

Requirements & Goals for Heavy Ion Testing

Module 5: Requirements & Goals

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Background: Physics->EE->Radiation Effects

Acronyms

ConOps	Concept of Operations
DSEE	Destructive Single Event Effects
LET	Linear Energy Transfer
NDSEE	Non Destructive Single Event Effects
RHA	Radiation Hardness Assurance
RHBD	Rad-Hard by Design
RHBP	Rad-Hard by Process
TSOP	Thin Small Outline Package
SEE	Single Event Effects
SEECA	Single Event Effects Criticality Analysis
SEFI	Single Event Functional Interrupt
SEL	Single Event Latchup
SET	Single Event Transient
SoC	System On a Chip
SysE	Systems Engineering
QML	Qualified Manufacturer List

Outline

- Background information
 - Motivations for SEE testing and categories
 - Testing as a part of RHA
 - Environments / Why LET requirements? Why fluence?
- Spaceflight end users example
 - Mission timeline impact on testing
 - Project goals impact the type of testing
 - Stakeholders
- Testing goals and strategies
 - Objectives and outcomes
 - Consequence vs. criticality
 - 3 Case Studies
- Notional test requirements
 - 3 Case Studies
 - Requirements Matrix

Motivations for SEE Testing

Manufacturers

- Qualification
- Characterization
- RHBP/RHBD
- Rad-tolerant
- Roadmaps

End Users

- Spaceflight Design
- Accelerator Facilities
- Man-made environments

Research/Academia

- RHBD/RHBP improvements
- Dosimetry
- Future technologies/mitigations

- Different environments will drive testing focus
- The different goals will tailor test planning
- All will have different sampling strategies

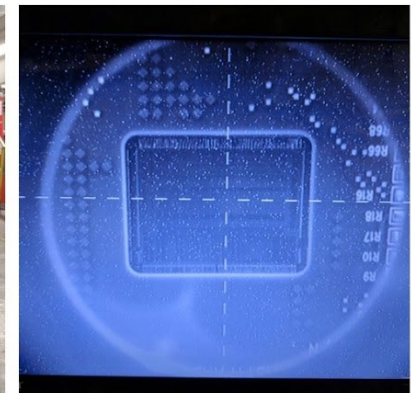
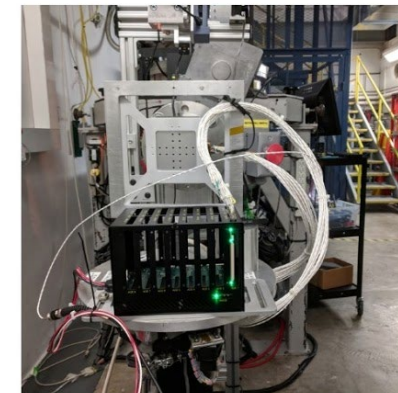
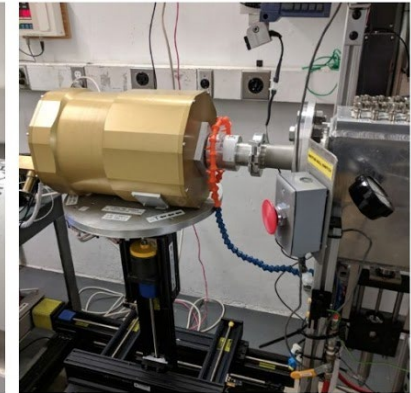
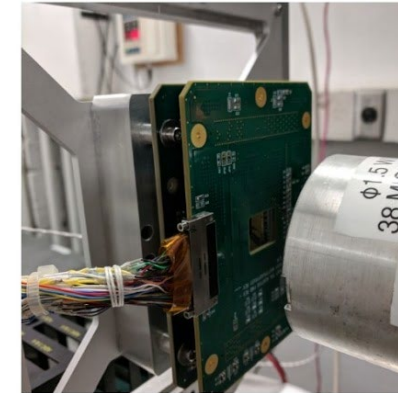
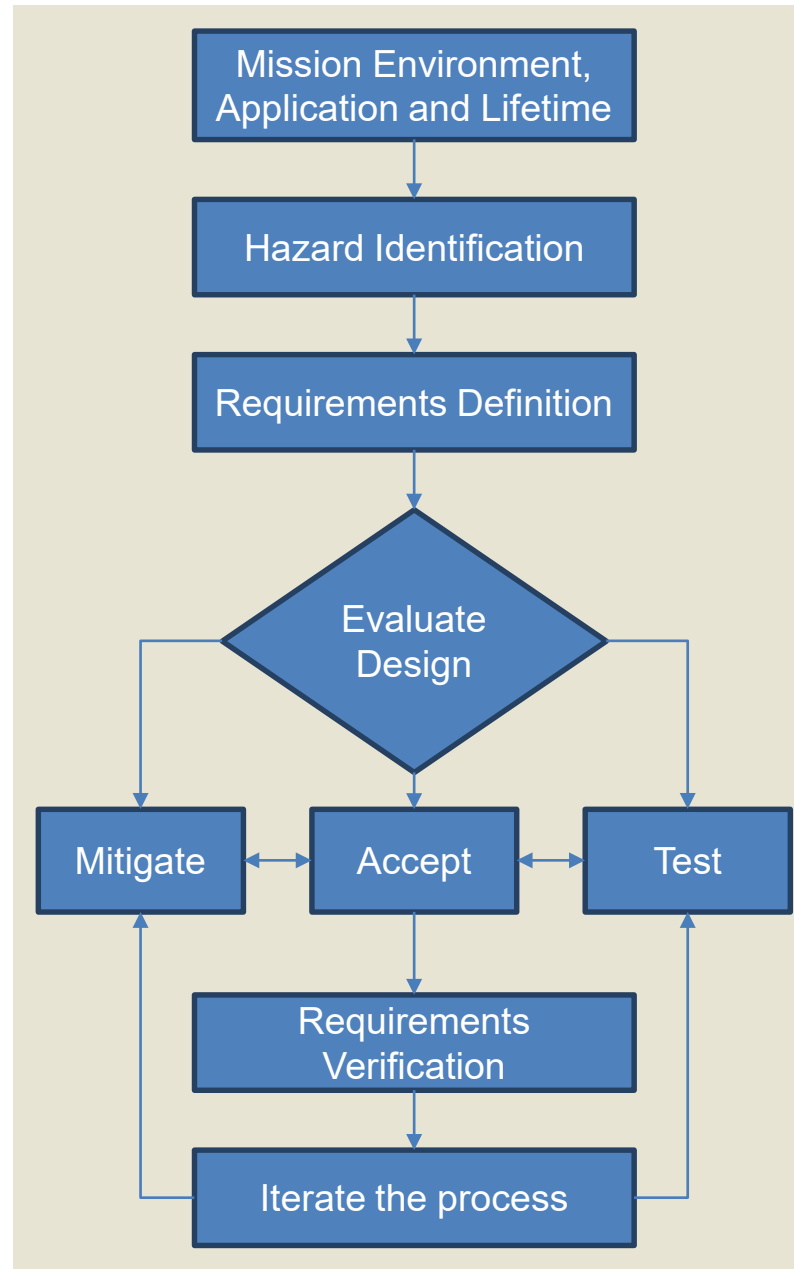
Test Categorization

Go/No-go	“Screening”	Characterization	Qualification
• SEE Signatures • Worst-case application	• DSEE • Availability • Worst-case application	• Application specific • Corner cases • Worst-case test condition identification	• Repeated testing • Standards enforce requirements

- No one is “quicker” or cheaper than the other necessarily
- No one is less complex in terms of test setup, that is mostly device driven
- All will have different sampling strategies

Testing and RHA

- RHA is an iterative process
 - Simplified view ->
- Testing plays a crucial role
 - Hazard identification
 - Requirements
 - Screening
 - Mitigation strategy
 - Technology insertion
 - Verification
- Impact
 - Not always obvious
 - Informs future decisions
- Results
 - Device/Design changes
 - Mitigation acceptance
- Following the process
 - Can tell you when more testing is necessary
 - Can inform what type of test is most relevant



Requirements information gathering

Before Testing:

- Environment Description
 - Sources/Destination
 - Spectra
- Radiation Hardness Assurance Plan
- Concept of Operations
 - Reliability/Availability
- Application information
 - Know your parts!
 - Design information / Parts list
 - Worst Case Analysis

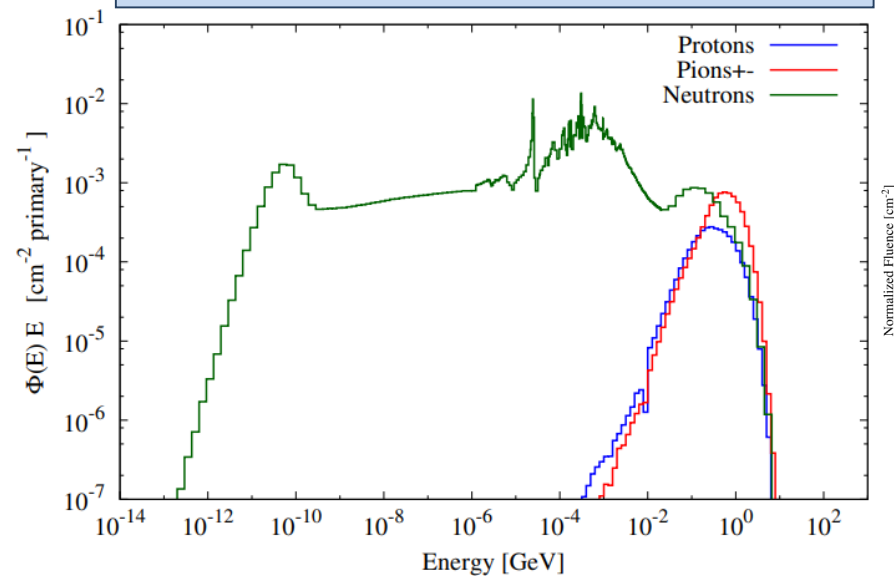
Test may provide:

