Radiation Hardness Assurance (RHA): Challenges and New Considerations

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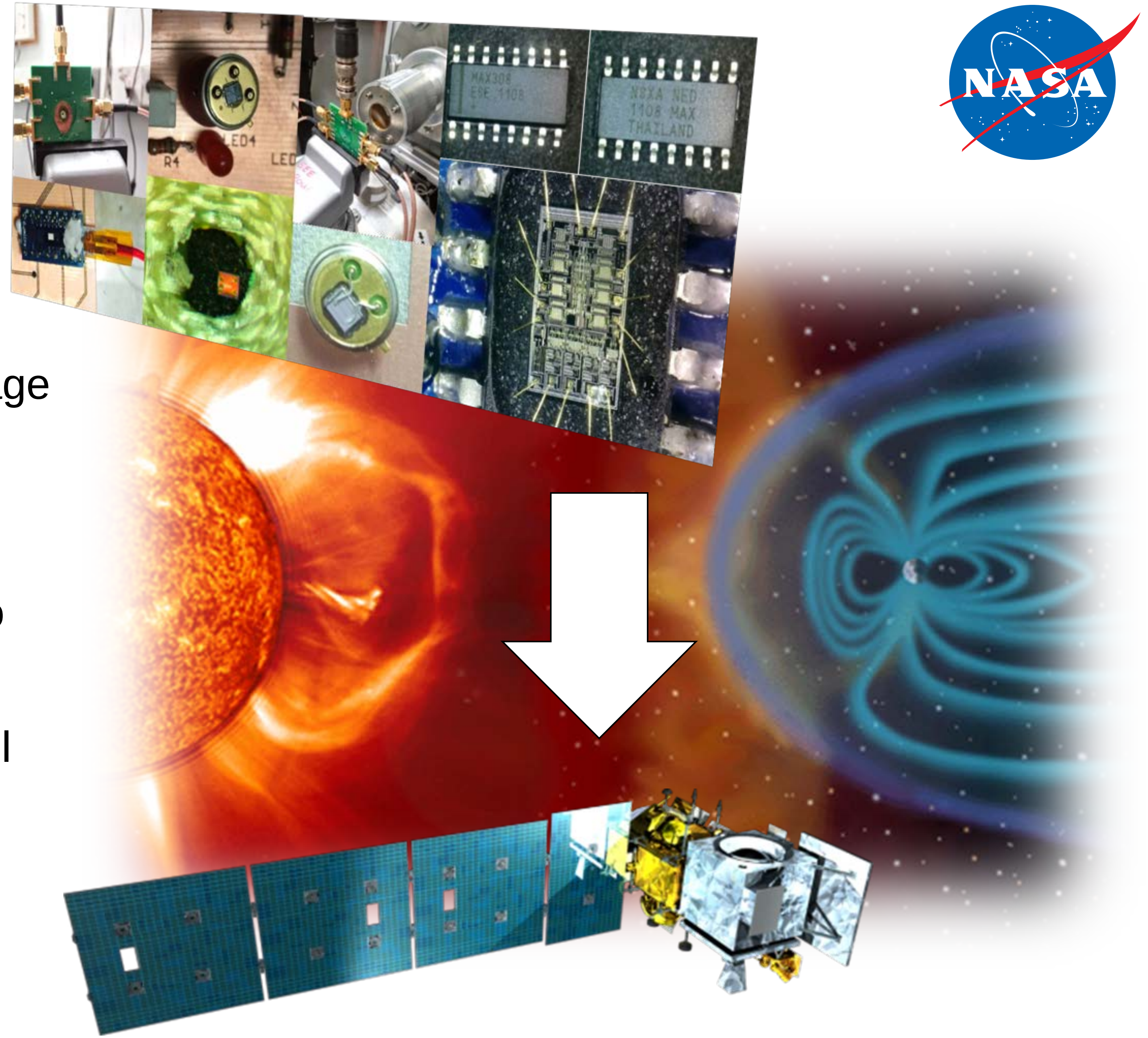
Acronyms

