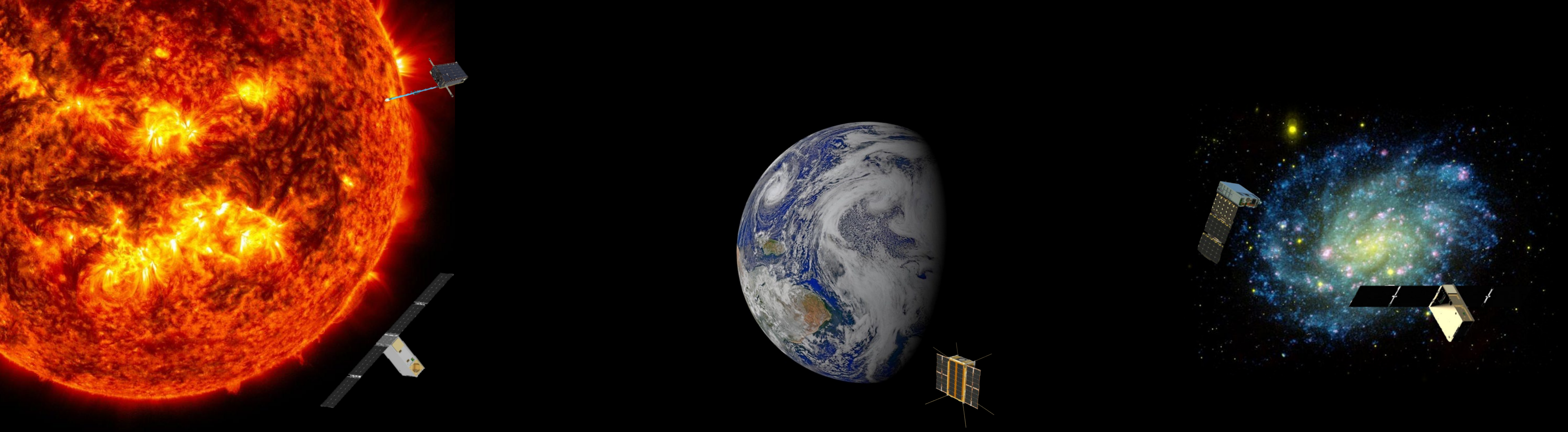
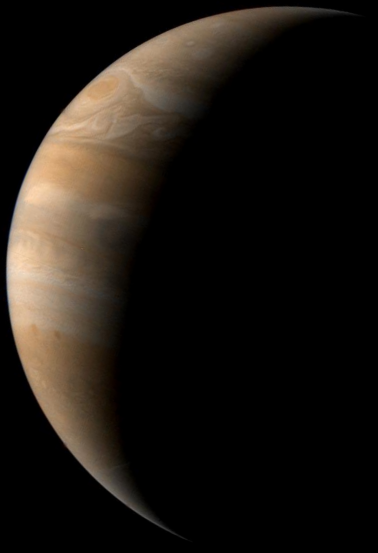


National Aeronautics and Space Administration

Designing Systems for Space Applications (Single Event Effects)

Rebekah Austin



NASA GODDARD SPACE FLIGHT CENTER

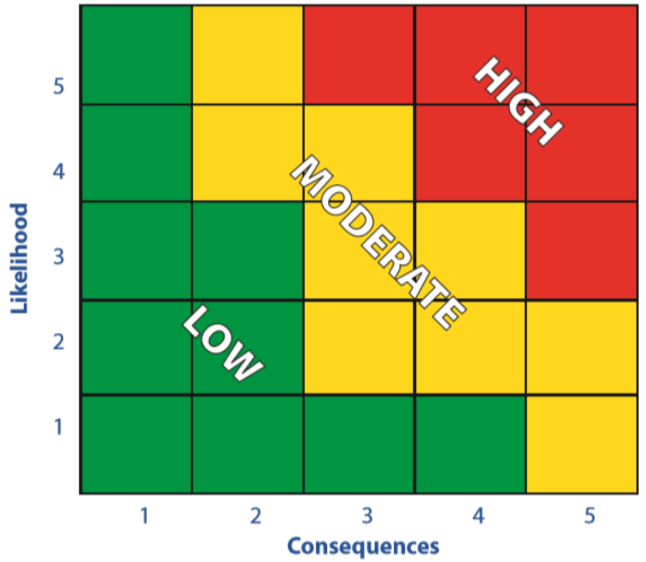
Why are we even testing in the first place?

- Radiation Hardness Assurance is the process of accessing and managing **RISK** from the space radiation environment

- Risk = Probability of failure X Consequence of failure

- Risk Assessment
  1. Identify possible faults
  2. Determine likelihood of faults
  3. Determine consequence of faults

- Risk Management
  1. Reduce types of faults
  2. Reduce likelihood of faults
  3. Reduce consequence of faults



Risk Matrix from NASA Systems Engineering Handbook Rev. 1: https://www.nasa.gov/sites/default/files/atoms/files/nasa_systems_engineering_handbook.pdf

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How do we go from a radiation – induced fault to a system-level failure?

Why are we even testing in the first place?

- Radiation Hardness Assurance (RHA) is the process of accessing and managing **RISK** from the space radiation environment

- Risk = Probability of failure X Consequence of failure

- Risk Assessment
  1. Identify possible faults
  2. Determine likelihood of faults
  3. Determine consequence of faults

- Risk Management
  1. Reduce types of faults
  2. Reduce likelihood of faults
  3. Reduce consequence of faults

How do we build a system that will survive and operate in the space radiation environment?

What is the end work project?

- Approved part list
  - Through a parts control board
  - Mostly focused on destructive SEEs

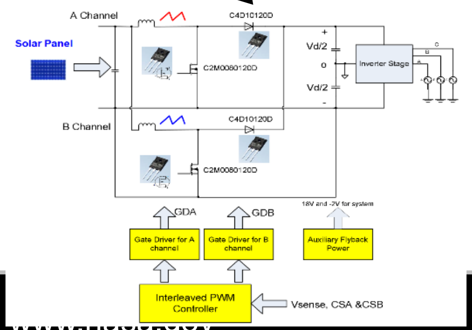
Part	Status	Radiation Comment
Regulator	Approved	Design can handle expected SETs
MOSFET	Approved with comments	Probability of failure of 2% at derating of 50% with current shielding

