Investigation of Accelerated Alpha Testing with Vacuum

10-27-2011

Agenda

- Motivation
- Accelerated Alpha SER (AASER) vs Source/DUT Spacing
- Vacuum System
- AASER vs. Source/DUT Spacing in Vacuum
- Geometric Effects
- Summary

JESD 89A Section 5.4.5

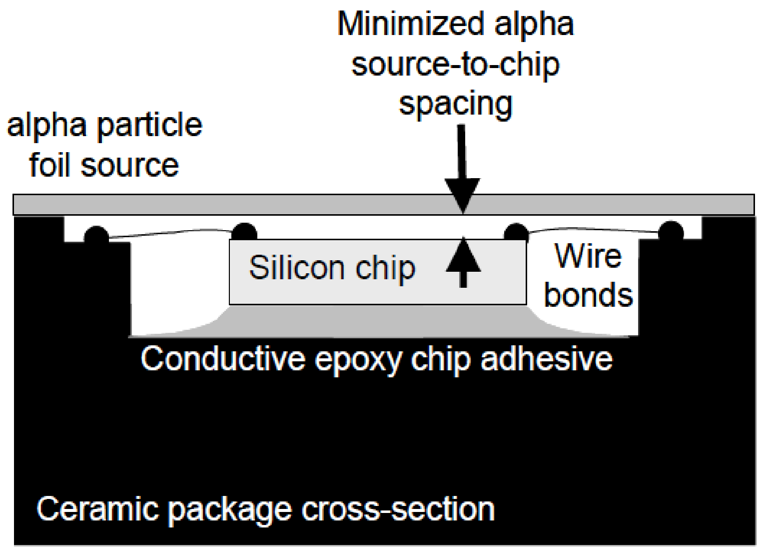
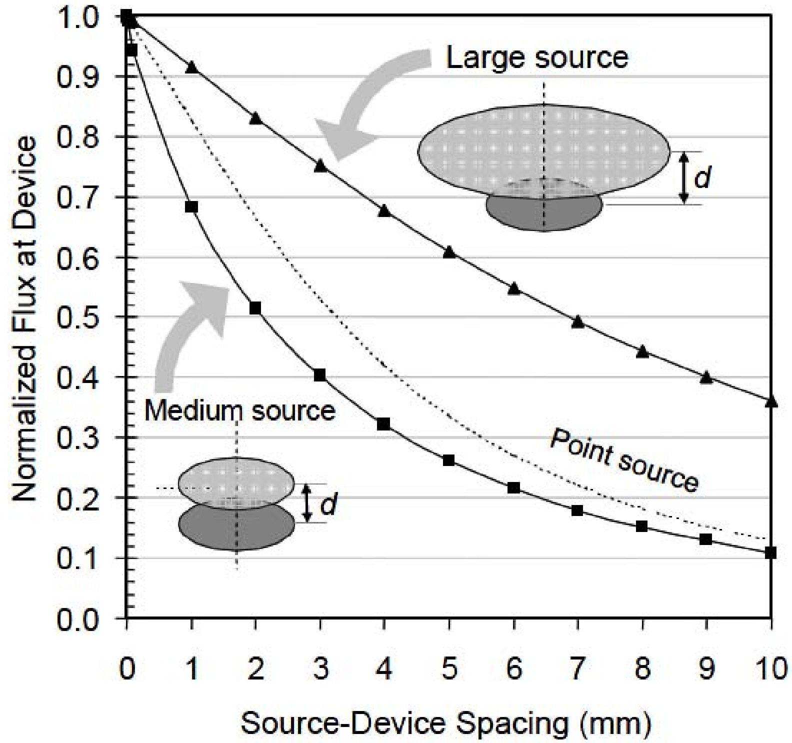


Figure 5.2 — Cross-section through ceramic package illustrating recommended alpha source size and placement – larger than the chip and as close to the chip as possible.

- A spacing with less than 1mm is recommended
- How does spacing between source and device affect the FIT rate measurements?

JESD 89A 5.6.3 – Geometric Effect

- Simple analytical model
- Flux highest when source is right on top of die
- 30% drop in flux at 1 mm spacing if source is same size as DUT
- 10% drop in flux at 1 mm spacing if source >> DUT



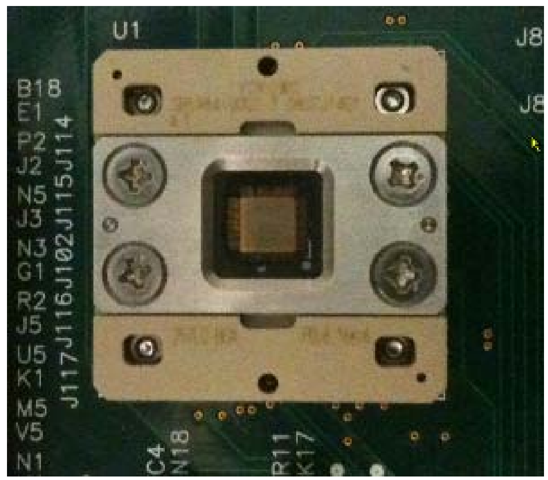
Am241 Alpha Source

- Sealed Am241 source with 0.1uCi activity from Eckert & Ziegler
- 5cm diameter with active area diameter of 4.7cm

Difficulty in Controlling the Spacing

- **Direct soldered on device vs. devices mounted in socket**
  - Various configurations could have 1 to 3 mm differences in the spacing between die and source.
  - The die is recessed from the top of the package or socket.

