

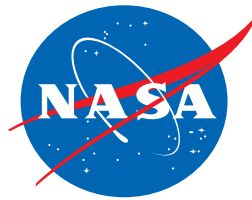
Small Mission Radiation Hardness Assurance (RHA)

Michael J. Campola

NASA Goddard Space Flight Center (GSFC)

NASA Electronic Parts and Packaging (NEPP) Program

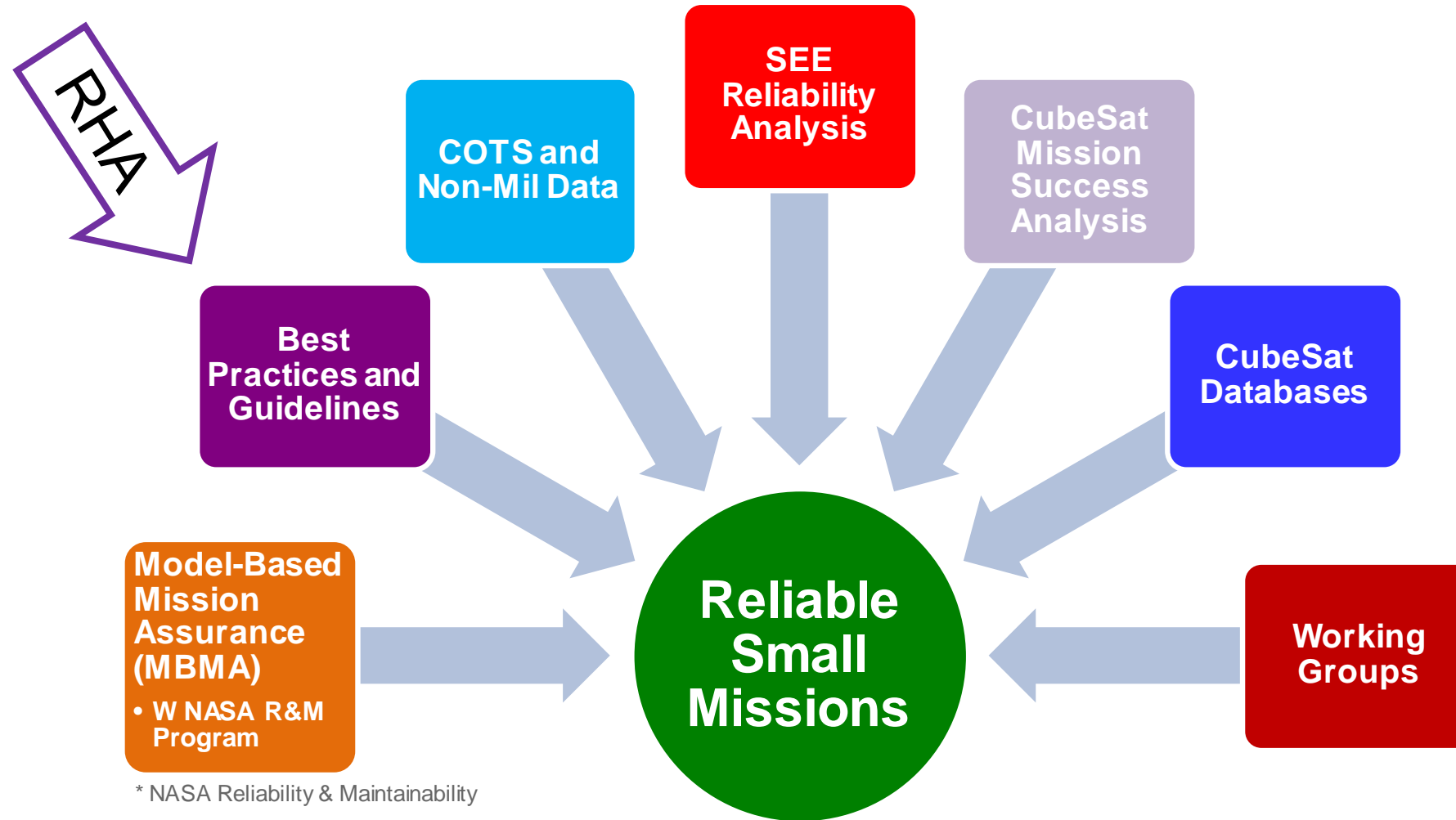
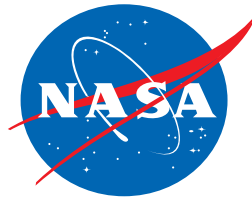
Acronyms



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

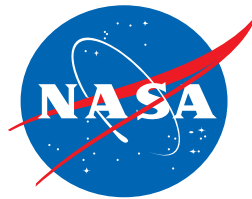




Introduction

- 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

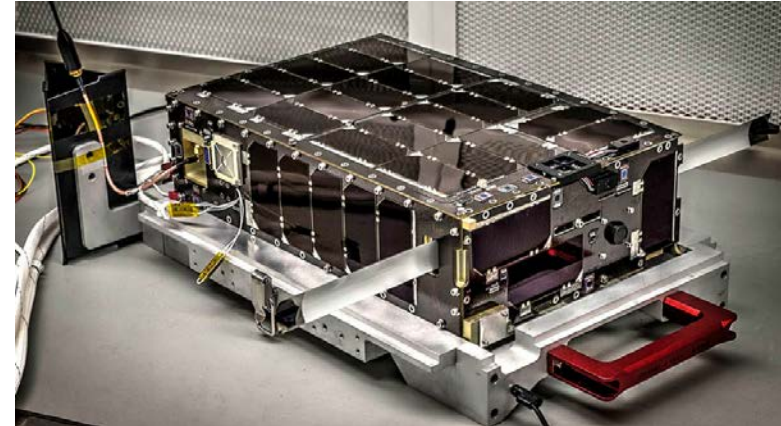
What Constitutes a Small Spacecraft/Mission?



