Small Mission Radiation Hardness Assurance (RHA)

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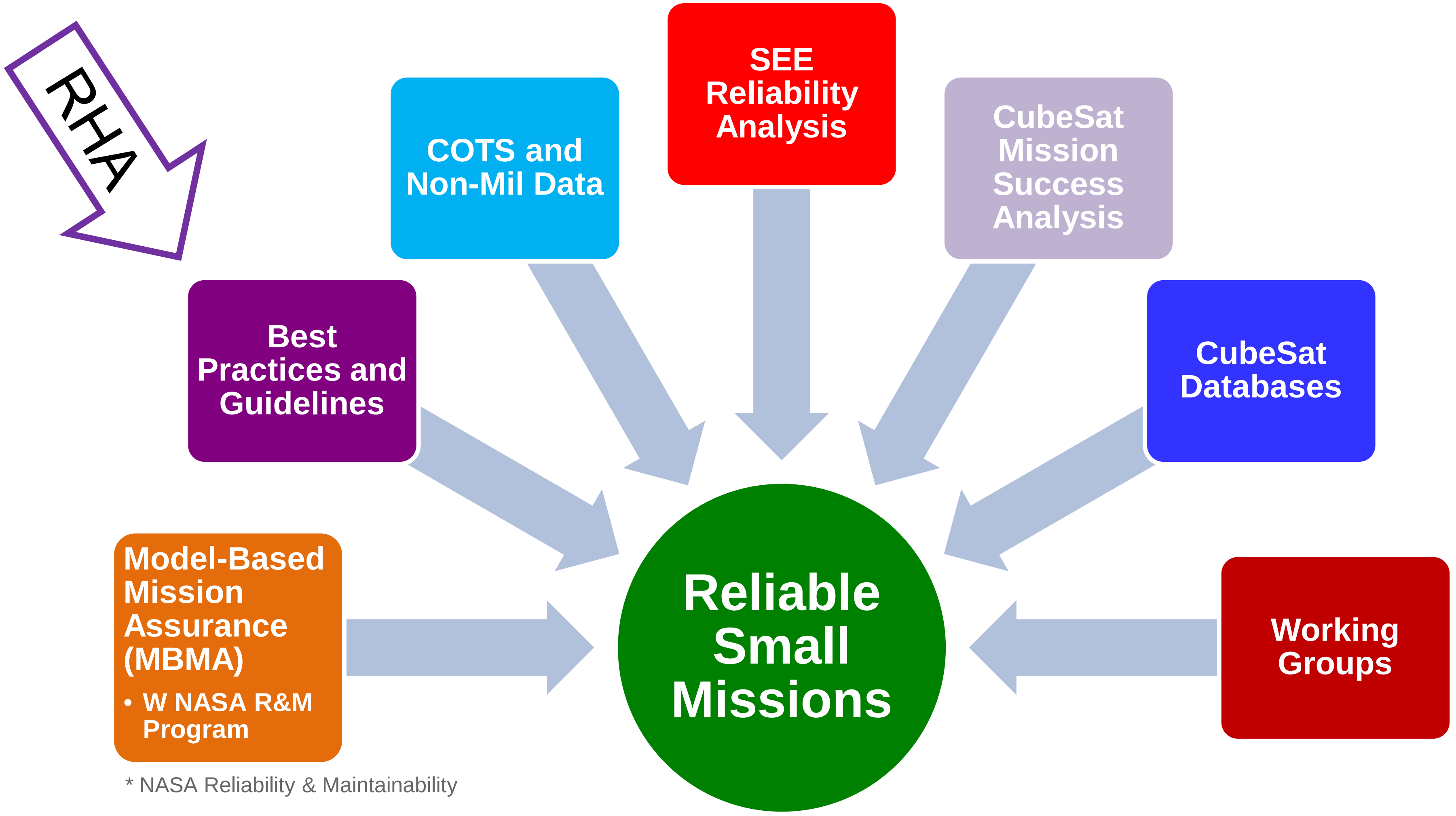
Acronyms

COTS	Commercial Off The Shelf
DD	Displacement Damage
GEO	Geostationary Earth Orbit
GSFC	Goddard Space Flight Center
LEO	Low Earth Orbit
LET	Linear Energy Transfer
MBU	Multi-Bit Upset
MCU	Multi-Cell Upset
NEPP	NASA Electronic Parts and Packaging

RDM	Radiation Design Margin
RHA	Radiation Hardness Assurance
SEB	Single Event Burnout
SEDR	Single Event Dielectric Rupture
SEE	Single Event Effects
SEFI	Single Event Functional Interrupt
SEGR	Single Event Gate Rupture
SEL	Single Event Latchup
SOA	Safe Operating Area
TID	Total Ionizing Dose

NEPP - Small Mission Efforts



* NASA Reliability & Maintainability

Introduction

- What constitutes a small mission? What is RHA?
- Implementing RHA in small missions gives unique challenges
  - No longer able to employ risk avoidance
  - Design trades impact radiation risks, cost, and schedule
  - Difficulty bounding risks to the system
- Useful risk practices and lessons
  - Risk identification and comparison
  - Categorizing risk based on manifestation at the system level
  - Leverage RHA from previous missions

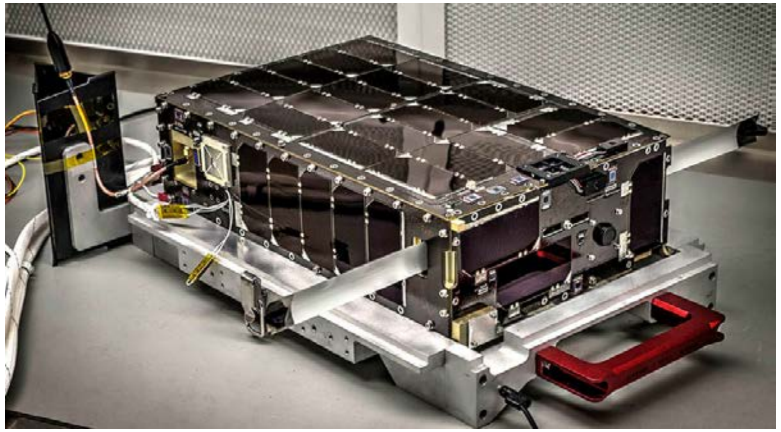
What Constitutes a Small Spacecraft/Mission?