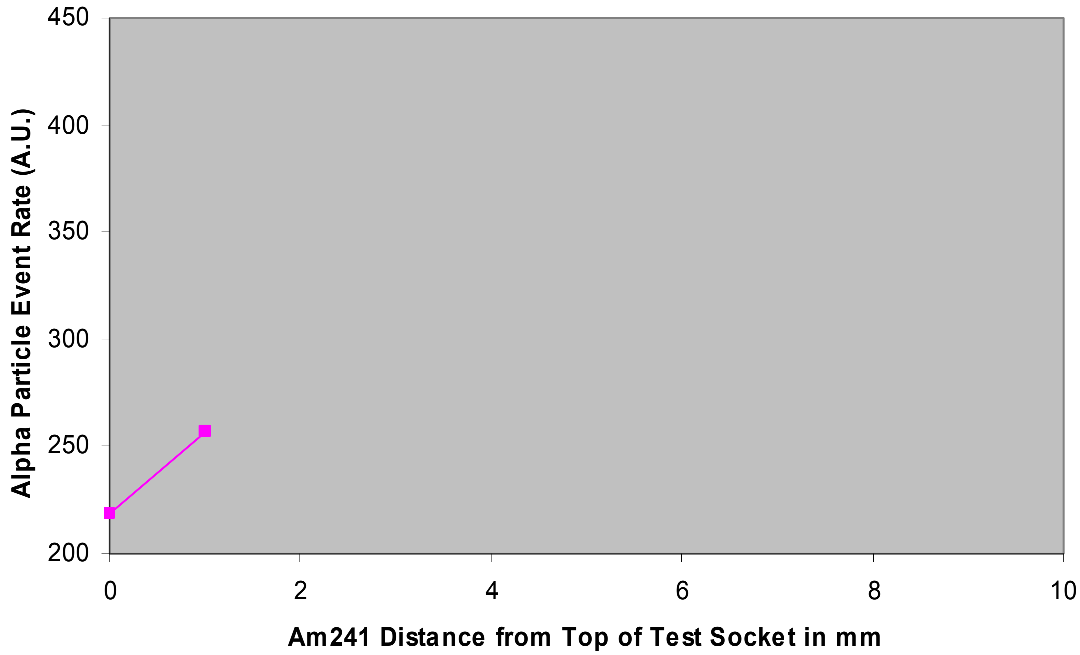
Soldered Device < 1mm



Custom Designed Socket < 2mm

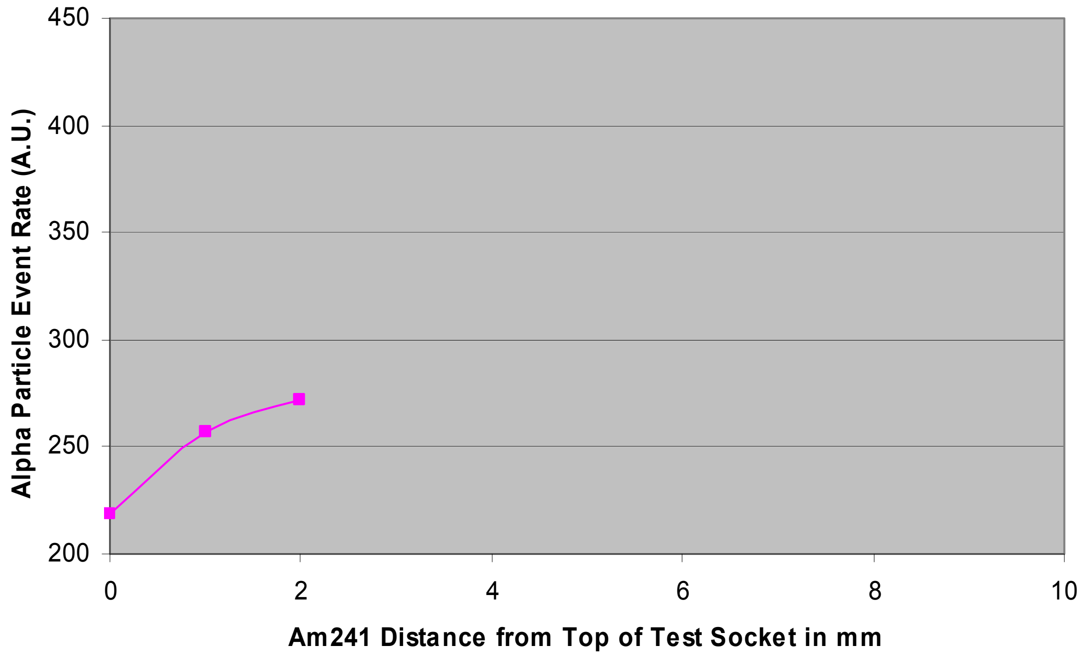
Debug Socket < 3mm

Alpha SER Rate vs Source and DUT Spacing Study



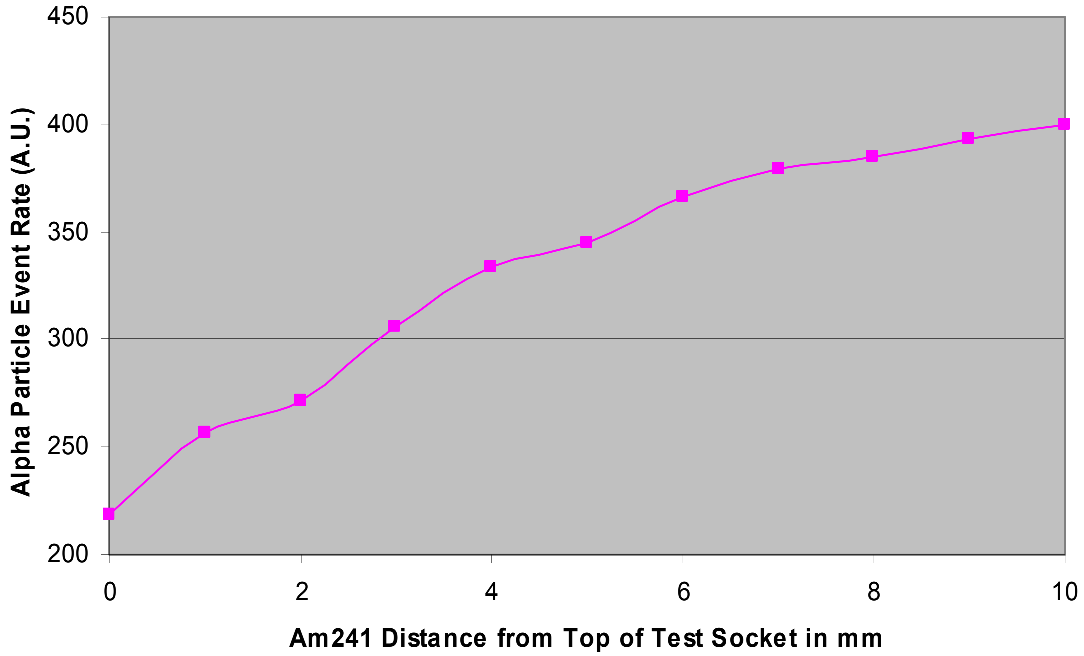
- 1 mm higher in spacing should have reduced the flux by ~10%