- **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

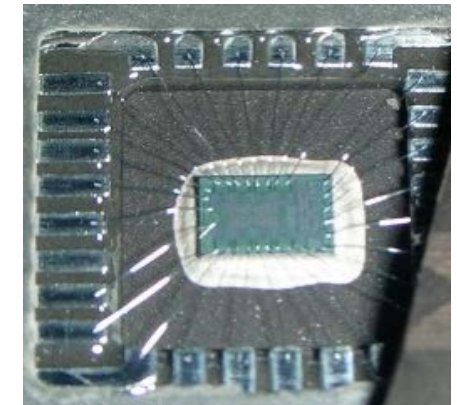
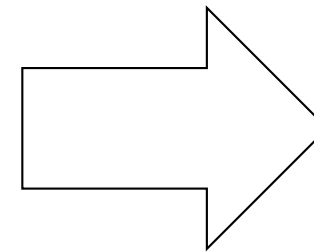
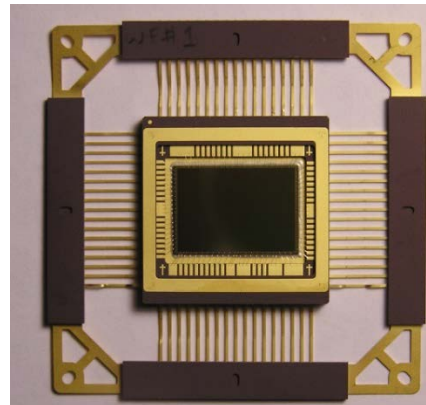
Risk Acceptance

- 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



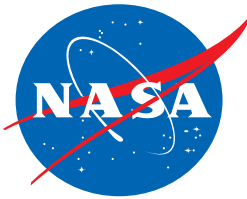
Credits: NASA's Goddard Space Flight Center/Bill Hrybyk

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



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

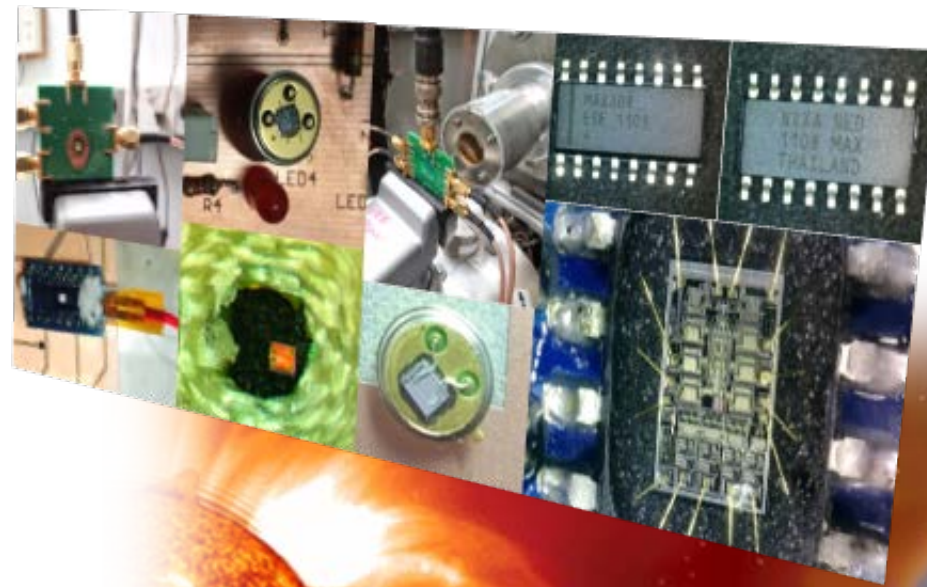
Notional RHA Questions to Start



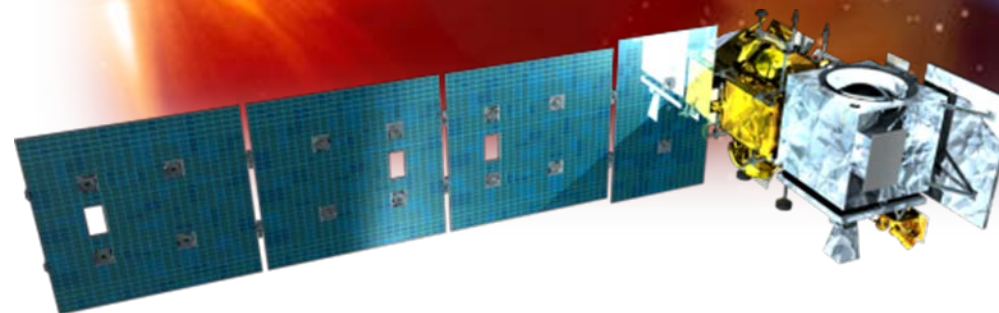
- Radiation risks: What are we dealing with? What are the challenges?
- How do similar systems/devices react in the space environment?
- What can you do to bring down the risk of that interaction?
- Need availability throughout the mission or at specific times?
- **What does changing the radiation environment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