- Categorization
 - Criticality vs. Consequence vs. Likelihood
 - Functional Analysis
- Realization
 - Rates of NDSEE where applicable
 - Likelihood of DSEE where applicable
- System-level risks
 - Threats to success
 - Recovery/Maintenance
- Insight on susceptibilities/RHBD/RHBP

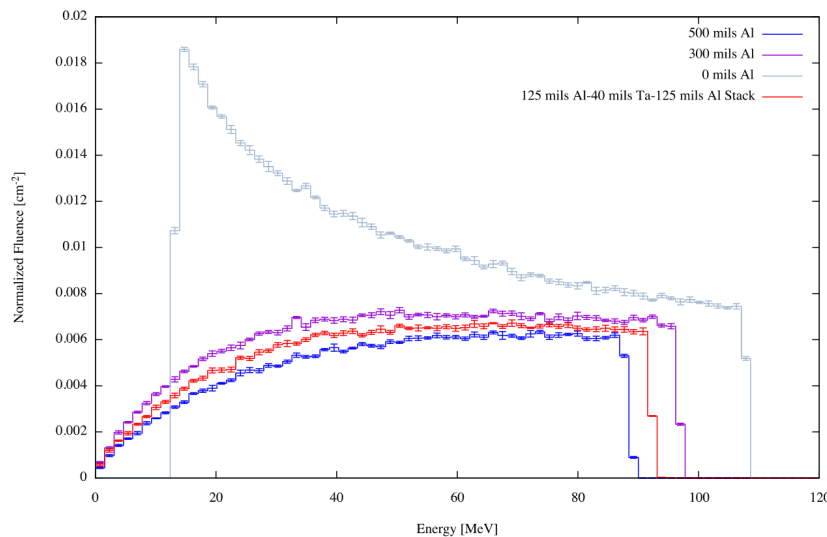
End user SEE concerns should be addressed with environment in mind

Different environments may need to be translated through materials before they are incident on your device

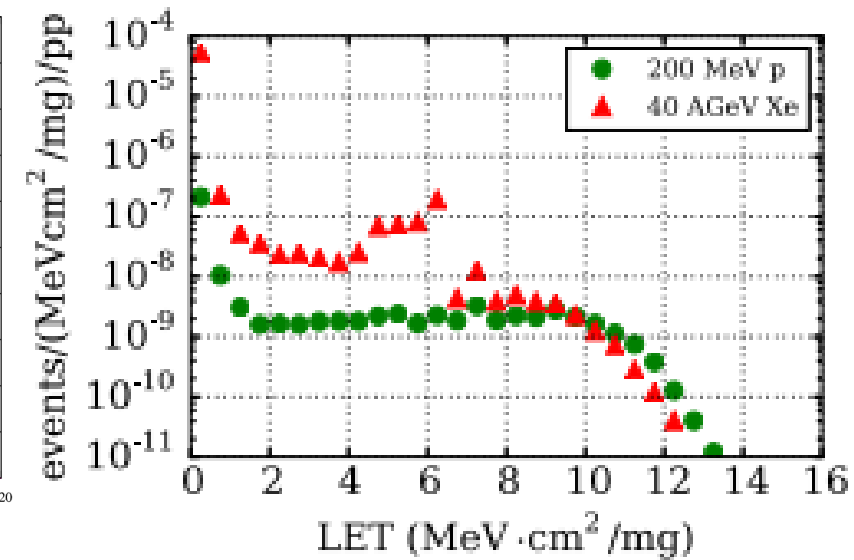
Mixed Field



Emerging Protons



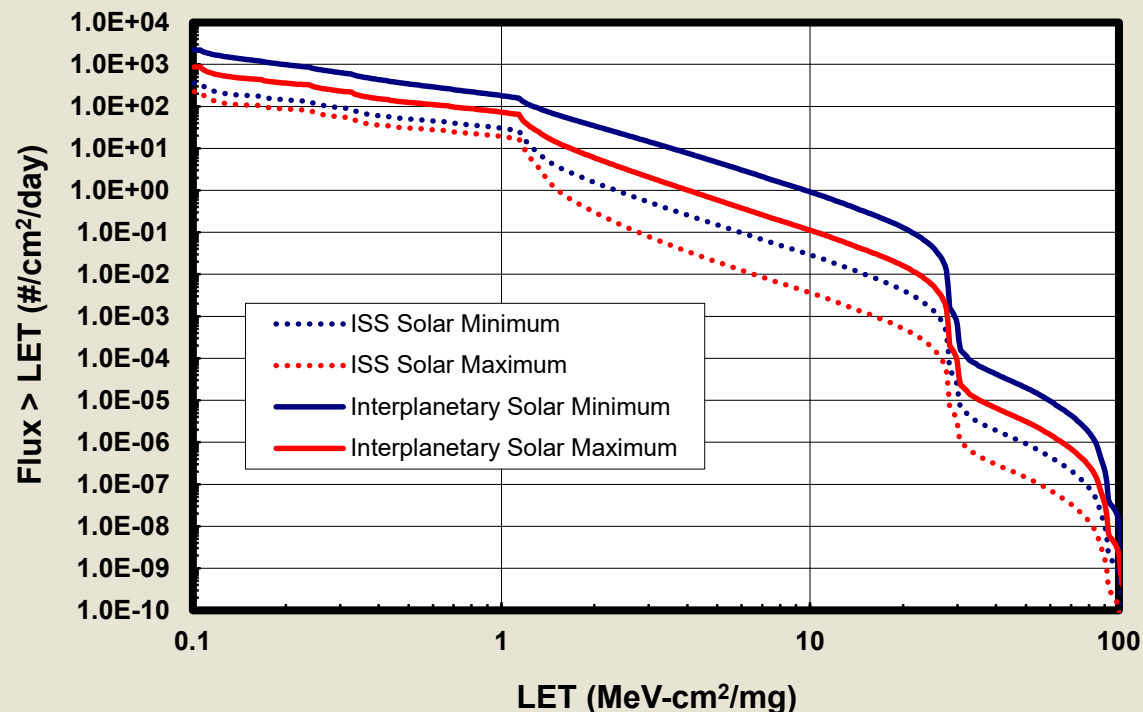
Transported LET



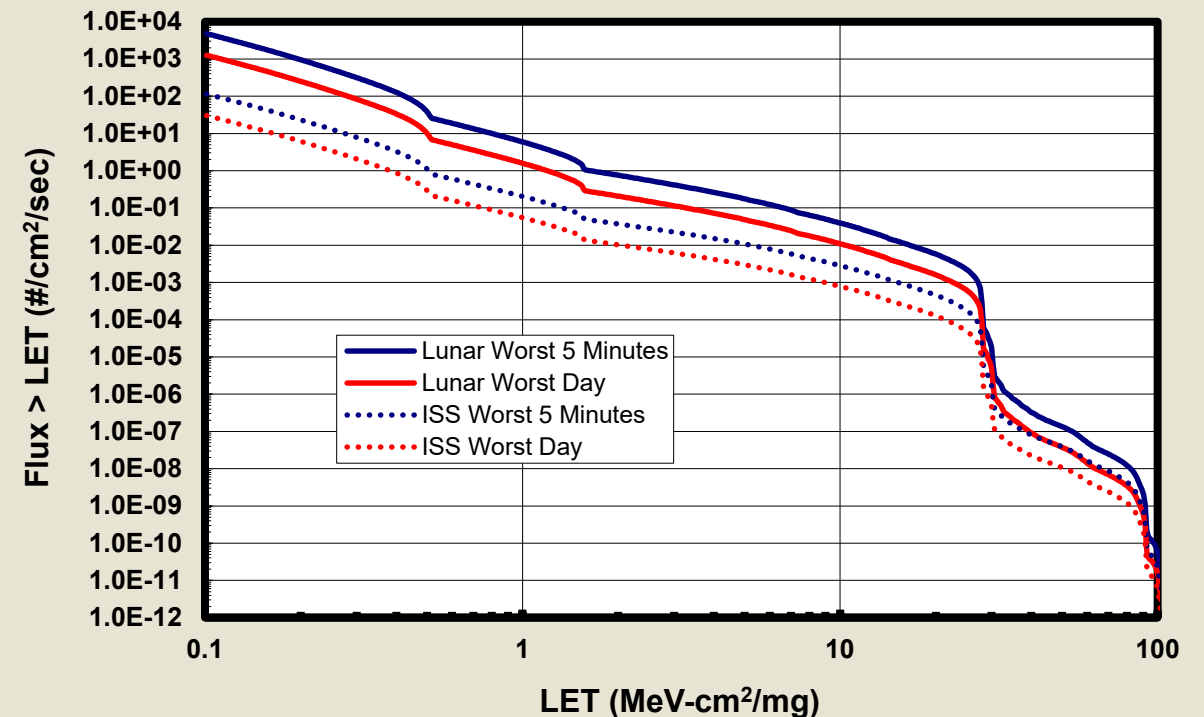
End user SEE concerns should be addressed with environment in mind

As you go to farther distances from the Earth, Galactic Cosmic Rays (GCR) and Solar Particle Event (SPE) no longer benefit from Geomagnetic field attenuation [1-2 orders of magnitude]