- The observed upset event rate jumped by more than 35%

Alpha SER Rate vs Source and DUT Spacing Study Cont'd



- **As the spacing is increased by another 1 mm, the observed rate is still increasing**

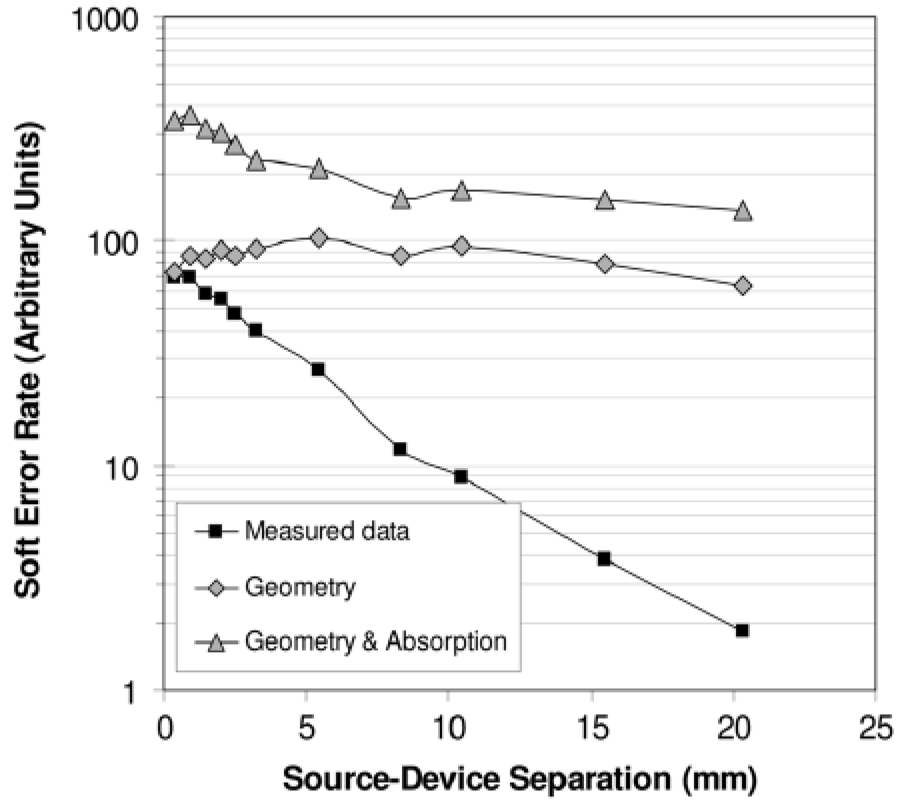
Alpha SER Rate vs Source and DUT Spacing Study Cont'd