- **Risk Acceptance**
- Partnerships
  - Universities
  - Government Institutions
  - Small Business Collaborations
- CubeSat/SmallSat Subsystem Vendors (cubesat.org)

- Not Small Goals
  - Mass < 180kg (Small Spacecraft Technology Program)
  - Can be any class mission! Not necessarily small budget
  - Mission goals for small spacecraft are growing as is the need for reliability

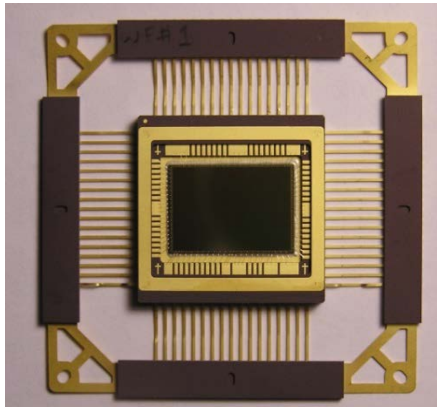
Risk Acceptance

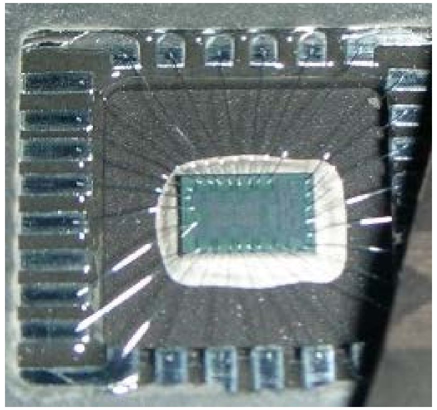
- Mission Profiles Are Expanding
  - Profiles were based on mission life, objective, and cost
  - Oversight gives way to insight for lower class
  - Ground systems, do no harm, hosted payloads
  - Similarity and heritage data requirement widening
  - In some cases **unbounded radiation risks are likely**



Credits: NASA's Goddard Space Flight Center/Bill Hrybyk

- Part Classifications Growing
  - Mil/Aero vs. Industrial vs. Medical
  - Automotive vs. Commercial





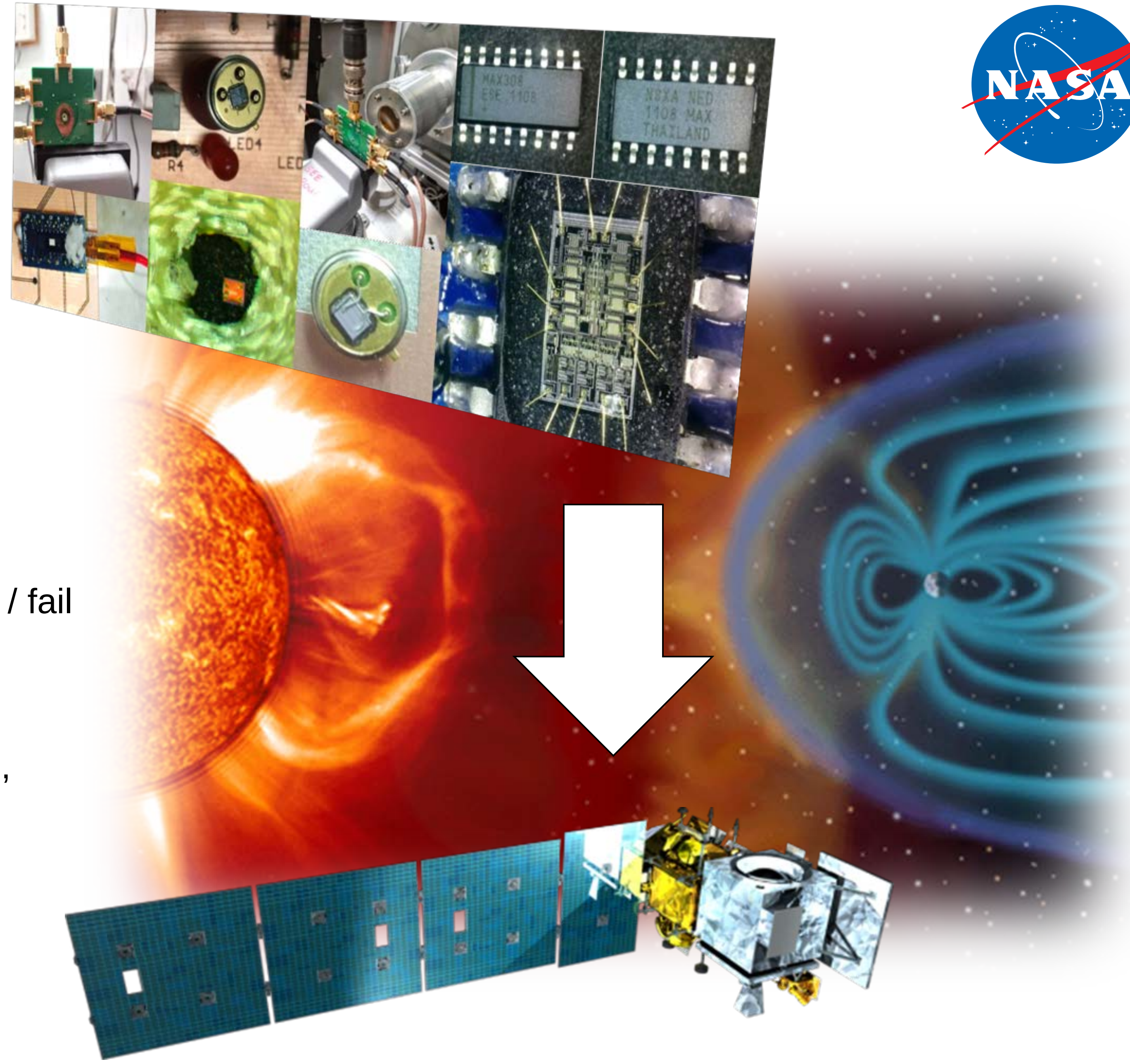
- *As a Result, Risk Types Have Increased and RHA is Necessary!*

Notional RHA Questions to Start

- Radiation risks: What are we dealing with? What are the challenges?
- How do similar systems/devices react in the space environment?
- What can you do to bring down the risk of that interaction?
- Need availability throughout the mission or at specific times?
- **What does changing the radiation environment look like to the system?**

