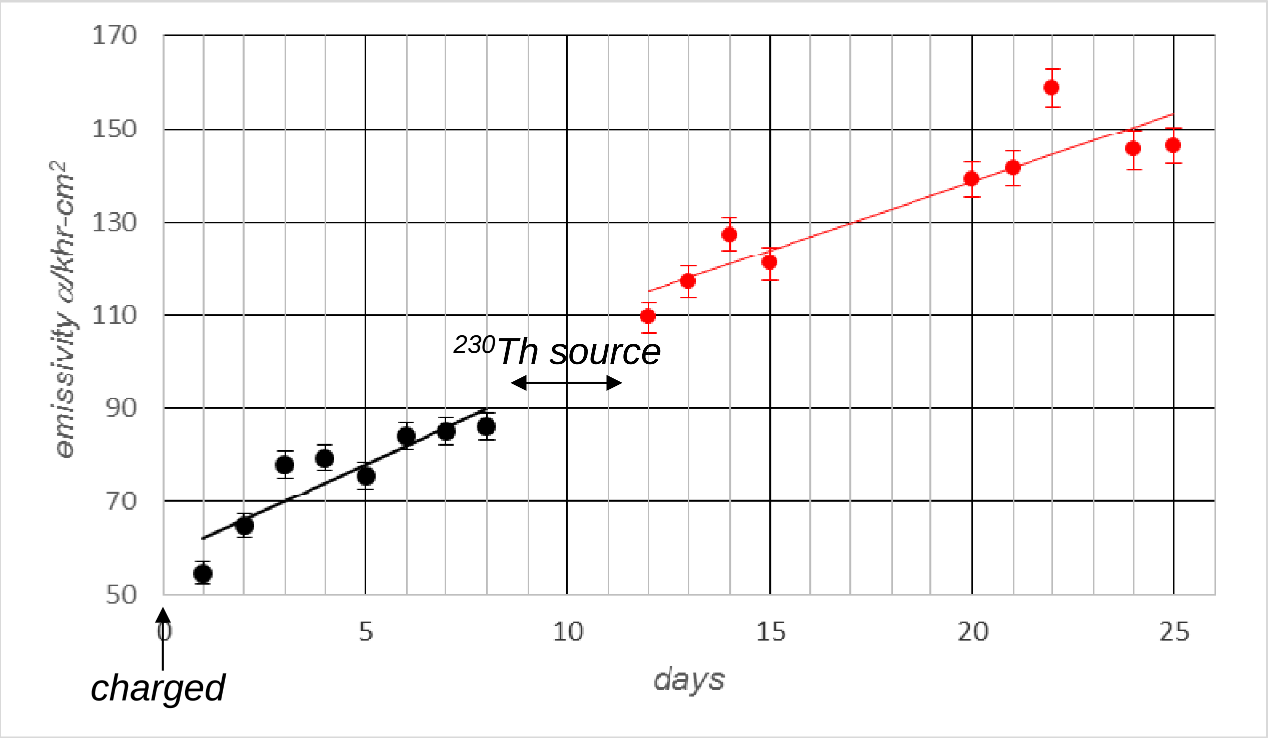
Gordon, et al., IEEE TNS, Vol. 59, No. 6, Dec. 2012, 3101

The effect of static electricity on insulating samples

Electrical insulators can charge to several kV which can distort the electric field in an ionization counter

The effect can be eliminated by discharging the samples of shielding their influence

An example of the emissivity vs time for a charged 300 mm diameter glass wafer is shown below



Time to discharge > 3 weeks!