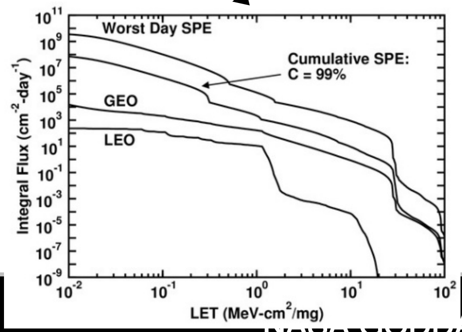
System Design

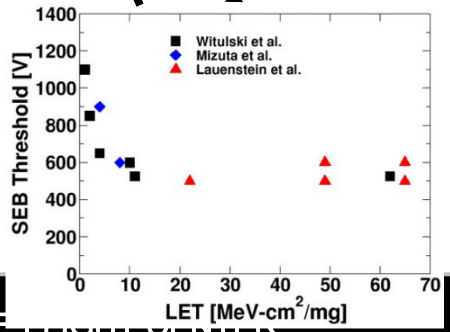
Radiation Environment

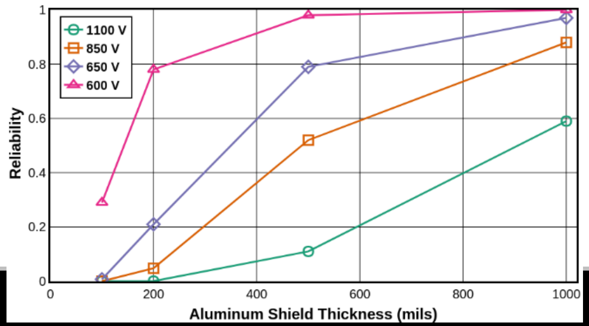
Radiation Test

Reliability Calculation



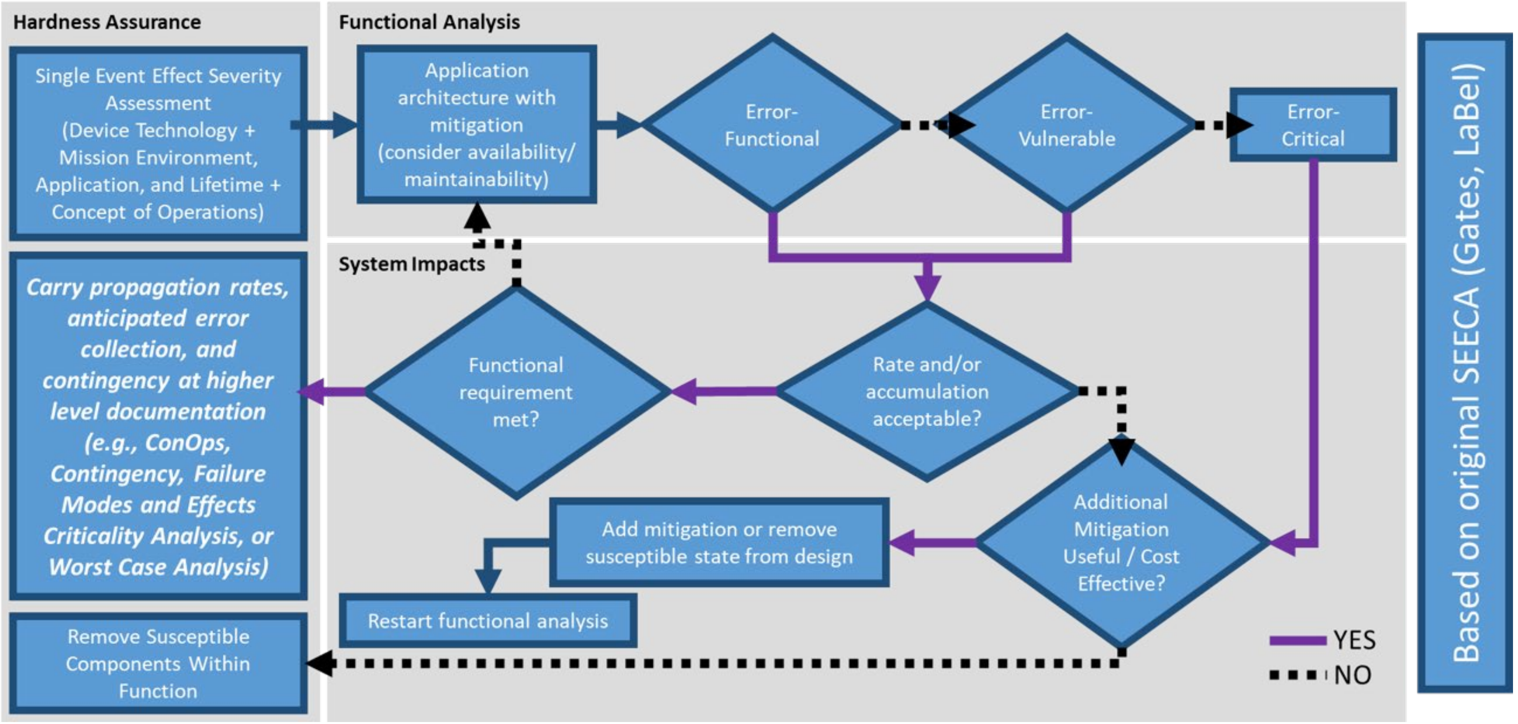






What is the end work project?

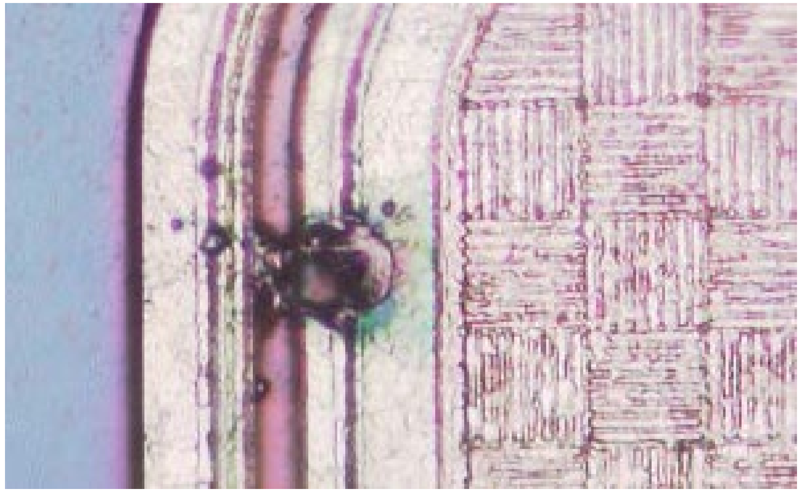
- Single-Event Criticality Analysis
  - Mostly focused on non-destructive SEEs



Radiation Effects on Active Microelectronic Devices

- Destructive Single Event Effects (SEEs)
  - Irreversible processes
  - Terms: Latchup, Burnout, Gate Rupture

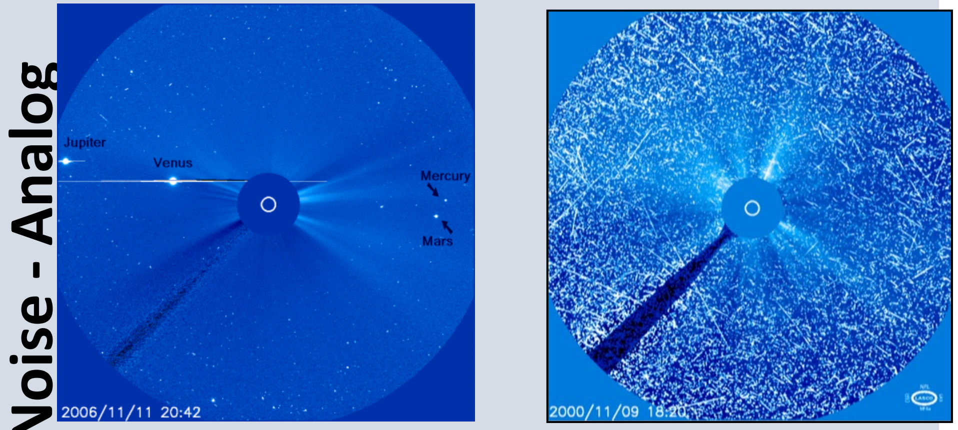
Dominant risk will depend on the device architecture and process.



Megan Casey - https://nepp.nasa.gov/files/26196/2014-561-Casey-Final-Web-Pres-ETW-Diodes-TN16278_v2.pdf

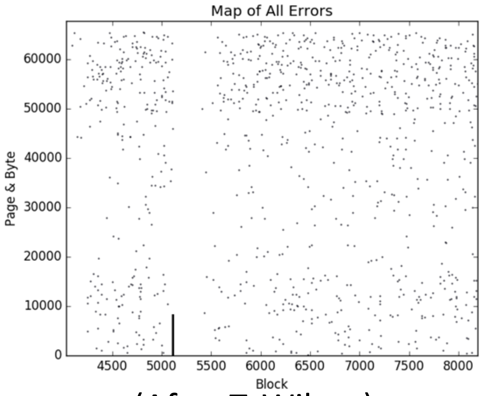
Radiation Effects on Active Microelectronic Devices

- Non-Destructive SEEs
  - Can lead to interruptions in operation and/or errors leading to unknown state spaces or loss of science / mission if not accounted for
  - Acronyms: SEFI, SET, SEU
  - Terms: Functional Interrupt, Transients, Upsets

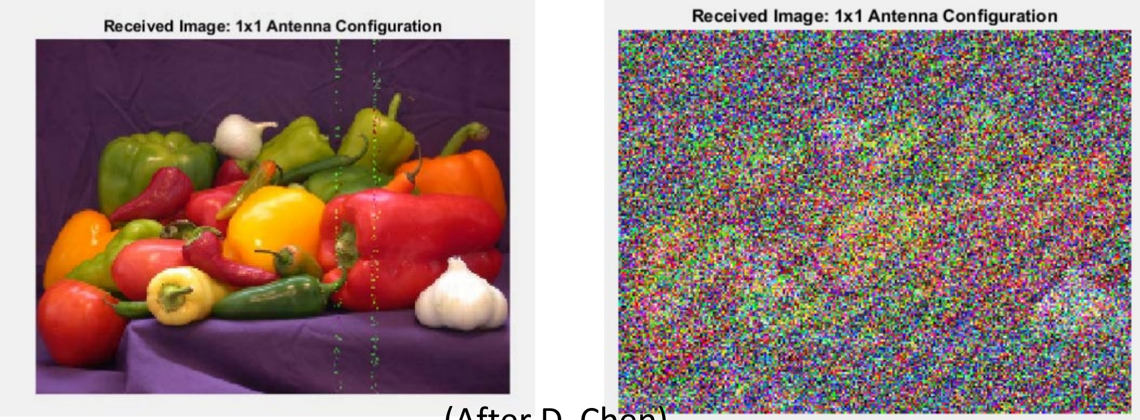


Noise on SOHO/LASCO imager during Nov. 8-9, 2000 solar particle event

Could lead to disruptive effects if not addressed by resets or power cycle.