RHA Challenges… Not So Small

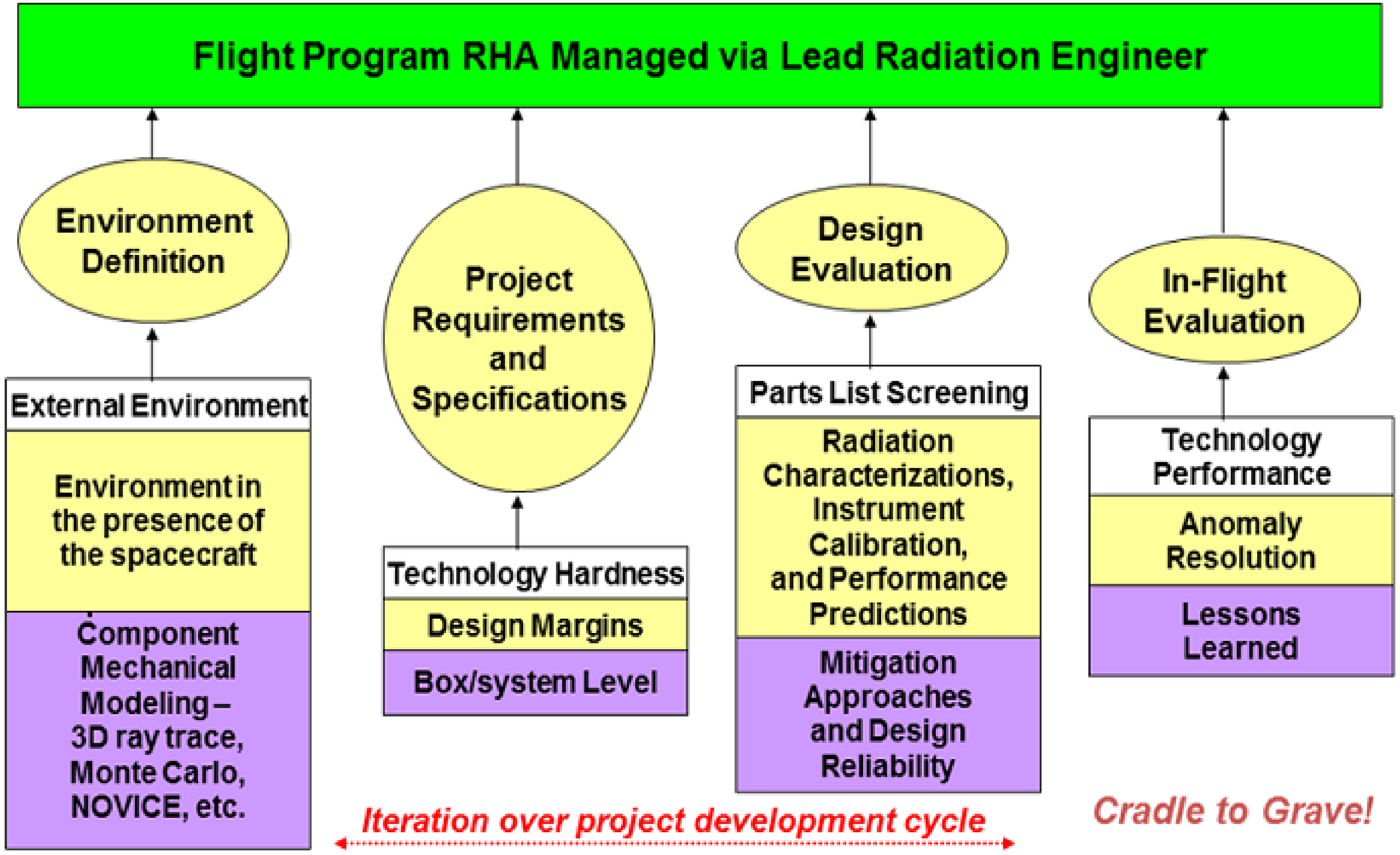
- New Technologies
  - Increased COTS parts / subsystem usage
  - Device Topology / Speed / Power
  - Modeling the Physics of Failure
- Quantifying Risk
  - Translation of system requirements into pass / fail criteria
  - Determining appropriate mitigation level (operational, system, circuit/software, device, material, etc.)
- Wide Range of Mission Profiles
- Always in a *dynamic* environment



RHA Definition and Overview

RHA consists of all activities undertaken to ensure that the electronics and materials of a space system perform to their *design* specifications throughout exposure to the mission space environment

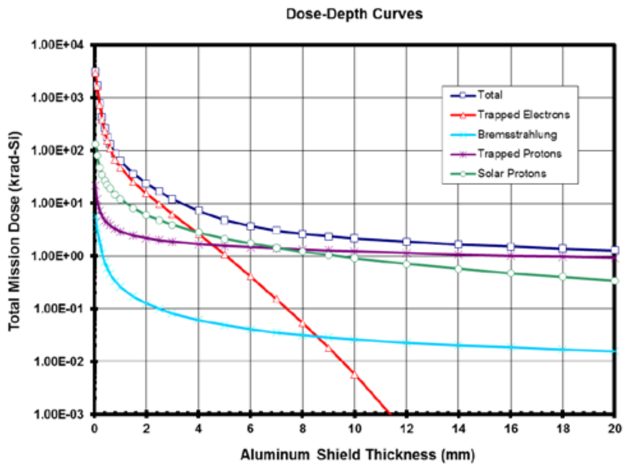
(After Poivey)

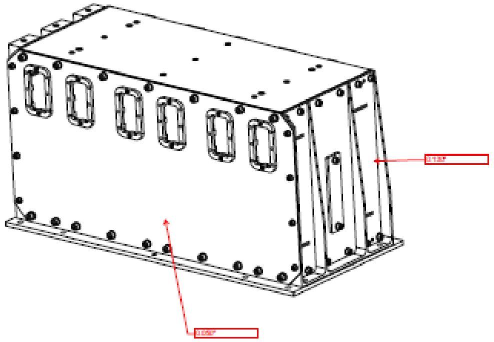


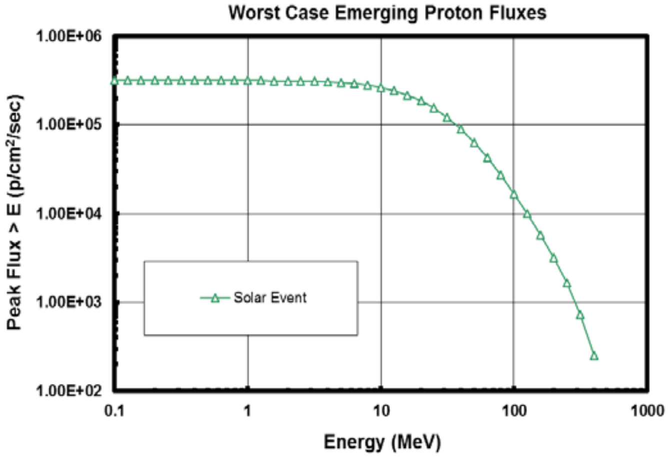
(After LaBel)

