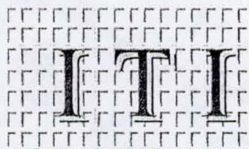




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**JAYCOR**



# *Radiation Requirements and Requirements Flowdown: Single Event Effects (SEEs) and Requirements*

Kenneth A. LaBel  
NASA/GSFC  
[ken.label@gsfc.nasa.gov](mailto:ken.label@gsfc.nasa.gov)  
12 March, 2003



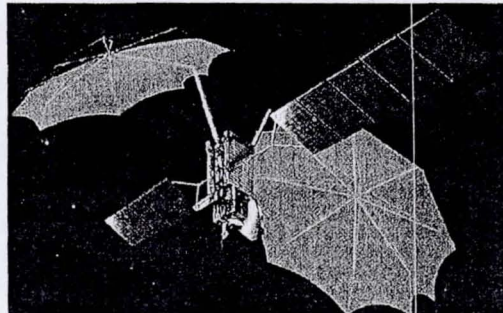


# Abstract



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- In this short course session, we will provide
  - An overview of the single particle-induced hazard for space systems as they apply in the natural space environment.
    - This shall focus on the implementation of a single event effects hardness assurance (SEEHA) program for systems including system engineering approach and mitigation of effects.
  - The final portion of this session shall provide relevant real-life examples of in-flight performance of systems.







# Outline (1 of 2)



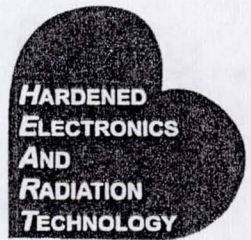
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- **Introduction**
  - SEE: Impacting Space Operation
  - The SEE Hazard
  - SEE Effects
- **Implementing SEEHA for a Space System**
  - Hazard definition
  - SEE Requirements – a criticality-based method
  - Parts list review
  - Testing
  - Mitigative approaches
  - Monitoring performance during flight



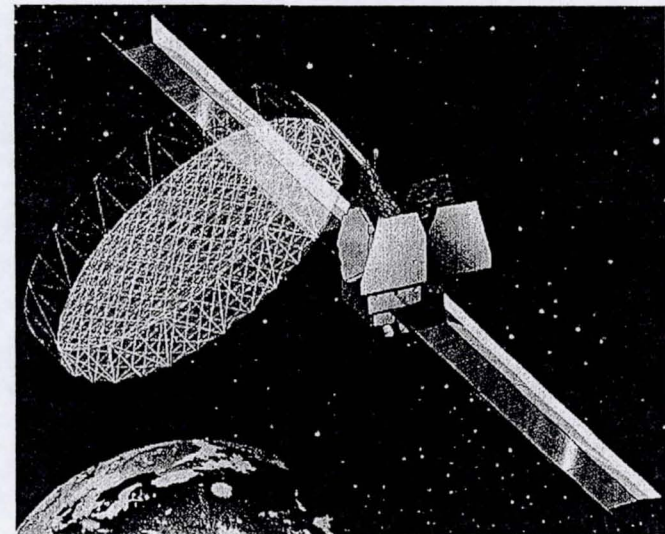


# Outline (2 of 2)



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- **In-flight performance of systems**
  - Systems with appropriate mitigation – success stories
  - Anomalies in flight
    - Examples of impacts in-flight
- **Summary**
- **Acknowledgements**







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# Introduction

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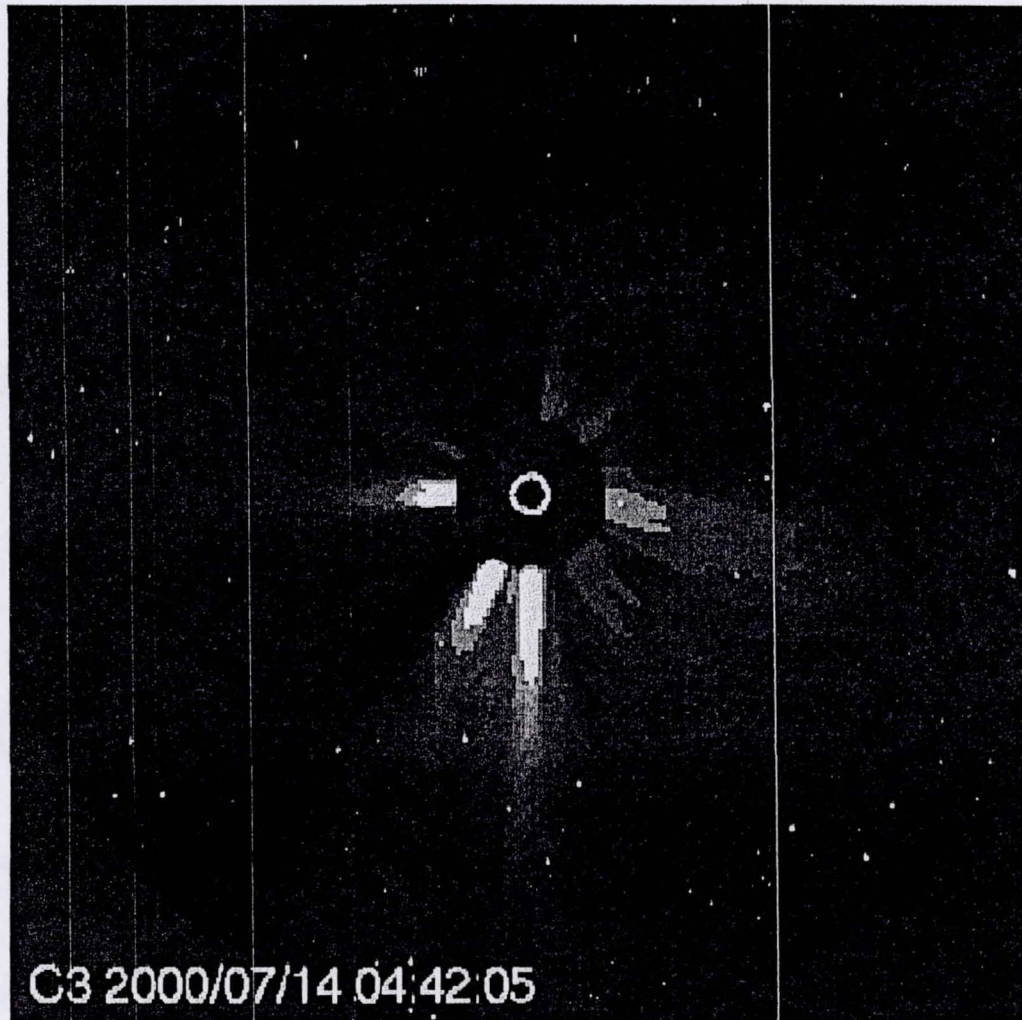


# SOHO/LASCO C3 Coronagraph

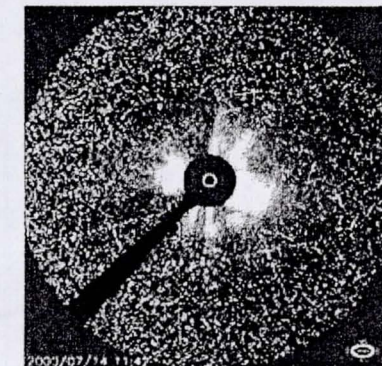
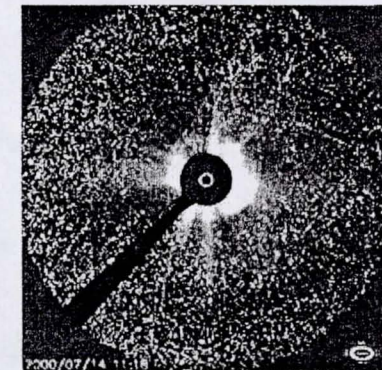
July 14, 2000

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AND  
RADIATION  
TECHNOLOGY

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Space Weather induces single particle-induced transients in a Charge-Coupled Device (CCD)



Kenneth A. LaBel, March 12, 2003, 6



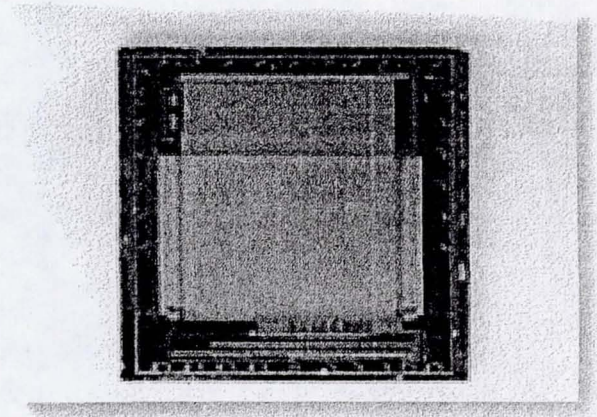


# Space Radiation May Affect:

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AND  
RADIATION  
TECHNOLOGY**

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- Microelectronics\*
- Photonics\*
- Materials
- Coatings/epoxies/etc.
- Humans/biological systems



A 1,300,000 Pixel CMOS Image Sensor for  
High-Resolution Digital Cameras  
<http://www.toshiba.co.jp/techno21/cmos01.htm>

*\* Focus of this talk*





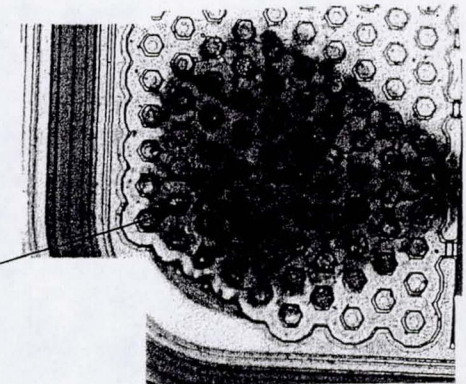
# SEE: Definition



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- An SEE is caused by a *single charged particle* as it passes through a semiconductor material
  - Heavy ions (direct ionization)
  - Protons (indirect ionization or even direct ionization for sensitive devices)
- Effects on electronics
  - If the LET of the particle 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 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*