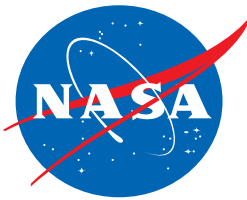
RHA Challenges... Not So Small



- 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

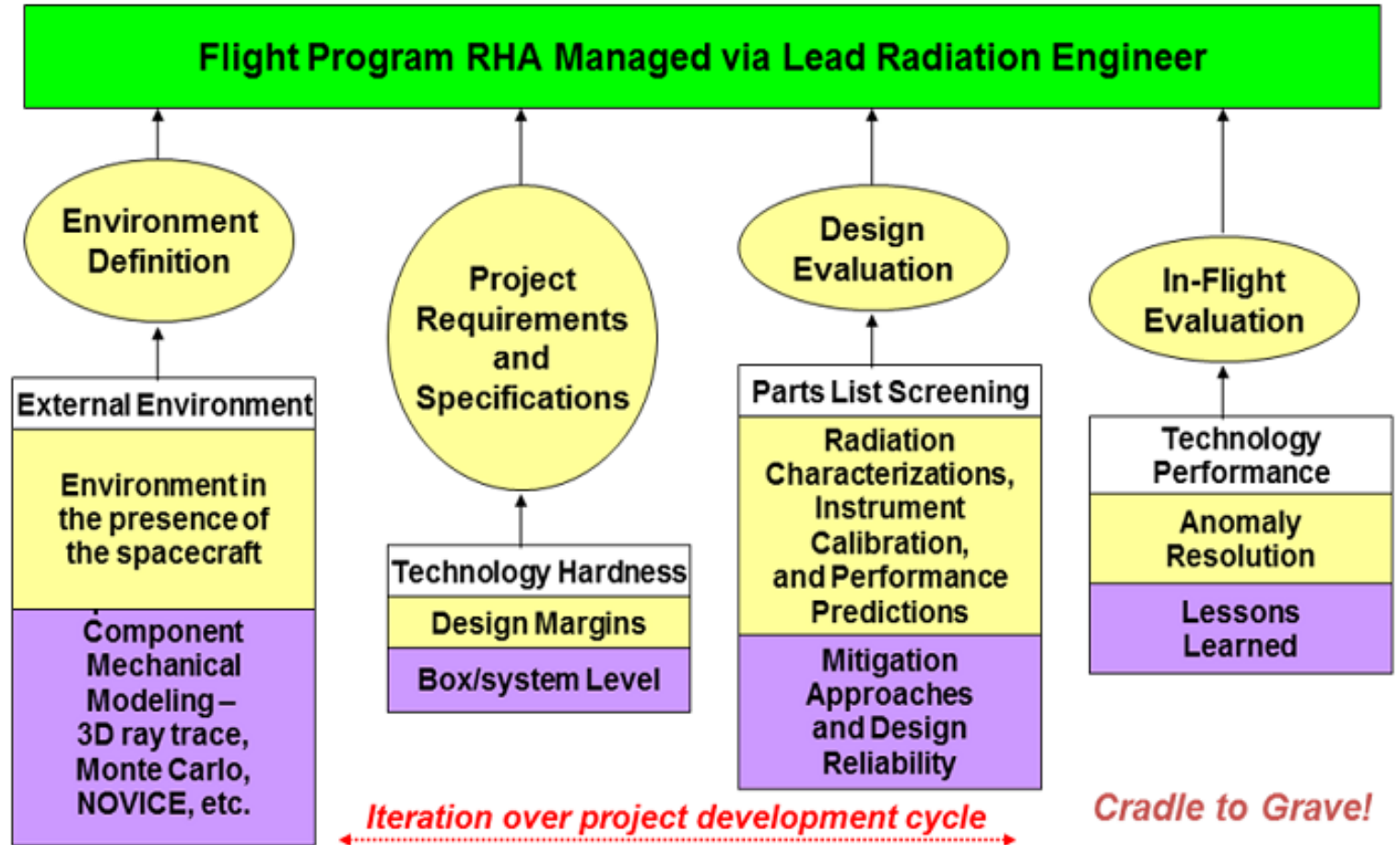


RHA Definition and Overview



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)

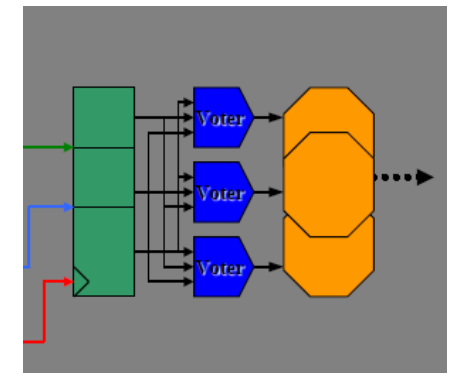
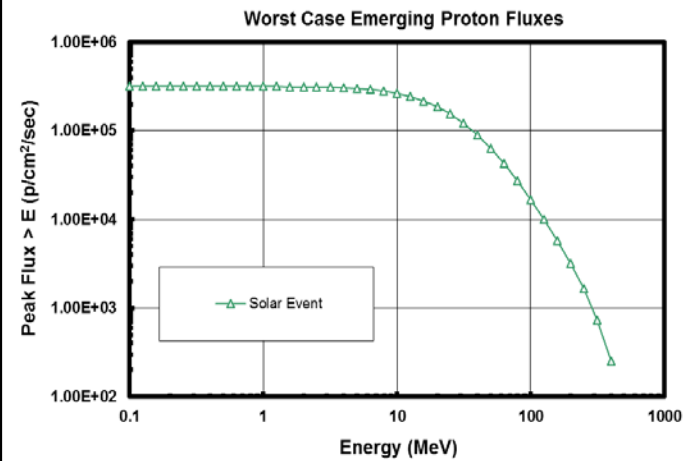
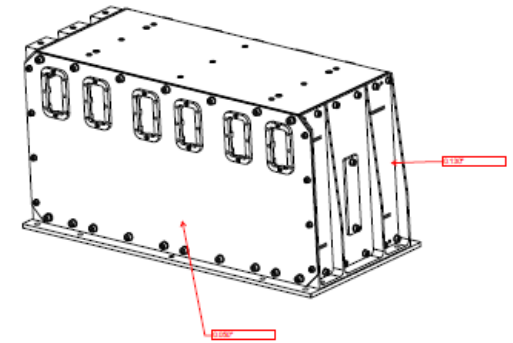
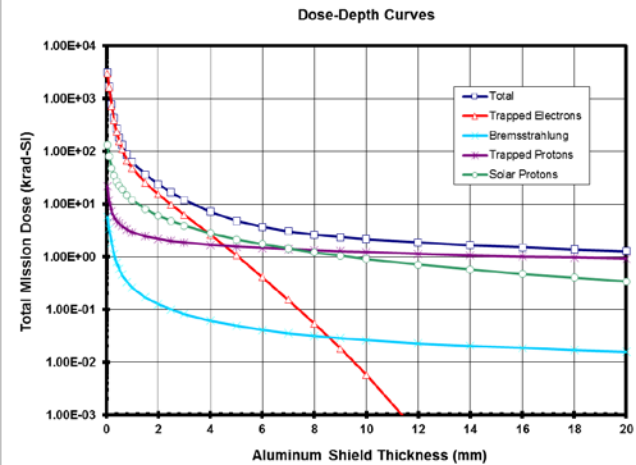