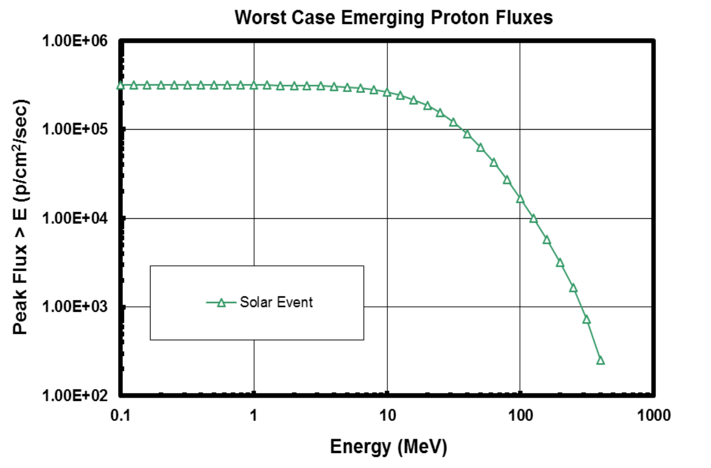
(After T. Wilcox)

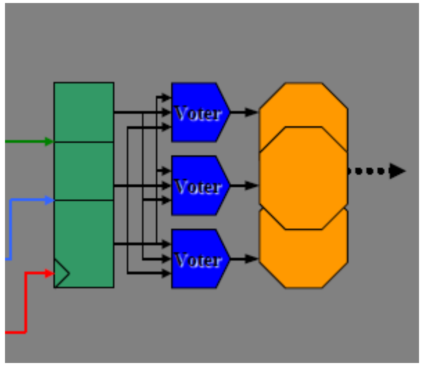


(After D. Chen)

RHA Step-by-Step

- **Define the Environment**
  - External to the spacecraft
- **Evaluate the Environment**
  - Internal to the spacecraft
- **Define the Requirements**
  - Define criticality factors
- **Evaluate Design/Components**
  - Existing data/Testing
  - Performance characteristics
- **"Engineer" with Designers**
  - Parts replacement/Mitigation schemes
- **Iterate Process**
  - Review parts list based on updated knowledge



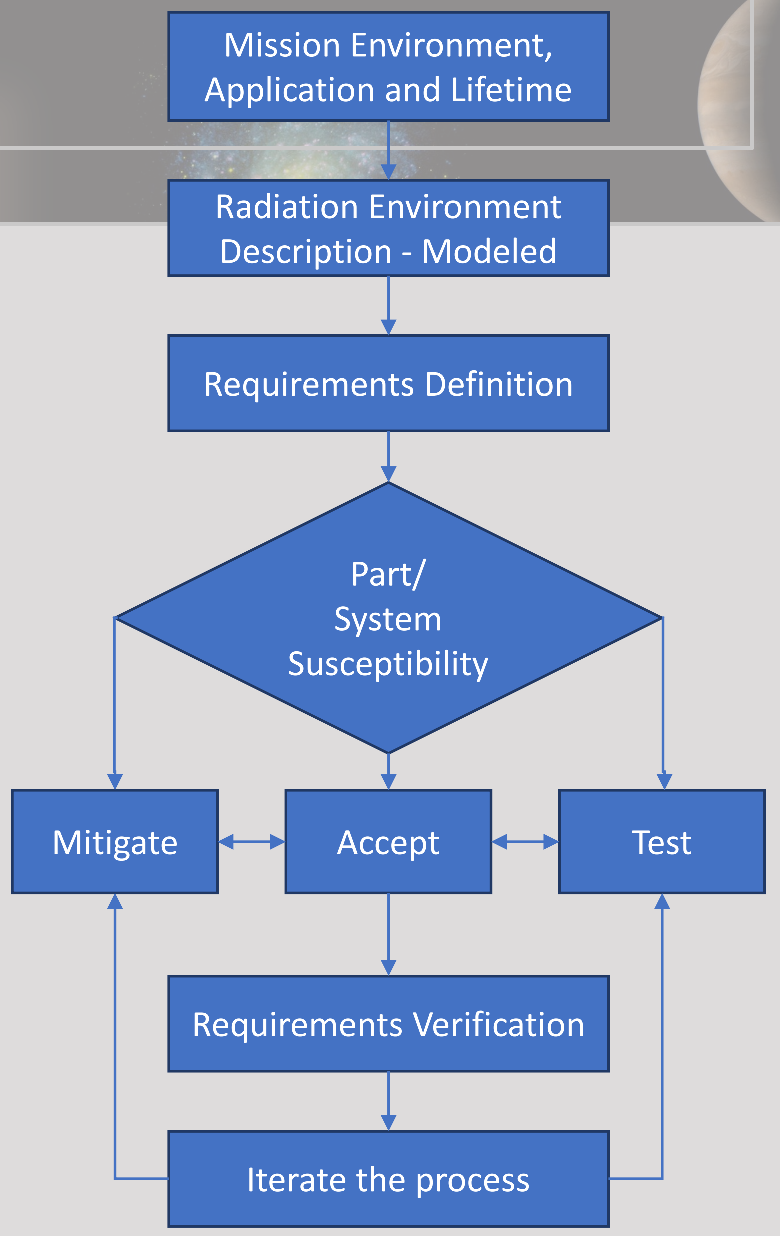


Following this process allows for building on mitigation strategies that have been successful.

K.A. LaBel, A.H. Johnston, J.L. Barth, R.A. Reed, C.E. Barnes, "Emerging Radiation Hardness Assurance (RHA) issues: A NASA approach for space flight programs," IEEE Trans. Nucl. Sci., pp. 2727-2736, Dec. 1998.

Testing and RHA

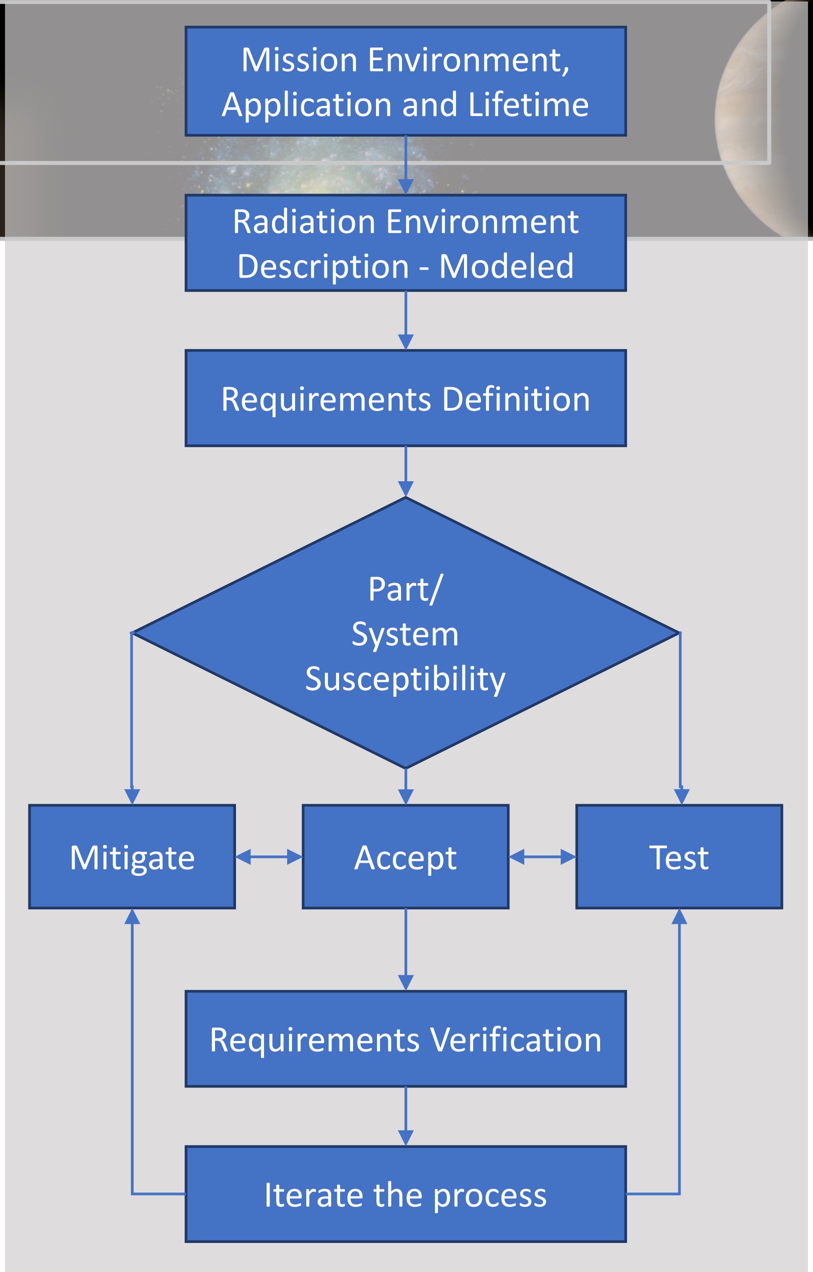
- RHA is an iterative process
  - Simplified view ->
  - Can tell you when more testing is necessary
  - Can inform what type of test is most relevant
- Testing plays a crucial role
  - Risk identification
  - Requirements
  - Screening
  - Mitigation strategy
  - Technology insertion
  - Verification