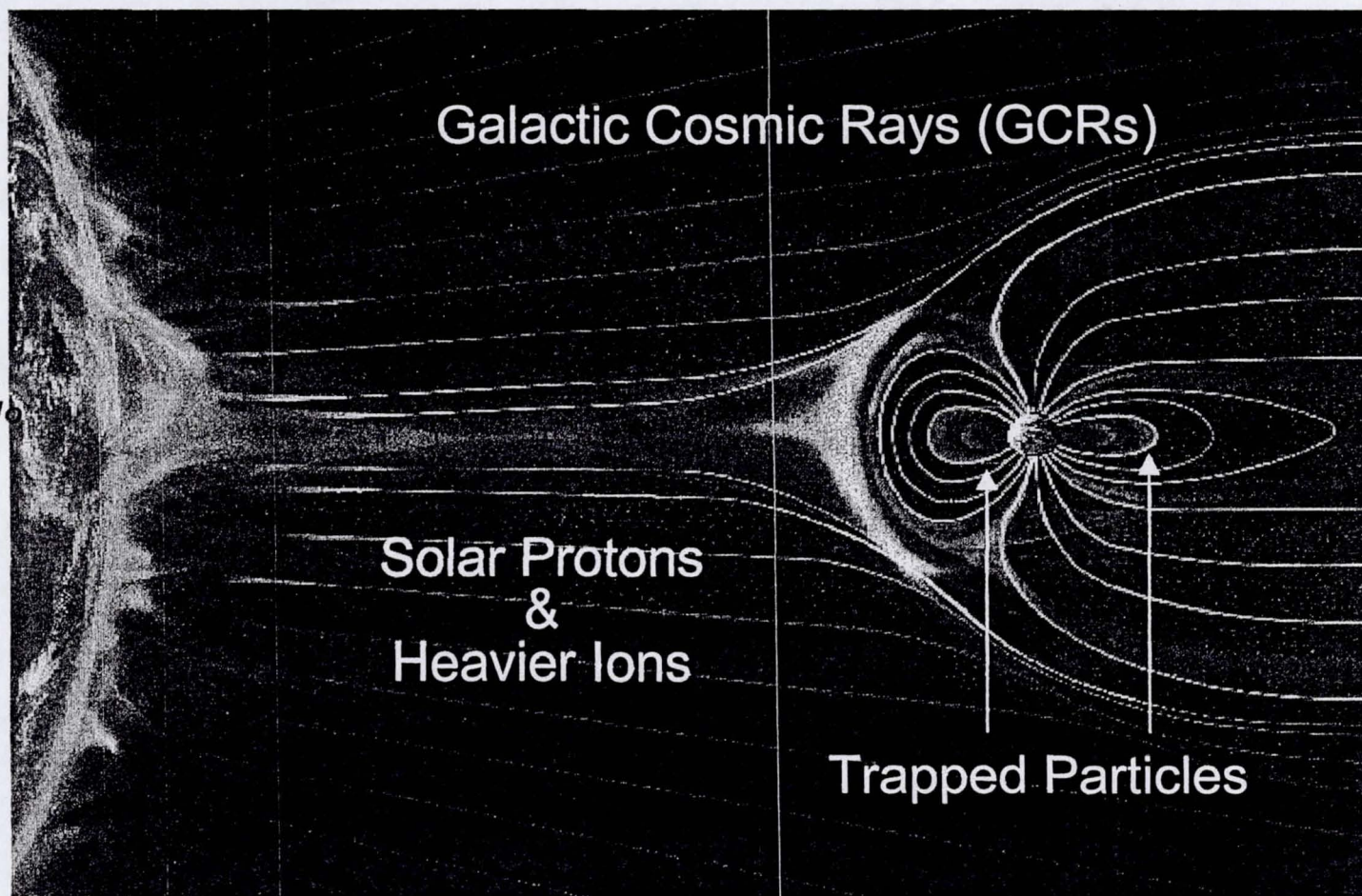




# Space Radiation Environment



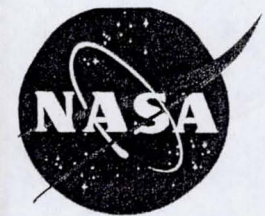
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Vikkei Science, Inc.  
of Japan, by K. Endo

*Deep-space missions may also see: neutrons from background  
or radioisotope thermal generators (RTGs)*





# The SEE Hazard from the Space Environment



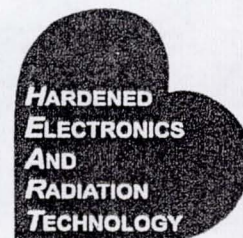
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- Three portions of the natural space environment contribute to the SEE hazard
  - Solar particles
    - Protons and heavier ions
  - Free-space particles
    - GCR
      - Important attribute for impact on electronics is how much energy is deposited by this particle as it passes through a semiconductor material. This is known as Linear Energy Transfer or LET ( $dE/dX$ ).
      - For earth-orbiting craft, the earth's magnetic field provide some protection for GCR
  - Trapped particles (in the belts)
    - Protons including the South Atlantic Anomaly (SAA)



The sun acts as a modulator and source in the space environment





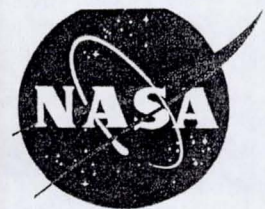
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# Implementing SEE Hardness Assurance (SEEHA) for a Space System

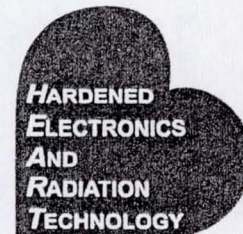
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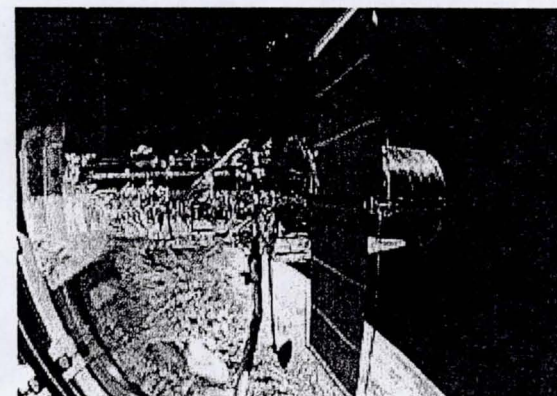
# Sensible Programmatic for SEEHA

## *A Two-Pronged Approach*



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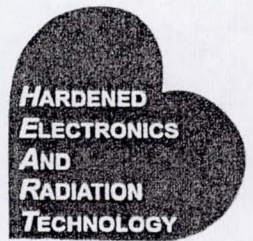
- Assign a lead radiation engineer to each spaceflight project
  - Treat radiation like other engineering disciplines
    - Parts, thermal,...
  - Provides a single point of contact for all radiation issues
    - Environment, parts evaluation, testing,...
- Each program follows a systematic approach to SEEHA
  - SEEHA active early in program reduces cost in the long run
    - Issues discovered late in programs can be expensive and stressful
      - What is the cost of reworking a flight board if a device has SEE issues?
- Mission requirements and philosophies vary to ensure mission performance
  - What works for a shuttle mission may not apply to a deep-space mission







# Radiation and Systems Engineering: A Rational Approach for Space Systems



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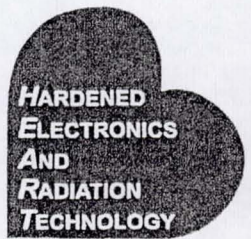


- **Define the Environment**
  - External to the spacecraft
  - Internal to the spacecraft
- **Develop SEE Specification based on Criticality Factors**
- **Evaluate Design/Components**
  - Existing data/Testing/Performance characteristics
- **Work with spacecraft designers**
  - Mitigative Approaches
- **Iterate Process**
  - Ex., Review parts list and usage on six month intervals based on updated knowledgebase
- **Monitor Performance During Flight**





# Define the Hazard for SEE: External Environment



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- The radiation environment external to the spacecraft
  - Trapped particles
    - Protons
    - Electrons
  - Galactic cosmic rays (heavy ions)
  - Solar particles (protons and heavy ions)
- Based on
  - Time of launch and mission duration
  - Orbital parameters, ...
- Provides
  - Nominal and worst-case trapped particle fluxes
  - Peak “operate-through” fluxes (solar or trapped)



GCR spectra for various orbit types

*Caveat: We are currently using static models for a dynamic environment*



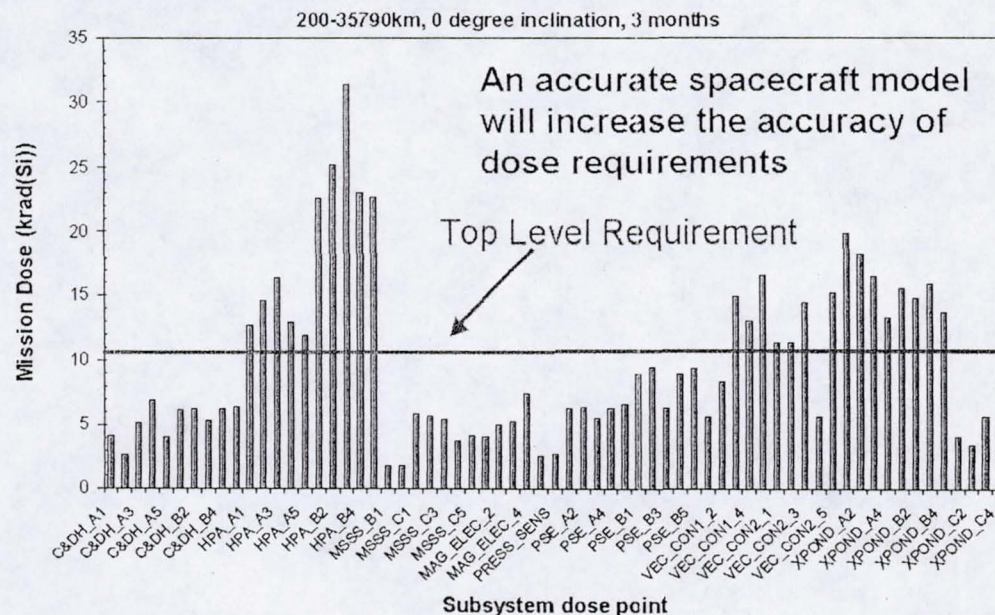


# Define the Hazard for SEE: Internal Environment



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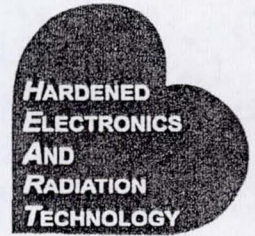
- Determine particle fluxes after transport through spacecraft to electronic systems
  - Top level specification may utilize a nominal shielding level such as 100 mills Al
- For more accurate predictions, utilize mission-specific geometry to determine particle fluxes at locations inside the spacecraft
  - 3-D ray trace (geometric sectoring)
    - Basic geometry (empty boxes,...) or single electronics box
    - Detailed geometry
      - » Include printed circuit boards (PCBs), cables, integrated circuits (ICs), thermal louvers, etc...
- Often an iterative process as spacecraft design is developed