(After LaBel)

RHA Flow Doesn't Change With Accepted Risk

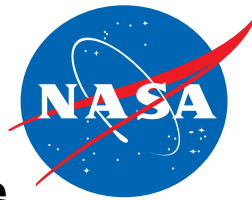


- **Define the Environment**
 - External to the spacecraft
- **Evaluate the Environment**
 - Internal to the spacecraft
- **Define the Requirements**
 - Define criticality factors
- **Evaluate Design/Components**
 - Existing data/Testing
 - Performance characteristics
- **“Engineer” with Designers**
 - 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



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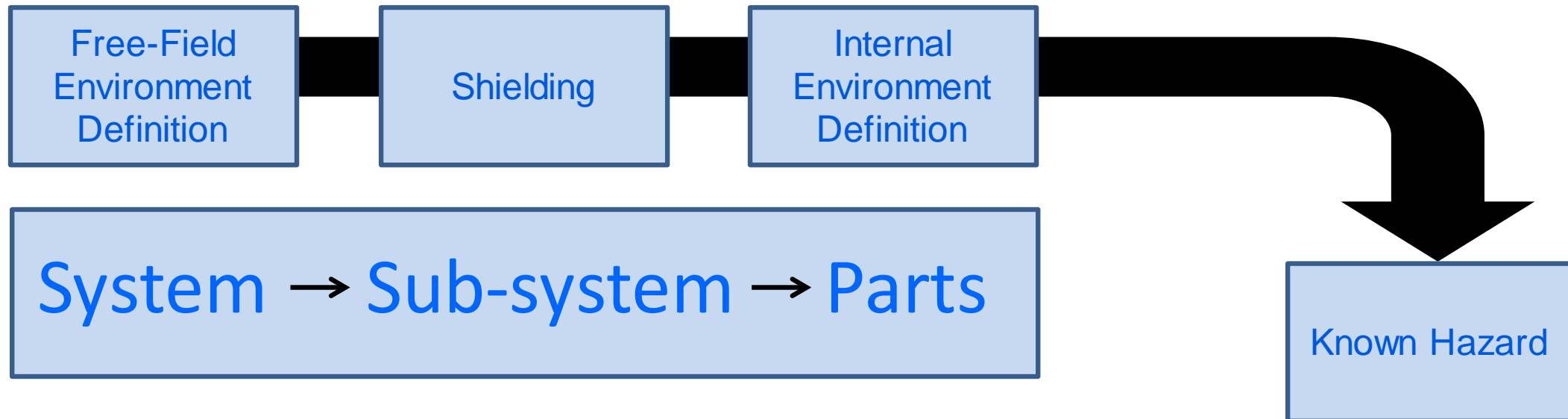
Environment Severity/Mission Lifetime

		Low	Medium	High
Evaluate RHA System Needs	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

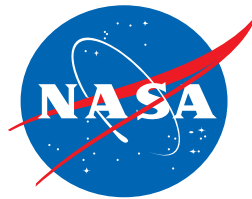


Define and Evaluate the Hazard

- 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



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



Environment Severity/Mission Lifetime

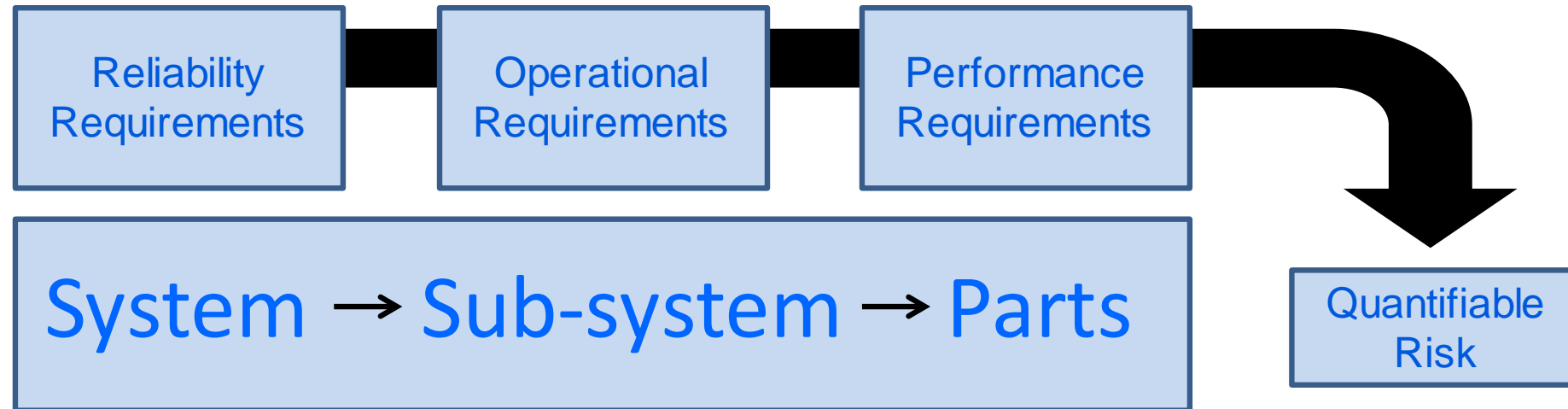
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		Low	Medium	High
Criticality	High	Dose-Depth / GCR and Proton Spectra for typical conditions	Dose-Depth evaluation at shielding / GCR and proton Spectra for all conditions	Ray-Trace for subsystem / GCR and proton Spectra for all conditions
	Medium	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