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

RHA Challenges

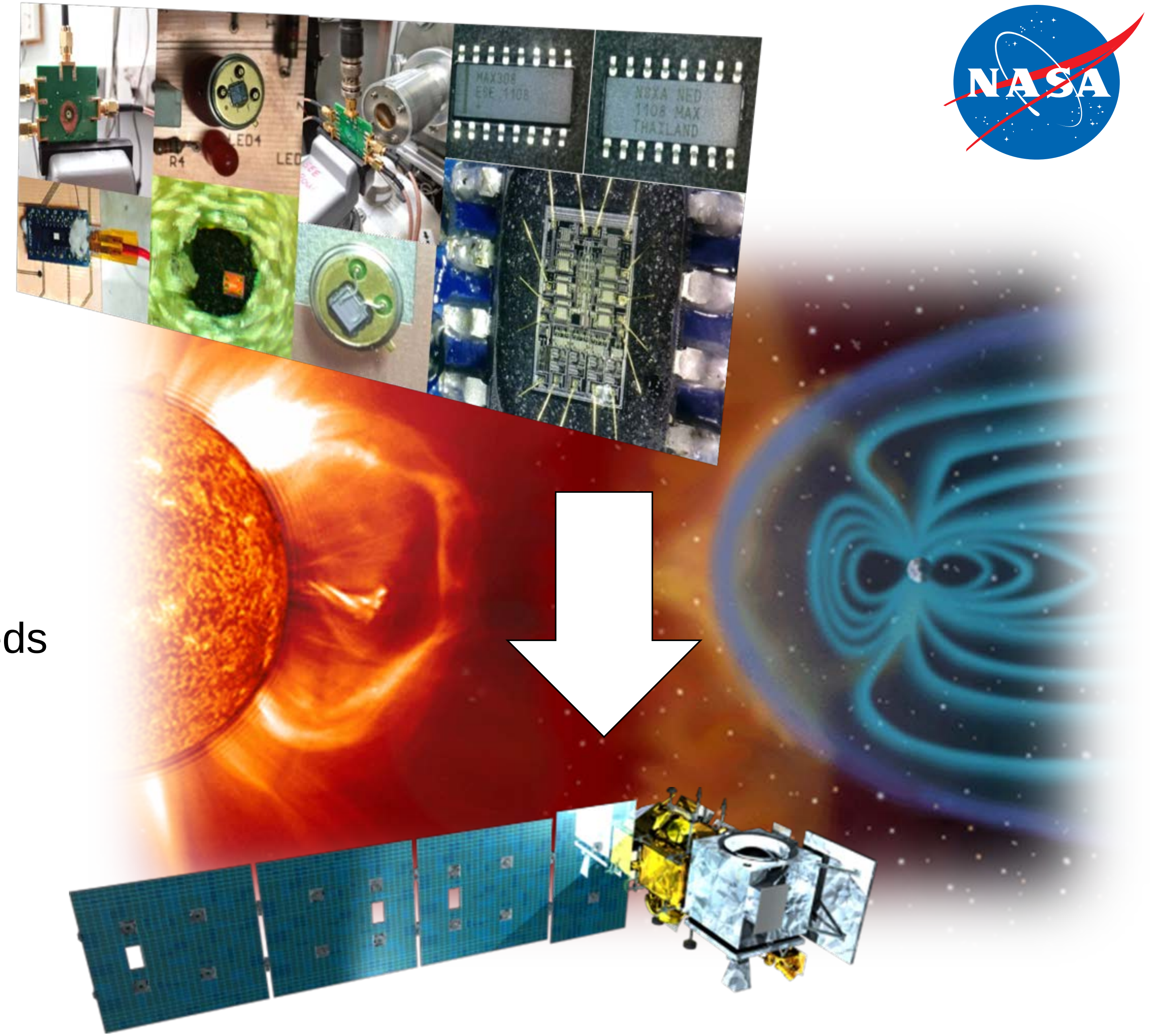
- New Technologies
  - Device Topology / Speed / Power
  - Modeling the Physics of Failure
- Increased COTS parts / subsystem usage
  - Traceability
  - Packaging / Copper bond wires
  - Thermal constraints
- Translation of system requirements into radiation pass / fail criteria
- Determining appropriate mitigation level (operational, system, circuit, software, device, material, etc.)