# Develop SEE Specification based on Criticality Factors



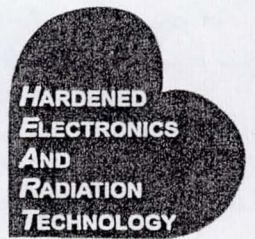
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- Performance requirements typically use “nominal shielding” such as 100 mils of Al or actual spacecraft configuration if 3-d ray trace has been performed
  - SEE criticality analysis (SEECA) method may be invoked since SEE is very application specific
    - Attempts to allow use of non-SEE immune devices in a rational manner
- Must remember to factor in not only nominal environment, but worst-case conditions
  - Probabilistic events, not long-term degradation
    - Relatively equal probabilities for 1st day of mission or last day of mission (maybe by definition!)
- Requirements may be defined by system-level parameters such as data coverage rather than by piecepart requirements





# SEE - System Requirements (1 of 2)

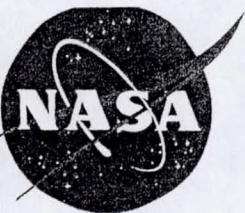


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- SEE (1 of 2)
  - based on predicted environment and criticality of function performed\*
  - Define 3 categories of criticality:
    - Error-critical: SEEs are unacceptable
    - Error-vulnerable: A low risk of SEE is acceptable
    - Error-functional: SEEs are acceptable. Mitigation means may be added to make these SEEs acceptable.
  - Examples:
    - Pyro controller would be *error-critical*
    - A processor with a predicted upset rate of 1 per 10 years for a 1 year mission may be deemed *error-vulnerable* by the project management
    - A solid state recorder (SSR) with a robust error detection and correction (EDAC) scheme would be SEU *error-functional*.

\* For further information see: *Single Event Effects Criticality Analysis (SEECA)* at <http://radhome.gsfc.nasa.gov/radhome/papers/seecai.htm>

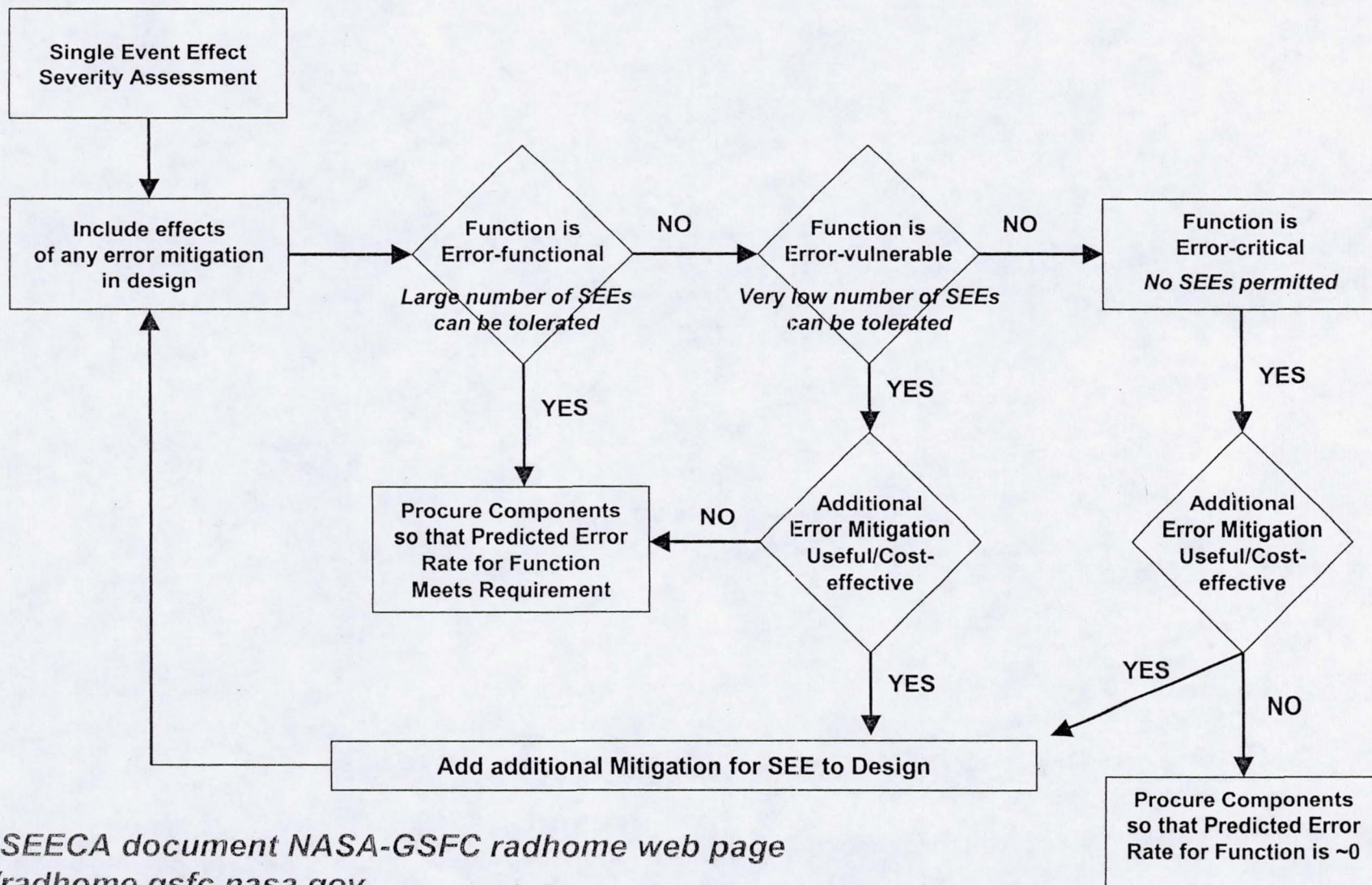




# SEE - Decision Tree

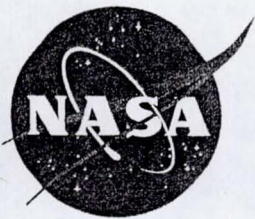
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TECHNOLOGY

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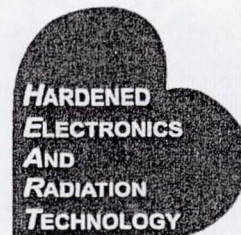


From SEECA document NASA-GSFC radhome web page  
<http://radhome.gsfc.nasa.gov>





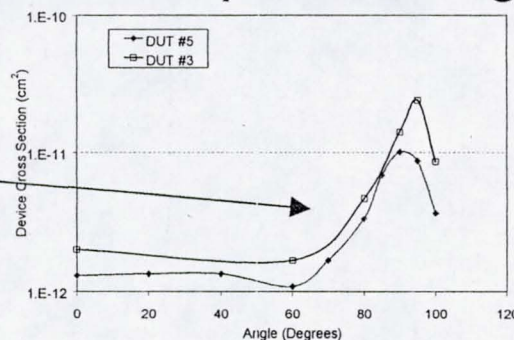
# SEE - System Requirements (2 of 2)



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- SEE (2 of 2)
  - No SEE may cause permanent damage to a system or subsystem
  - 3 Areas of device categories to evaluate based on Linear Energy Transfer (LET) threshold (LETth) criteria. LETth is the maximum LET value at which no SEE is observed.
    - $\text{LETth} > 100 \text{ MeV} \cdot \text{cm}^2/\text{mg}$ . No analysis required.
    - $\text{LETth}$  between  $15^* - 100 \text{ MeV} \cdot \text{cm}^2/\text{mg}$ . Analysis performed for heavy ion component.
    - $\text{LETth} < 15 \text{ MeV} \cdot \text{cm}^2/\text{mg}$ . Analysis performed for heavy ion and proton components.
  - Analysis (SEE rate prediction) must be performed not only for nominal conditions, but worst-case operate-through conditions.

*Proton-induced  
angular effects  
in SOI device with high  
aspect ratio*

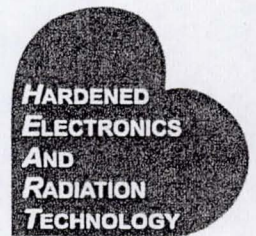


\* These numbers are technology and mission specific. The numbers here are simply examples.





# Sample Single Event Effects Specification (1 of 3)



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## 1. Definitions and Terms

**Single Event Effect (SEE)** - any measurable effect to a circuit due to an ion strike. This includes (but is not limited to) SEUs, SHEs, SELs, SEBs, SEGRs, and Single Event Dielectric Rupture (SEDR).

**Single Event Upset (SEU)** - a change of state or transient induced by an energetic particle such as a cosmic ray or proton in a device. This may occur in digital, analog, and optical components or may have effects in surrounding interface circuitry (a subset known as Single Event Transients (SETs)). These are "soft" errors in that a reset or rewriting of the device causes normal device behavior thereafter.

**Single Hard Error (SHE)** - an SEU which causes a permanent change to the operation of a device. An example is a stuck bit in a memory device.

**Single Event Latchup (SEL)** - a condition which causes loss of device functionality due to a single event induced high current state. An SEL may or may not cause permanent device damage, but requires power strobing of the device to resume normal device operations.

**Single Event Burnout (SEB)** - a condition which can cause device destruction due to a high current state in a power transistor.

**Single Event Gate Rupture (SEGR)** - a single ion induced condition in power MOSFETs which may result in the formation of a conducting path in the gate oxide.

**Multiple Bit Upset (MBU)** - an event induced by a single energetic particle such as a cosmic ray or proton that causes multiple upsets or transients during its path through a device or system.

**Linear Energy Transfer (LET)** - a measure of the energy deposited per unit length as a energetic particle travels through a material. The common LET unit is MeV\*cm<sup>2</sup>/mg of material (Si for MOS devices, etc.).

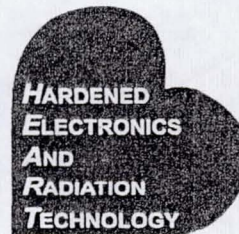
**Onset Threshold LET ( $LET_{th0}$ )** - the minimum LET to cause an effect at a particle fluence of 1E7 ions/cm<sup>2</sup>(per JEDEC). Typically, a particle fluence of 1E5 ions/cm<sup>2</sup> is used for SEB and SEGR testing.