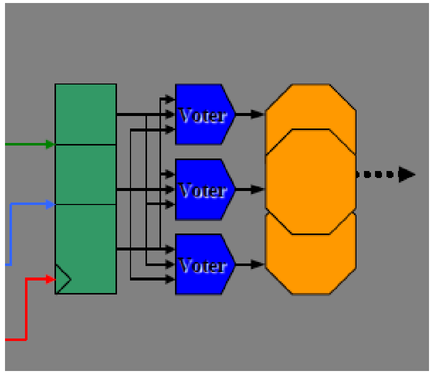
RHA Flow Doesn't Change With Accepted Risk

- **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









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.

Define and Evaluate the Hazard

- **Define the Environment**
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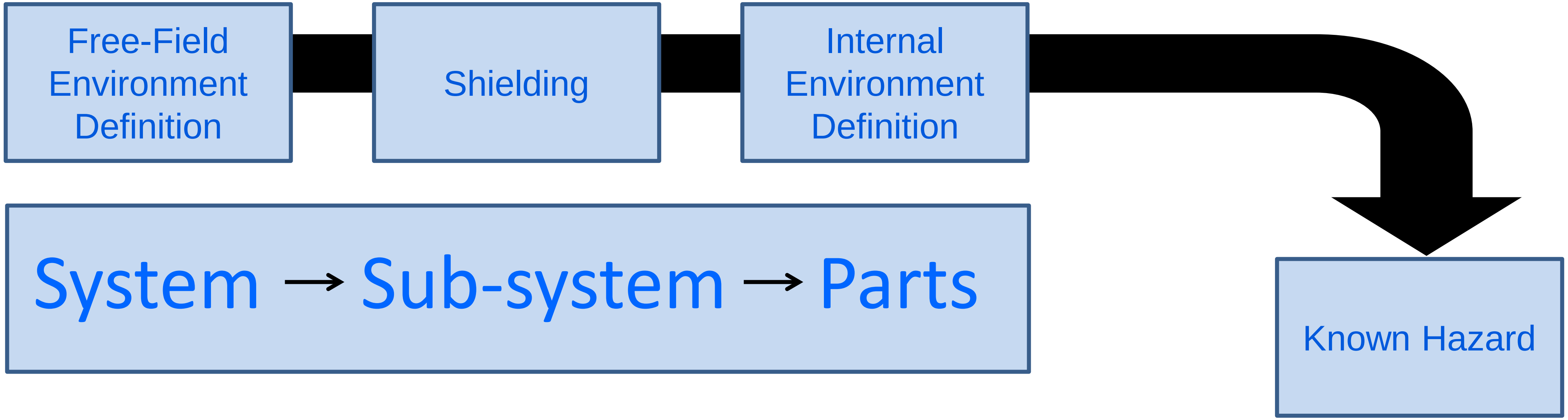
Environment Severity/Mission Lifetime

Evaluate RHA System Needs	Low	Medium	High
High	Manageable Dose / SEE impact to survivability or availability	Moderate Dose / SEE impact to survivability or availability	High Dose / SEE impact to survivability or availability
Medium	Manageable Dose / SEE needs mitigation	Moderate Dose / SEE needs mitigation	High Dose / SEE needs mitigation
Low	Manageable Dose / SEE do no harm	Moderate Dose / SEE do no harm	High Dose / SEE do no harm

Define and Evaluate the Hazard

- Same process for big or small missions, no short cuts
- Know the contributions
  - » Trapped particles (p+,e-)
  - » Solar protons, cycle, events
  - » Galactic Cosmic Rays
- Calculate the Dose
- Transport flux and fluence of particles
- Consider different conditions or phases of the mission separately



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Summary of Environmental Hazards

	Plasma (charging)	Trapped Protons	Trapped Electrons	Solar Particles	Cosmic Rays	Human Presence	Long Lifetime (>10 years)	Nuclear Exposure	Repeated Launch	Extreme Temperature	Planetary Contaminates (Dust, etc)
GEO	Yes	No	Severe	Yes	Yes	No	Yes	No	No	No	No
LEO (low-incl)	No	Yes	Moderate	No	No	No	Not usual	No	No	No	No
LEO Polar	No	Yes	Moderate	Yes	Yes	No	Not usual	No	No	No	No
International Space Station	No	Yes	Moderate	Yes - partial	Minimal	Yes	Yes	No	Yes	No	No
Interplanetary	During phasing orbits; Possible Other Planet	During phasing orbits; Possible Other Planet	During phasing orbits; Possible Other Planet	Yes	Yes	No	Yes	Maybe	No	Yes	Maybe
Exploration – Lunar, Mars, Jupiter	Phasing orbits	During phasing orbits	During phasing orbits	Yes	Yes	Possibly	Yes	Maybe	No	Yes	Yes

https://radhome.gsfc.nasa.gov/radhome/papers/SSPVSE05_LaBel.pdf

Derive Smart Requirements

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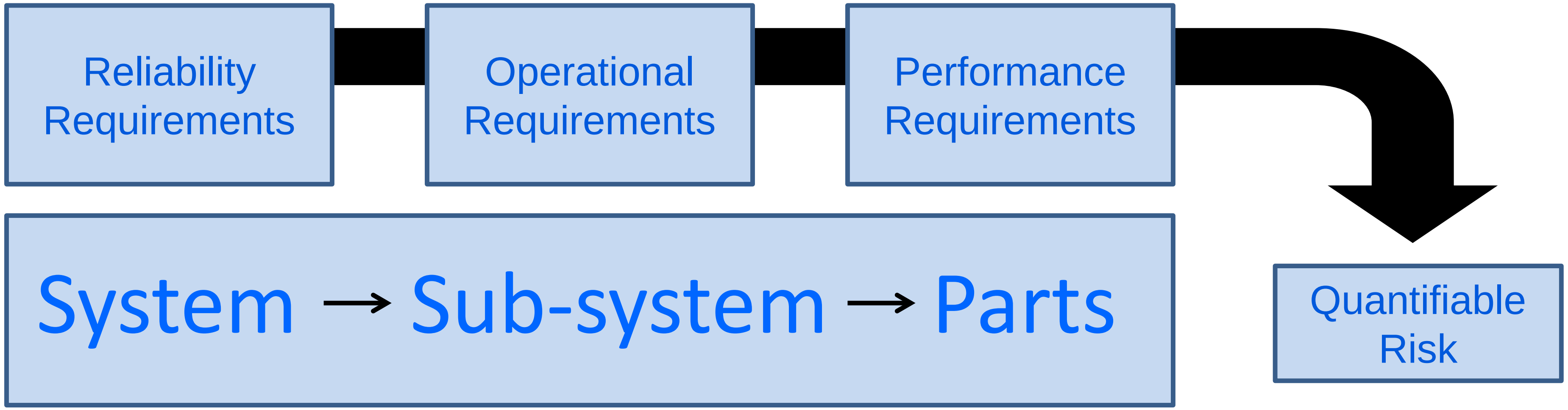
Environment Severity/Mission Lifetime