RHA Challenges

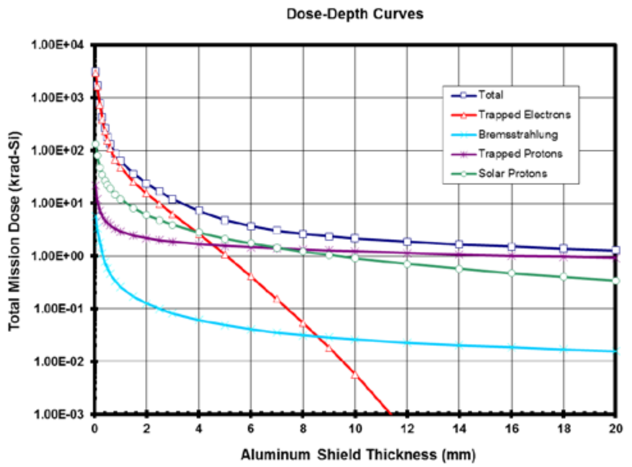
(The list goes on…)

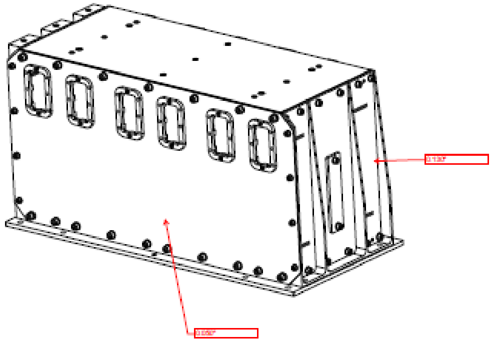
- Testing
  - Device topology / beam access
  - Specialized equipment needs
- Test Facility Access
  - More users / less time
- Wide range of mission profiles and needs
  - CubeSats / SmallSats
  - New targets
  - Continued service builds
- Always in a <u>dynamic</u> environment

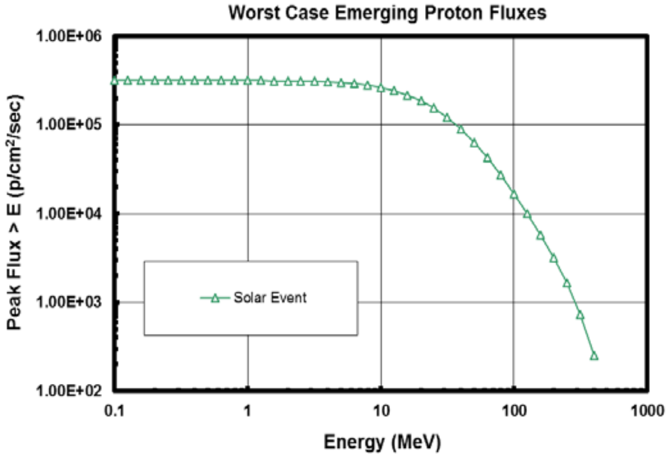


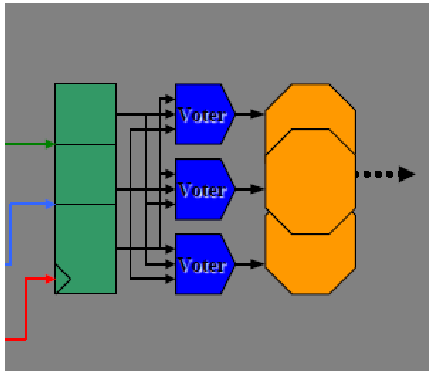
RHA Flow Doesn't Change With Risk or Mission

- **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





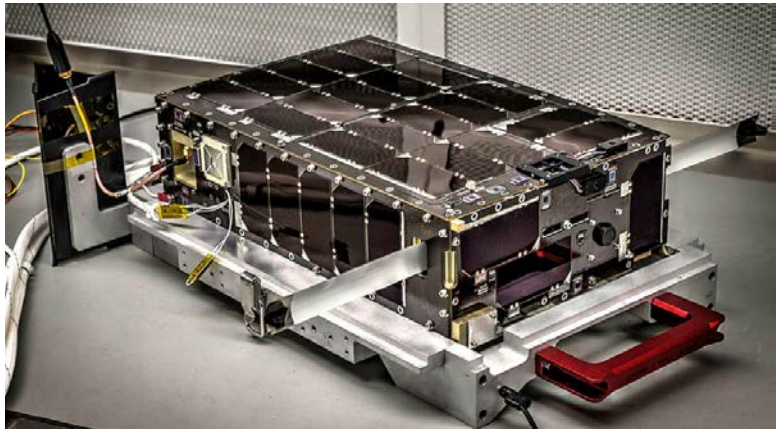




K.A. LaBel, A.H. Johnston, J.L. Barth, R.A. Reed, C.E. Barnes, "Emerging Radiation Hardness Assurance (RHA) issues: A NASA approach for space flight programs," IEEE Trans. Nucl. Sci., pp. 2727-2736, Dec. 1998.

