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Single Event Effects (SEE) Challenges: Testing and Modeling Shortfalls

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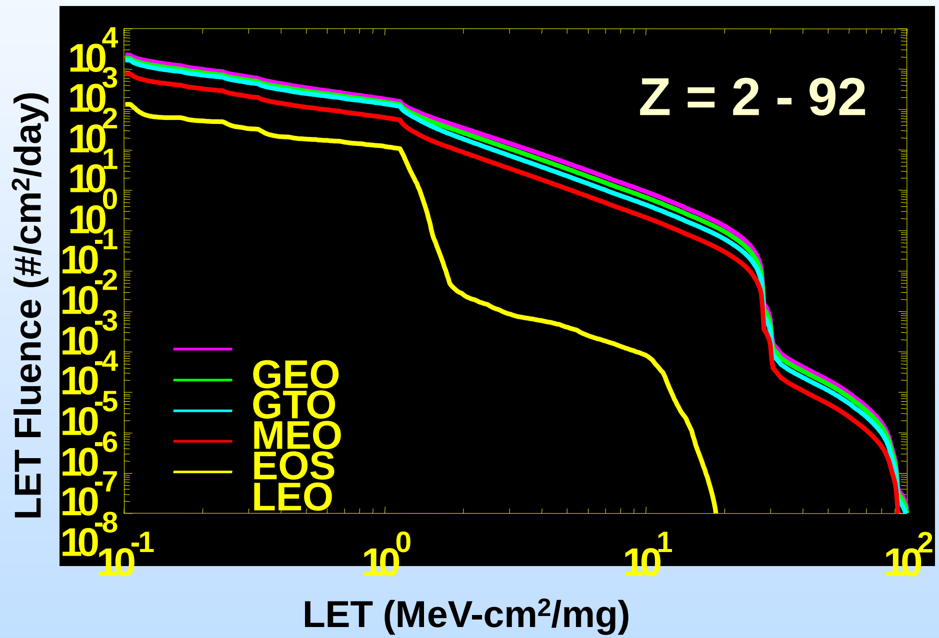
Space Hazard: Galactic Cosmic Rays (GCRs)

- **Definition**
  - **A GCR ion is a charged particle (H, He, Fe, etc)**
  - **Typically found in free space (galactic cosmic rays or GCRs)**
    - **Energies range from MeV to GeVs for particles of concern for SEE**
    - **Origin is unknown**
  - **Important attribute for impact on electronics is how much energy is deposited by this particle as it passes through a semiconductor material. This is known as Linear Energy Transfer or LET (dE/dX).**
- **Solar events can also spew heavy ions**

CREME 96, Solar Minimum, 100 mils (2.54 mm) Al



Time

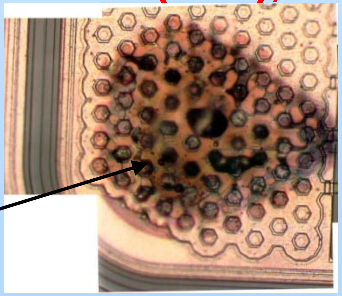
Commercial Technology Sensitivity

After J. Barth

Single Event Effects (SEEs)

- An SEE is caused by a *single charged particle* as it passes through a semiconductor material
  - Heavy ions
    - Direct ionization
  - Protons for sensitive devices
    - Nuclear reactions for standard devices; Direct ionization for newer more sensitive devices
- Effects on electronics
  - If the LET of the particle (or reaction) is greater than the amount of energy or critical charge required, an effect may be seen
    - Soft errors such as upsets (SEUs) or transients (SETs), or
    - Hard (destructive) errors such as latchup (SEL), burnout (SEB), or gate rupture (SEGR)
- Severity of effect is dependent on
  - type of effect
  - system criticality