Criticality	Low	Medium	High
High	Dose-Depth / GCR and Proton Spectra for typical conditions	Dose-Depth evaluation at shielding / GCR and proton Spectra for all conditions	Ray-Trace for subsystem / GCR and proton Spectra for all conditions
Medium	Dose-Depth / GCR and proton spectra for background	Dose-Depth / GCR and Proton Spectra For background	Dose-Depth evaluation at shielding / All spectra conditions
Low	Similar mission dose, same solar cycle / GCR spectra	Dose-Depth / GCR spectra	Dose-Depth / GCR and Proton Spectra For background

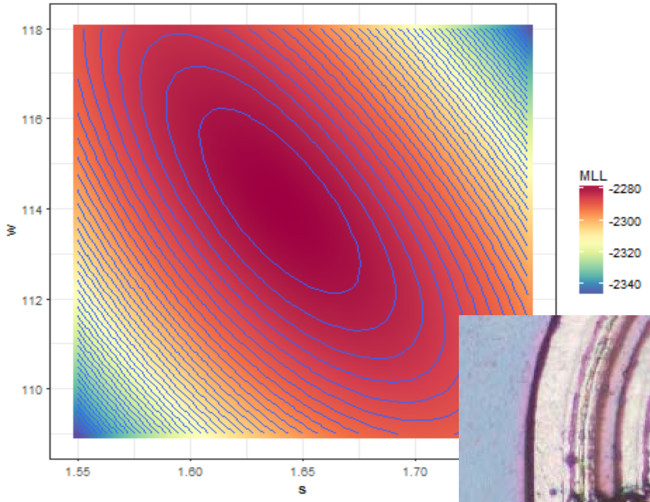
Derive Smart Requirements

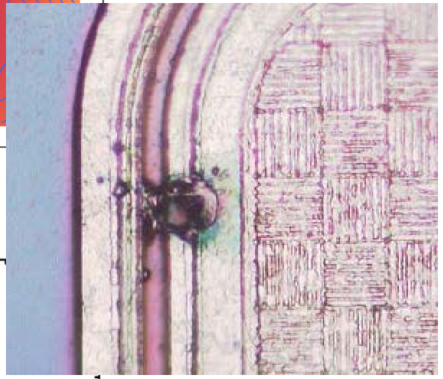
- **Requirements by Technology**
- Take into account the environment
- Take into account the application and criticality/availability needs

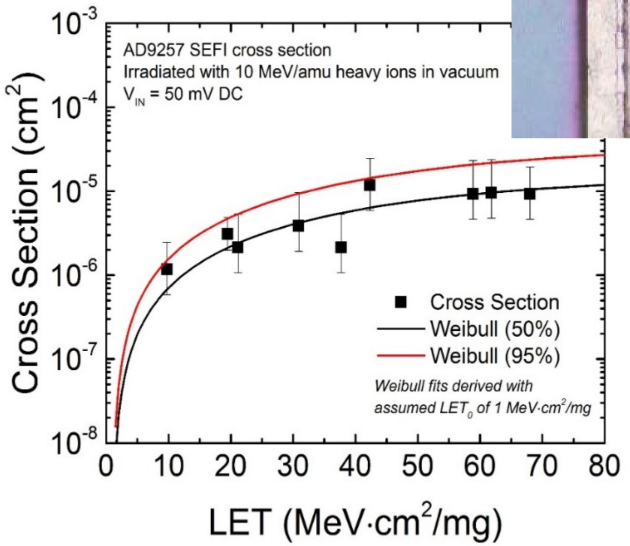


Requirements by Technology

- SEE, SET
  - Confidence intervals for rate estimations
- SEL, SEB
  - Environment driven, risk avoidance
  - Protection circuitry / diode deratings
- SEGR, SEDR
  - Effect driven, normally incident is worst case
  - Testing to establish Safe Operating Area (SOA)
- MBU, MCU, SEFI, Locked States
  - Only invoked on devices that can exhibit the effect
  - Watchdogs / reset capability
- Proton SEE susceptible parts are evaluated as determined here: https://nepp.nasa.gov/files/25401/Proton_RHAGuide_NASAAug09.pdf







Engineering Trades / Parts Evaluation

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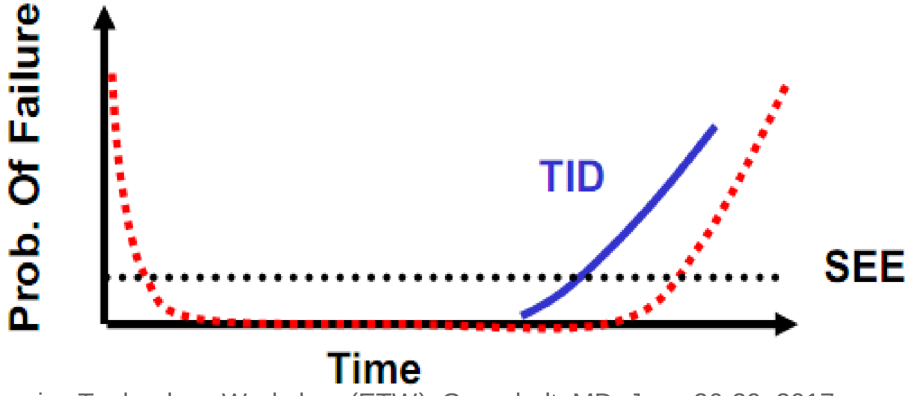
Environment Severity/Mission Lifetime