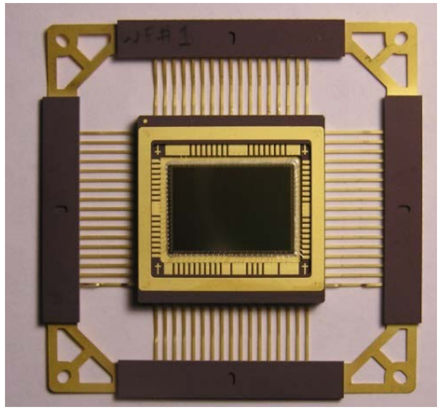
Risk Acceptance Will Change

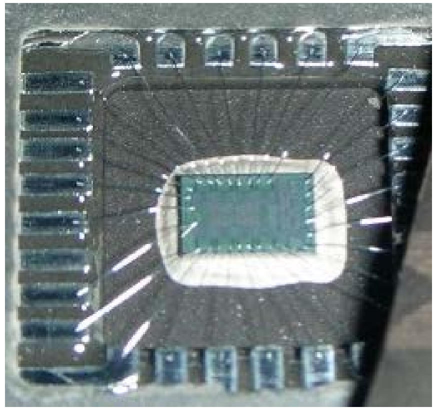
- Mission Profiles Are Expanding
  - Based on mission life, objective, and cost
  - Oversight gives way to insight for lower class
  - Ground systems, do no harm, hosted payloads
  - Similarity and heritage data requirement widening
  - In some cases **unbounded radiation risks are likely**



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

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





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
ISS	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

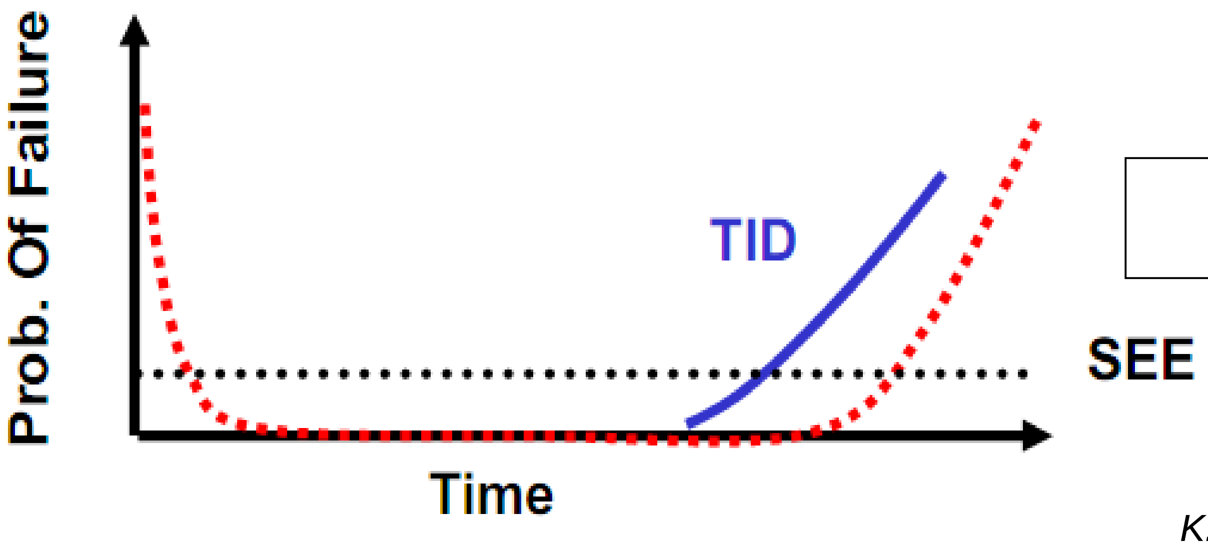
https://radhome.gsfc.nasa.gov/radhome/papers/SSPVSE05_LaBel.pdf

Two Example Missions

- **LEO Technology Demonstration**
  - SEE more of a driver than TID
  - Un-vetted technology

VS.