- **The observed rate is almost 2X higher at 1cm above the socket than when it is right on top of the socket**

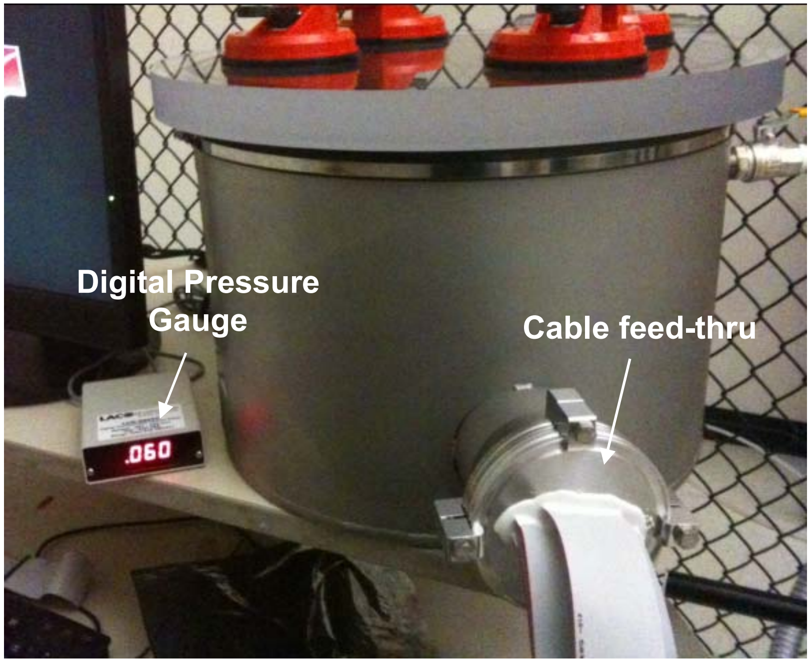
Geometry and Absorption Effects

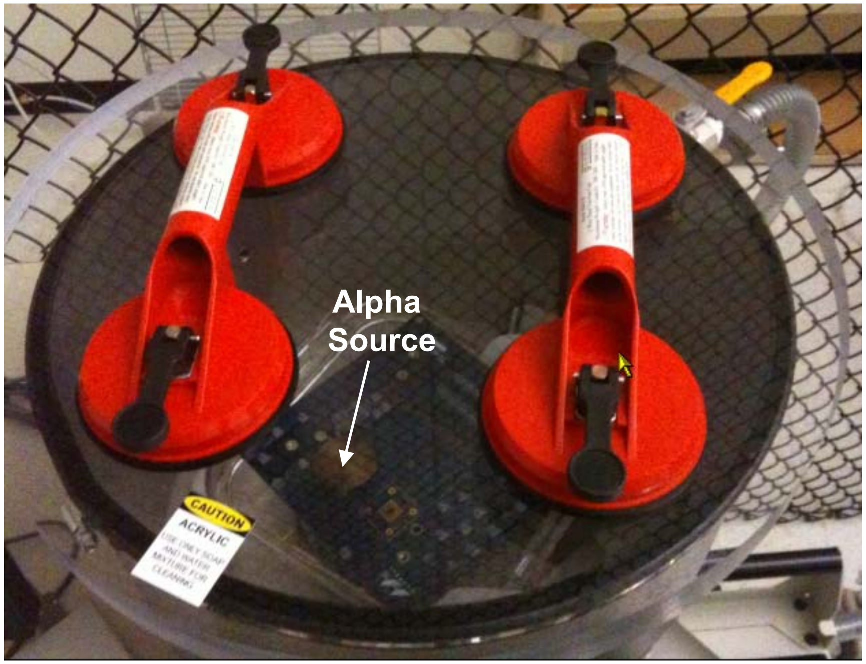
- **The SER vs spacing trend is opposite to published data**
  - Rectangular source
  - Die area is 4% of source area
- **Difficult to separate the absorption and geometric effects**
- **Absorption in air and Si top layers can shift the Bragg peak to affect error rate**
- **Vacuum environment could enable the study of geometry effect by eliminating absorption by air**



Baumann et. al., IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 54, NO. 6, DECEMBER 2007