Testing and RHA

- Testing Impact
  - Not always obvious
  - Informs future decisions

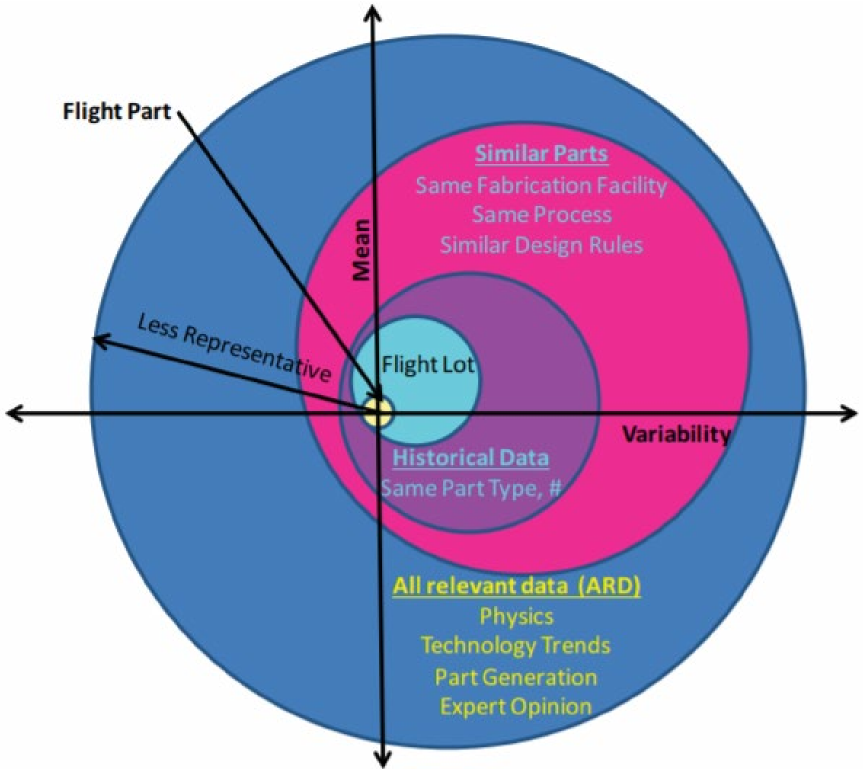
- Test Results can help
  - Device/Design changes
  - Mitigation acceptance



Risk Acceptance

- Part Classifications Growing
  - Mil/Aero vs. Industrial vs. Medical
  - Automotive vs. Commercial vs. Modified HiRel
- Substitute COTS in this diagram
  - Now you have another degree of separation
  - Failure modes not fully understood
  - Unlikely to have historical data
  - Similarity data no applicable due to fab, process, or design rules
  - Cost of testing usually too high

Structure of constraining data



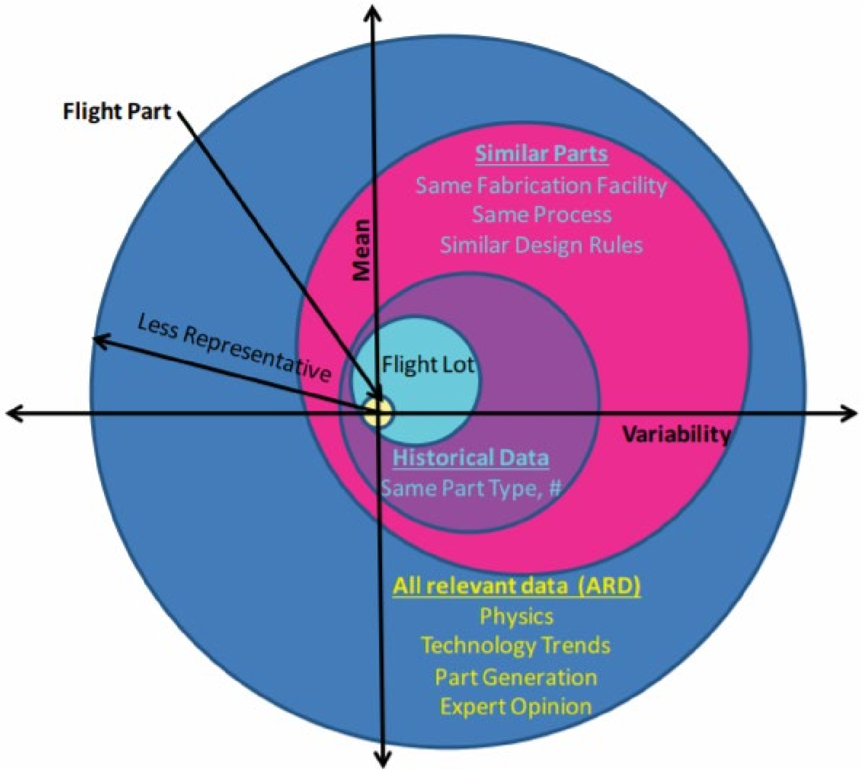
Ray Ladbury, NSREC2017 SC, https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20170006865.pdf

Risk Acceptance

- Radiation tests are destructive
  - Never done on the parts that will fly
  - As you move away from the flight lot, you get more and more variability
  - Less traceability, application similarity means less useful results

Without traceability you may inadvertently be depending on non-representative data.

Structure of constraining data



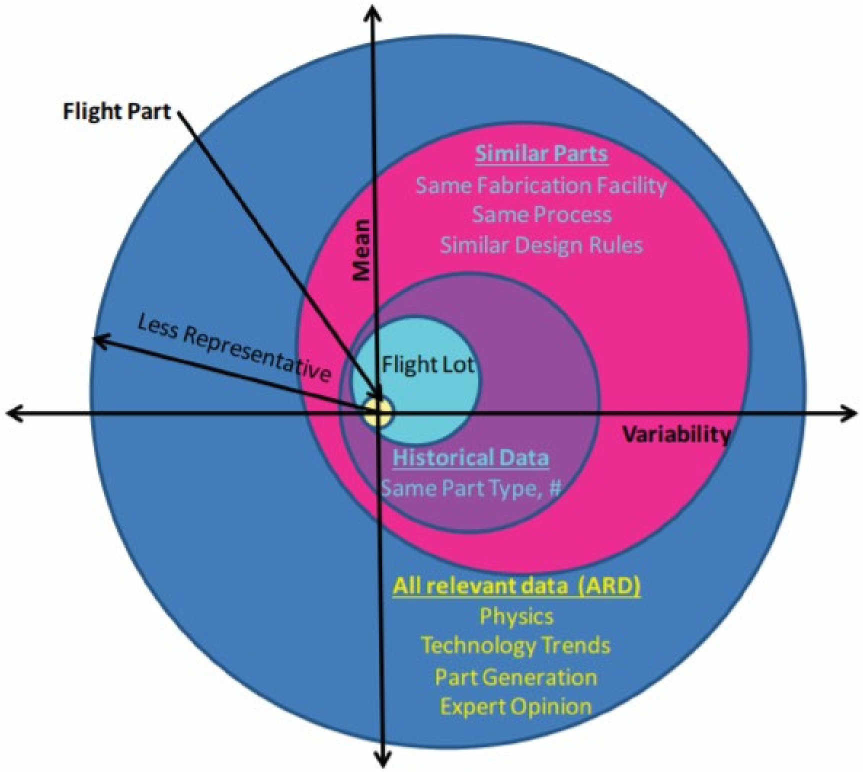
Ray Ladbury, NSREC2017 SC,
https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20170006865.pdf

Risk Acceptance

- Heritage Parts
  - Profiles of mission life, objective, and cost are evolving
  - Similarity and heritage data requirements widenir
  - One environment not equaling another in terms c radiation drivers or contributors
  - Always in a dynamic environment
  - Translation of system requirements to radiation requirements not always straightforward
  - Determining appropriate mitigation level (operational, system, circuit/software, device, material, etc.)