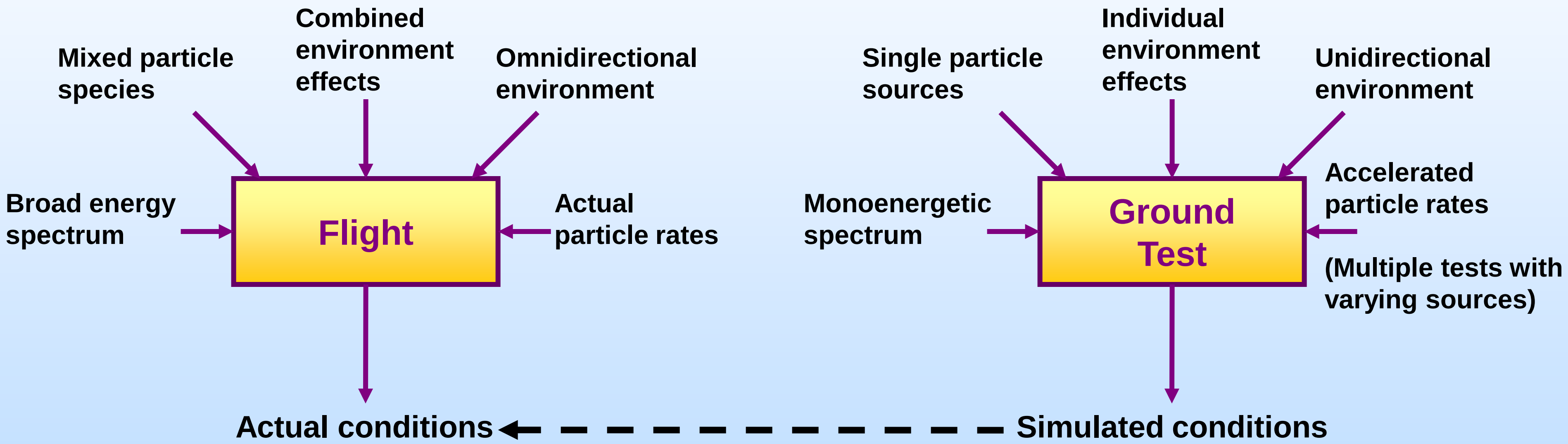
Destructive event in a COTS 120V DC-DC Converter



Sample Issues for Radiation Effects Simulation at Cyclotrons and Accelerators

- **Particle**
  - Dosimetry
  - Uniformity
  - Energy mapping to the space environment
  - Particle localization
  - Stray/secondary particles (neutrons, for example)
  - Particle range
  - Flux rates and stability
  - Beam structure
    - Beam spills versus continuous wave (CW)
- **Practical**
  - Cabling
  - Thermal
  - Speed/performance
  - Test conditions
  - Power
  - Mechanical
  - Vacuum

Radiation Test Issues – Fidelity?



How accurate are the ground test condition for predicting Space Performance?

After E. G. Stassinopoulos

Two Types of Space Electronics Investigations with Heavy Ions

- ***Research***
  - Investigates the basic response of the semiconductor technology to irradiation for use in developing technology models
  - Investigates the specific technology/circuit parameters that determine the device/technologies radiation tolerance or susceptibility

- ***Qualification***
  - Provides the irradiation of (typically) the flight lot of a device in order to determine the device's suitability for a specific mission and/or application

Qualification Radiation Tests – Two Types

- *Piecepart tests*
  - Provides greatest insight into a device's performance
  - All ground radiation tests can be performed
    - Heavy ion
    - Proton
    - Co-60 (TID)

Ziatech ZT-6500 3U Compact PCI Pentium Board.

- *Board level tests*
  - Provides insight as to how the system responds to a single device or system irradiation or accumulated board-level dose
    - Useful for system level validation and limited specific issues
  - Facilities
    - Co-60 (TID)
    - Proton is possible
    - Heavy ion tests can be problematic due to penetration ranges of ground-based ions at many facilities without excessive preparation as well as obtaining significant statistical fault coverage

Both Test Methods have limitations. Board Level tests can only be used for special cases..

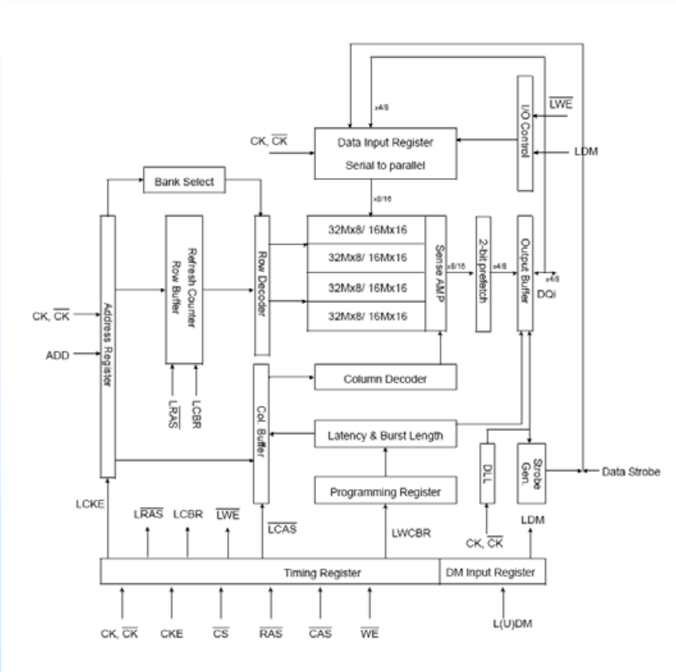
The Top Six Predicted Challenges from a NASA Perspective