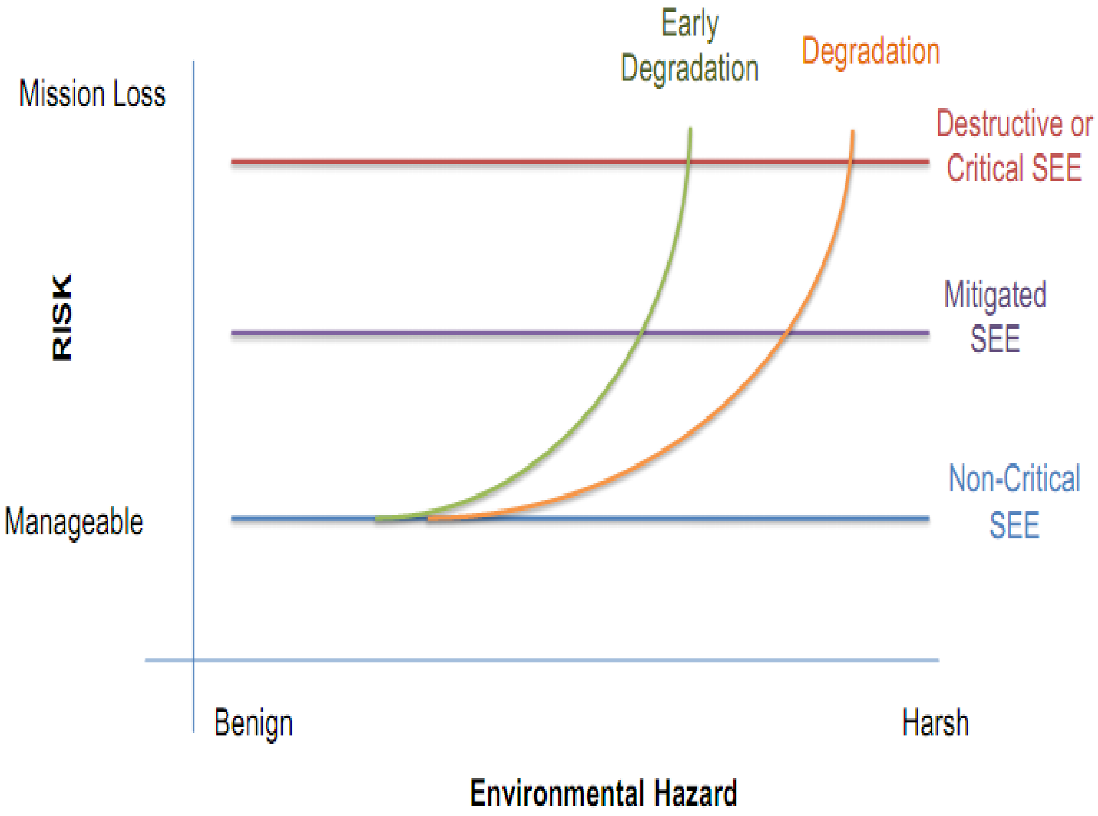
Part Criticality	Low	Medium	High
High	Mitigate parameter drift / design to have upsets occur	Add Shielding / Mitigation	Add Shielding / Mitigation if known response Change parts or TEST
Medium			
Low	Carry Risk		

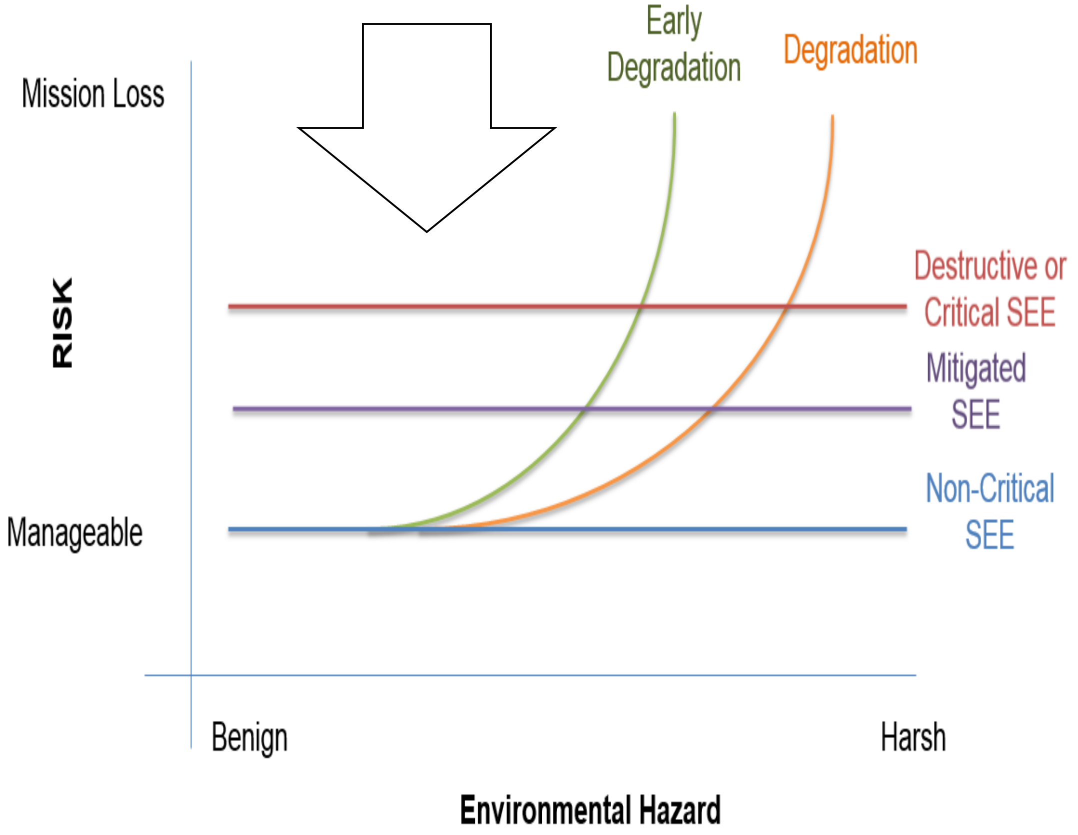
Engineering Trades / Parts Evaluation

- Weigh the hazard and risk
  - Mission parameter changes impact the radiation hazard
  - Look at each part's response, compare with part criticality
  - Utilize applicable data and the physics of failure
  - Determine if error will manifest at a higher level
- Be conscious of design trades
  - Size, Weight, and Power (SWaP) trades need to be carefully considered
  - Parts replacement/mitigation is not necessarily the best
  - **Single strain vs. allowable losses**
- Testing sparingly
  - The "we can't test everything" notion
  - Test where it solves problems and reduces system risk (risk buy down)
  - Requirements and risk impacts to the system should determine the order of operations when limited
  - Only when failure modes are understood can we take liberties to predict and extrapolate results



Single Strain vs. Allowable Losses





- Redundancy alone does not remove the threat
- Adds complexity to the design
- Diverse redundancy

Iterate the Process!