Vacuum Chamber





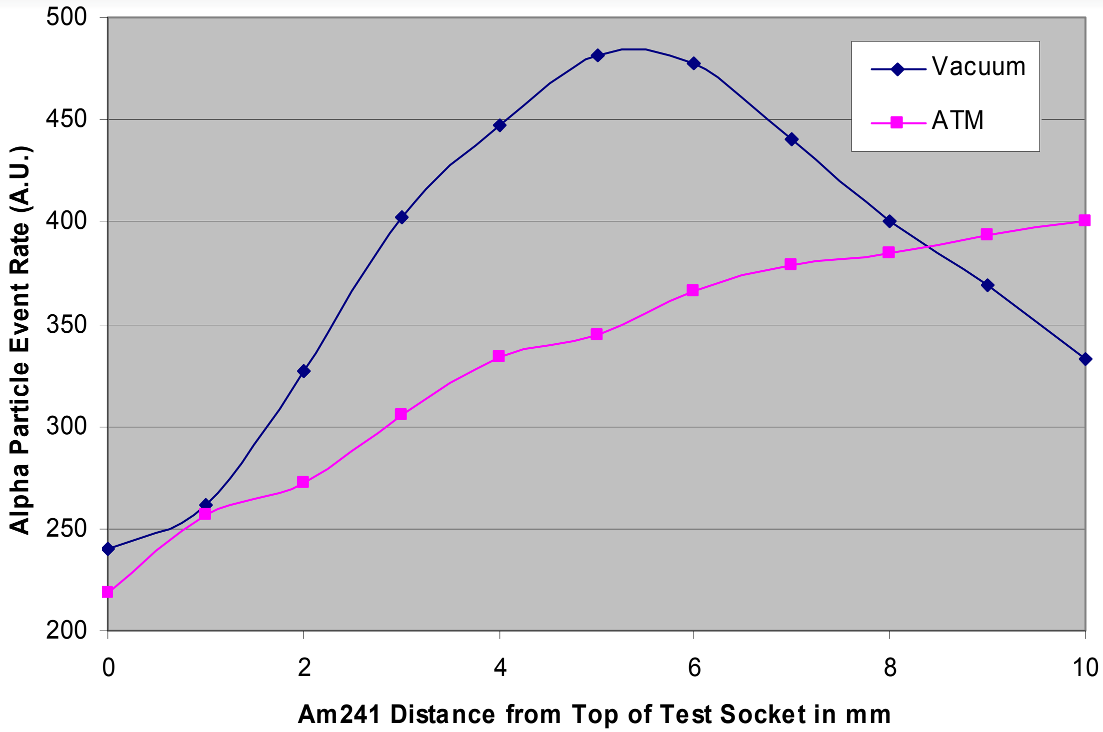
- **Laco Technologies 18" diameter, 12" height cylindrical chamber with an acrylic top**
  - Custom designed cable feed-through via an ISO 100 port with epoxy cement seal
  - Vacuum level down to below 100 mtorr

SRAM Test Chip

- **40nm SRAM test chip with a mixture of SRAM arrays**
  - Die size is approximately 6mm x 6mm
  - Total memory bits are greater than 6 Mbits
  - Data pattern is solid 1's at nominal voltage
  - Custom designed socket minimizing the spacing between DUT and source
- **Two pressure conditions are used**
  - Atmospheric pressure (760 torr)
  - Vacuum: < 200 mtorr
- **Source position varied from directly on top of socket to 1cm above socket via 1mm thick Aluminum ring shape spacers**
- **Test program does continuous read until 5000 errors are collected**
  - Multiple-bit upsets are identified via a post-processing script
  - The upset event counts are generated to eliminate variations in error rate due to change in multi-cell upset rate