Unknown radiation risks are likely.

Structure of constraining data



Ray Ladbury, NSREC2017 SC, https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20170006865.pdf

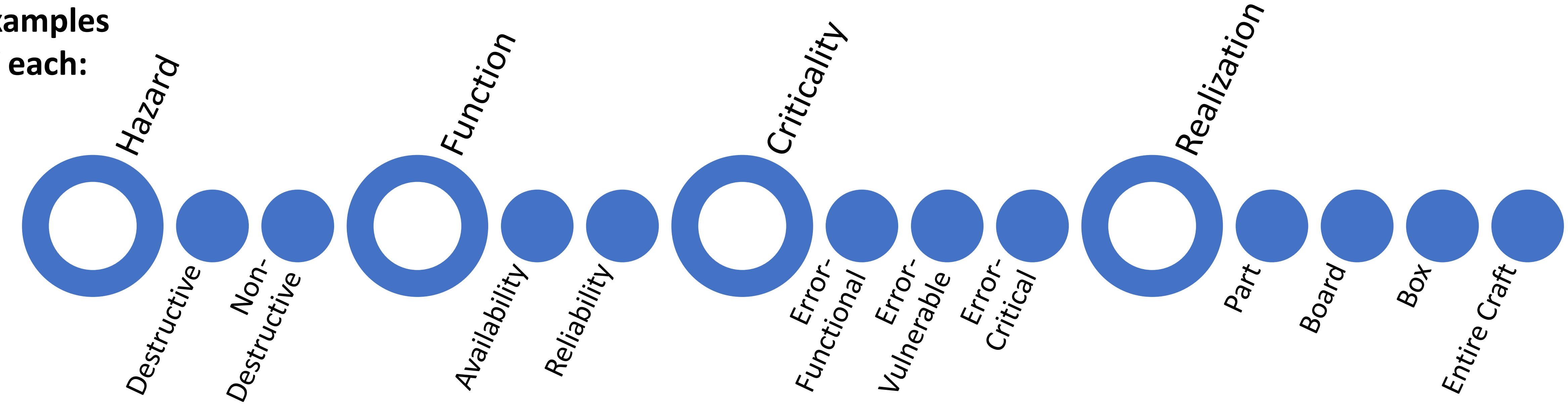
SEECA Definitions

- Single Event Effect Criticality Analysis – Documentation and identification of the disruptive error propagation within a system caused by single event effects. Equivalent to failure modes and effects criticality analysis with a focus on single events.
- Function – Electrical properties and capability goal across parts and subsystems.
  - Example: Science Data Downlink
    - Instrument -> Command and Data Handling -> Radios

SEECA Uses a Systems-Level Approach

- **Hazard** driven by environment conditions and device mechanisms
- **Function** is implemented or required of the system – informs criticality
- **Criticality** determines the disruptive impact of SEE signature to the function
- **Realization** determines architecture adaptations needed to meet functional need

Examples of each:



Adapted from SEE/MAPLD 2020: Guidance for Implementation of a SEECA

Functional Analysis

Error-Functional

- High number of SEE signature allowable
- Design may inherently be indifferent to SEE signature with mitigation in place or robust design practices
- Nuisance or manageable function impacts (e.g. filtered transients, error detection and correction on memories) beyond part responses
- No action needed

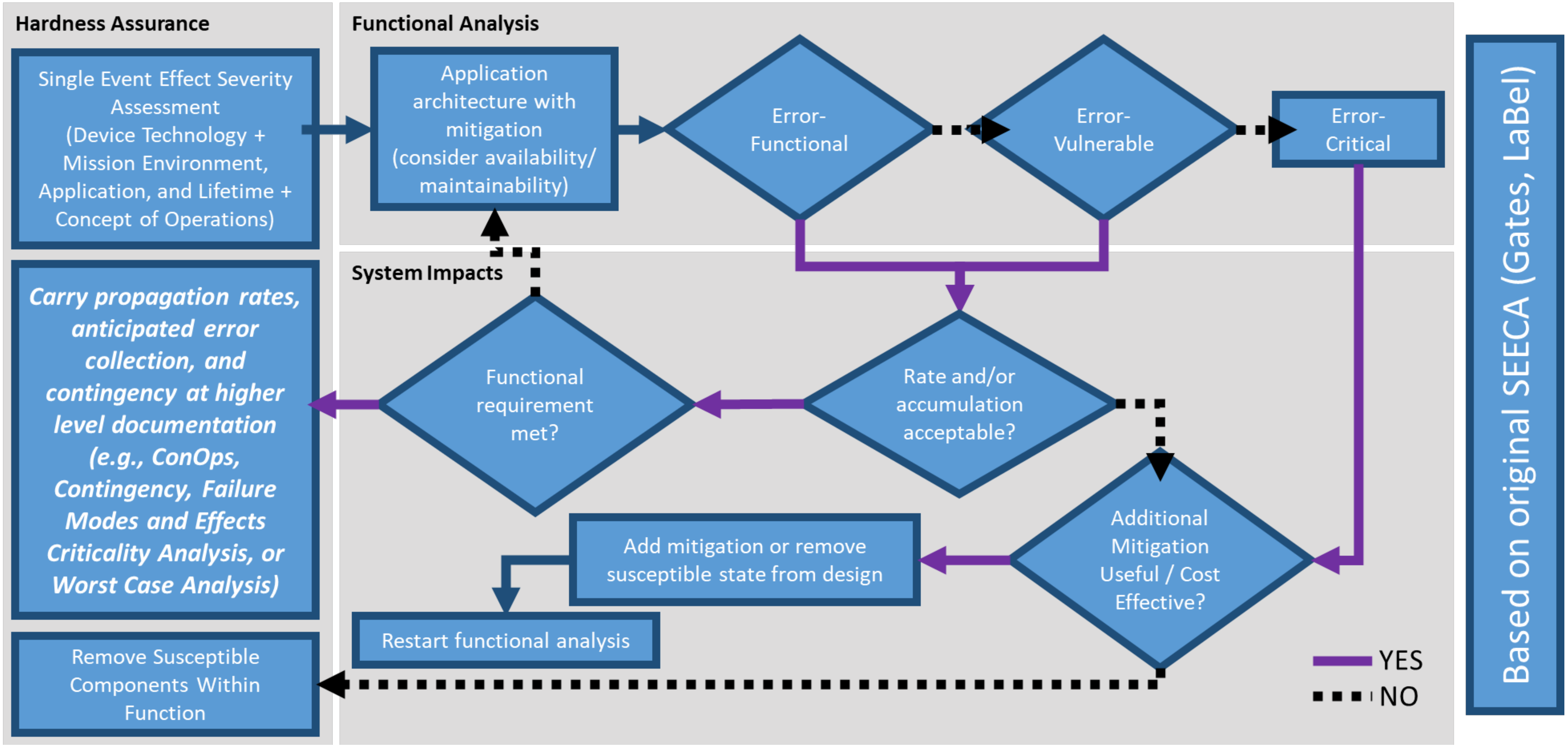
Error-Vulnerable

- Low number of SEE signature tolerable
- Design may require function for small window of availability or spend very little time in the susceptible state
- Mitigation needed in order to be reclassified as error-functional (e.g. SEFI of Flash, Multi-bit upsets)
- Ground or autonomous operations must be anticipated

Error-Critical

- SEE signature not allowable
- Disruption of function identified as single point of failure or design cannot continue to perform after SEE
- Mitigation needed in order to be reclassified as error-vulnerable (e.g. destructive SEL, many error accumulation, boot image corrupted due to error accumulation, SEFI that requires ground intervention or box level reset waiting on ground)
- Anomaly review needed or loss of mission