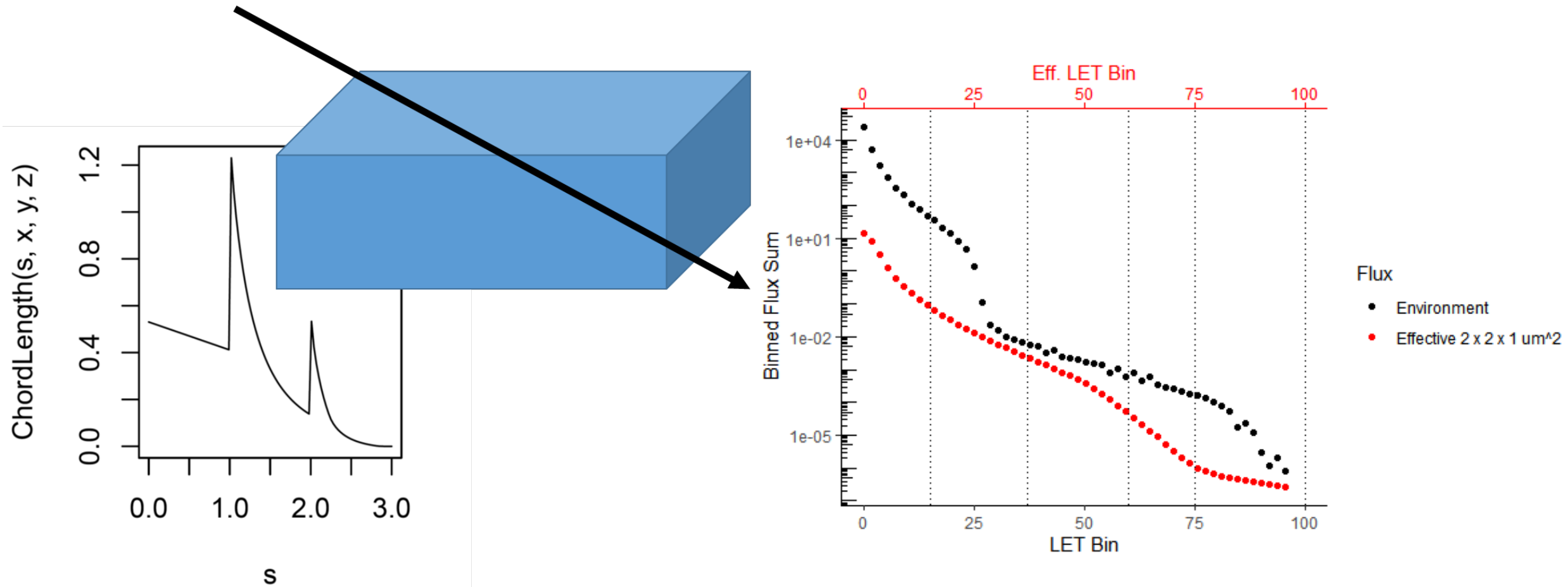
Galactic Cosmic Ray LET Spectra



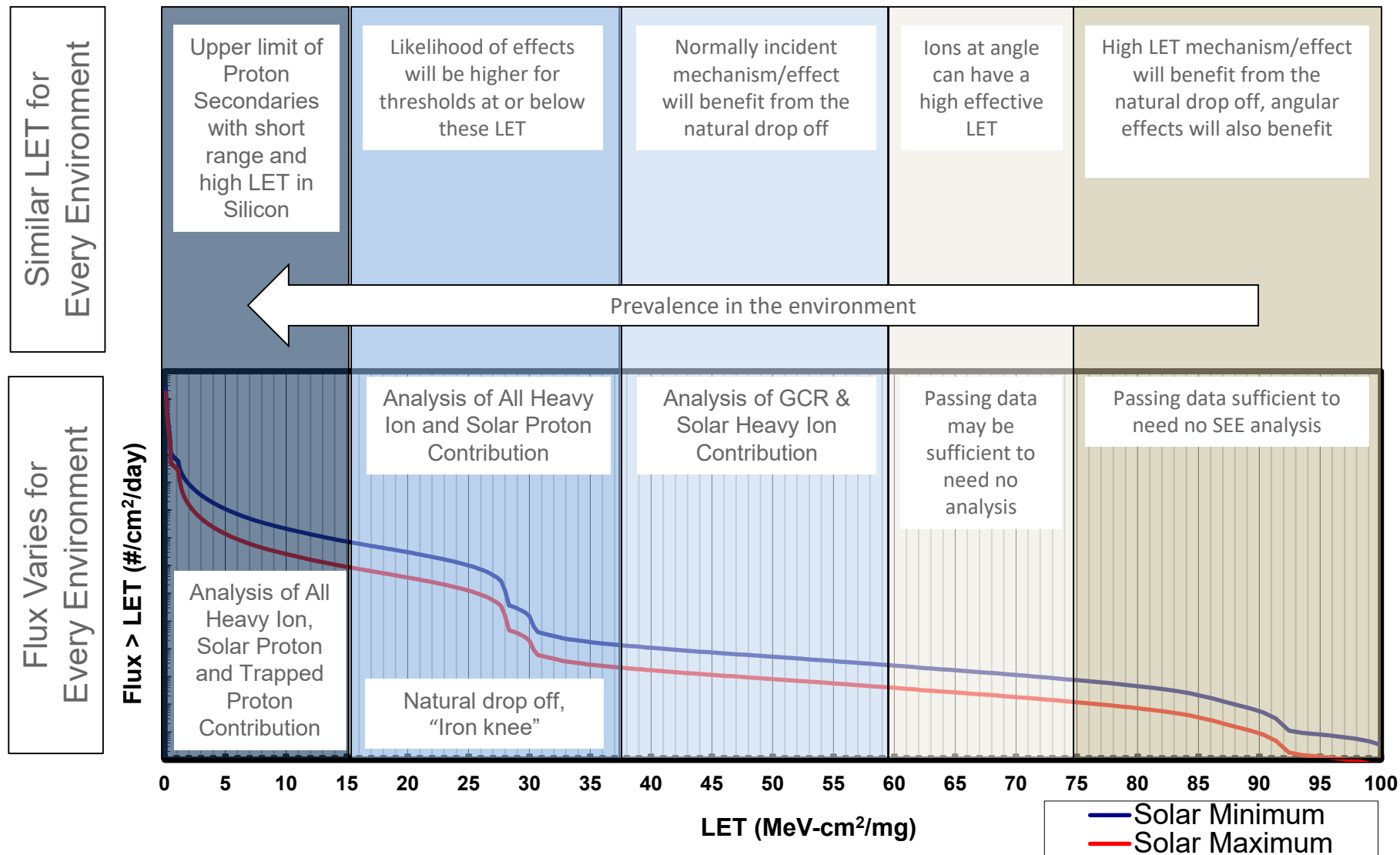
Worst Case Solar Particle Event Spectra



A note on the omni-directional environment and devices



Single Event Effects and LET Threshold



Why Linear Energy Transfer (LET) requirements?

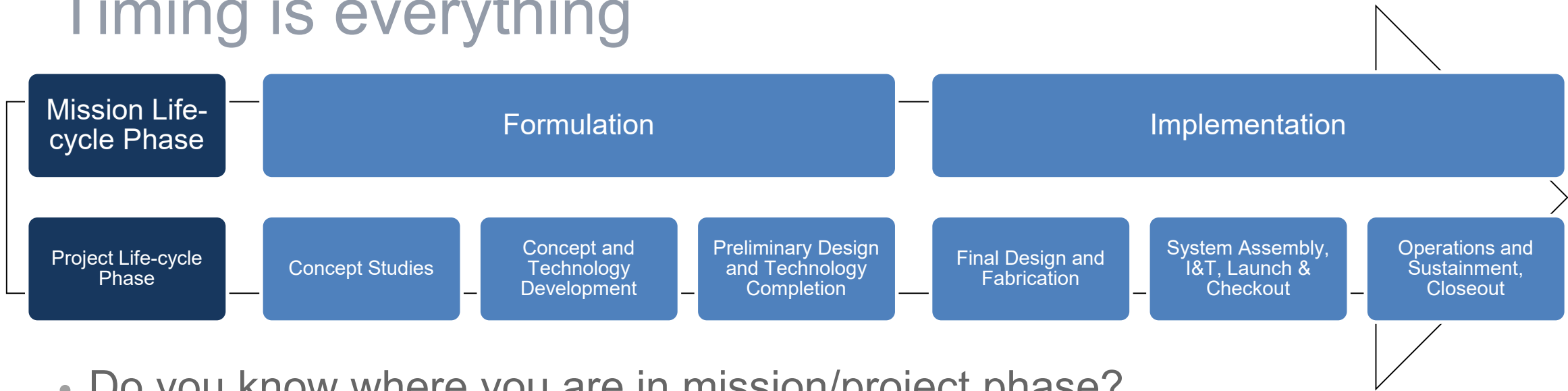
- Can require a threshold LET
 - High LET can be used to assert that events are rare
 - Can help determine test type or facility needs
- Enables ground-based testing of all environment contributors

Why Fluence requirements?