Kenneth A. LaBel, March 12, 2003, 20





# Single Event Effects Specification (2 of 3)



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## 2. Component SEU Specification

2.1 No SEE may cause permanent damage to a system or subsystem.

2.2 Electronic components shall be designed to be immune to SEE induced performance anomalies, or outages which require ground intervention to correct. Electronic component reliability shall be met in the SEU environment.

2.3 If a device is not immune to SEUs, analysis for SEU rates and effects must take place based on  $LET_{th}$  of the candidate devices as follows:

| Device Threshold                                                | Environment to be Assessed                       |
|-----------------------------------------------------------------|--------------------------------------------------|
| $LET_{th} < 15^* \text{ MeV} \cdot \text{cm}^2/\text{mg}$       | Cosmic Ray, Trapped Protons, Solar Proton Events |
| $LET_{th} = 15^* - 100 \text{ MeV} \cdot \text{cm}^2/\text{mg}$ | Galactic Cosmic Ray Heavy Ions, Solar Heavy Ions |
| $LET_{th} > 100 \text{ MeV} \cdot \text{cm}^2/\text{mg}$        | No analysis required                             |

2.4 The cosmic ray induced LET spectrum which shall be used for analysis is given in Figure TBD.

2.5 The trapped proton environment to be used for analysis is given in Figures TBD. Both nominal and peak particle flux rates must be analyzed.

2.6 The solar event environment to be used for analysis is given in Figure TBD.

2.7 For any device that is not immune to SEL or other potentially destructive conditions, protective circuitry must be added to eliminate the possibility of damage and verified by analysis or test.

*\*This number is somewhat arbitrary and is applicable to "standard" devices.  
Some newer devices may require this number to be higher.*





# Single Event Effects Specification (3 of 3)



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## 2. Component SEU Specification (Cont.)

2.8 For SEU, the *criticality* of a device in it's specific application must be defined into one of three categories: error-critical, error-functional, or error-vulnerable. Please refer to the </radhome/papers/seecai.htm> Single Event Effect Criticality Analysis (SEECA) document for details. A SEECA analysis should be performed at the system level.

2.9 The improper operation caused by an SEU shall be reduced to acceptable levels. Systems engineering analysis of circuit design, operating modes, duty cycle, device criticality etc. shall be used to determine acceptable levels for that device. Means of gaining acceptable levels include part selection, error detection and correction schemes, redundancy and voting methods, error tolerant coding, or acceptance of errors in non-critical areas.

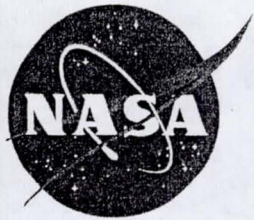
2.10 A design's resistance to SEE for the specified radiation environment must be demonstrated.

## 3. SEU Guidelines

Wherever practical, procure SEE immune devices. SEE immune is defined as a device having an  $LET_{th} > 100 \text{ MeV*cm}^2/\text{mg}$ .

If device test data does not exist, ground testing is required. For commercial components, testing is recommended on the flight procurement lot.





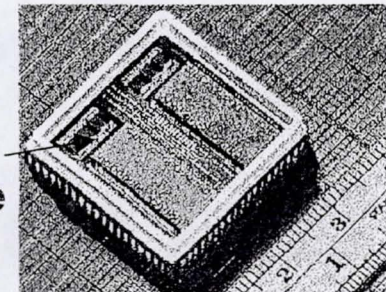
# Evaluate Design/Component Usage



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- Screen/review parts list
  - Use existing databases
    - DTRA's ERRIC, RADATA, REDEX, Radhome, ESA Database, IEEE TNS, IEEE Data Workshop Records, Proceedings of RADECS, etc.
    - Evaluate completeness and relevance of test data
  - Look for processes or products with known radiation tolerance (beware of SEE and displacement damage!)
    - BAE Systems, Honeywell Solid State Electronics, UTMC, Intersil, etc.
- Radiation test unknowns or non-RH guaranteed devices
  - Lot qualification recommended
  - Qualification by similarity is a risk trade
- Provide performance characteristics
  - Usually requires application specific information: understand the designer's sensitive parameters
    - SEE rates and impacts to system

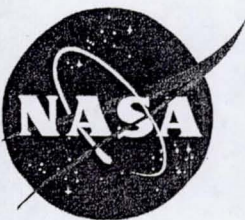
Stacked devices and hybrids  
can present a unique challenge  
for review and test







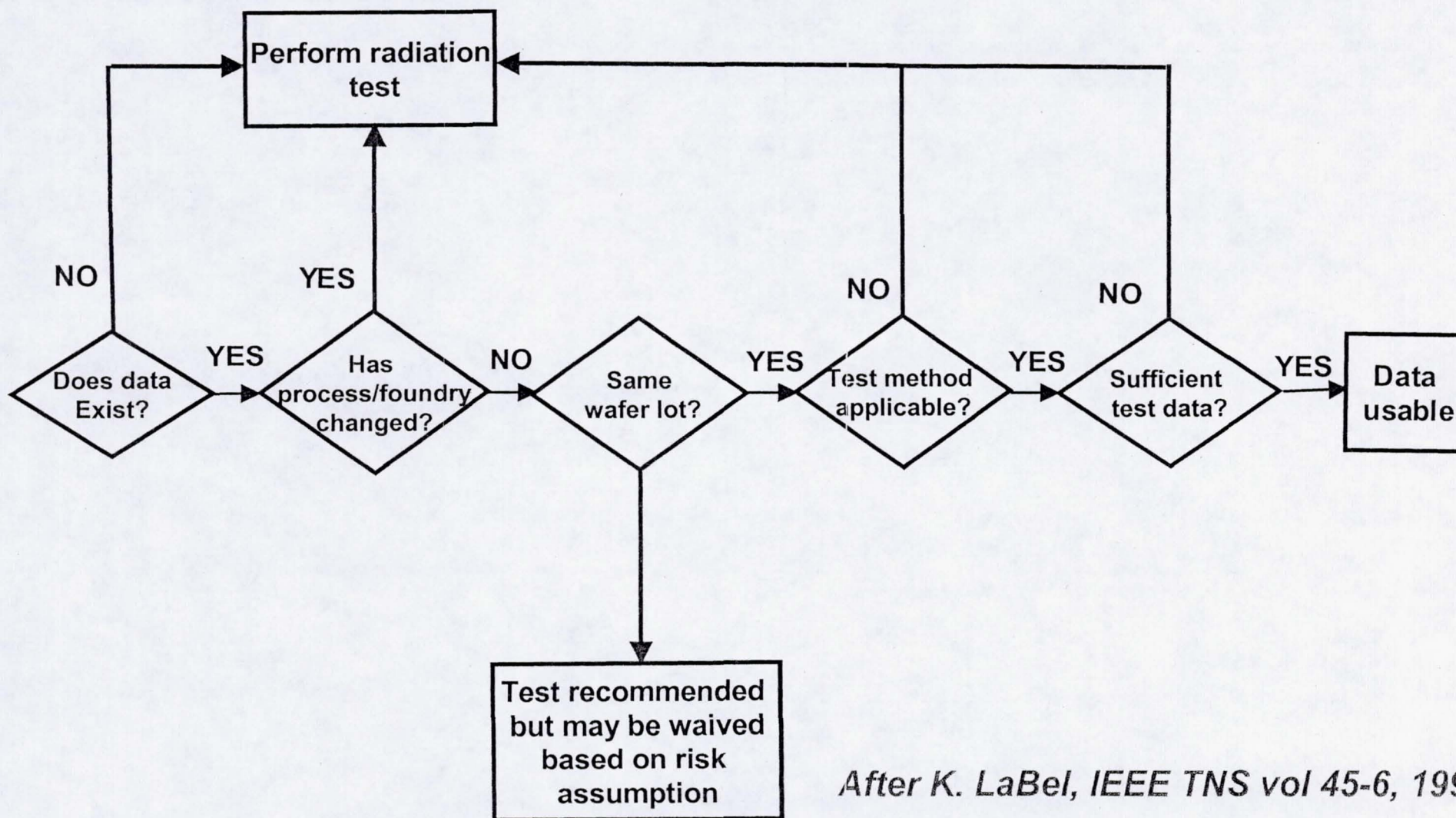




# Data Search and Definition of Data Usability Flow

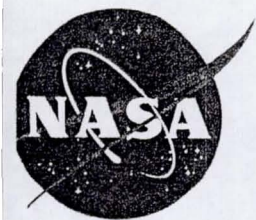


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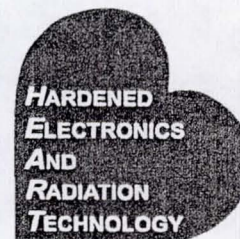


*After K. LaBel, IEEE TNS vol 45-6, 1998*





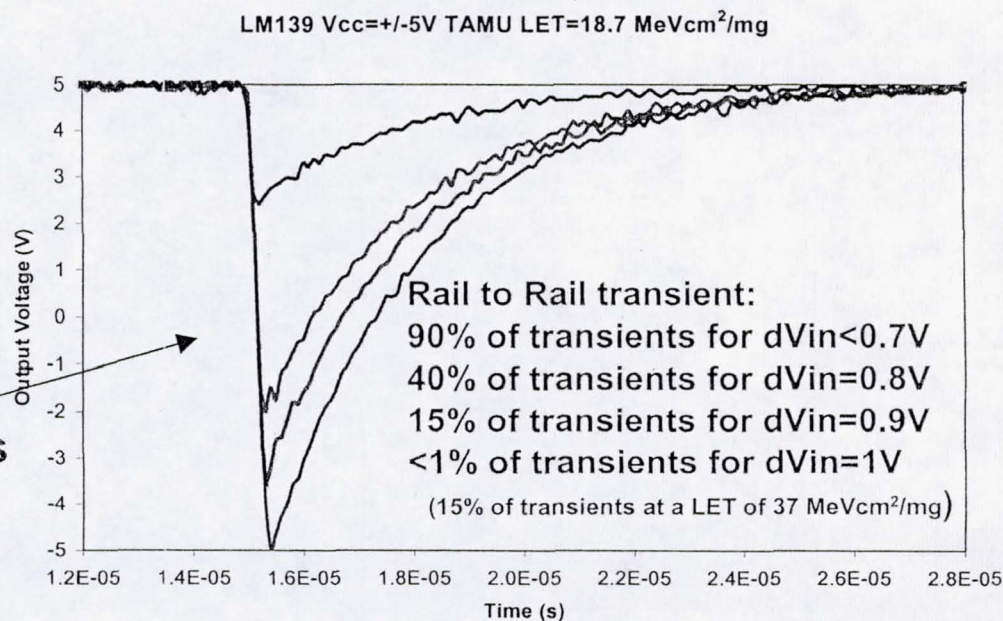
# Data Applicability – Example 1



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- Most SEE data available is application-specific
  - Power supply voltages
  - Operating frequency
    - Fidelity of response measured
      - Ex., Was the scope fast enough to capture “small” transients that might perturb sensitive data?
  - Circuit load
  - Test patterns
  - Temperature
  - Bias configuration