- **Interplanetary Asset**
  - Mission objectives
  - Exotic environment at target



Criticality	Environment/Lifetime: Low	Medium	High
Low	COTS upscreening/ testing optional; do no harm (to others)	COTS upscreening/ testing recommended; fault-tolerance suggested; do no harm (to others)	Rad hard suggested. COTS upscreening/ testing recommended; fault tolerance recommended
Medium	COTS upscreening/ testing recommended; fault-tolerance suggested	COTS upscreening/ testing recommended; fault-tolerance recommended	Level 1 or 2, rad hard suggested. Full upscreening for COTS. Fault tolerant designs for COTS.
High	Level 1 or 2 suggested. COTS upscreening/ testing recommended. Fault tolerant designs for COTS.	Level 1 or 2, rad hard suggested. Full upscreening for COTS. Fault tolerant designs for COTS.	Level 1 or 2, rad hard recommended. Full upscreening for COTS. Fault tolerant designs for COTS.

K.A. LaBel, J.A. Pellish, "Notional Radiation Hardness Assurance (RHA) Planning For NASA Missions: Updated Guidance" HEART Conference 2014.

RHA Risk Acceptance

- **Define the Environment**
  - External to the spacecraft
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  - Internal to the spacecraft
- **Define the Requirements**
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LEO Tech Demo

Environment/Lifetime

Criticality	Low	Medium	High
High	**Dose-Depth / Worst Case SEE Rate**	**Dose-Depth evaluation at thinnest shielding / SEE Rate Calculation**	**Ray-Trace for subsystem / SEE Criticality Analysis**
Medium	**Dose-Depth / SEE do no harm**	**Dose-Depth / Worst Case SEE Rate**	**Dose-Depth evaluation at thinnest shielding / SEE Rate Calculation**
Low	**Similar mission dose, same solar cycle / SEE do no harm**	**Dose-Depth / Worst Case SEE Rate**	**Dose-Depth / SEE Rate Calculation**

Interplanetary Asset

Environment/Lifetime

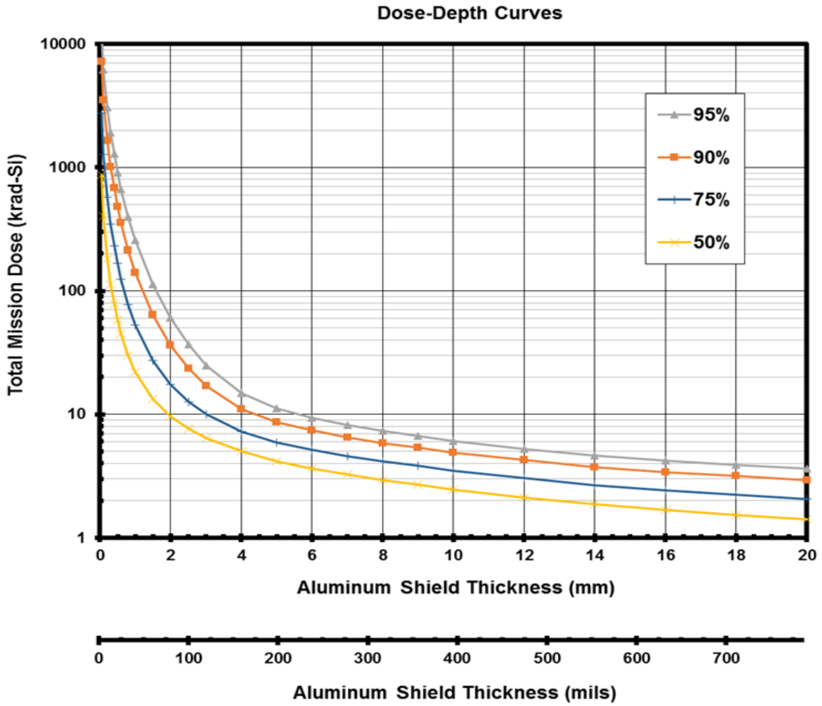
Criticality	Low	Medium	High
High	**Ray-Trace for subsystem / SEE Criticality Analysis**	**Ray-Trace for subsystem / SEE Criticality Analysis**	**Full Ray-Trace / SEE Criticality Analysis**
Medium	**Dose-Depth evaluation at thinnest shielding / SEE Rate Calculation**	**Ray-Trace for subsystem / SEE Rate Calculation**	**Ray-Trace for subsystem / SEE Criticality Analysis**
Low	**Dose-Depth / SEE do no harm**	**Dose-Depth / Worst Case SEE Rate**	**Dose-Depth evaluation at thinnest shielding / SEE Rate Calculation**