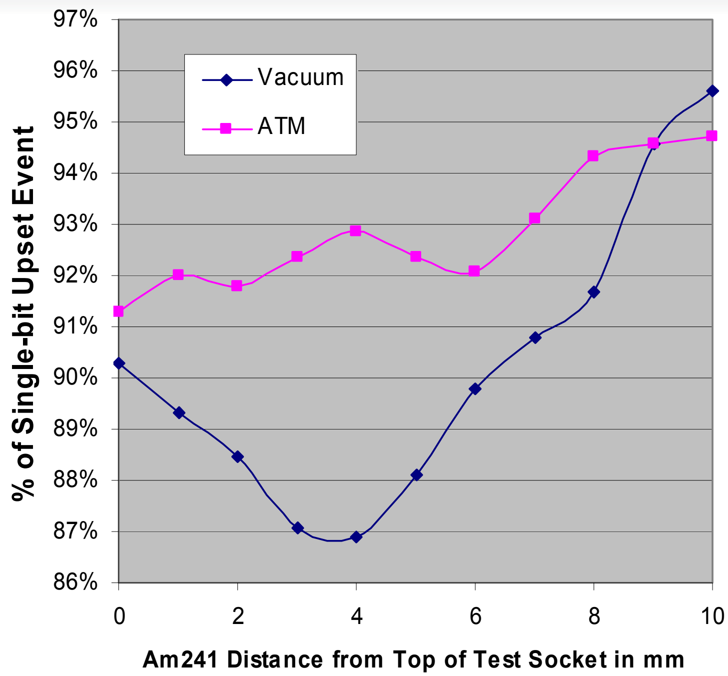
Aluminum Spacer for Separation Control

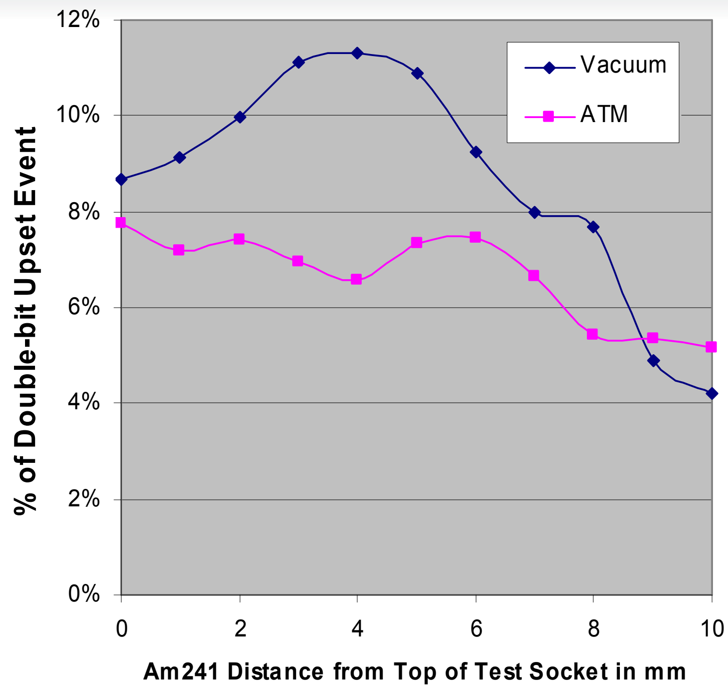
Upset Event Rate vs. Spacing between Source and DUT (Socket)



- **Event rates below 2mm spacing are quite similar**
- **There are significant differences after the spacing is increased beyond 2mm**
  - There is a peak event rate between 5 and 6 mm but the curve drops off after 6 mm
  - At 10mm, the atmospheric event rate is higher than vacuum
- **The vacuum data can be attributed to geometric effects only**

Single and Double-bit Upset Events

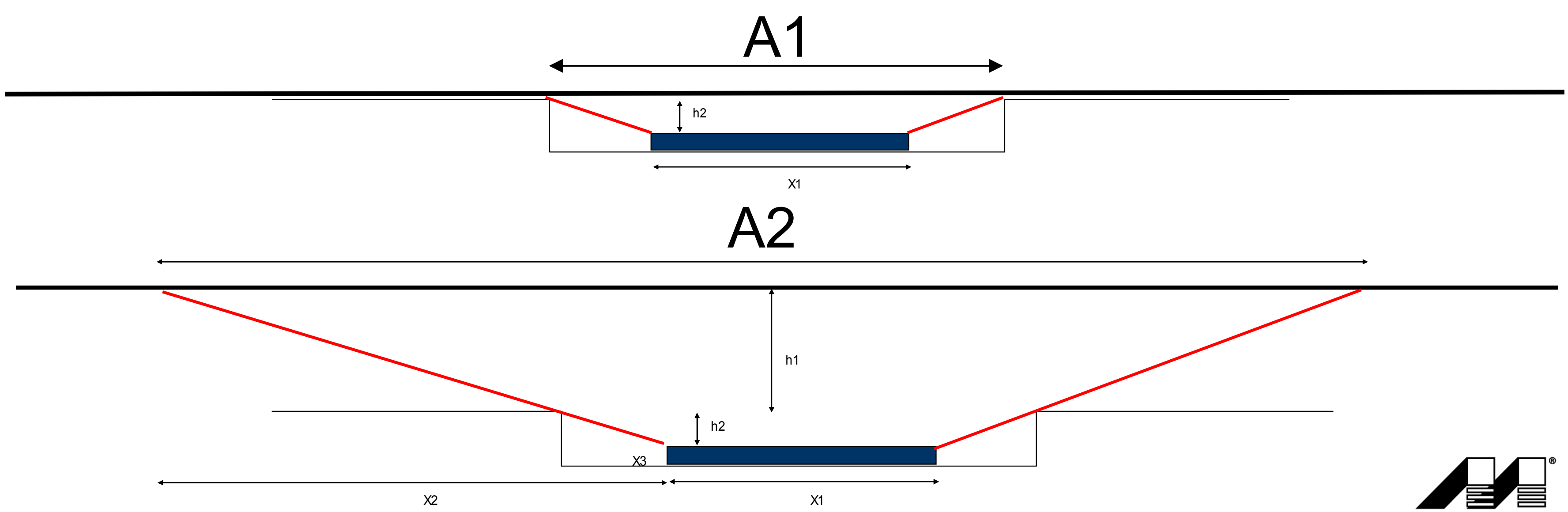




- **In vacuum, double-bit upset rate trends higher from 0 to 5 mm spacing**
  - More contribution from the outer radial area of the source
- **As the source is pulled further away, only near normal incident angles alpha particles would hit the die and so the vacuum DBU trends lower**
  - Multi-cell upsets from alpha are mostly caused by alpha particles with shallow angles of incident
- **Under atmospheric pressure, the collision with air molecules scattered the alpha particles and make the DBU more uniform**