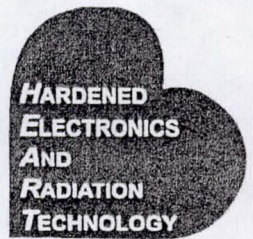
Transients in a linear device  
can vary with input parameters





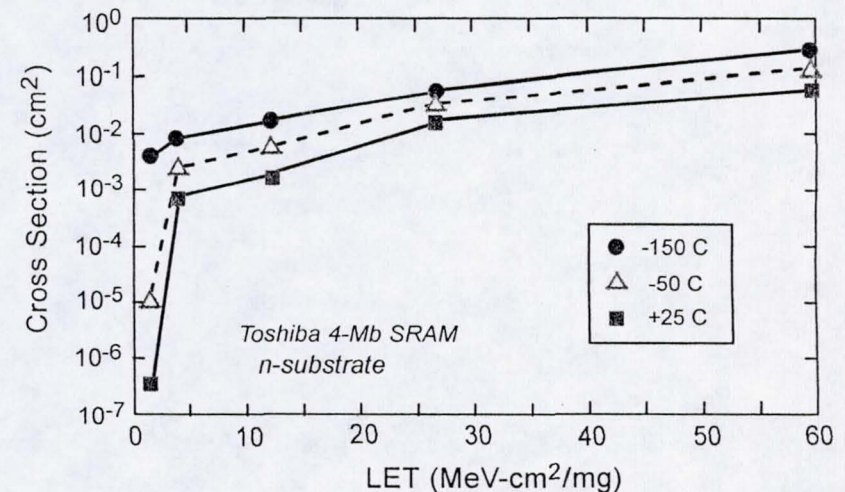


# Data Applicability - Example 2



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- SRAM used in a solid state recorder (SSR)
  - SEE ground test data may have been in dynamic mode with a 1 MHz operating frequency
  - Application may be quasi-static
    - Write once an orbit (collect data)
    - Read once an orbit (downlink data)
  - There is often a duty cycle effect for SEE sensitivity
    - Device may be more or less sensitive in a quasi-static mode of operation
  - Device may also have a prevalence of 0-1 vs. 1-0 upset
    - Implies SEU sensitivity is a function of data patterns
      - If test pattern is all 1's or all 0s, data may not be applicable
        - » Hitachi 1 Mbit SRAM was 49X more sensitive in one direction than the other!



Effect of temperature on SEE sensitivity





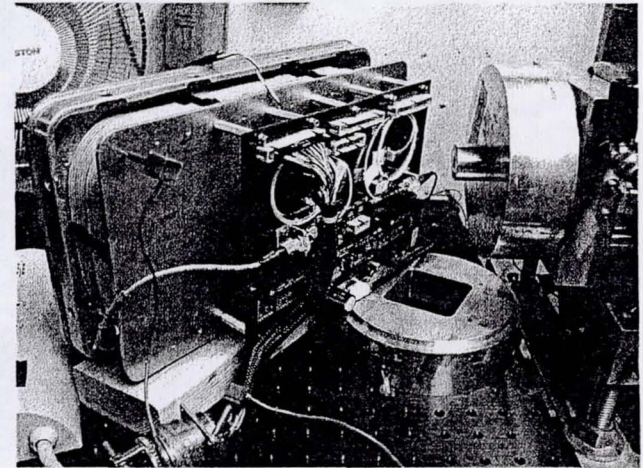
# SEE Radiation Test Requirements

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ELECTRONICS  
AND  
RADIATION  
TECHNOLOGY

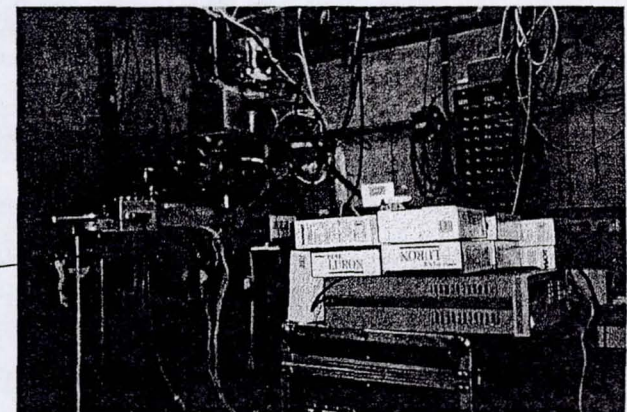
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- Determine if heavy ion, proton, or both types of test are needed
  - Mission-specific issues
- Define appropriate test levels
  - Sample size, particle, and fluence
- SEE testing should mimic or bound the flight usage, if possible
  - *Worst-case issues should be included*
- It may be acceptable to avoid testing if the design is robust to SEUs/SETs
  - Ex., A transient filter is added to the output of linear device

Beware of stray neutrons on your test equipment.  
Here, Borax is shown on top of a power supply.  
We have seen failures in test equipment from stray neutrons.



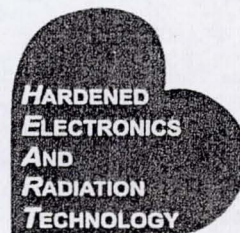
A fiber optic link awaiting protons for SEE tests at UC Davis



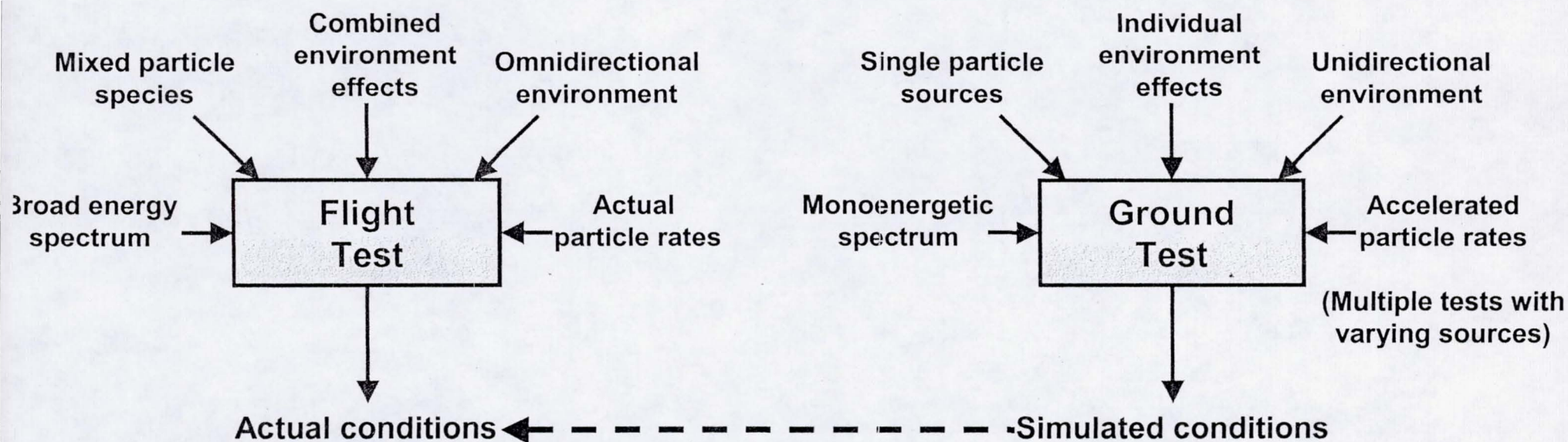




# Radiation Test Issues - Fidelity



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*How accurate is the  
ground test in predicting Space Performance?*

*Example, how does dose degradation and aging effects affect SEE performance?*





# Work with Space System Designers

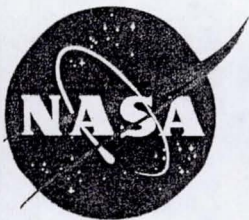


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- Determine and validate “acceptable” performance characteristics
  - E.g., SEU rates using accepted methods
    - By test
    - By simulation or circuit analysis
    - By determining SEU rate (CREME96, SPACERAD, etc) and managing risk
      - I.e., is the probability/risk of observing an SEU sufficiently low?
        - » e.g., a SEU rate of 1 per 10 years for a 1 month mission
- Recommend mitigation schemes
  - Recommend alternate parts that meet performance requirements
  - Recommend error detection and correction (EDAC) schemes, redundancy, voting,...





# Radiation Risk Management: Levels of Hardening

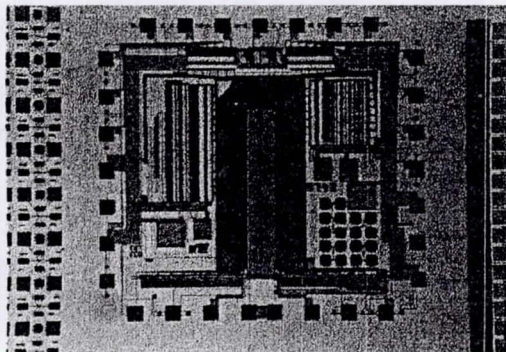


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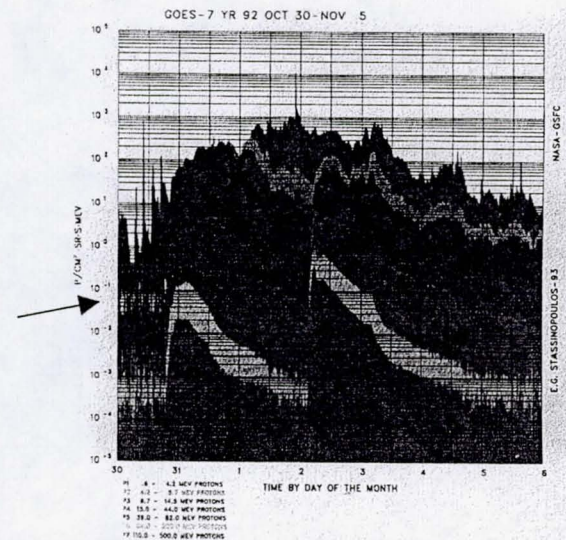
- Transistor/Integrated Circuit (IC)\*
- Circuit design/board\*
- Subsystem and system
- Satellite systems (constellations)