Decision tree for SEECA

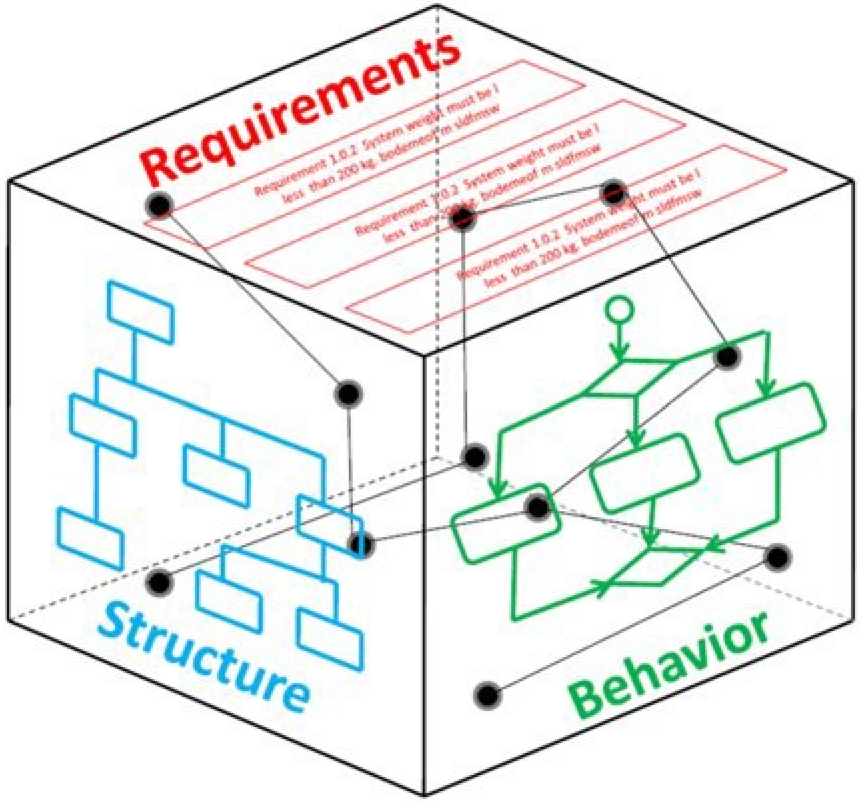


Future Directions: Digital Transformation

- The Department of Defense defines a model as "A physical, mathematical, or otherwise logical representation of a system, entity, phenomenon, or process".

  Modeling and Simulation Coordination Office, Ed., Modeling and Simulation (M&S) Glossary. 1901 N. Beauregard St., Suite 500 Alexandria, VA 22311: Department of Defense, Oct. 2011. https://www.msco.mil/MSReferences/Glossary/TermsDefinitionsI-M.aspx

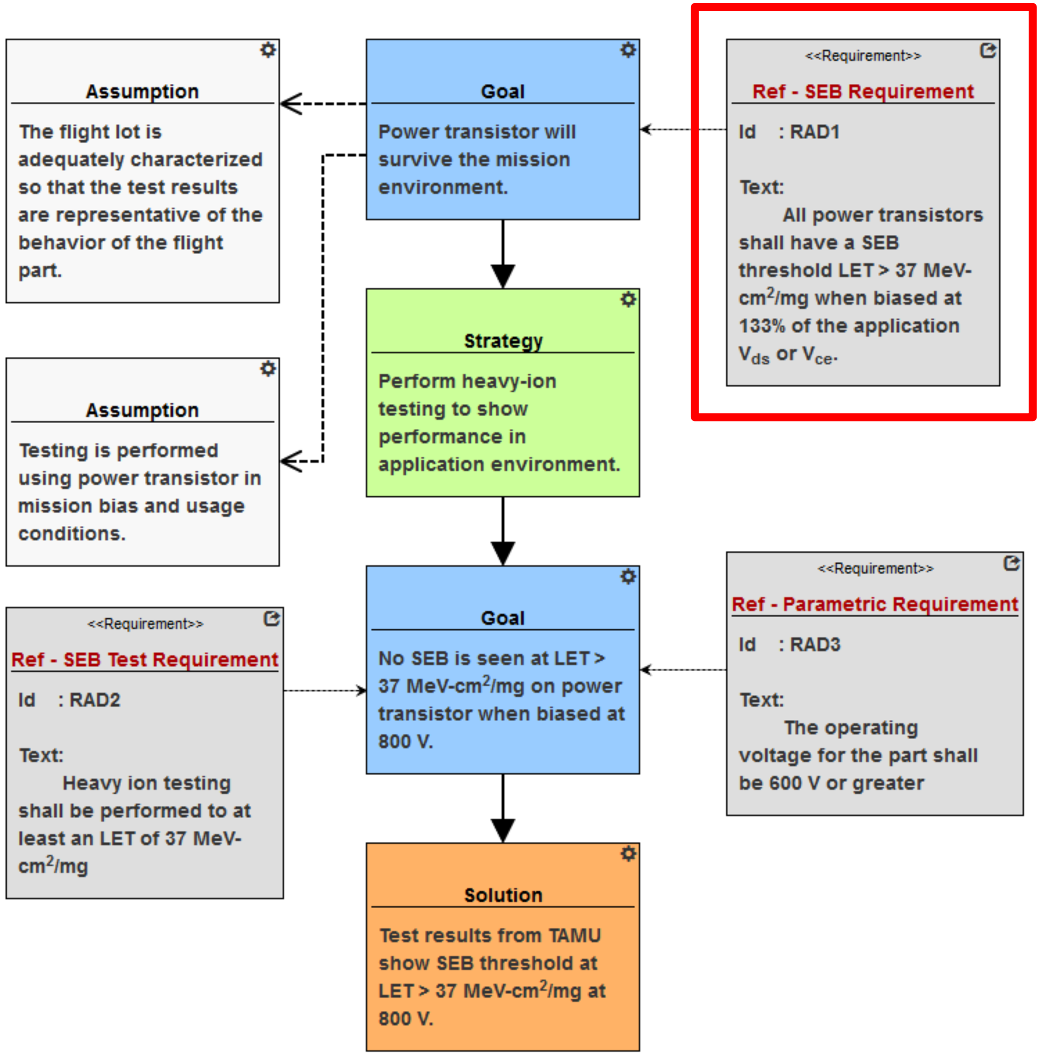
- We are used to working with mathematical representations of systems, entities, phenomenon, or processes
- Model-Based Mission Assurance (MBMA) is adding logical representations of our systems and processes to enhance and improve Radiation Hardness Assurance (RHA)



M. Bajaj, B. Cole, and D. Zwemer, "Architecture to geometry - integrating system models with mechanical design," in *Proc. AIAA SPACE*, 2016. The U.S. Government has a royalty-free license to exercise all rights for Governmental purposes.