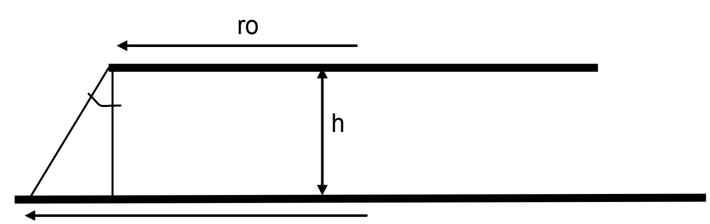
Geometric Effects with Recessed Die Configuration

- **Increasing distance will reduce the flux due to a larger area of exposure**
- **As the source is raised from the surface of the socket, more area of the source will come into the effect.**
  - In example below, area A2 is much larger than A1.
  - The angle distribution will also change as more alphas are coming from the outer radial area of the source.
  - Effect will peak when the entire source is within the line of sight of the DUT.



Simple Model for Geometric Effects with Recessed Die

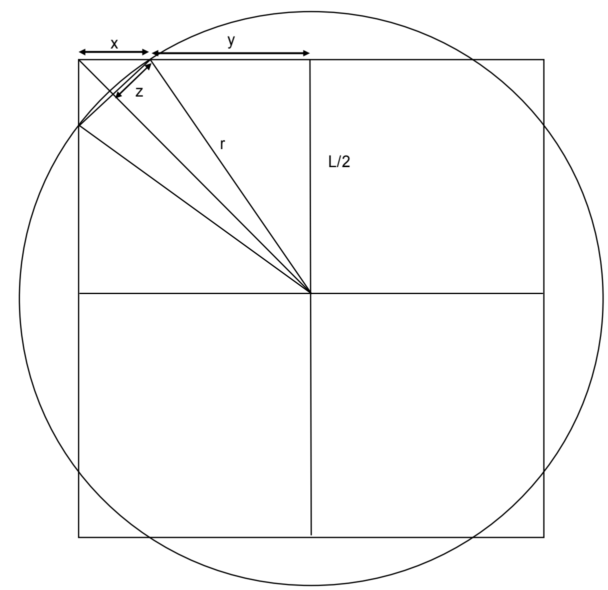
- **Flux divergence approximation**
  - Area of exposure increases as h is increased