Radon, Cosmic Rays and Static Electricity

- *Radon adsorbed on samples can take several days to die off before the true emissivity of the sample can be measured*

  This can be mitigated by sealing samples in air tight enclosures

- *Cosmic rays (neutrons) add to the counter background*

  Ar (n,α) and Si (n,α) reactions in gas above sample and wafers
  This leads to an "altitude effect" (background larger at higher elevations)

  (n,p) computed for reactions on plastic, gas and wafers (source of round event)

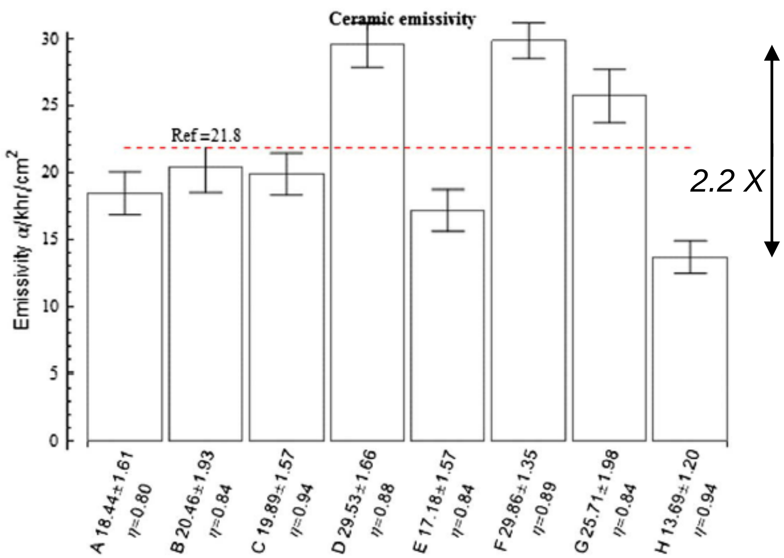
- *Static Electricity on insulating samples can distort the electric field in ionization detectors, which can reduce the measured alpha emissivity*