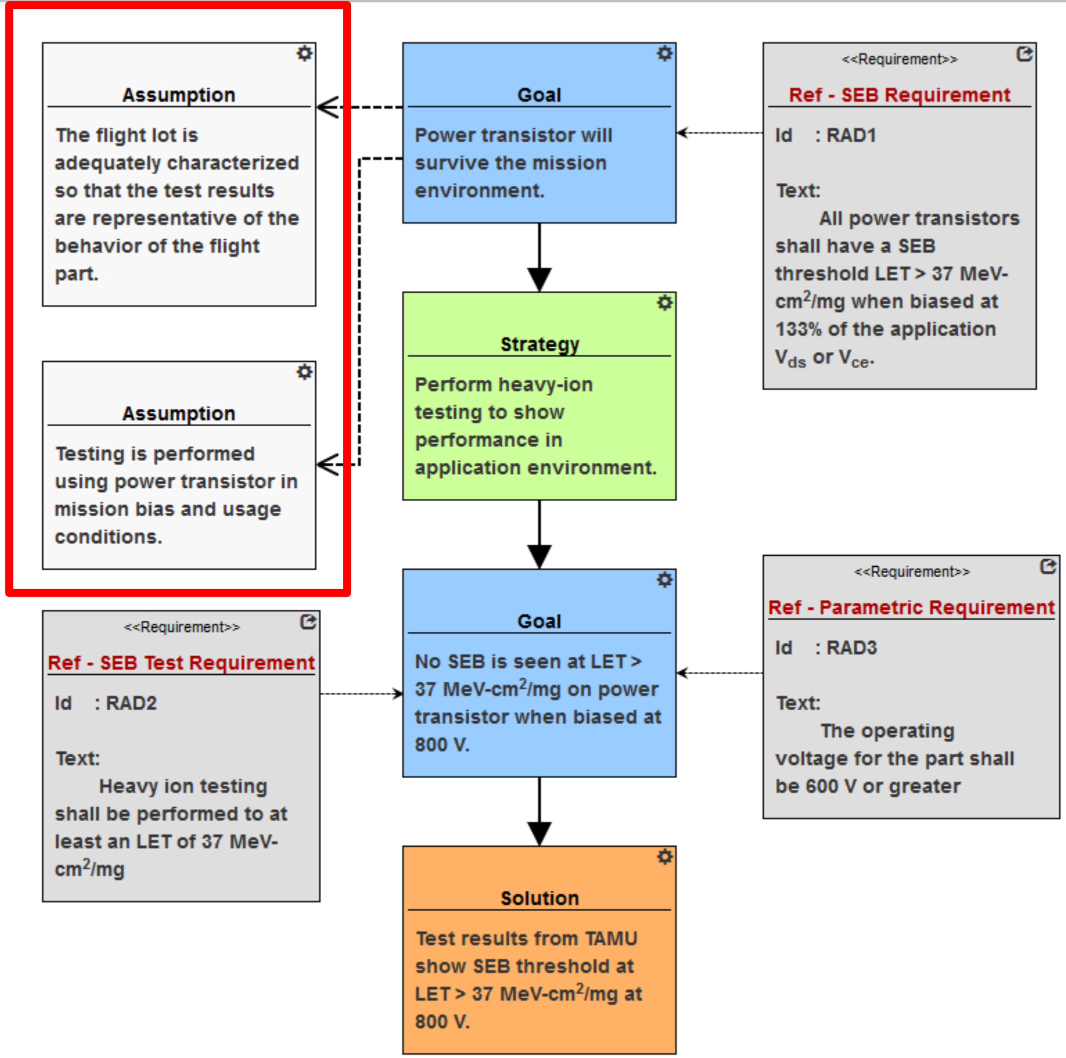
Digital Transformation Examples

- Verify Requirements with SEE Test Data
  - Standard requirement verified through heavy-ion testing



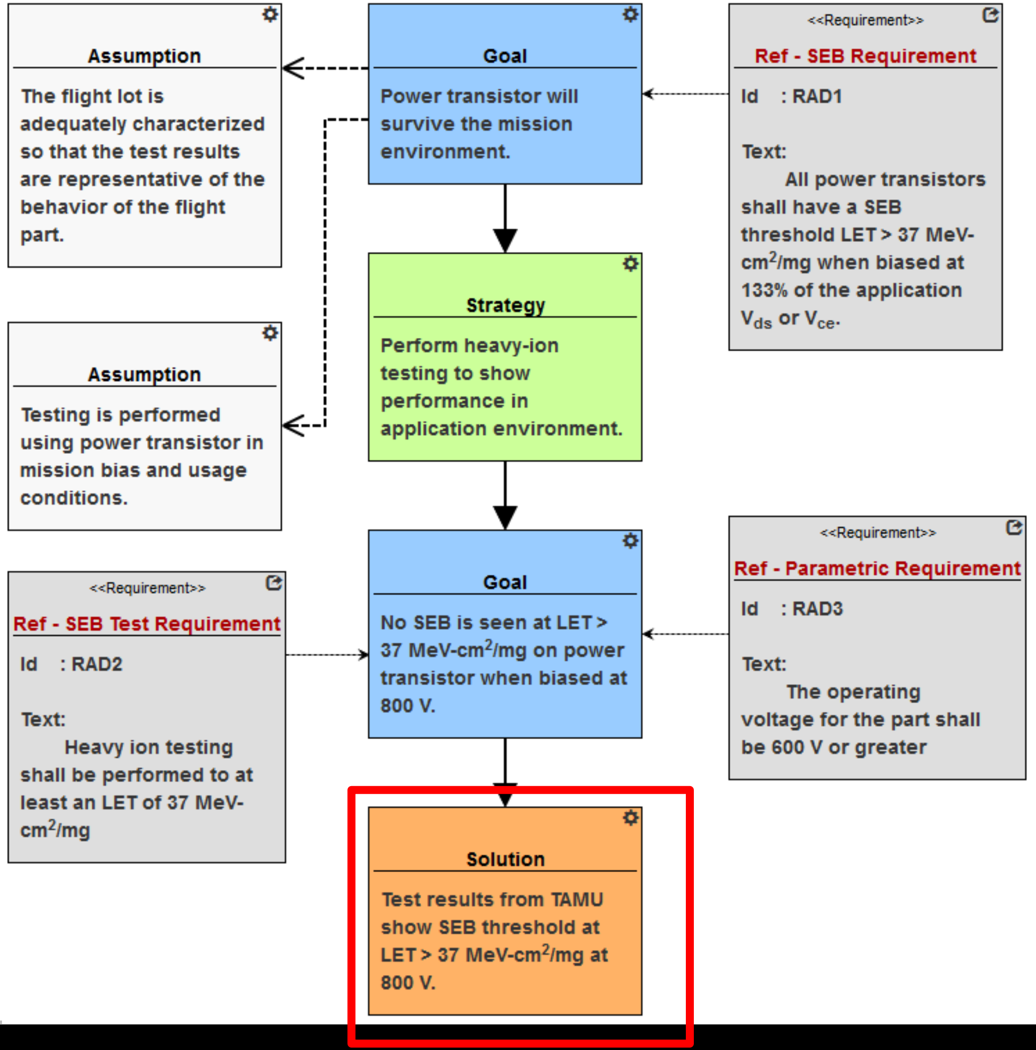
Digital Transformation Examples

- Verify Requirements with SEE Test Data
  - Standard requirement verified through heavy-ion testing
  - Assumptions explicitly stated



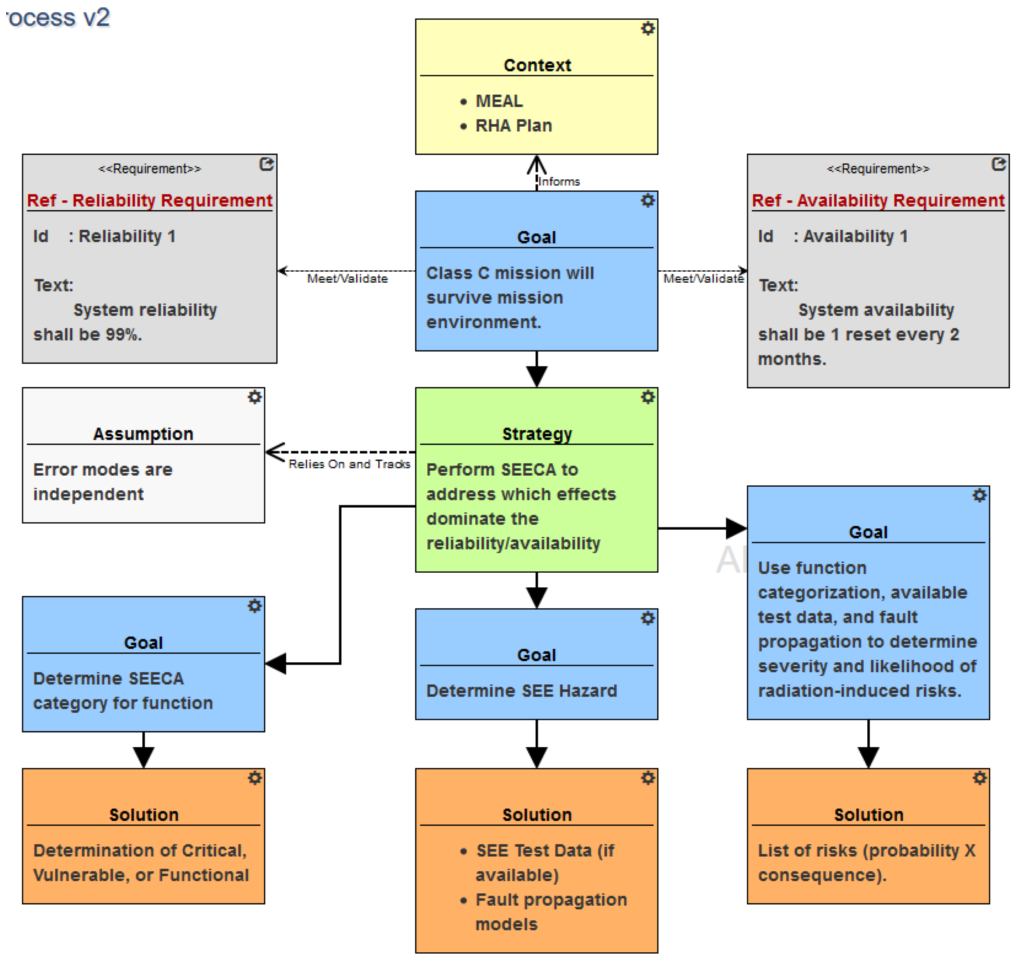
Digital Transformation Examples

- Verify Requirements with SEE Test Data
  - Standard requirement verified through heavy-ion testing
  - Assumptions explicitly stated
  - Verification of requirement is backed by the graphical argument AND the test data