r1=ro + tan(angle) * h

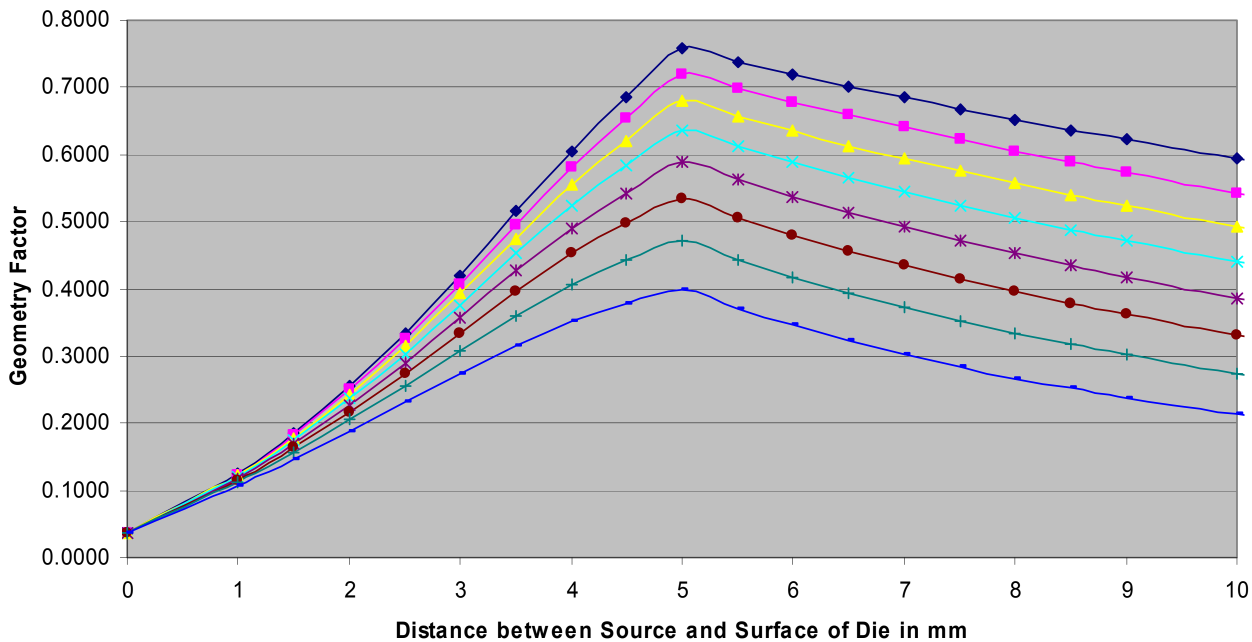
A0/A1 = ro^2 / (ro + tan(angle) * h))^2

- **Observed area of source is a concentric square that increases in size as the spacing is increased**
  - As square corners extend outside the active area of the source, the exposed area is near the peak
  - When the square completely engulfs the active area, the peak is reached

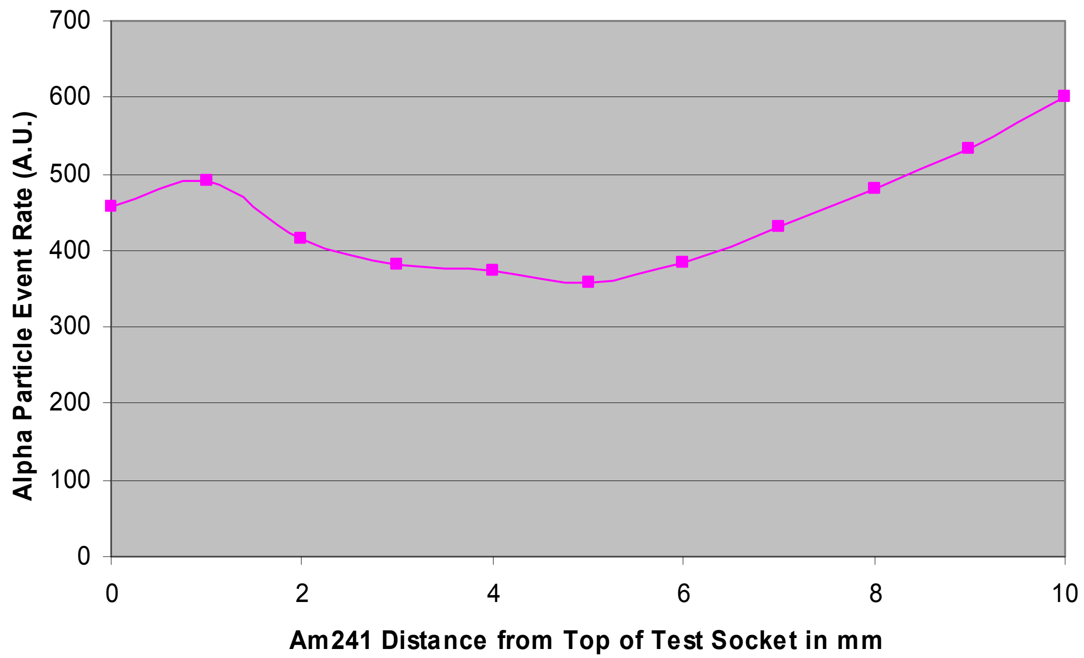


Geometric Effect Modeling

- **Combination of two effects using parameters from the 40nm SRAM test chip, the model shows that if there is no absorption by air, there should be an increase in flux as the source is raised above the socket.**
- **The geometric factor would peak at about 5 mm spacing and gradually decrease due the divergence effect dominating at larger spacing.**
  - The model showed similar trend as the experimental data.



Atmospheric Data Corrected for Geometric Effect



- **Alpha particles lose more energies as the spacing is increased**
- **Higher event rate could be due to the Bragg peak shifted for higher energy transfer to the active regions of the device**

Summary

- **Accelerated alpha SER testing is easy to perform but difficult to get accurate results due to limitations in real world set up**
  - Spacing control of < 1mm between source and DUT is prohibitively expensive
- **Observed SER rate as a function of spacing depends on**
  - Source and DUT configuration
    - Measured alpha SER rate of de-capsulated device with recessed die configuration has different spacing dependence than standard geometric model.
  - DUT Process Technology
- **Vacuum chamber can be used to characterize the geometric effect**
  - At < 2mm spacing, vacuum and atmospheric error rates are found to be very similar.
  - At larger spacing distances, the results could be different by up to 2X.
- **Multiple-upset events from alpha particles are mostly due to particles from shallow angles of incident passing through multiple-diffusion areas.**

Follow-up Questions

- **Is JESD 89A the most appropriate number to be used for the "measured" alpha SER rate?**
  - What does the alpha particle incident angle distribution look like inside the package? Would it be different for wire-bonded package and flip-chip?
  - Vacuum vs. atmospheric pressure measurement?
  - Should it be the average over a range of spacing between source and DUT, or the worse case?