1. **Availability of beam time at existing SEE facilities**
2. **Validated rate prediction tool for complex “commercial” devices (i.e., commercial-off-the-shelf, COTS, with no radiation guarantee)**
3. **Test standards and technology evolution**
4. **Affordable availability of higher energy heavy ion facilities**
5. **Understanding of ion/energy/linear energy transfer (LET)**
6. **Improved error identification tools (microbeam, LASER, etc…)**

1. Not Enough Beam Time Availability at the Existing Heavy Ion Facilities?

- Multiple factors are driving the shortage of time at our "bread and butter" heavy ion test facilities
  - More complex devices require much more time at the facility
    - 15 years ago a "qual" test on a memory took ~8 hours
    - Now, 24-48 hours is needed
  - More specific conditions are often needed to evaluate
    - Angular response,
    - Energy dependence, …
  - More commercial devices being used
    - More devices mean more hours needed
  - More research needed to understand the physics and circuit responses on "new" technologies/architecture to develop appropriate models
- Competition with the scientists

Can we test anything completely?



Commercial 1 Gb SDRAM
68 operating modes
operates to >500 MHz
Vdd 1.8V external, 1.25V internal

Sample Single Event Effect Test Matrix

full generic testing

Amount	*Item*
3	Number of Samples
68	Modes of Operation
4	Test Patterns
3	Frequencies of Operation
3	Power Supply Voltages
3	Ions
3	Hours per Ion per Test Matrix Point

66096 Hours

2754 Days

7.54 Years

and this didn't include temperature variations!!!

Test planning requires much more thought in the modern age as does understanding of data collected (be wary of databases). Only so much can be done in a 12 hour beam run – application-oriented

2. Rate Tool for Use With COTS

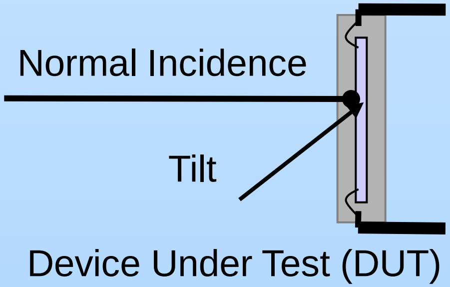
- For nearly the last 15 years, CREME96 has been the industry standard to utilize when making rate predictions for space.
- In the last few years, a newer Monte Carlo-based version has been developed taking into account the import of new mechanisms and improved circuit modeling on sub 90 nm technologies
  - Focused on the needs of those building radiation hardened devices, but not the needs of those utilizing COTS electronics
  - In other words, you can use it when you know lots about the technology and circuit design, but a not so much with a billion transistor COTS device with lots of circuit and technology unknowns
- Need to have a “bounding” tool using generic knowledge and just test data

3. SEE Test Standards

- Given the rapidly changing nature of both technology and the related SEE issues being discovered, it would be nearly impossible to create up-to-date test standards in a timely fashion
  - New materials
  - New mechanisms for upset
  - New questions on what the proper test metrics are
- We have been trying to develop guidelines for individual issues, but even then, it's winning a battle, not a war
- Plans for:
  - Field Programmable Gate Arrays
  - Low Proton Energy Sensitivity
  - Flash Memories
  - DDR Memories, …