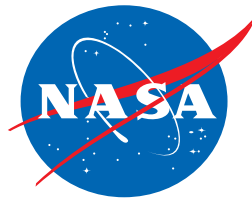


Derive Smart Requirements

- **Requirements by Technology**
 - By function or expected response (power, digital, analog, memory)
 - By semiconductor or fab (GaN, GaAs, SiGe, Si, 3D stacks, hybrids)
- Take into account the environment
- Take into account the application and criticality/availability needs
- Don't overburden subsystems

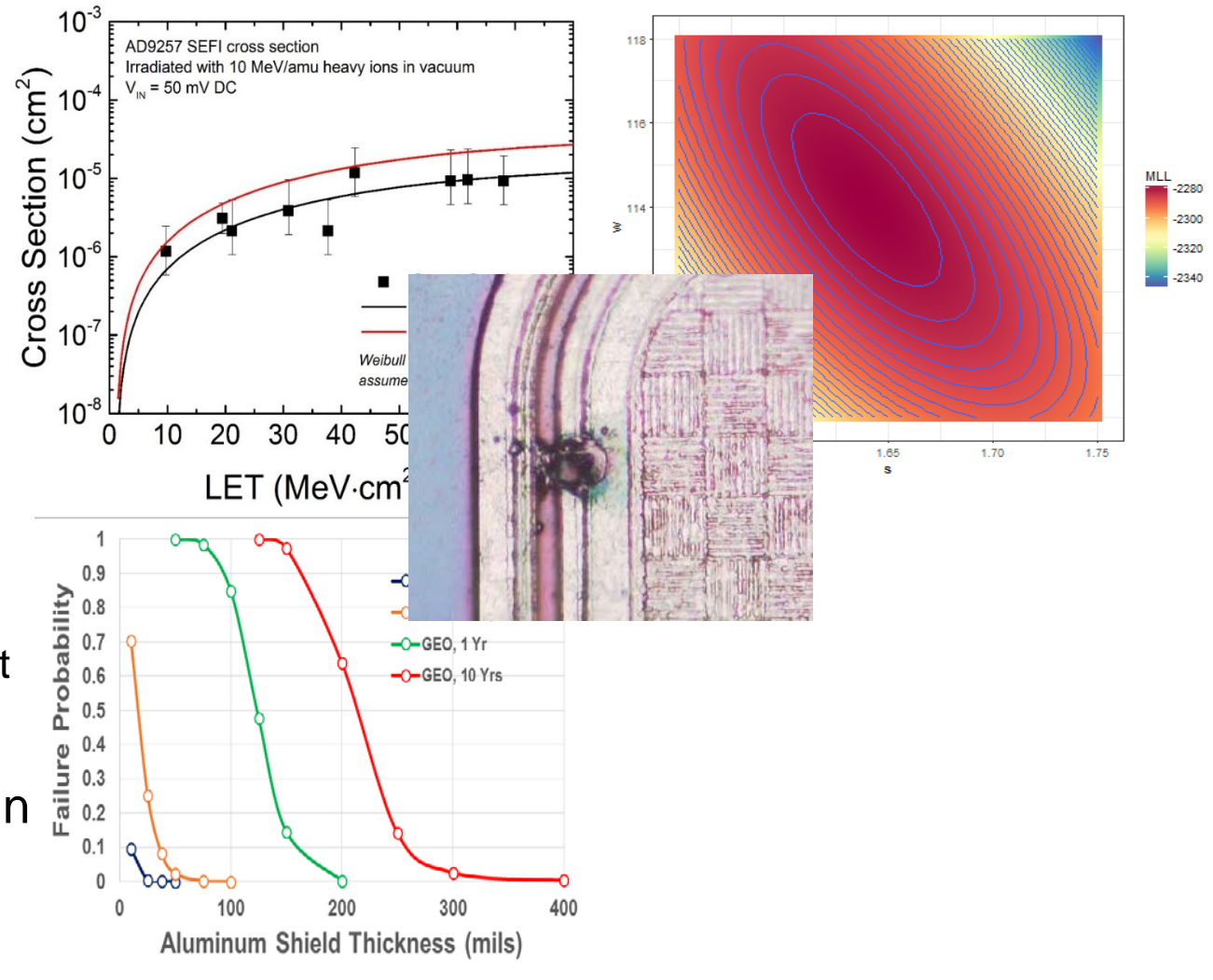


Requirements by Technology



- 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 need evaluated in detail:

https://nepp.nasa.gov/files/25401/Proton_RHAGuide_NASAAug09.pdf



Engineering Trades / Parts Evaluation



Environment Severity/Mission Lifetime

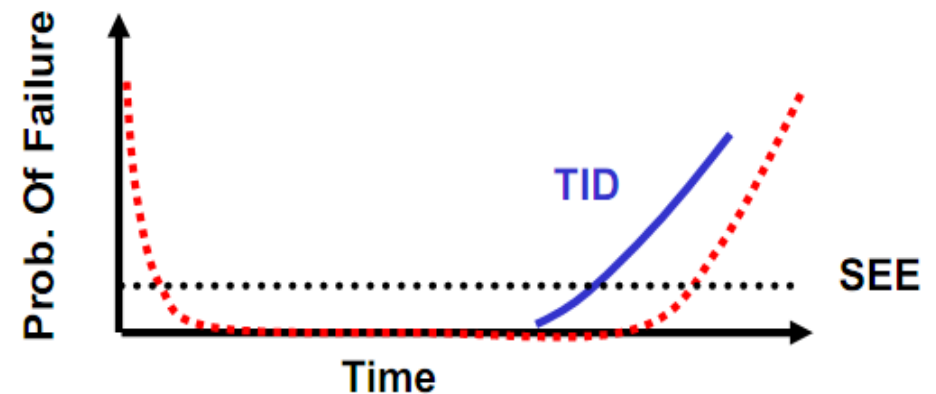
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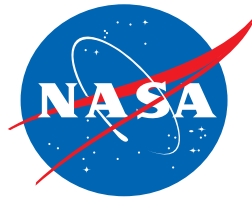
		Low	Medium	High
Part Criticality	High	Mitigate parameter drift / design to have upsets or resets occur	Add Shielding/ Mitigation to have upsets or resets occurring	Add Shielding/ Mitigation if known response Change parts or TEST
	Medium	Accept change in precision parameters / allow upsets	Accept change in precision parameters / mitigate upsets allow for reset	Add Shielding/ mitigation to have upsets or resets occurring
	Low	Carry High Risk	Accept change in precision parameters / allow upsets	Mitigate parameter drift / design to have upsets or resets occur

Engineering Trades / Parts Evaluation

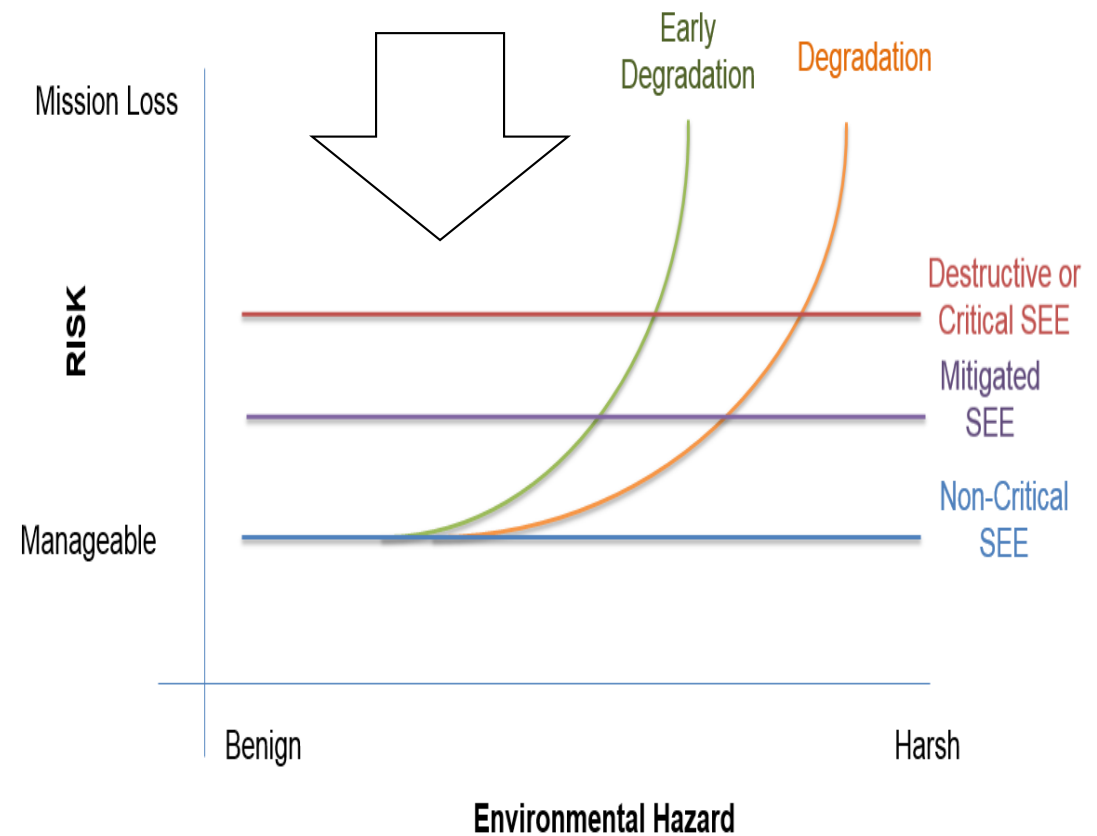
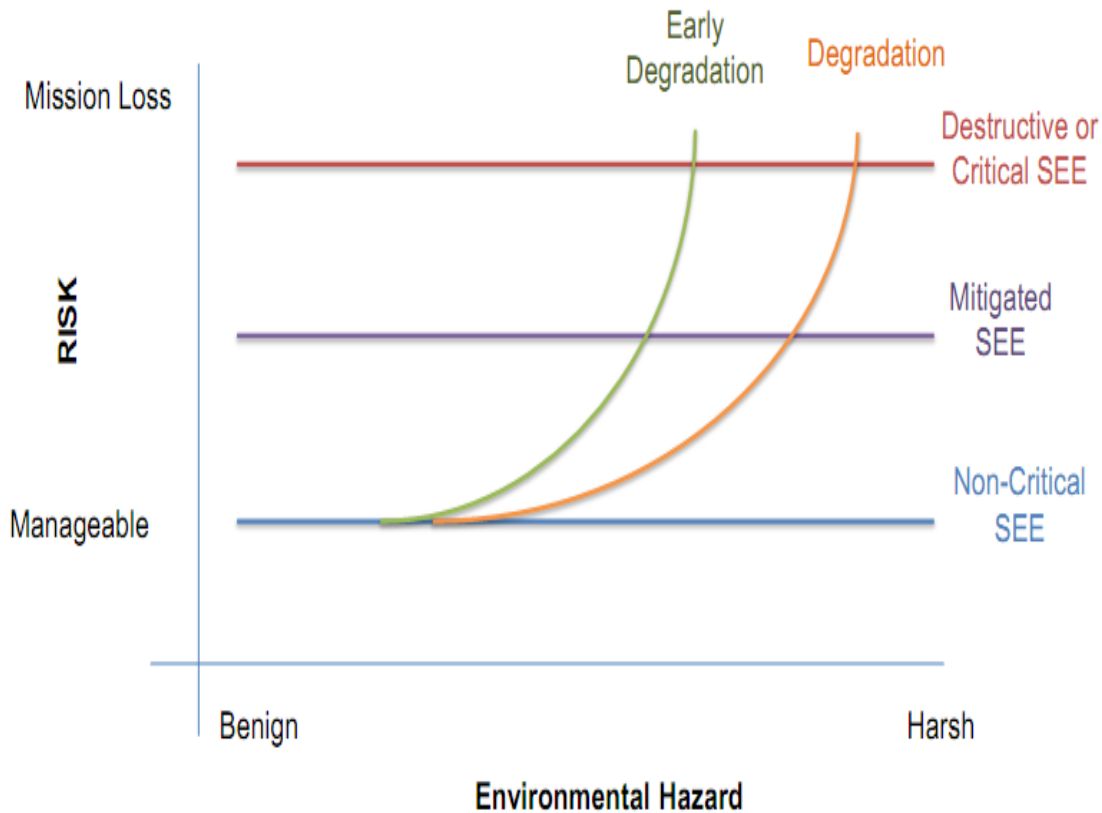