- Not specifically trying to test to what amount you see in application
 - *Coverage!*
 - Can be driven by test type or dictate facility needs
- Enables statistical interpretations of results, signature counts

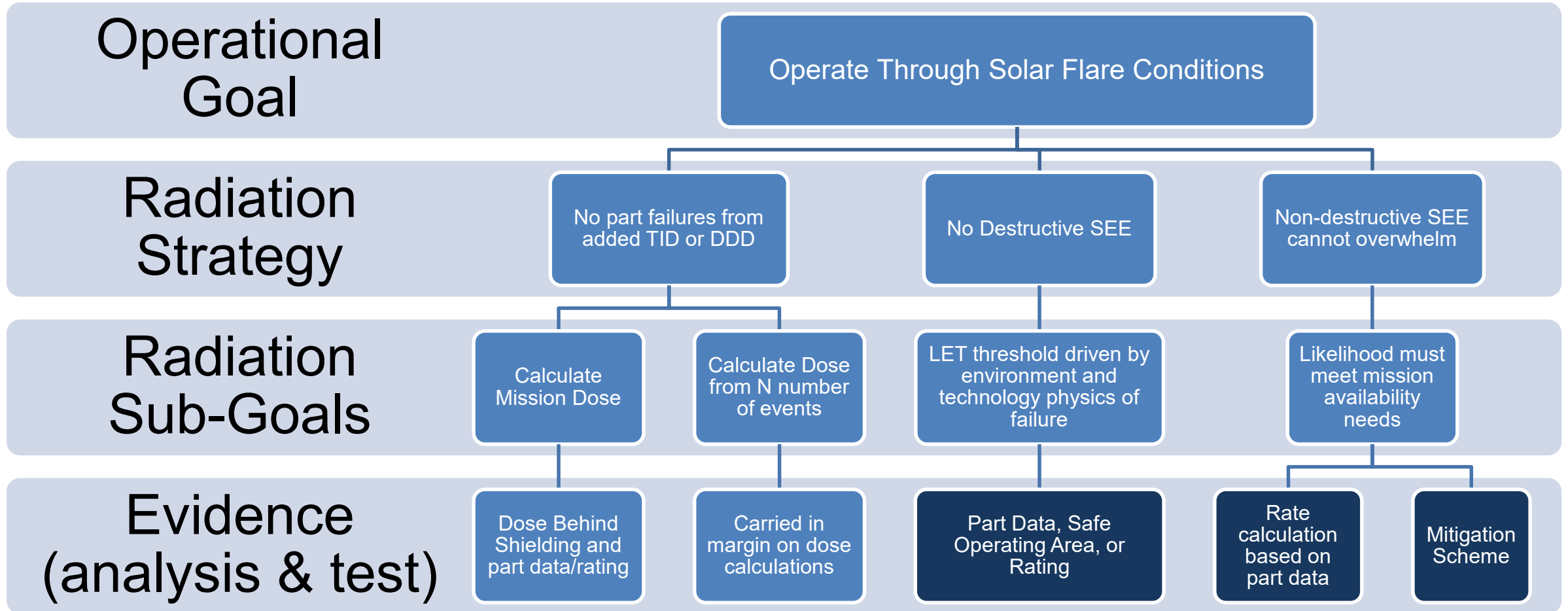
Space Flight Projects as an end user example

Timing is everything



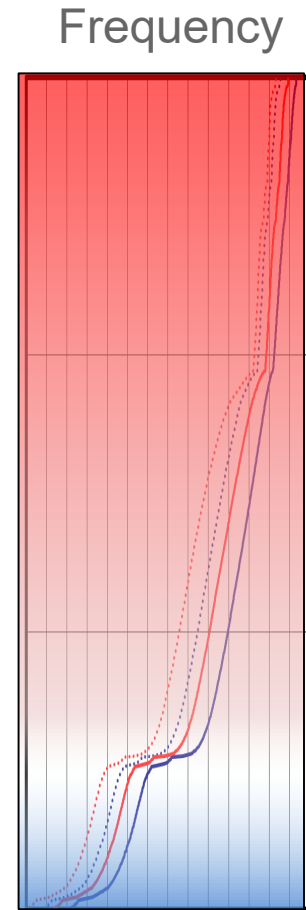
- Do you know where you are in mission/project phase?
 - Mitigation changes or replacement may not be an option if too late
 - Anomaly resolution testing will look a lot different than screening for SEE signatures
 - Determines your test needs for risk acceptance vs. risk avoidance
- New technologies?
 - Necessitate early life-cycle testing
 - Limited funding: corner cases, limited characterization

Goals and strategies need evidence

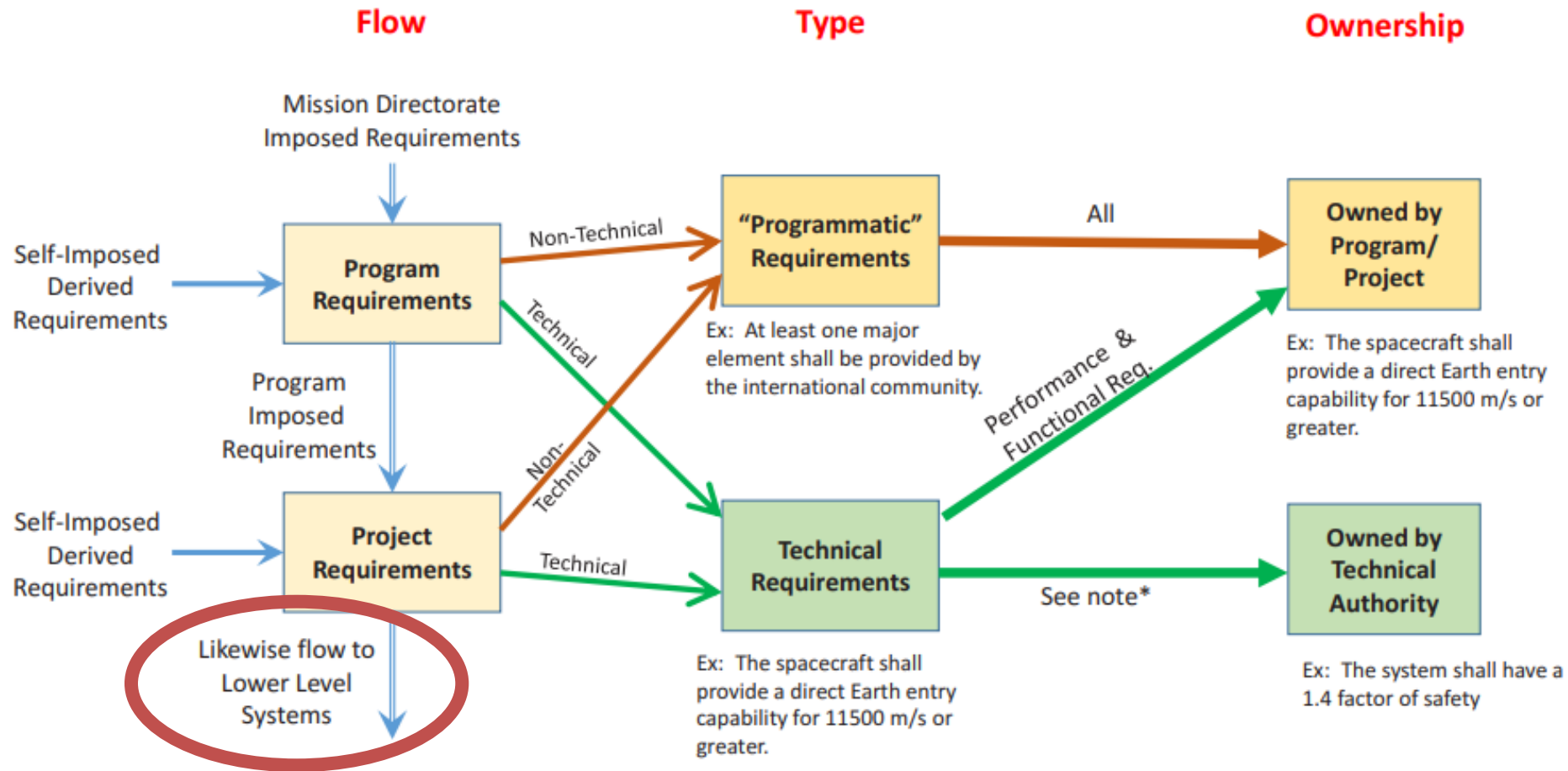


Project Supplied Radiation Requirements

- “You tell me”
- “Future Heritage”
- “I’d like it to work in space”
- “It’s flown already on mission X”
- Specific orbit and mission dates
- Environment predictions and application
- Radiation requirements you can plan a test to



Requirements ownership from NASA SysE handbook



* Requirements invoked by OCE, OSMA and OCHMO directives, technical standards and Center institutional requirements

Test goals: what are you trying to ascertain?

Test validation requirements

- Number of samples
- Device information
 - Process, lot, manufacturer, etc.
 - # of repeated structures on die
- Die coverage
- Application information
- Temperature

Data capture requirements

- Keep an independent run log
- Facility provided information
 - Fluences, Flux, Energy, Ion Species, Dosimetry
- LET, range, angle (sometimes)
 - Calculated or provided
- Take Pictures!
- Method of counting signatures independently
- What are the signatures: length of transients, current draw, # of upsets, etc.?
- What does it take to recover from the fault?