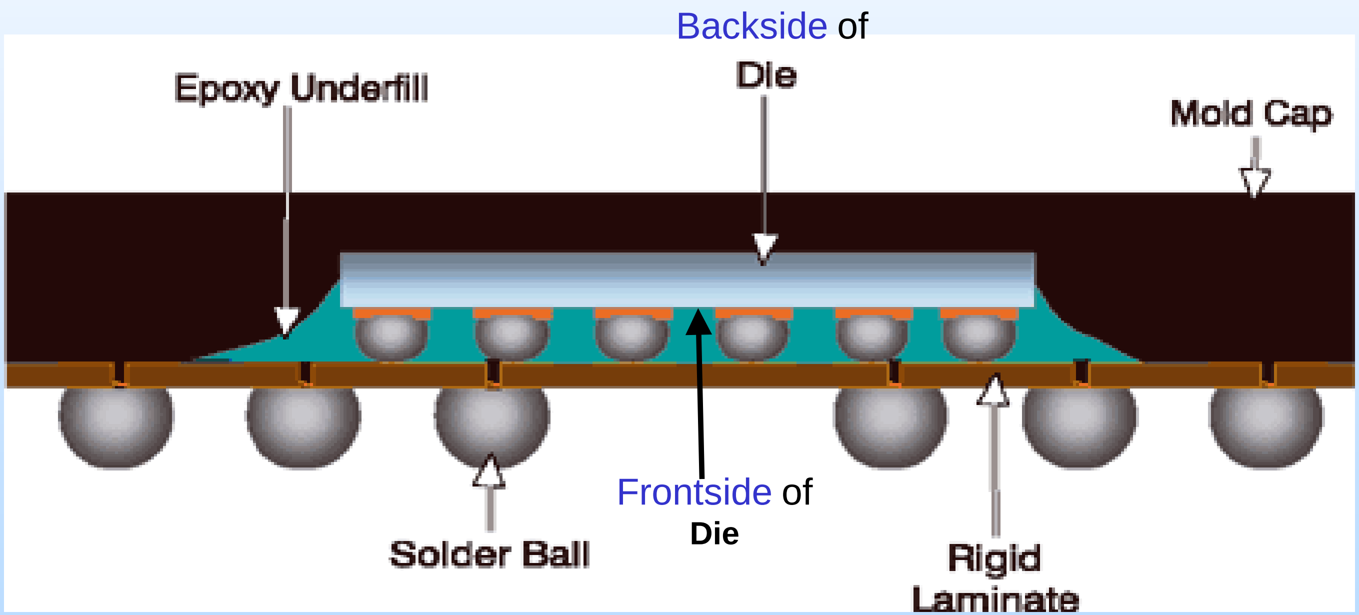
JESD57 – A Starting Point

- **JEDEC JESD57 is the prime test standard utilized within the US for heavy ion SEE testing**
  - **Developed in the early and mid ’90s, it provides a reasonable starting base for planning SEE tests**
- **However, many new SEE-related considerations have forced us to consider some of the advice provided in JESD57. For example:**
    - **Section 3.1.2.1: “The beam angle is normally limited to a maximum of 60 degrees…’**
      - **This doesn’t require that you test to 60 degrees, just a recommended normal limit. Multiple results showing differing sensitivities at higher angles has made angular work a requirement for some technologies.**
    - **No discussion is present on asymmetric angular effects (i.e., tilting in both directions as well as changing the roll of the device sample to the incident beam) stemming from technology and circuit layout**



Device Package and Particle Penetration – Example: Flip-Chip Ball Grid Array (FBGA)

Must remove sufficient amount of material to penetrate to backside of die AND penetrate to sensitive volumes