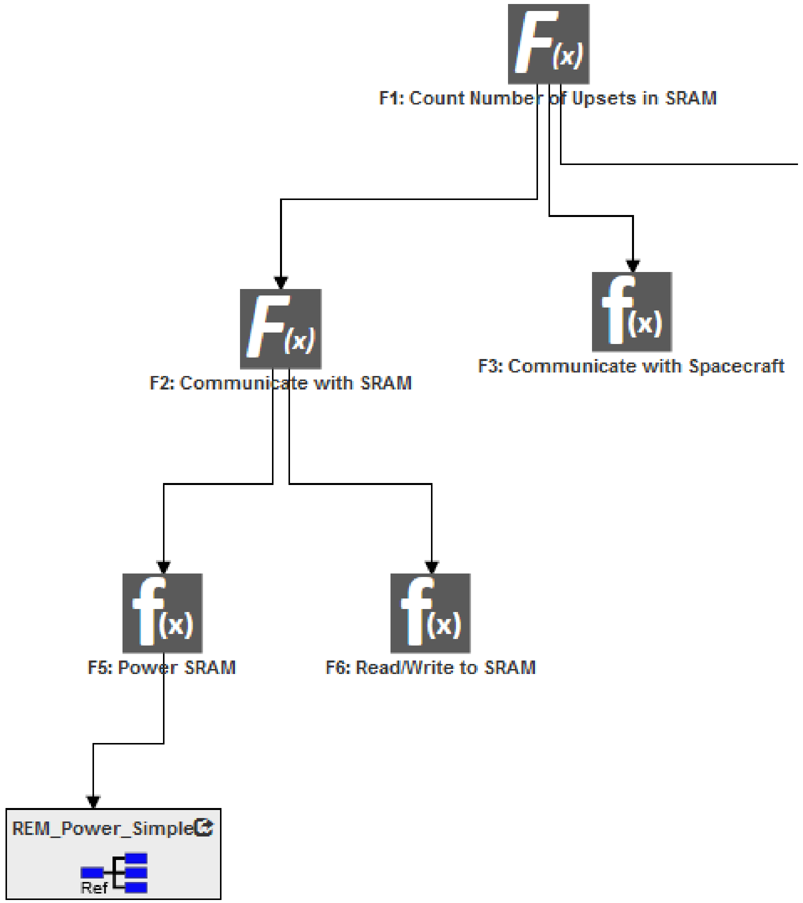
Digital Transformation Examples

- Prioritization of SEE Testing for Maximum Risk Reduction
  - The SEECA process can be documented and supplemented using MBMA
  - Graphical argument links together steps and logic



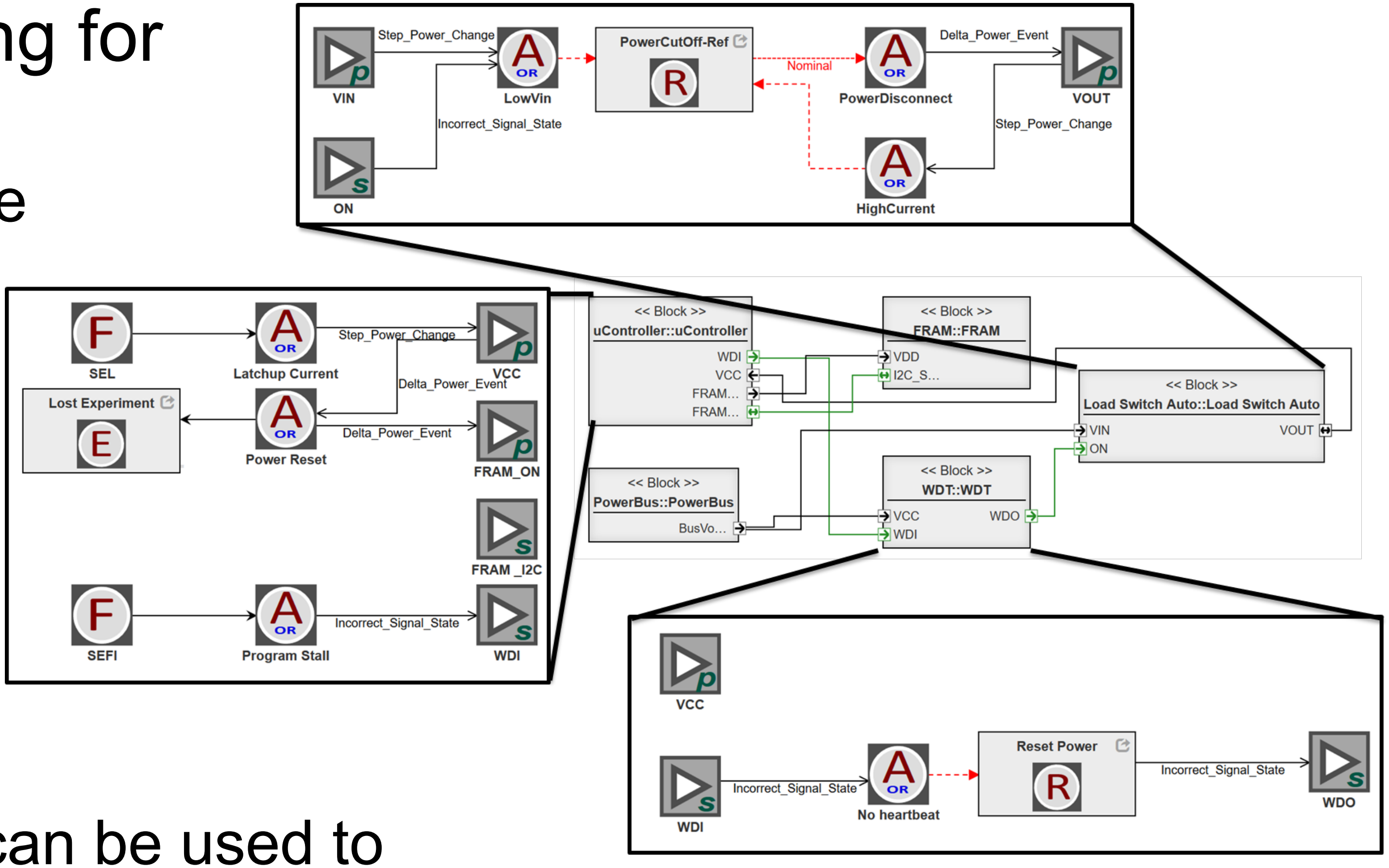
Digital Transformation Examples

- Prioritization of SEE Testing for Maximum Risk Reduction
  - The SEECA process can be documented and supplemented using MBMA
  - Graphical argument links together steps and logic
  - Functional decomposition can be used to determine SEECA categories



Digital Transformation Examples

- Prioritization of SEE Testing for Maximum Risk Reduction
  - The SEECA process can be documented and supplemented using MBMA
  - Graphical argument links together steps and logic
  - Functional decomposition can be used to determine SEECA categories
  - Fault propagation models can be used to determine consequence of SEE hazard



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Questions

- Thank you for your time
- Special thanks to the REAG group at GSFC for slides, graphics, and support

Acronyms and Abbreviations

- ConOps: Concept of Operations
- COTS: Commercial Off The Shelf
- Hi-Rel: High Reliability
- LASCO: Large Angle and Spectrometric COronagraph
- LET: Linear Energy Transfer
- MBMA: Model-Based Mission Assurance
- Mil/Aero: Military Aerospace
- MOSFET: Metal-on-Silicon Field Effect Transistor
- RHA: Radiation Hardness Assurance
- SEB: Single-Event Burnout
- SEE: Single Event Effects
- SEECA: Single Event Effects Criticality Assessment
- SEFI: Single-Event Functional Interrupt
- SEGR: Single-Event Gate Rupture
- SEL: Single-Event Latch-up
- SET: Single-Event Transient
- SEU: Single-Event Upset
- SOHO: Solar and Hemispheric Observatory
- SPE: Solar Particle Event
- SRAM: Static Random Access Memory
- TAMU: Texas A&M University