*\*Emphasized in this talk*



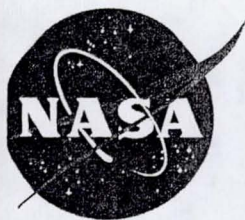
SiGe IC

A harsh “operate-through”  
solar particle event



SEU/SET is a challenge  
at ultra-high speeds



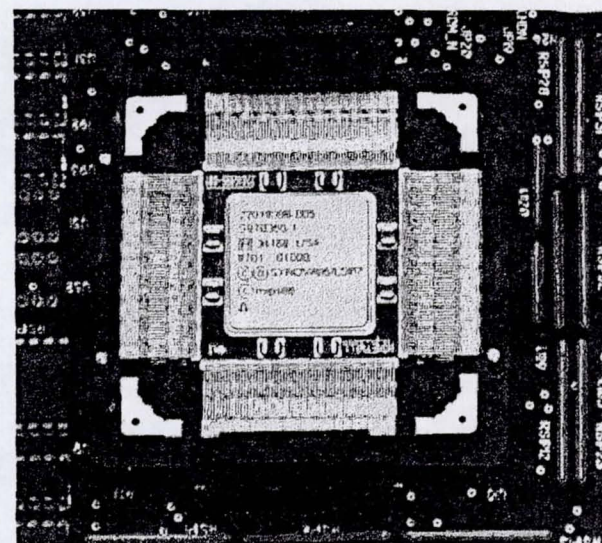


# IC Hardening (1 of 2)

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- Implies building an IC that meets system radiation requirements
- Features may include:
  - SEL immune process
  - Hardened transistors
  - Internal redundancy/voting
  - Internal error correction, etc.
- Examples
  - Temporal and spatial latches



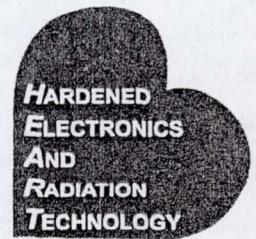
Mongoose V

<http://www.synova.com/proc/mg5.html>





# IC Hardening (2 of 2)



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- **Advantages**
  - Simplifies system design to meet radiation requirements
- **Challenges**
  - Performance, Cost, Schedule
- **Examples**
  - Hardened process
  - Compiled or hardened library design (hardness by design (HBD) techniques)



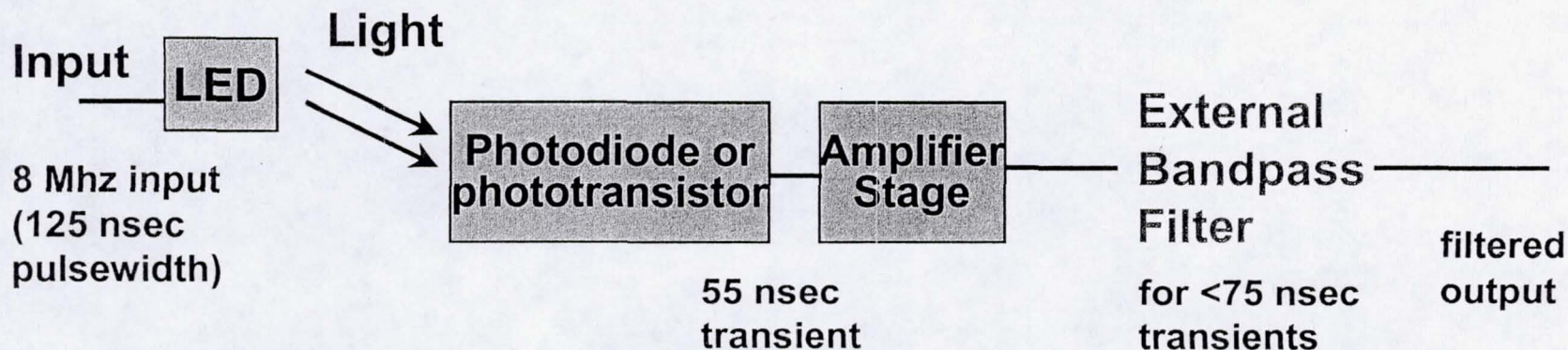


# Circuit Hardening (1 of 2)



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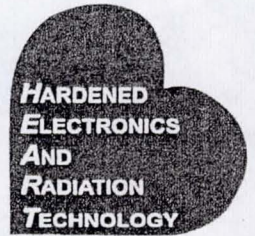
- Implies adding an external feature to an IC to reduce radiation sensitivity
  - Shielding
  - RC filter
  - Voting logic
  - Error detection and correction (EDAC) codes
  - Watchdog timers, etc.
- Maybe be implemented or controlled by either hardware, software, or firmware







# Circuit Hardening (2 of 2)

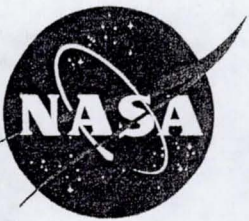


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- **Advantages**
  - Allows use of higher (non-radiation) performance ICs
    - Faster processors
    - Denser memories, etc...
- **Challenges**
  - Adds complexity (cost and schedule?) to design
  - Often difficult to retrofit if problem is discovered late
    - Modification to flight hardware



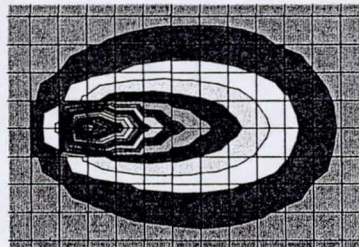


# Mitigation of SEUs



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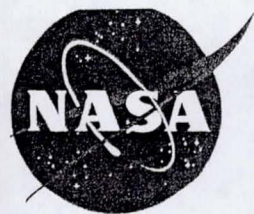
- Three types of SEUs
  - Data (Ex., bit-flip to a memory cell or error on a communication link)
  - Control (Ex., bit-flip to a control register)
    - May sometimes be called single event functional interrupts (SEFIs)
  - Transient (noise spike that may or may not propagate)
- Some overlap may exist
  - Ex., RAM with program memory stored inside



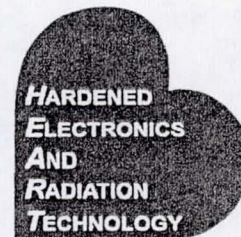
75°

Energetic particle diffusing in a silicon device





# Data SEUs - Sample Error Detection and Correction (EDAC) Methods



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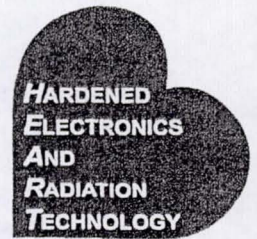


| EDAC Method                   | EDAC Capability                                           |
|-------------------------------|-----------------------------------------------------------|
| Parity                        | Single bit error detect                                   |
| Cyclic Redundancy Check (CRC) | Detects if any errors have occurred in a given structure  |
| Hamming Code                  | Single bit correct, double bit detect                     |
| Reed-Solomon Code             | Corrects multiple and consecutive bytes in error          |
| Convolutional Code            | Corrects isolated burst noise in a communication stream   |
| Overlying Protocol            | Specific to each system. Example: retransmission protocol |





# Control SEUs - Sample EDAC Schemes



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- Software-based health and safety (H&S) tasks
- Watchdog timers
- Redundancy
- Lockstep
- Voting
- IC Design techniques
- “Good engineering practices”
  - Ex., send two commands with different values to initiate a sequence
- Improved Designs (i.e., noise margins, method of sampling, etc.)





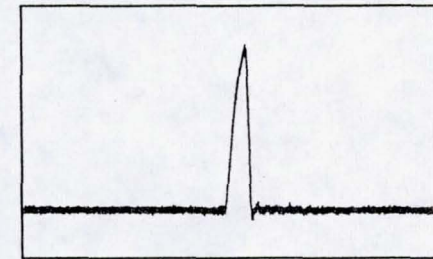
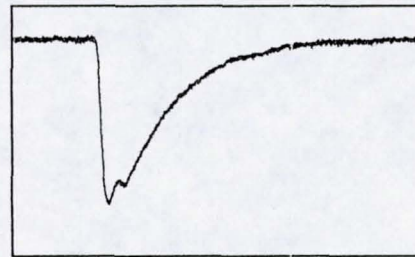
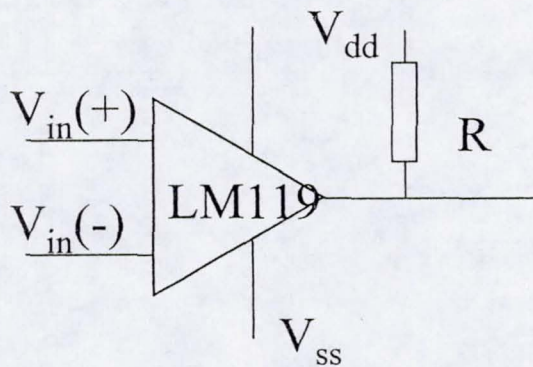


# Transient SEUs (Single Event Transients – SETs)

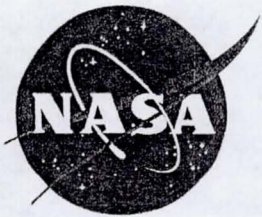
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- Examples of issue
  - ADCs, Analog, and Optical Links are among the device types affected
  - Optocoupler transients in HST and Terra (and IRIDIUM!)
  - Linear devices such as LM139 analog comparator (MAP, MPTB)
- Most commonly mitigated by
  - Filtering techniques
  - Over-sampling
  - High-speed device with a slow response following circuit







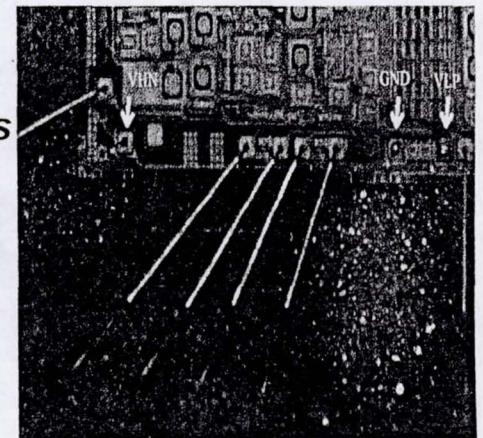
# Destructive Conditions - Mitigation

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- Recommendation 1: Do not use devices that exhibit destructive conditions in your environment and application
- Difficulties:
  - May require redundant components/systems
  - Conditions such as low current SELs may be difficult to detect
- MANY DESTRUCTIVE CONDITIONS MAY NOT BE MITIGATED
- Mitigation methods
  - Current limiting
  - Current limiting w/autonomous reset
  - Periodic power cycles
  - Device functionality check
- Latent damage is also a grave issue
  - “Non-destructive” events may be false!