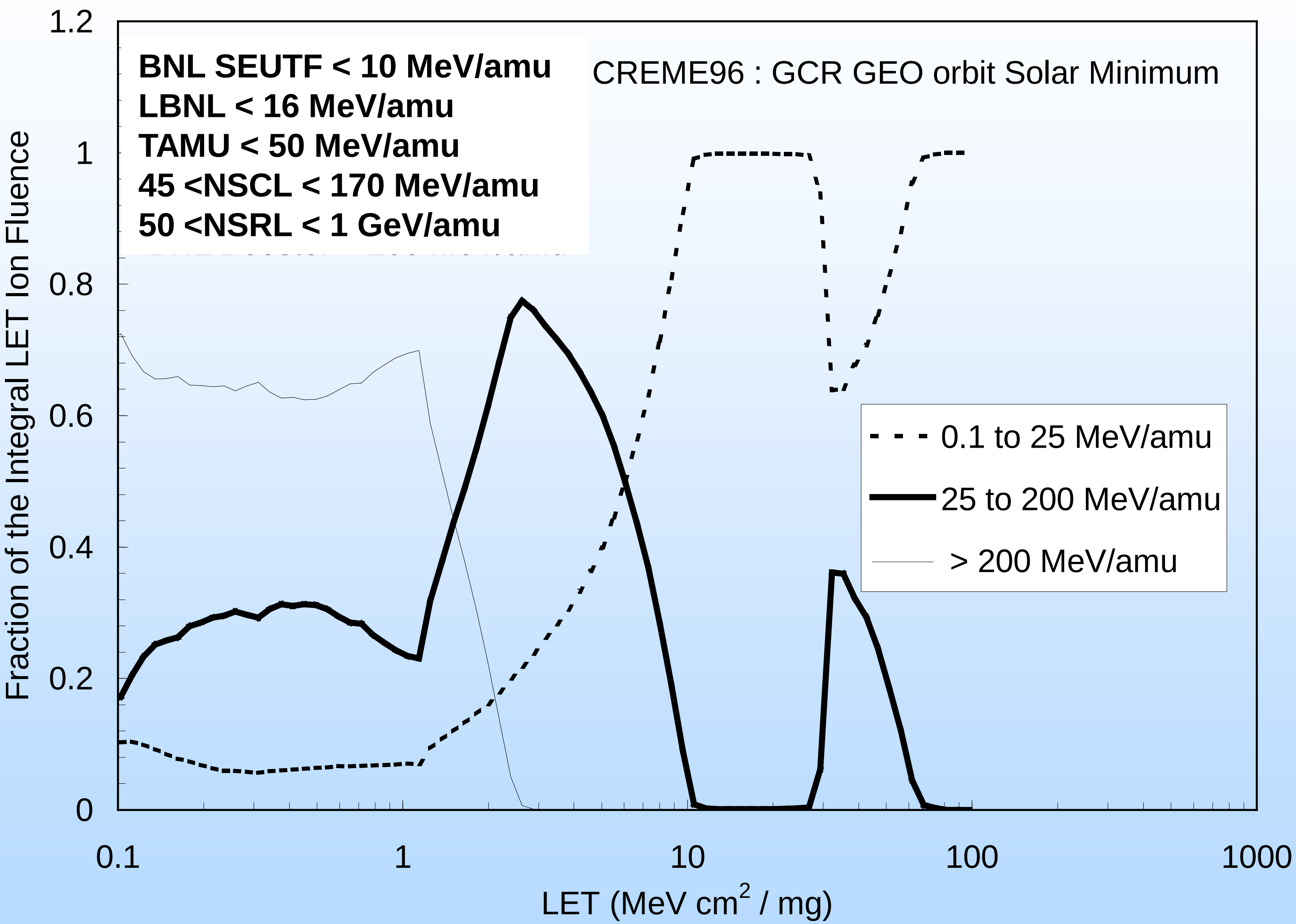
Challenges
Thermal
Integrity
Accuracy
Interactions

Heavy Ion Beam Won't Penetrate Through Balls = Can Not Irradiate Frontside of Die

4. Improved Access and Affordability to High Energy Heavy Ion Sources

- Multiple items drive the desire to use a high energy facility
  - Higher energy = more ion range (penetration)
    - Can test packaged or even stacked devices
  - Ability to perform grazing angle and backside testing
    - Important for sub-90 nm devices
  - Ability to perform system/board level validation tests
  - Improved fidelity to the natural space environment
- Facility limitations need to be understood
  - Beam structure, for example
- Current costs of ~$5K are prohibitive to many potential users

Study from 2000: Space LET Coverage



Close to 99% of the space heavy ions that have LETs > 3 MeV cm^2 / mg have energies < 200 MeV/amu

5. For Radiation Hardness Assurance (RHA), Do We Know the Right Factors in Choosing Ions To Test With?

- **This is a very technical issue, but to summarize**
  - **LET is proposed NOT to necessarily be the correct metric for sub-90 nm technologies, and,**
  - **Data shows for Power MOSFETs that Ion and Energy need to be taken into account (though the answer is still being researched)**
- **Need to be clear on understanding the Ion/Energy/LET relationships to bound risk**

6. Tools for Identifying Failure Sites

- In general, there are two kinds of tools we use
  - LASERs, and
  - Microbeam
- As the devices become smaller and more complex, problems such as spot size (10 um spot versus 22 nm transistor, for example) are challenges
- There are several LASER sites around the country that are being used as a tool in conjunction with heavy ion exposures
  - No test guidelines exist and are needed
- Current Microbeam at Sandia is low energy and while a great tool on a unhardened test structure, isn't very useful for full devices

Summary

- **Consider this presentation as “food for thought”**
  - **The idea is to think about what you have, but also about what you need**
- **To someone who is a tester, items like higher energy have practical test applications as well**
  - **No vacuum required,**
  - **Easier thermal management,**
  - **Improved cabling (no feedthru), and so on.**
- **The current facilities like LBL and TAMU are tremendous assets to the space community and we truly appreciate their efforts to fill our needs.**