Heavy Ion Test Goals

- *Functional Analysis*

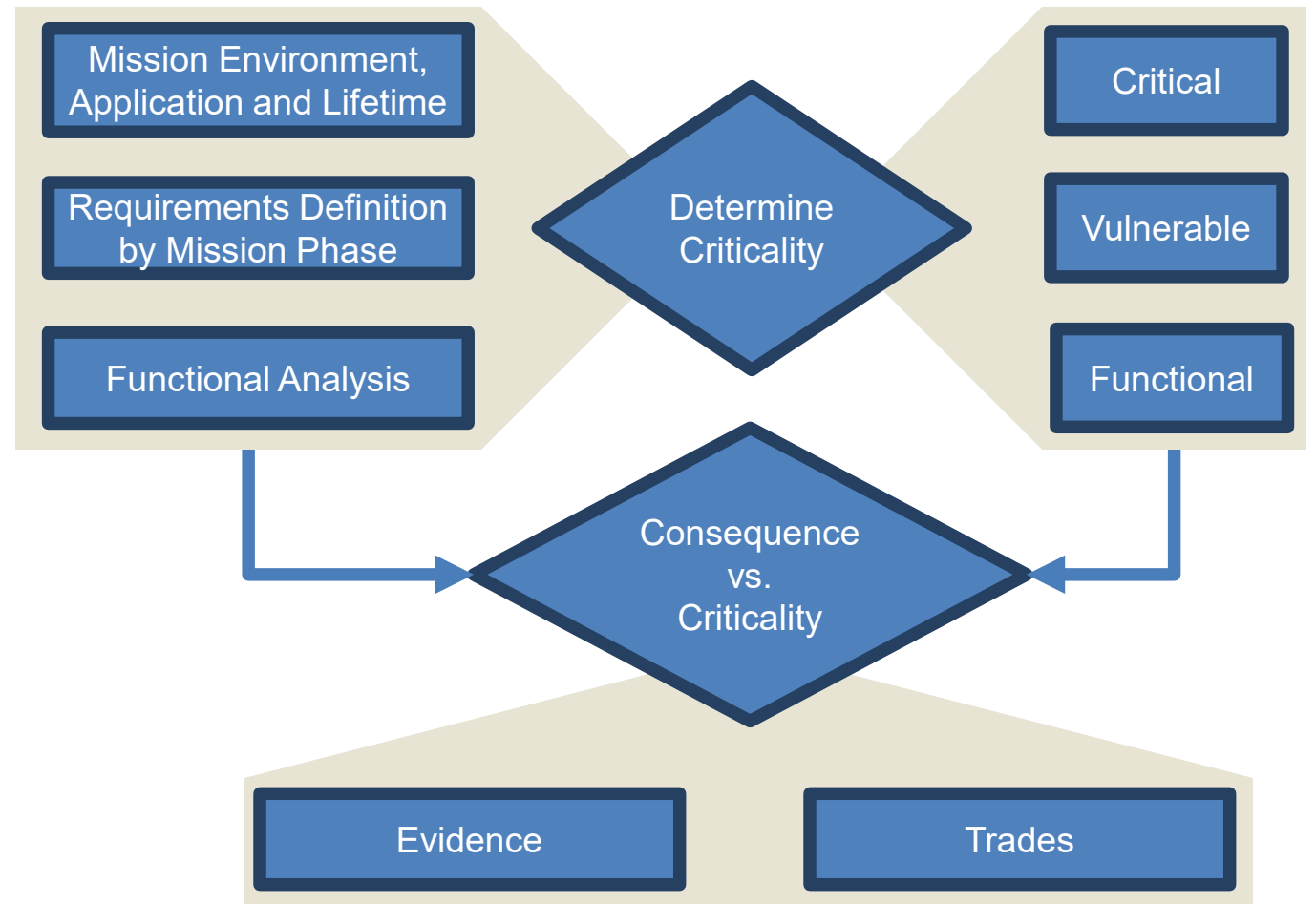
- Identify critical functions
- Determine subsystems and components/structures across function

- *Determine Criticality*

- Critical
- Vulnerable
- Functional

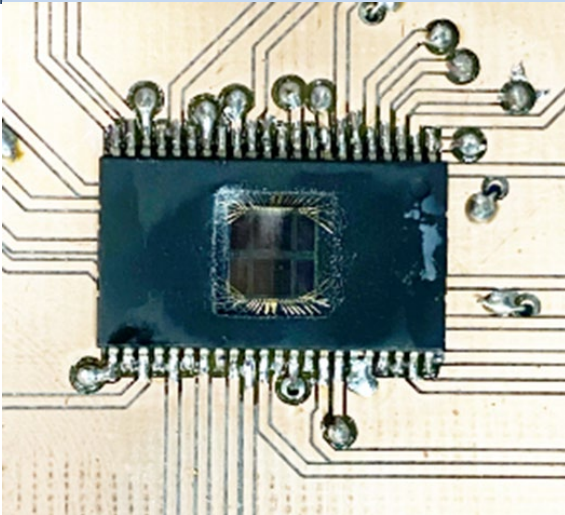
- *Evidence & Trades*

- Test data
- Mitigation or Maintenance



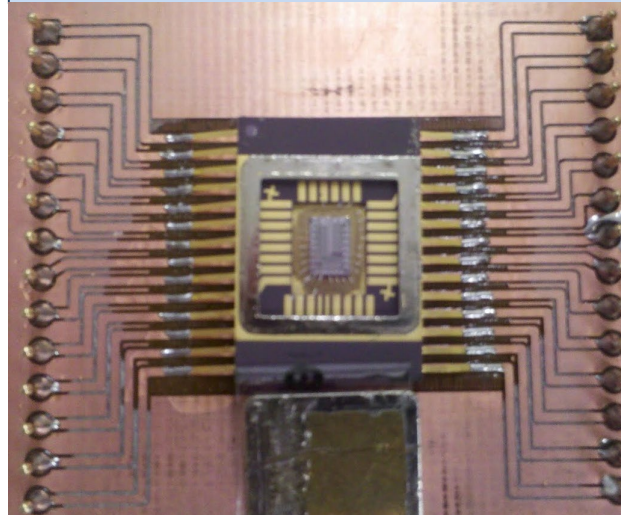
Case Studies: Three Devices

TSOP SRAM



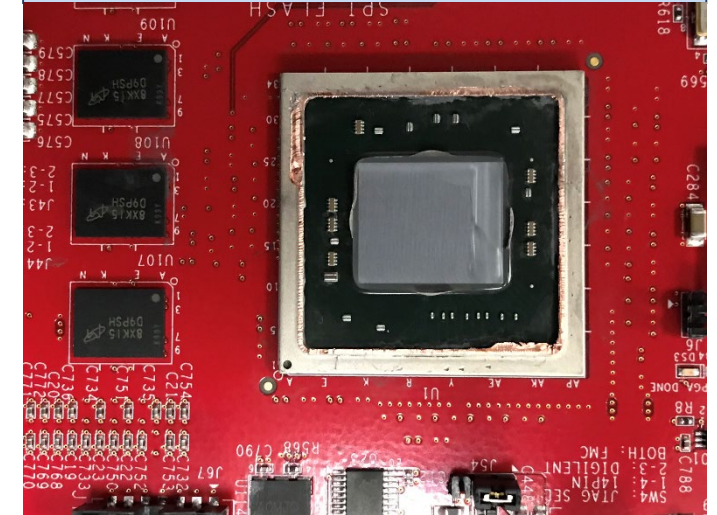
- Understood that there will be SEU/SBU
- Want to “screen” for SEL

QML Amplifier



- Already guaranteed to not have DSEE
- Want to characterize SET

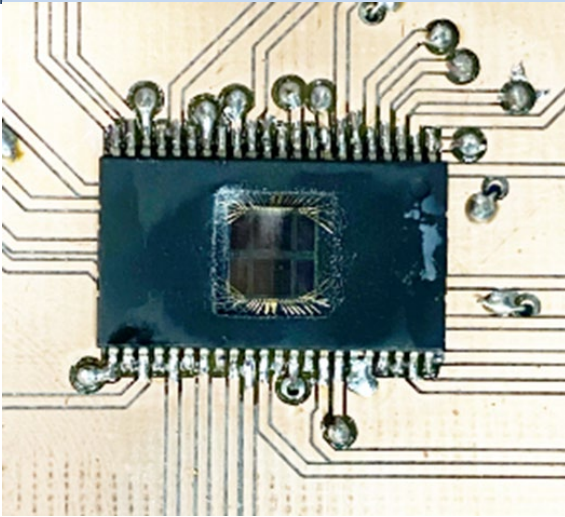
COTS SoC



- Very little known on radiation response
- Want to characterize as many signatures as possible