- Weigh the hazard and risk
 - Mission parameter changes impact the radiation hazard
 - Look at each part's response, compare with part criticality
 - Utilize applicable data and the physics of failure
 - Determine if error will manifest at a higher level
- Be conscious of design trades
 - Size, Weight, and Power (SWaP) trades need to be carefully considered
 - Parts replacement/mitigation is not necessarily the best
 - **Single strain vs. allowable losses**
- When 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

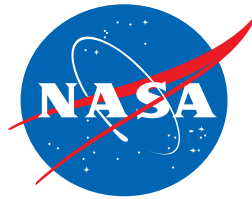




Single Strain vs. Allowable Losses



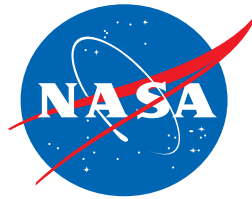
- Redundancy alone does not remove the threat
- Adds complexity to the design
- Diverse redundancy



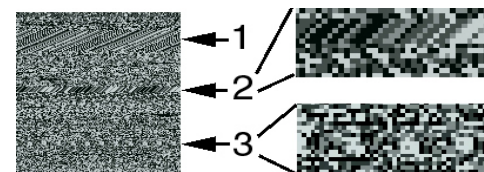
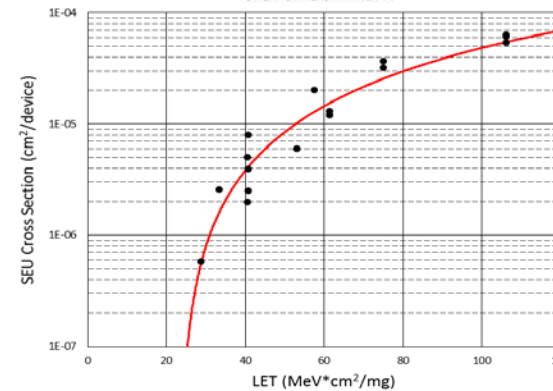
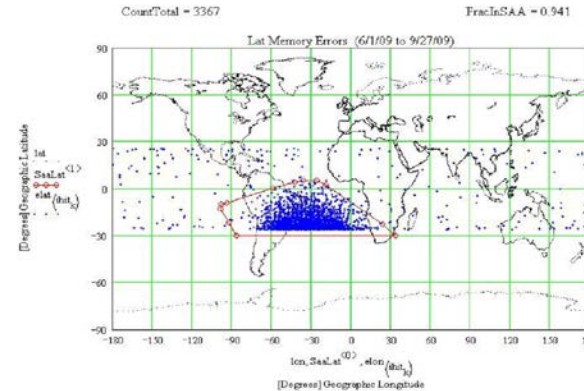
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Risk Hierarchy and Classification