  This can be mitigated by discharging sample or shielding its influence

Alpha Measurements, select results of round robin studies

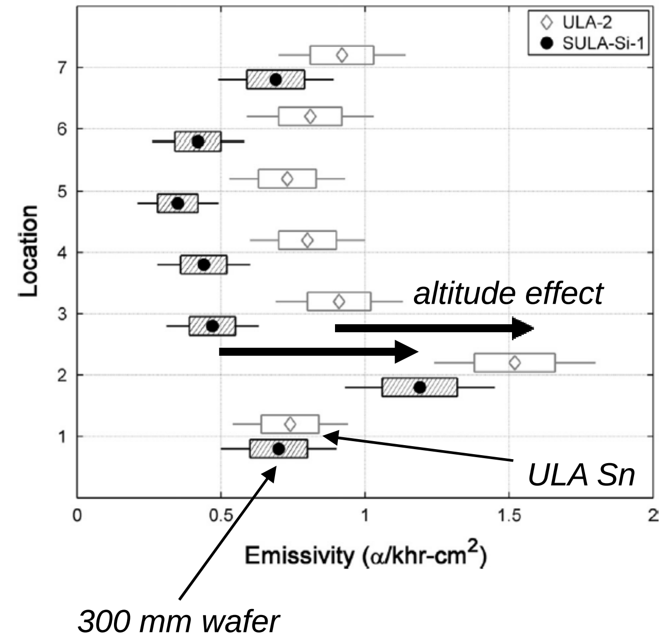
Two round robins- similar results

Low Alpha Ceramic Sample



Alpha Sciences, Ordella Proportional and XIA Ionization Counter

All participants used new XIA counters



XIA counters only

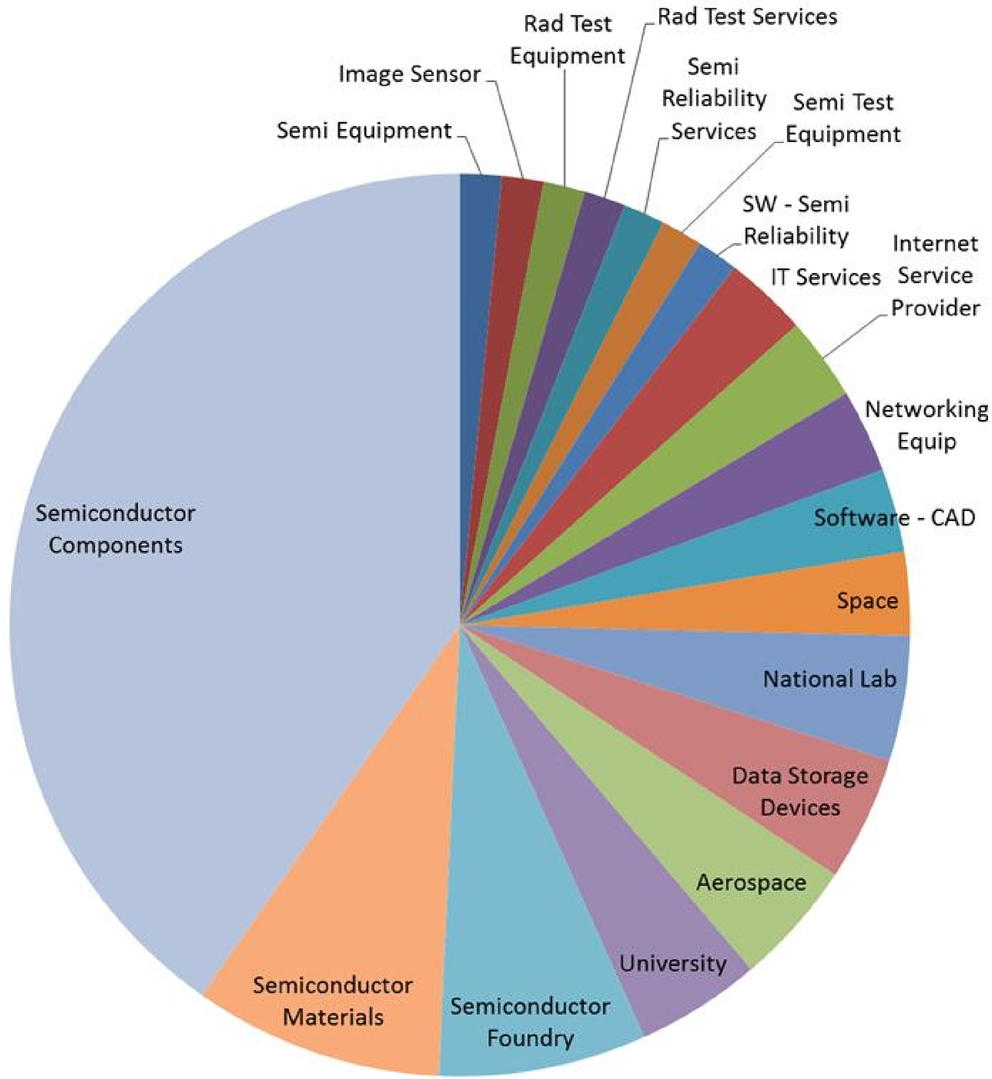
Huge variation on LA samples *Probably due to source to cathode height variation*	*Excellent consistency* *Altitude dependence*

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

Demographics of attendees of 1st six Cisco SER workshop

Workshop focus is on α –particle detection, reduction, effect on SER



Requirements for an industry-wide standard

- *Lab to lab variability (in the first consortium, rounds I & II) is 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 (to mimic most samples), 1MeV < E_α < 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*
  - *Emissivity should be uniform within ~ 1 cm^2 area*
  - *Ideally we would have several "identical" standards available*
  - *Minimize contamination by radon*

Acknowledgements:

Brett Clark (Honeywell)

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Rick Wong, Charlie Slayman (Cisco)

Summary

- *Alpha particle are a major contributor to soft error rates in CMOS devices*
  - *The semiconductor industry is using materials at the ULA ($<2\alpha$/khr-cm^2) level, with lower levels in the foreseeable future*
  - *A new class of detectors is capable of making these measurements reliably*
  - *Radon, cosmic rays and static on the surface of insulating samples can affect the measurement results*
    - *Radon: high results die off in a few hours to few days*
    - *Cosmic rays: higher constant background*
    - *Static: glass samples (+ charge) show lower results initially*
  - *The industry needs a NIST-traceable ULA standard to confirm proper detector operation at these ultra-low levels*