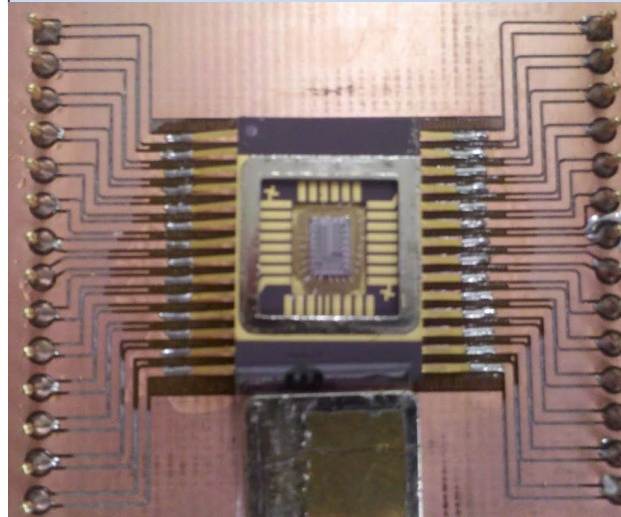
Case Studies: Goals

TSOP SRAM



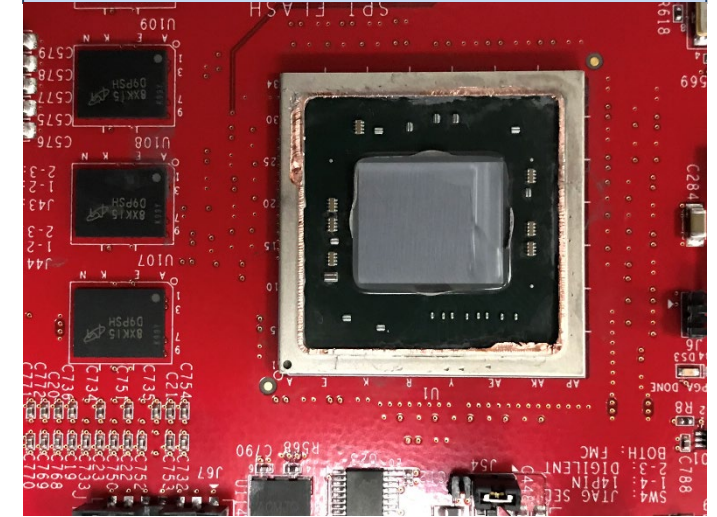
- Confirm SEU
- Determine SEL threshold

QML Amplifier



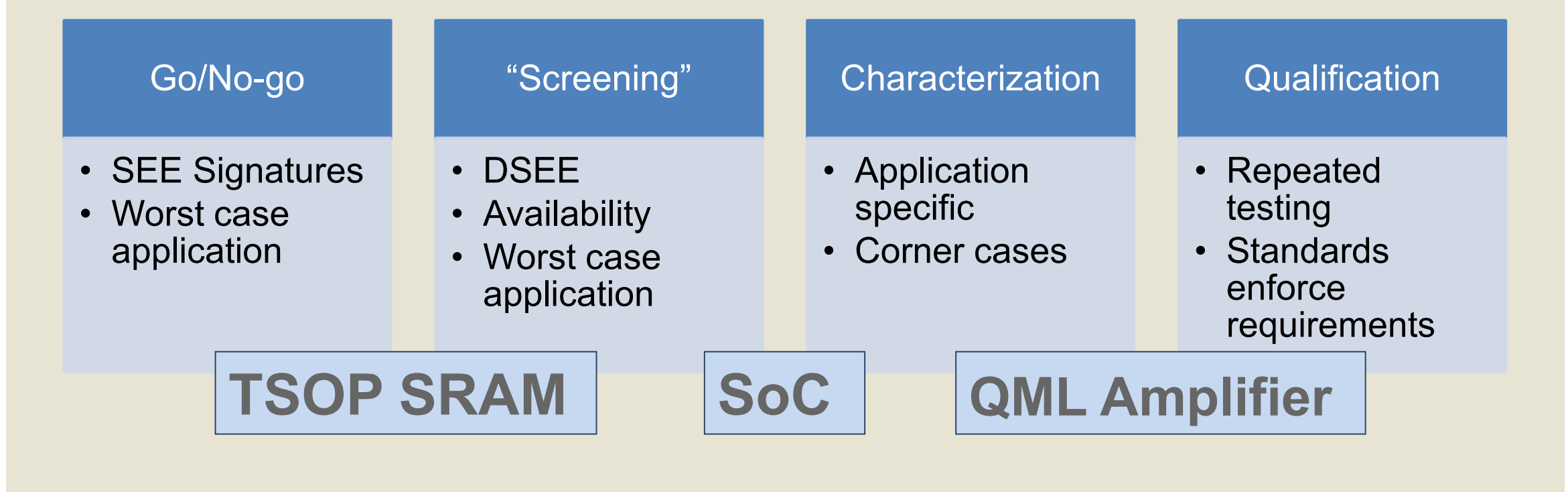
- Application specific SET
- SET response with/without mitigation

COTS SoC



- Want to characterize as many signatures as possible

Test Categorization



Helps narrow down what your test requirements are going to be

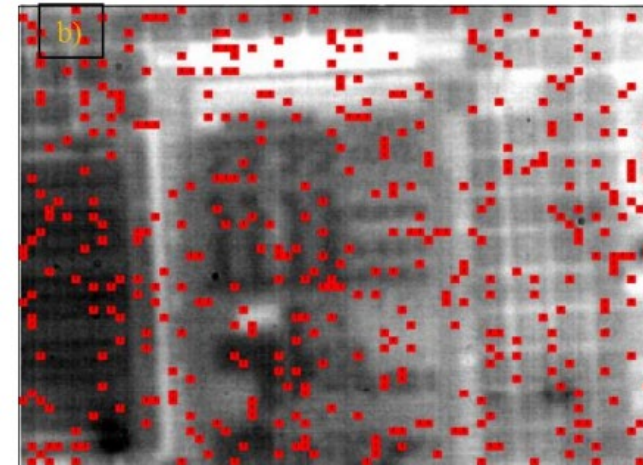
Test Requirements

LET requirements

- Threshold $> X$ ($\text{MeV}\cdot\text{cm}^2/\text{mg}$)
 - If true
 - » SEE contributors that matter
 - » no further analysis required
 - If false more test/analysis
 - » SEE contributors uncharacterized
 - » Rates/Likelihoods

Fluence requirements

- Latent Damage
- Coverage
 - Repeated structures
 - Minimize dose



10^7 heavy ions/ cm^2
1.25 rad(Si) (for Ar ions)
1 ion per $10\ \mu\text{m}^2$
Single, Z, angle, LET,
energy

Test Requirements

of samples

- Increased if
 - Destructive effects
 - » Latent damage
 - » One part one data point
 - Multiple test setups
 - Part-to-part, lot-to-lot variability
- Decreased if
 - Previous data exists
 - Test setup accommodates many applications
- You always want control devices

Temperature

- Some SEE mechanisms are temperature dependent
 - Will not happen unless at an elevated or cooled temperature
- Some applications have temperature profiles that present the hazard

Case Study: SEL on TSOP SRAM

Intent

- Have enough devices
- Confirm that SEL is rare enough for a given environment
 - High fluence for small sensitive structures
- Confirm that error cross section is in family
- Worst case application for SEL

Requirements

- Minimum 5 + control
- $LET_{th} > 75 \text{ MeV}\cdot\text{cm}^2/\text{mg}$
 - Fluence of $1 \times 10^7 \text{ p/cm}^2$ for coverage
- Test at varied LET to get error cross-section data
- 110% of nominal supply Voltage, 85°C dwell

Case Study: SET on QML Amplifier

Intent

- Sample size may be eased by effects that are numerous and repeatable
 - Still need more samples to quantify variability
- Transients will change in shape/size
 - Angle, Frequency, Bias, circuit, etc.
 - Large number of records to gather worst case transients

Requirement

- Sample size - won't lose parts
 - Minimum 3 + control
- Test all considerations/states at each LET to gather variable independent cross-sections
 - Angle, Frequency, Bias, circuit, etc.
 - Dynamic operation, 100s of counts per variable states

Case Study: Research on SoC

Intent

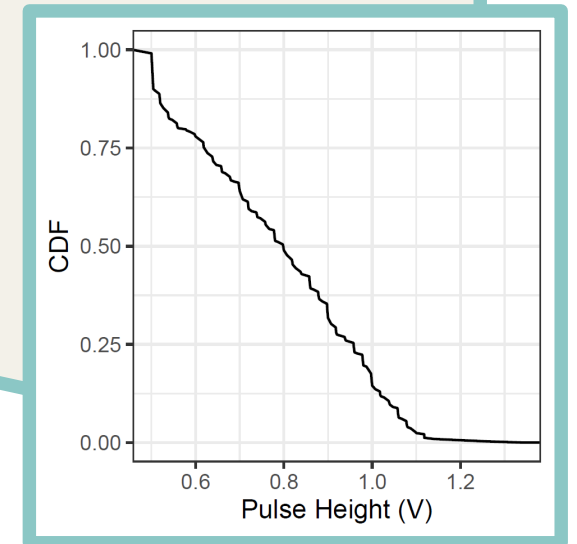
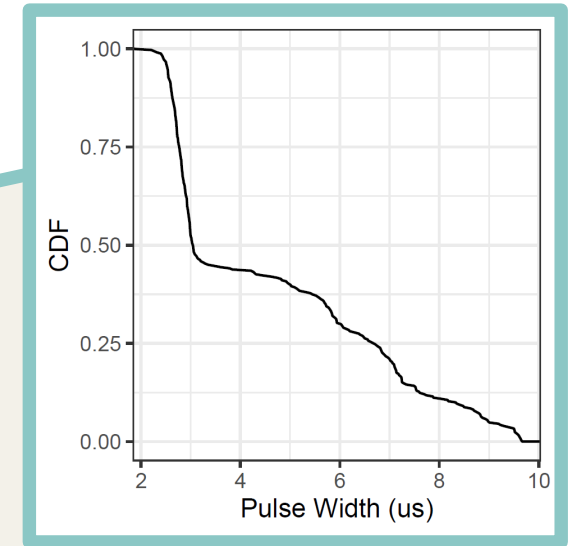
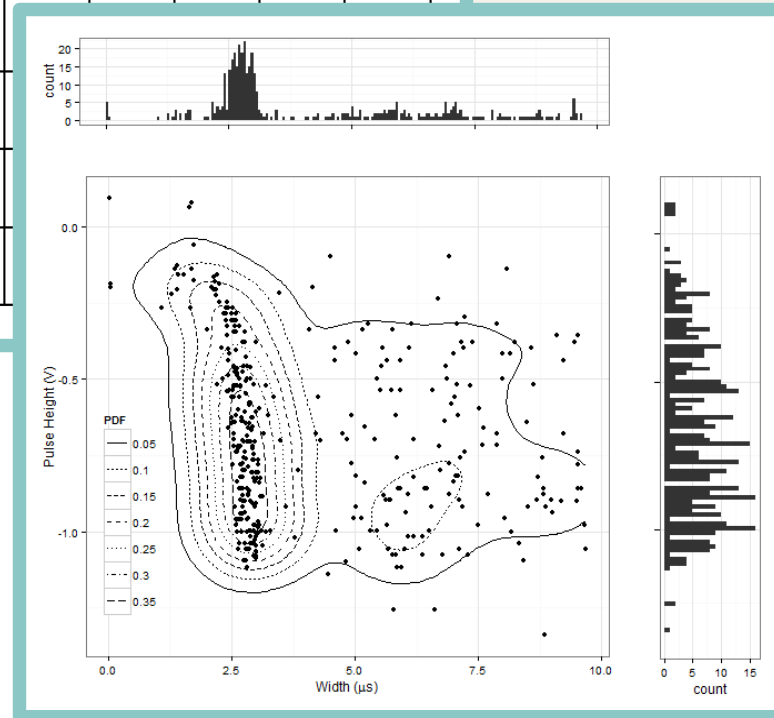
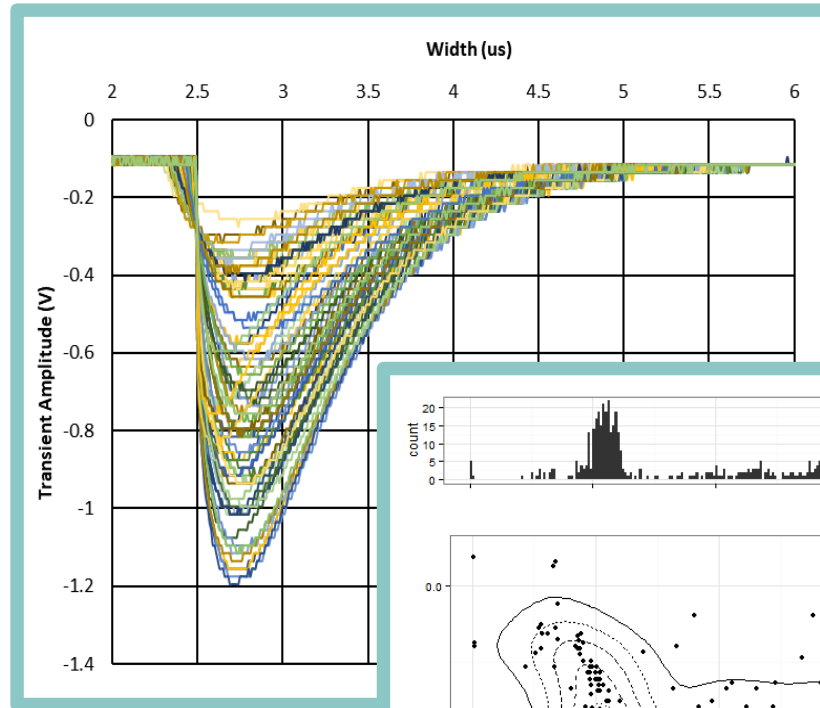
- Identify destructive signatures
 - High fluences for small structures
 - Minimize dose
- Identify SEFI signatures
 - Fluences until they occur to not mix/accumulate signatures
- Identify SEU/nuisance signatures
- Cover operating variations