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

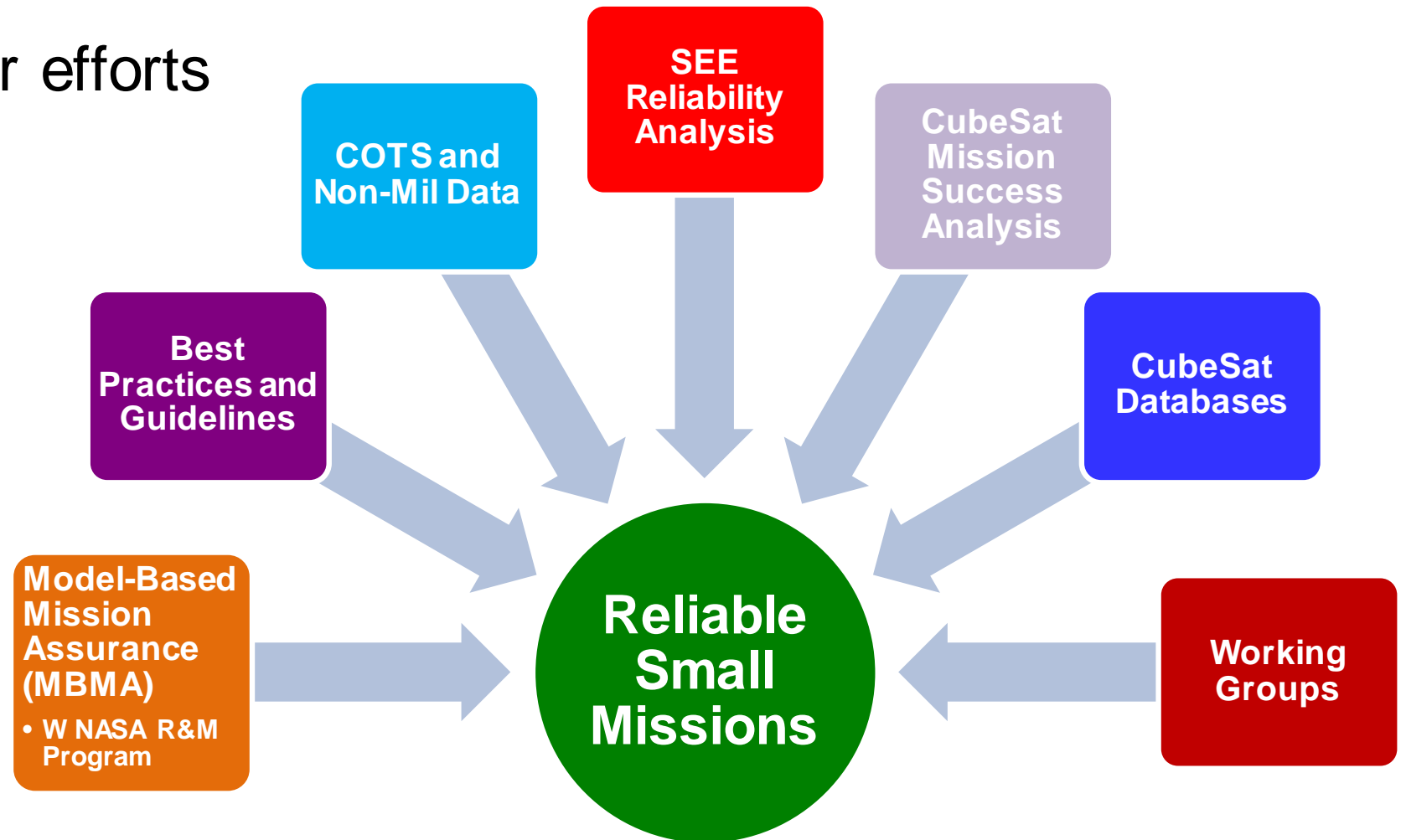


Part No.	Generic Part No.	Part Description	Package Type	Manufacturer	FM Part No.	Risk	SEU/SEGR/SEB	SEU ^b	SET ^b	SEFI ^b	TID/ELDRS ^c	DD ^d
375	AT27C512R-90T	EPROM	28-TSOP	ATMEL	AT27C512R-90T	Medium	Ta	Ta	As	Ta	Ta	As
380	AT49BV1614T-11T	Flash Ram	48-TSOP	ATMEL	AT49BV1614T-11T	Medium	Ta	Ta	As	Ta	Ta	As
500	BAT54	Schottky Barrier	SOT23	ZETEX	BAT54	Low	As	As	As	N/A	As	As
510	BAT54C	Schottky Barrier	SOT23	ZETEX	BAT54C	Low	As	As	As	N/A	As	As
505	BAT54S	Schottky Barrier	SOT23	ZETEX	BAT54S	Low	As	As	As	N/A	As	As
485	BAV170 (Pb Free)	Double diode	SOT23	Philips Semiconductor	BAV170 (Pb Free)	Low	As	As	As	N/A	As	As
490	BAV23	Double diode	SOT143	Philips Semiconductor	BAV23	Low	As	As	As	N/A	As	As
495	BAV99W	High-speed double diode	SOT323	Philips Semiconductor	BAV99W	Low	As	As	As	N/A	As	As
415	BC847BS	NPN double transistor	SC-88	Philips Semiconductor	BC847BS	Medium	As	As	As	N/A	Ta	As
420	BCV61C (Pb Free)	NPN double transistor	SOT143B	Philips Semiconductor	BCV61C (Pb Free)	Medium	As	As	As	N/A	Ta	As
425	BCV62C (Pb Free)	transistor	SOT143B	Philips Semiconductor	BCV62C (Pb Free)	Medium	As	As	As	N/A	Ta	As
410	BFR92	Wideband PNP double transistor	SOT23	Philips Semiconductor	BFR92	Medium	As	As	As	N/A	Ta	As
430	BFT92	PNP double transistor	SOT23	Philips Semiconductor	BFT92	Medium	As	As	As	N/A	Ta	As
385	CD74HC04M	Inverter	SO-14	Harris	CD74HC04M	Medium	As	As	As	As	Ta	As
395	CXA1439M	CDS	SO-8	SONY	CXA1439M	High	Ta	Ta	As	As	Ta	As
405	CXD1261AR	Timing Pulse Generator	QFP-64	SONY	CXD1261AR	High	Ta	Ta	As	As	Ta	As
400	CXD1267AN	Clock Driver	SO-20	SONY	CXD1267AN	High	Ta	Ta	As	As	Ta	As
315	ElanSC520-100A	CPU	388-PBGA	AMD	ElanSC520-100A	High	Ta	Ta	As	Ta	Ta	As
465	F-102	Current regulator diode	TBD	Sicovend	F-102	Low	As	As	As	N/A	As	As
445	FDC650P	FET	SSOT-6	Fairchild	FDC650P	High	Ta	As	As	N/A	Ta	As
325	HYS7V651620BLTC-10S	SDRAM	TSOPII	Hyundai	HYS7V651620BLTC-10S	High	Ta	Ta	As	Ta	Ta	As

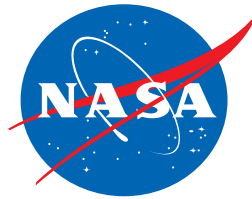


In-Flight Evaluation

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



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
- 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

Sponsor: NASA Electronic Parts and Packaging (NEPP) Program



michael.j.campola@nasa.gov

THANK YOU