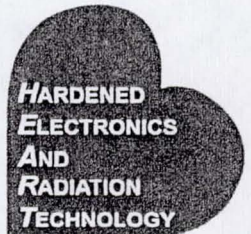
*Vaporized wirebonds  
in a  
Agere LSP2916  
MEMS Driver  
from an SEL*





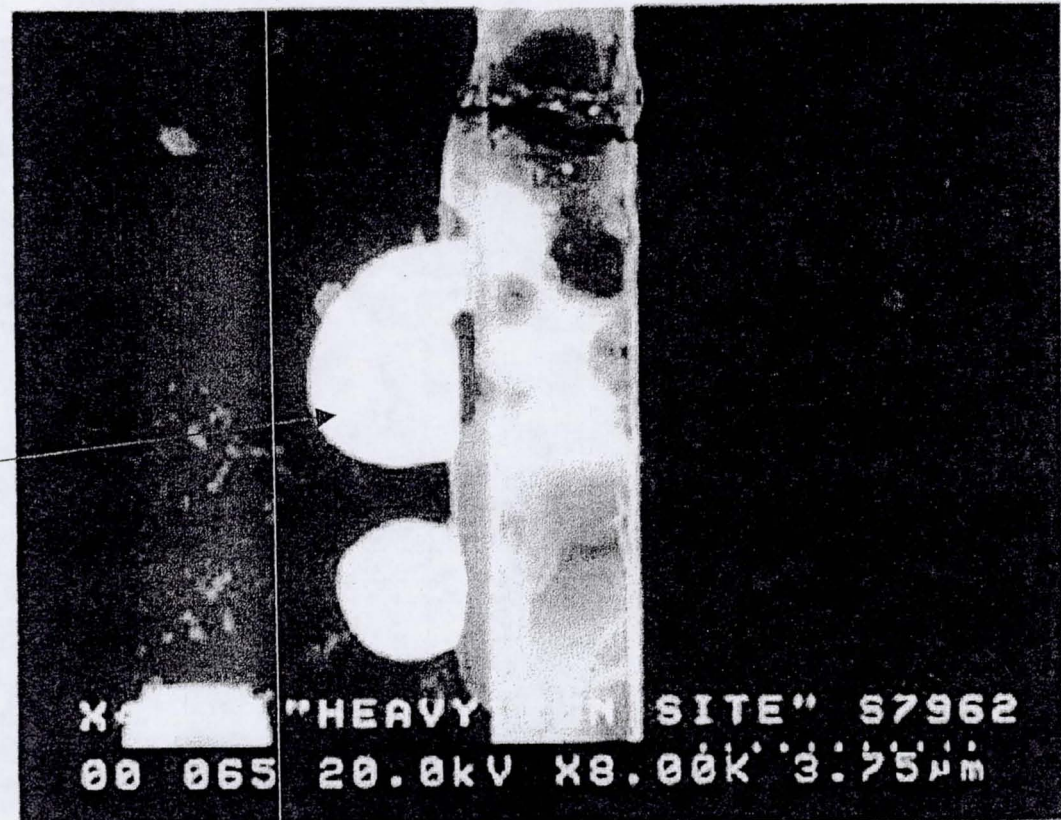


# Latent Damage: Implications to SEE



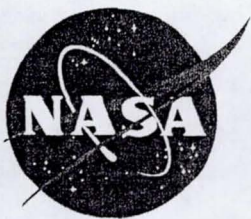
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- SEL events are observed in some modern CMOS devices
  - Device may not fail immediately, but recover after a power cycling
- However, in some cases
  - Metal is ejected from thin metal lines that may fail catastrophically at some time after event occurrence



***SEL test qualification methods need to take latent;  
Post-SEL screening techniques required;  
Mitigative approaches may not be effective***





# Iterate Process as Necessary



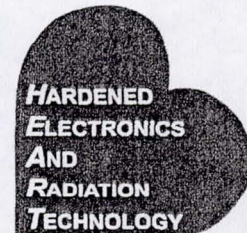
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- Spacecraft structure, box positioning, parts lists, system functions, etc. often change during mission development
  - New parts need review
  - Hazard may require re-evaluation
- Mission requirements may change forcing redesign
  - Ex., Device application has changed making it more sensitive to SEE
- New information sometimes is uncovered
  - If the design/development is more than a few months, new knowledge is sometimes obtained making “old parts, new issues”
    - Presentations at conferences highlight new sensitivities in devices/technologies
      - Ex., optocoupler SETs





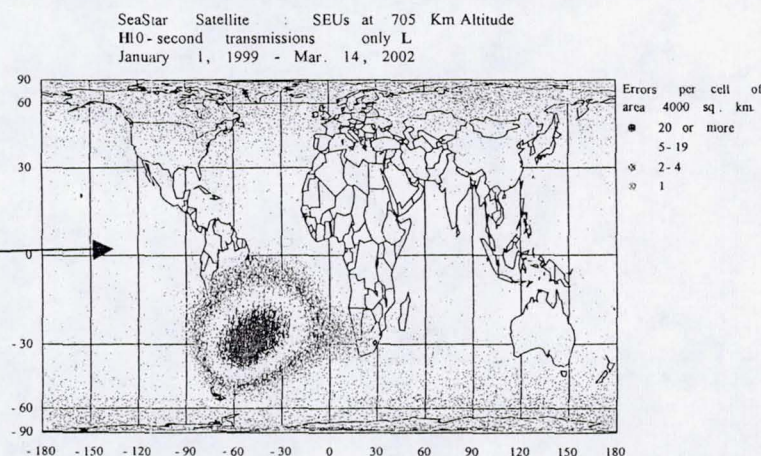
# Monitor System Performance In-Flight



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- It is recommended that adequate measures be taken to gather appropriate in-flight performance information
  - Ex.
    - Number and type of errors observed in SSRs
  - This includes correlative information
    - When and where events are occurring
    - Environment monitoring (proton fluxes, etc...)
- Helps determine effectiveness of system hardening approaches and provides lessons learned for next-generation designs

Memory upsets in a  
polar orbiting mission







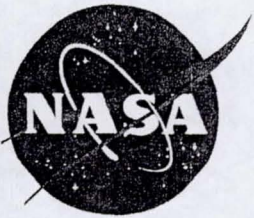
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# In-Flight Performance of Actual NASA Systems

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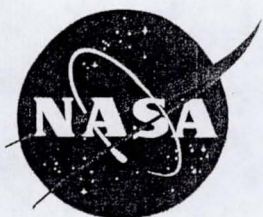
# Success Stories



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- **A brief overview will be provided of several NASA missions which performed as expected in space due to SEEHA**
  - Each can be traced back to particular lessons they provided
- **Three examples**
  - **Solid State Recorders (SSRs)**
    - SeaStar
    - Hubble Space Telescope (HST)
  - **COTS Processors**
    - HST Co-processor



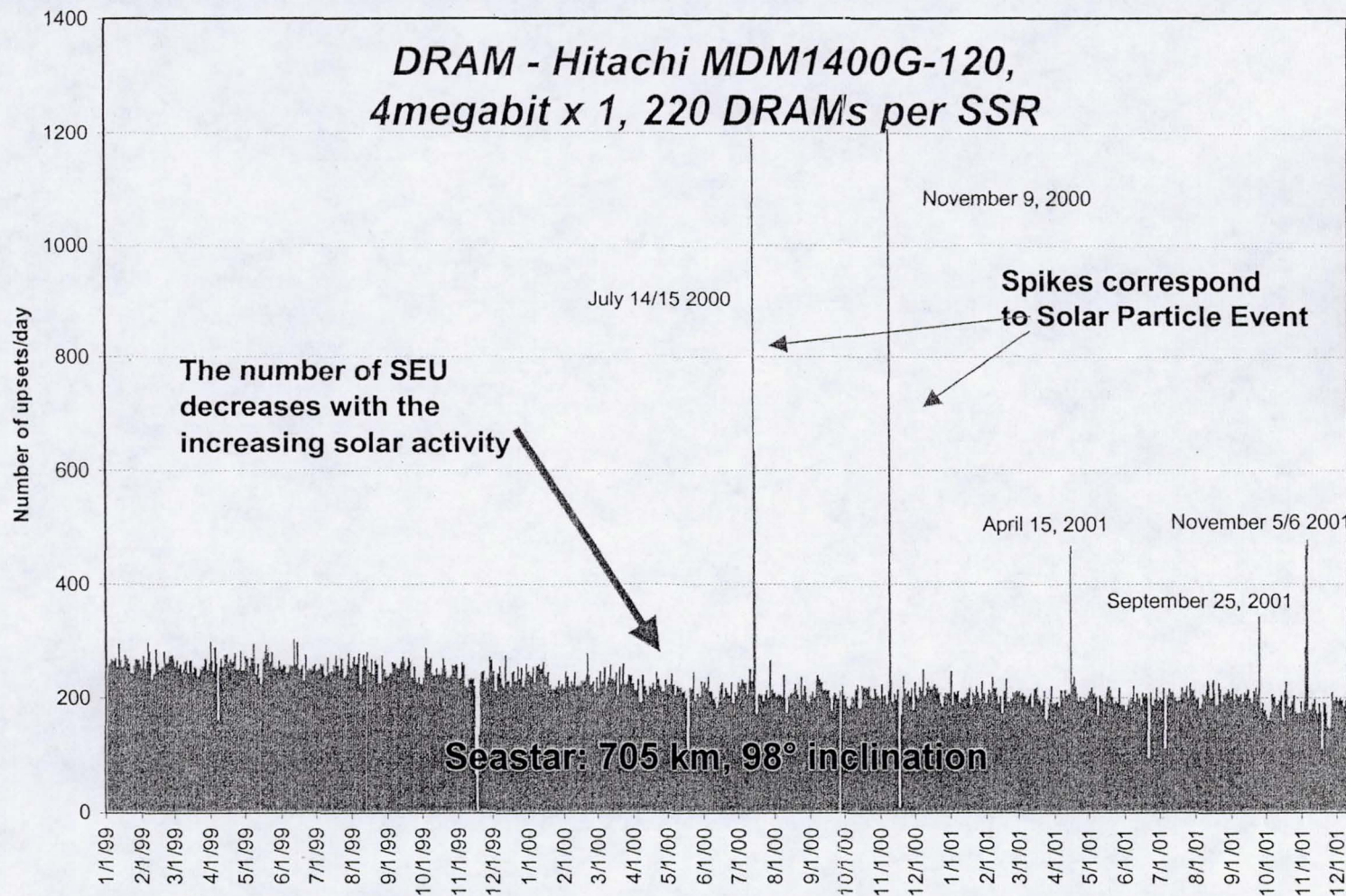


# SeaStar SSR:

*Single bit correction can be effective*

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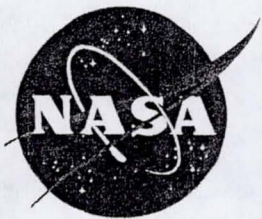
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**Single bit EDAC can be used effectively with x1 devices  
in most system implementations**