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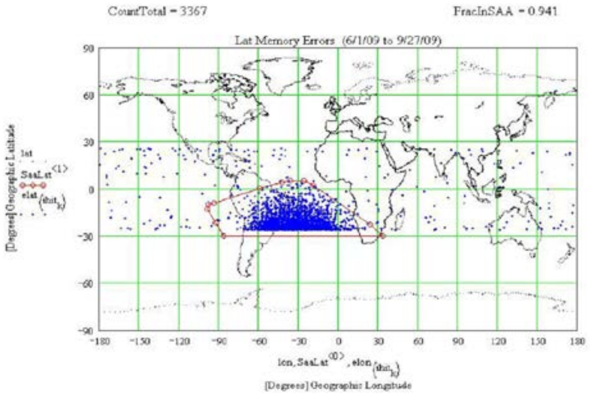
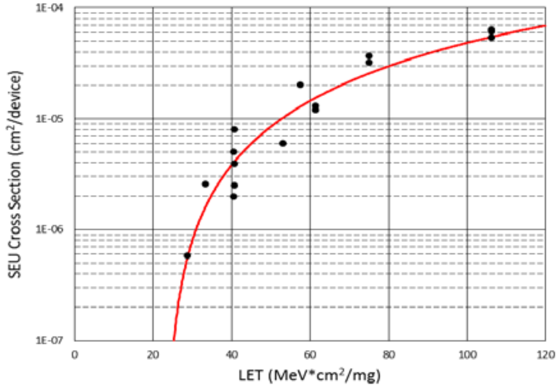
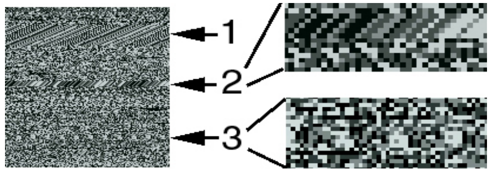
Risk Hierarchy and Classification

- Parts
  - o Predicted radiation response
  - o Downstream/peripheral circuits considered
- Subsystem
  - o Criticality
  - o Complexity
  - o Interfaces
- System
  - o Power and mission life
  - o Availability
  - o Data retention
  - o Communication
  - o Attitude determination