Requirement

- Anticipate many runs / more samples
 - stopping runs when SEFI occurs
 - to get to an accumulated fluence (10^7 p/cm²) without interruption or wear-out
- Many operating regimes
 - Angle, Frequency, Bias, circuit, etc.
 - Dynamic operation, 100s of counts per variable states

Requirement Matrix

Attribute	TSOP SRAM	QML Amplifier	COTS SoC
<i>Single Event Investigation</i>	SEL, SEU	SET	SEL, SEFI, SEU/MBU, SET
<i>Sample Size (always + control)</i>	5 – need 3 passing to establish no SEL	3 – non-destructive, can use parts to collect a lot of transients	As available for prep. First look – back ups will allow for continued testing
<i>Test Objective</i>	Find LET threshold of destructive events	Characterize transients for all variable conditions	Have a representative sample of the potential radiation faults that could occur
<i>Fluence</i>	10^7 with no SEL signature for coverage	Fluence to get enough transient captures optimize for test time (typical 10^6 /run)	Fluence will be limited per run by signatures that show up, still need adequate coverage over entire test campaign
<i>Flux</i>	Varied flux increase for long runs	Choose flux to optimize data capture – don't want to lose events	Low flux to avoid error accumulation/stacking (10^3 lower limit of facilities)
<i>Temperature</i>	Room + elevated (near operating limits of device)	Room	Room
<i>Application</i>	Worst Case (near operating limits of device)	All application biases / loads	Key functional modes / capabilities

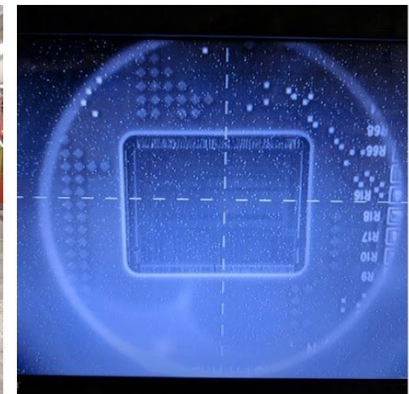
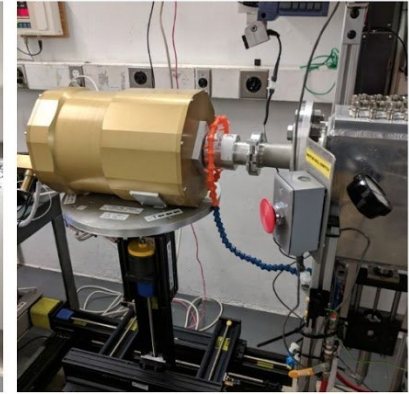
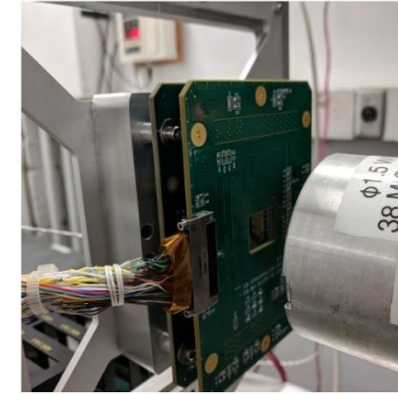
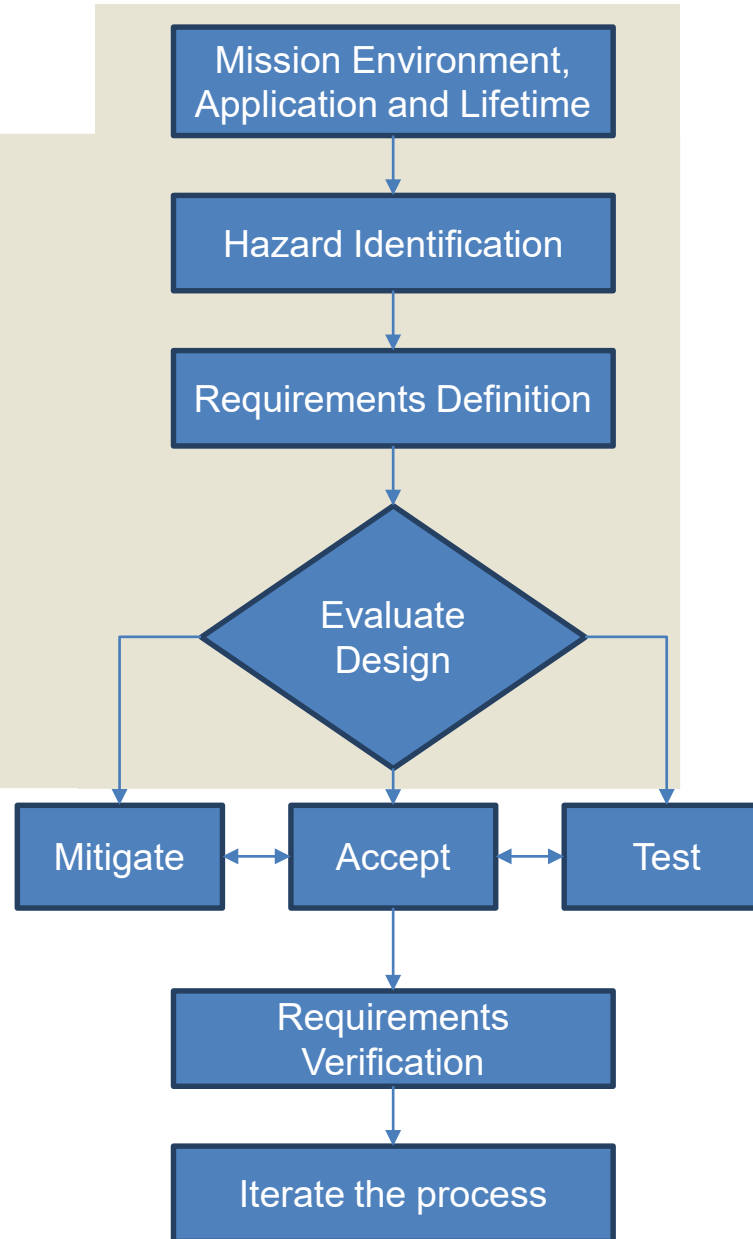