**Caveat: beware of more modern devices that have SEFIs**





# Hubble Space Telescope (HST) SSR:

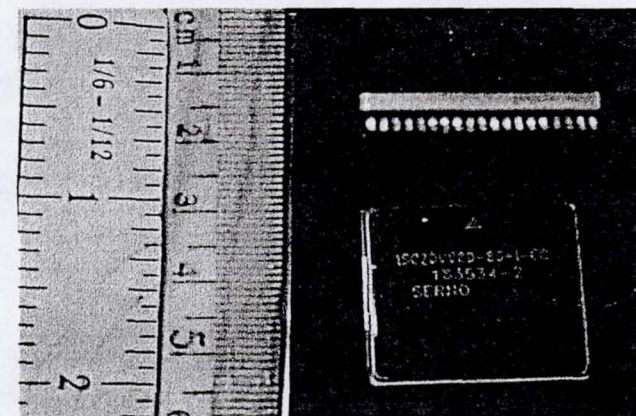
*Use of a robust EDAC scheme and  
Testing significant sample size*



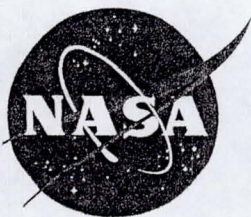
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- Feb 1996 Hubble Space Telescope
  - Upgraded SSR installed on HST with 1440 16Mbit IBM Luna ES Rev C DRAMs (12 Gbits)
- Ground testing performed on small sample sizes
  - Row and column errors observed with heavy ions, but not protons: concept of limiting cross-section
- HST is a low-inclination, low altitude mission
  - Very few heavy ions expected
- However
  - Row and column errors observed in flight!
  - Larger sample size proton tested
    - Events similar to flight anomalies noted at a rate consistent with flight observations
- RS Encoding scrubbed all errors = no data lost

Stacked IBM DRAMs





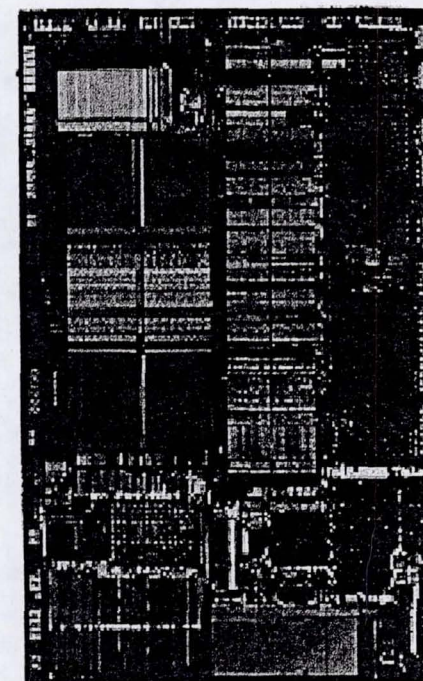


# HST Co-Processor: *Acceptable Mission Risk*

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- HST wanted to increase in-flight processing capabilities
  - GSFC Radiation Group was hired to evaluate the Intel 80486DX33 (CHMOS III) processors radiation characteristics
    - A sample of a Intel 80486DX2-66 (CHMOS IV) was also available for tests
  - High currents noted on DX33 device, but not on DX2-66
- Decision made to go forward with design using DX2-66
  - 3 additional lots tested (first 2 had procurement issues)
  - 3<sup>rd</sup> lot (“same process”) showed high current events NOT observed in previous lots
    - This is the lot that was procured for flight
- Despite high current events, probability of occurrence in-flight for HST orbit was low
  - < 1 per 100,000 years
- Deemed acceptable risk
  - No incidents noted in over 6 years in flight

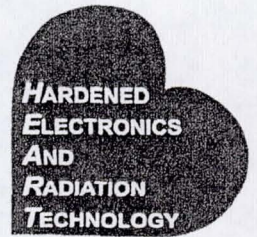


INTEL 80486DX





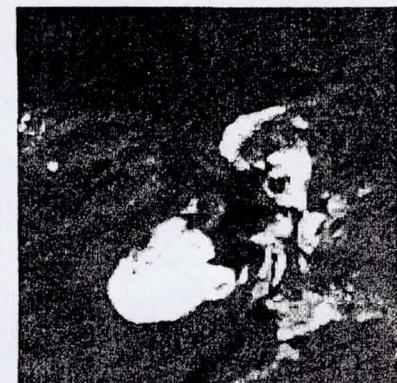
# Anomalies In-Flight



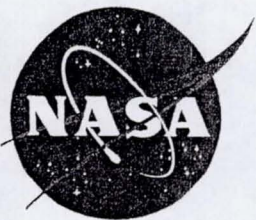
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- **Anomalies can have a wide variety of impacts on space systems from minimal to mission failure**
- **Examples include**
  - Data loss
  - Misoperation
  - Safing of spacecraft
- **Two samples of anomalies are presented**
  - An impact to science data operations, and
  - A system periodic outage

A proton-rich solar event can cause anomalies →







# HST Optocouplers

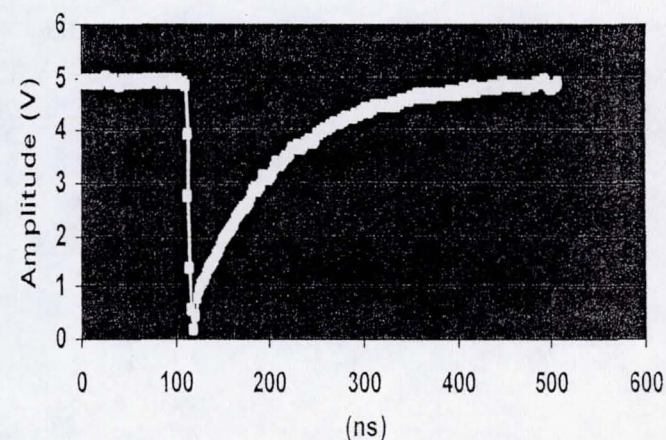
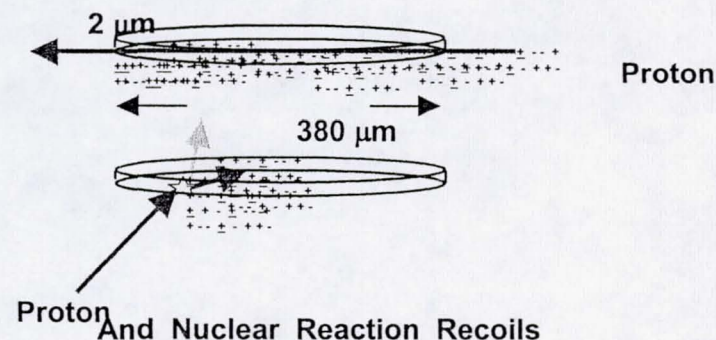
*Changes in technology make old devices, new issues*

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- In February of 1997, several anomalies occurred in a HST instrument while transiting through the SAA
  - High-speed optocoupler identified as the potential source
    - This was verified by ground testing in March 1997
  - Device was not reviewed for radiation issues other than total dose
    - Common thought before this timeframe on slower optocouplers
- Science instrument operations modified such that no operations were active during SAA transits
  - Loss of some (luckily non-critical) science data

Direct Ionization Across Long Pathlengths







# Microwave Anisotropy Probe (MAP):

## SETs in a Linear Device

*Robust system design despite changes in design requirements*

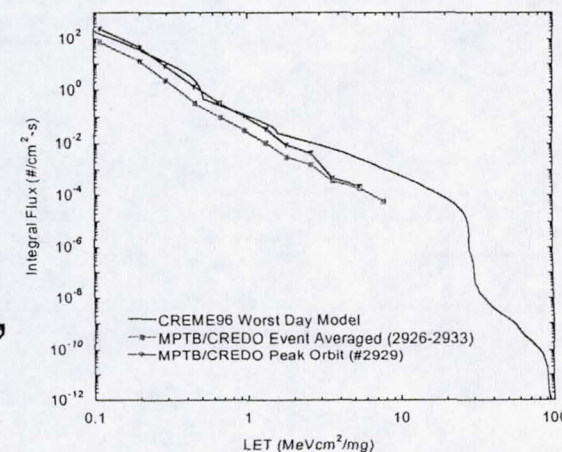
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TECHNOLOGY**

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- **MAP was launched in June 2001 to a L2 orbit**
  - Anomaly occurred in Nov 2001 causing the command and data handling processor to reset
    - System worked as designed for recovery of anomalies
- **Event occurred during a solar particle event**
  - Heavy ion contribution was likely the cause
- **Sensitive design issue: linear comparator used with a small differential input**
  - Much more sensitive than with larger differential input
- **Design requirements changed and what was originally a tolerant application became “soft” to SETs**
- **Potential for further processor resets from both solar events and GCR**



MAP Spacecraft



Heavy ion spectra  
from solar particle event





# Summary



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- In this brief time, we have presented an system-level approach to dealing with space system design and SEE
- It is important to start ANY radiation assurance planning early in mission design and to continue throughout
- It is the challenge of every design engineer to make sure his or her design is robust with the aid of the radiation specialist





# Acknowledgements



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- The entire Radiation Effects and Analysis Group at GSFC NASA HQ Code AE for supporting the NASA Electronic Parts and Packaging (NEPP) Program including the Program Manager, Chuck Barnes of JPL
- Lew Cohn at Defense Threat Reduction Agency (DTRA)
- The designers and systems engineers I've had the privilege to work with
- Martha O'Bryan for graphics support