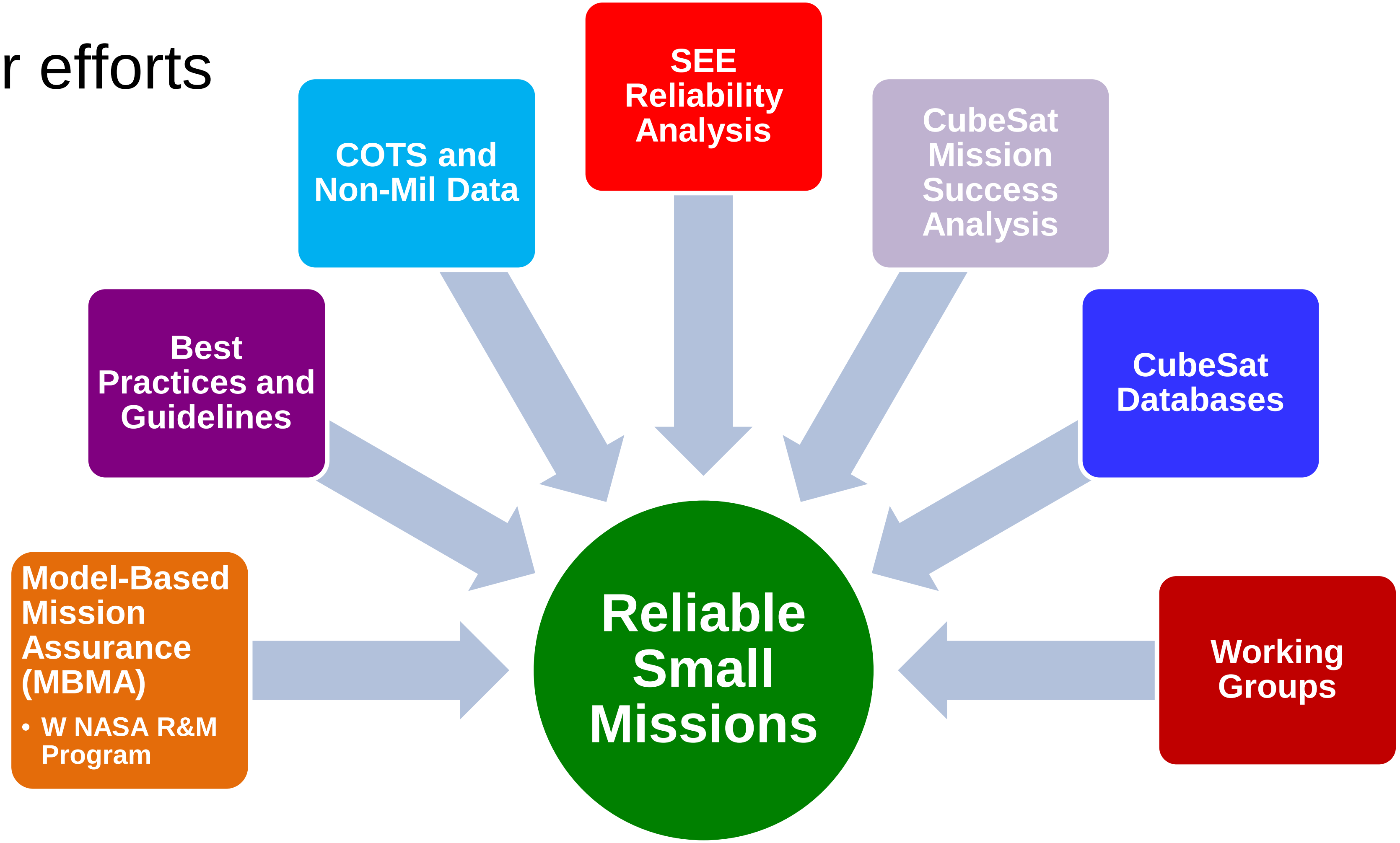




PIN	Generic Part No.	Part Description	Package Type	Manufacturer	FM Part No	Risk	SEL/ SEGR/ SEB	SEU	SET	SEFI	TID/ELDRS	DD
375	AT27C512R-90TI	EPROM	28 TSOP	ATMEL	AT27C512R-90TI	Medium	T	T	A	T	T	A
380	AT49BV1614T-11TI	Flash Ram	48 TSOP	ATMEL	AT49BV1614T-11TI	Medium	T	T	A	T	T	A
500	BAT54	Schottky Barrier	SOT23	ZETEX	BAT54	Low	A	A	A	N/A	A	A
510	BAT54C	Schottky Barrier	SOT23	ZETEX	BAT54C	Low	A	A	A	N/A	A	A
505	BAT54S	Schottky Barrier	SOT23	ZETEX	BAT54S	Low	A	A	A	N/A	A	A
485	BAV170 (Pb Free)	Double diode	SOT23	Philips Semiconductor	BAV170 (Pb Free)	Low	A	A	A	N/A	A	A
490	BAV23	Double diode	SOT143	Philips Semiconductor	BAV23	Low	A	A	A	N/A	A	A
495	BAV99W	High-speed double diode	SOT323	Philips Semiconductor	BAV99W	Low	A	A	A	N/A	A	A
415	BC847BS	NPN double transistor	SC-88	Philips Semiconductor	BC847BS	Medium	A	A	A	N/A	T	A
420	BCV61C (Pb Free)	NPN double transistor	SOT143B	Philips Semiconductor	BCV61C (Pb Free)	Medium	A	A	A	N/A	T	A
425	BCV62C (Pb Free)	transistor	SOT143B	Philips Semiconductor	BCV62C (Pb Free)	Medium	A	A	A	N/A	T	A
410	BFR92	Wideband	SOT23	Philips Semiconductor	BFR92	Medium	A	A	A	N/A	T	A
430	BFT92	PNP double transistor	SOT23	Philips Semiconductor	BFT92	Medium	A	A	A	N/A	T	A
385	CD74HC04M	Inverter	SO-14	Harris	CD74HC04M	Medium	A	A	A	A	T	A
395	CXA1439M	CDS	SO-8	SONY	CXA1439M	High	T	T	A	A	T	A
405	CXD1261AR	Timing Pulse Generator	QFP-64	SONY	CXD1261AR	High	T	T	A	A	T	A
400	CXD1267AN	Clock Driver	SO-20	SONY	CXD1267AN	High	T	T	A	A	T	A
315	ElanSC520-100AI	CPU	388 PBGA	AMD	ElanSC520-100AI	High	T	T	A	T	T	A
465	F-102	Current regulator diode	TBD	Sicovend	F-102	Low	A	A	A	N/A	A	A
445	FDC6506P	FET	SSOT-6	Fairchild	FDC6506P	High	T	A	A	N/A	T	A
325	HY57V651620BLTC-10S	SDRAM	TSOPII	Hyundai	HY57V651620BLTC-10S	High	T	T	A	T	T	A

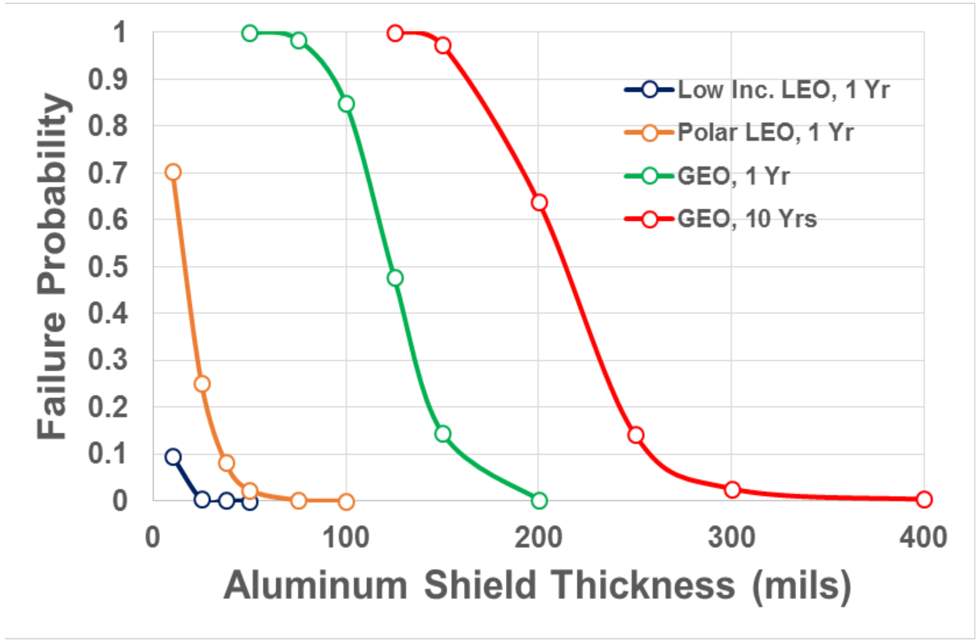
In-Flight Evaluation

- Key to future mission success
- Feeds back into our efforts



RHA Improvements

- **Confidence levels vs. Radiation Design Margins**
  - Trapped models AE8/AP8 to AE9/AP9
  - Solar particles already handled this way
- **Statistics on datasets**
  - Careful analysis can bound response from different test sets and results
  - Ground based testing more sophisticated
- **Requirements are getting more specific**
  - By function or expected response (power, digital, analog, memory)
  - By semiconductor or fab (GaN, GaAs, SiGe, Si, 3D stacks, hybrids)
- **Communication with Systems Engineers**



Summary

- RHA for Small missions
  - Challenges identified in the past are here to stay
  - Highlighted with increasing COTS usage
- Small missions benefit from detailed hazard definition and evaluation as done in the past
- RHA flow doesn't change, risk acceptance needs to be tailored
    - We need data with statistical methods in mind
- Varied mission environment and complexity is growing for small spacecraft
  - Don't necessarily benefit from the same risk reduction efforts or cost reduction attempts
- Requirements need to not overburden
  - Flow from the system down to the parts level
  - Aid system level radiation tolerance
- Risks versus rewards can have big impact on mission enabling technologies

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