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THANK YOU

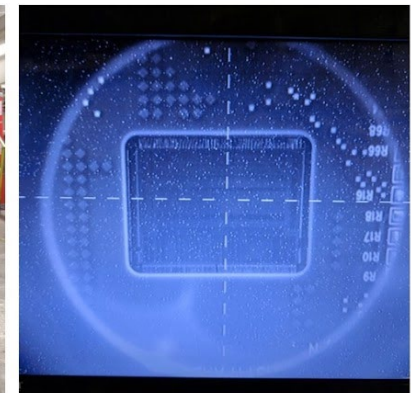
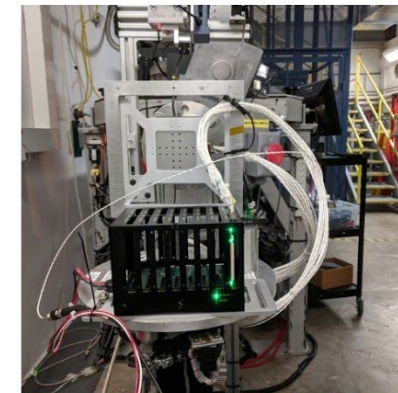
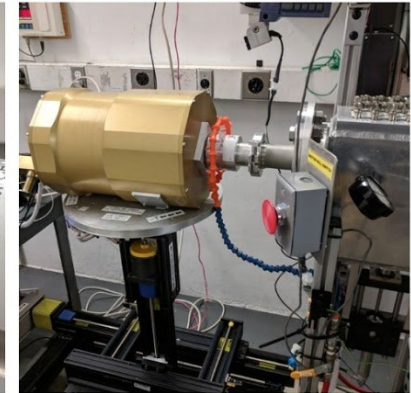
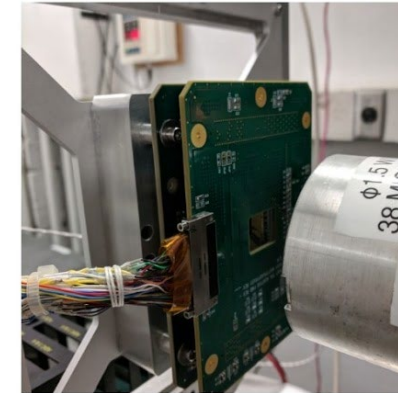
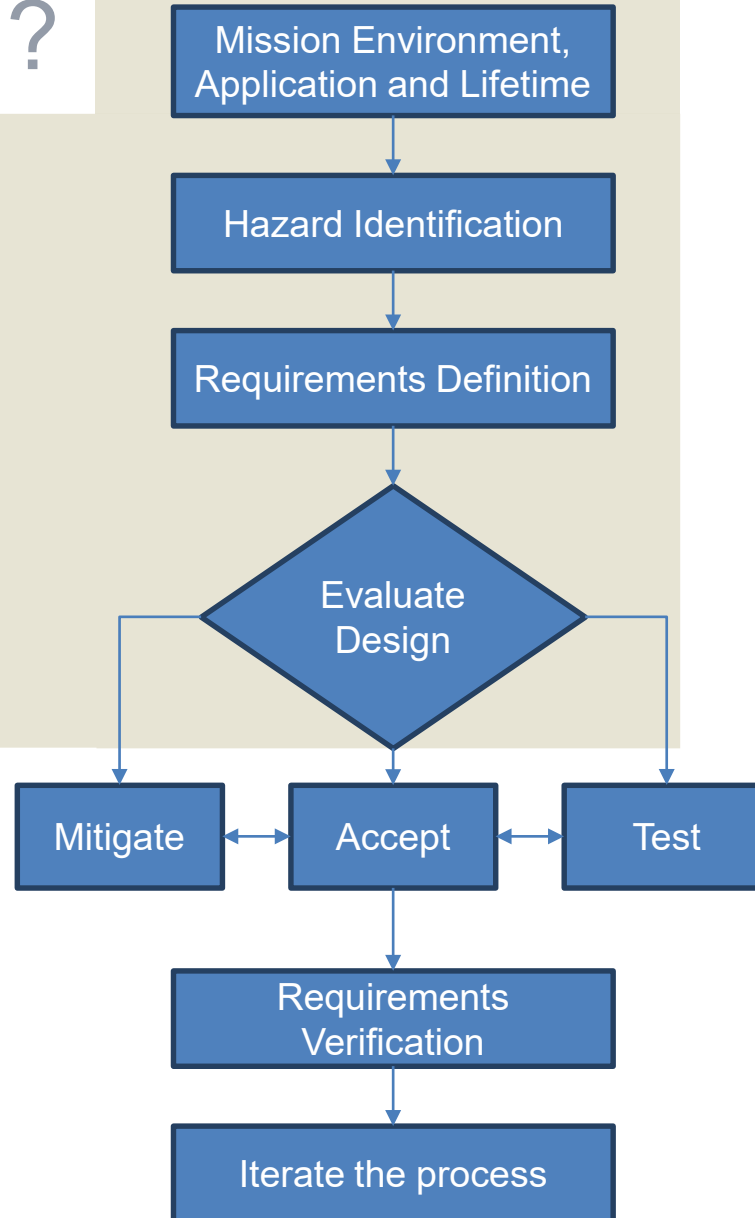
Before you test

- **Know your risk threshold**
 - Reliability/Availability
 - Criticality of functions
- **Identify unknown failure modes that would not be acceptable to the mission**
 - Known unknowns can be carried as a risk
 - New technologies should be identified early on
- **Understand fault propagation / applications**



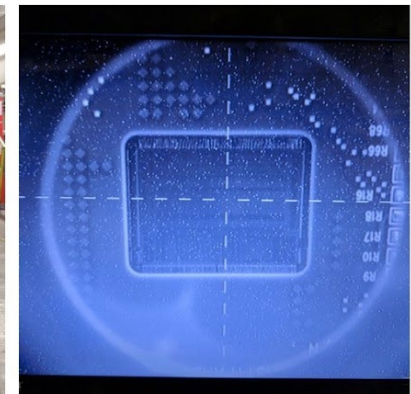
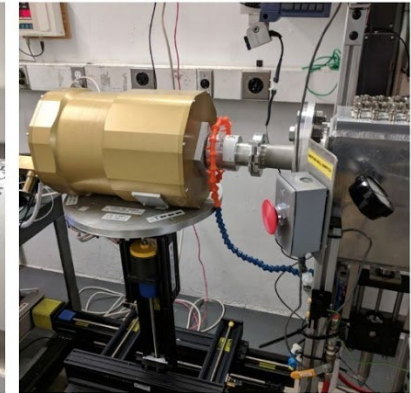
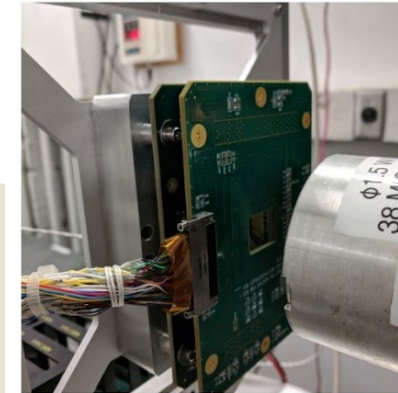
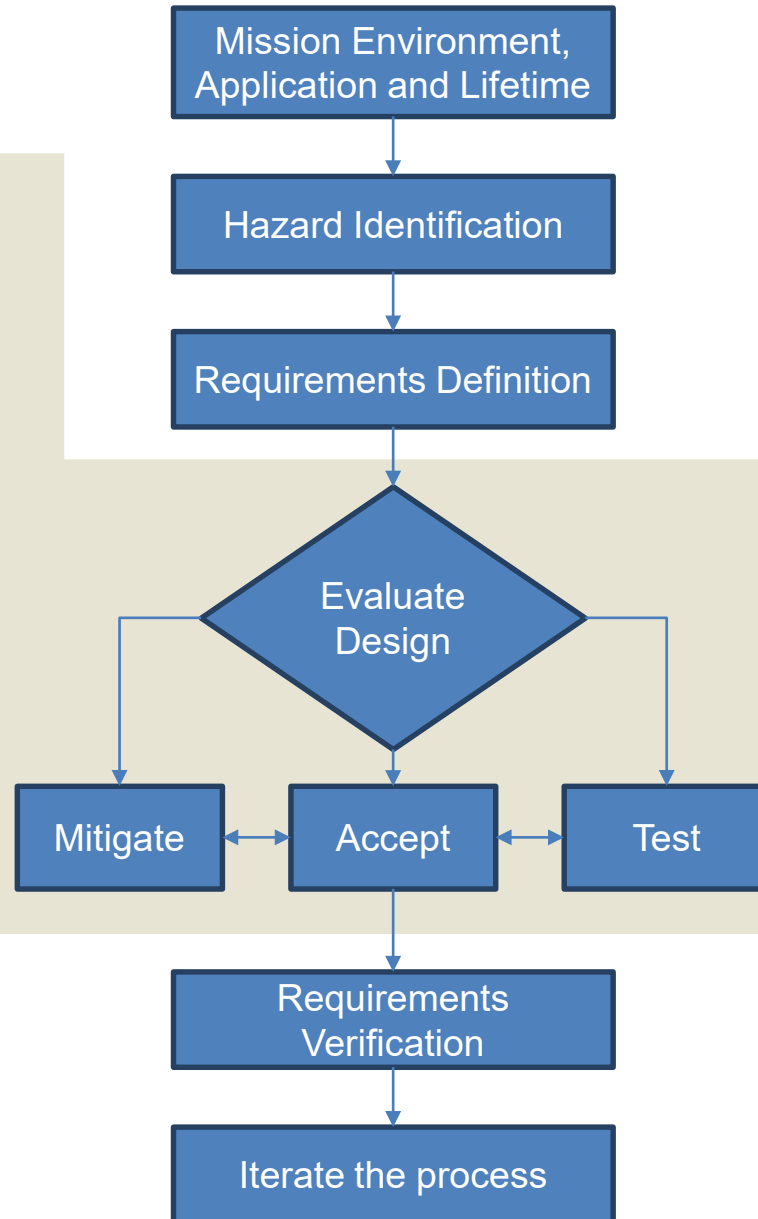
Why are you testing?

- **Know your project requirements**
 - Reliability/Availability concerns?
 - Critical functions susceptible?
- **Unknown failure modes that would not be acceptable to the mission?**
- **Fault propagation may be the problem you wish to mitigate**
 - Fault injection may not be able to cover the state space (see past talks from [Melanie Berg](#))



Tailor your test

- **Fault propagation may be the problem you wish to mitigate**
 - This can include cumulative effects!
 - With/without mitigation?
- **What signatures are you expecting?**
 - Telemetry needs
 - Test complexity
- **Do you have the ability to have a minimal test if things aren't working out?**



Got test results?

- **Unexpected Results?**
 - Get communicating!
 - Criticality of functions, impact
 - Follow-on testing?
- **Do you have enough evidence?**
 - Enough to calculate rates?
 - Statistics?
- **Can you tolerate a part replacement in your design cycle?**
 - Lead times,
 - board re-spins,
 - Chip redesign, etc.