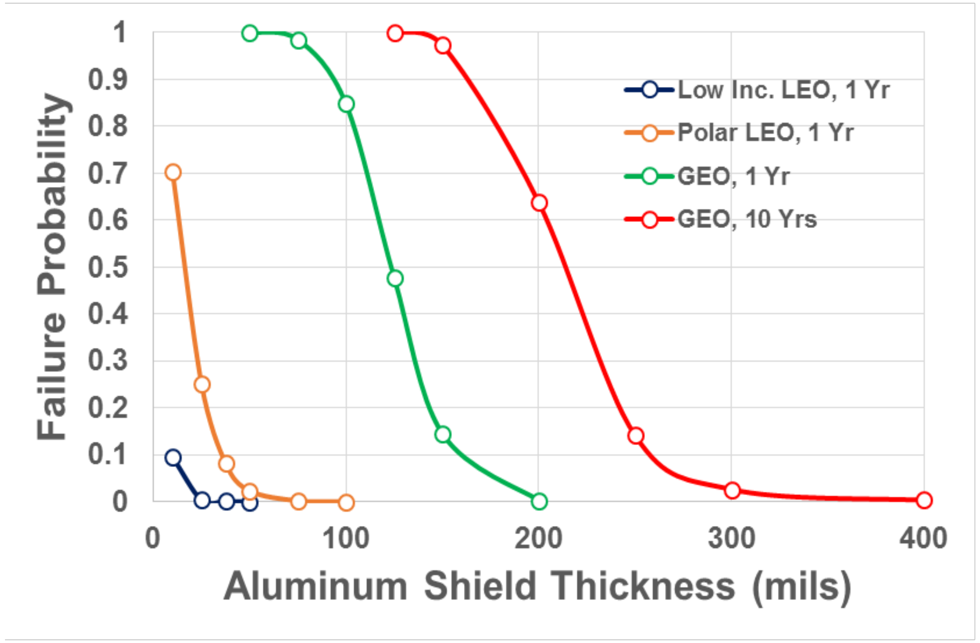
New Considerations: NEPP Efforts to Improve RHA

- <u>Define / Evaluate the Environment</u>
  - Inclusion of Environment Variability
    - » M. Xapsos; C. Stauffer; A. Phan; S. McClure; R. Ladbury; J. Pellish; M. Campola; K. LaBel, "Inclusion of Radiation Environment Variability in Total Dose Hardness Assurance Methodology," in *IEEE Transactions on Nuclear Science* , vol.PP, no.99, pp.1-1.
- <u>Define the Requirements</u>
  - Requirements by Technology
    - » JESD57 updates, establishes testing procedures.
    - » NEPP RHA guideline & Small Mission RHA .
- <u>Evaluate Design/Components and “Engineer” with Designers</u>
  - Bayesian Methodologies
    - » R. Ladbury, J. L. Gorelick, M. A. Xapsos, T. O'Connor and S. Demosthenes, "A Bayesian Treatment of Risk for Radiation Hardness Assurance," *2005 8th European Conference on Radiation and Its Effects on Components and Systems*, Cap d'Agde, 2005, pp. PB1-1-PB1-8.
    - » Ron Schrimpf’s MRQW talk before the break.

Inclusion of Environment Variability

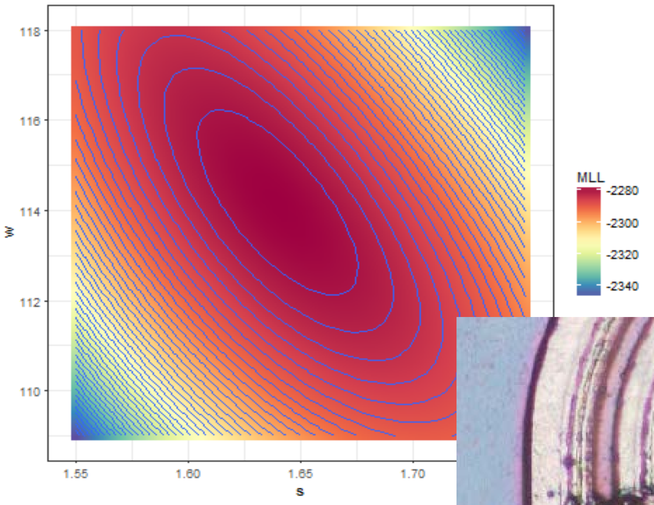
- Confidence levels on environment external to the spacecraft account for variation.
- Transport to spacecraft's internal environment remains the same.
- Convolution of part failure distribution with environment confidence removes the ambiguity of RDM while maintaining/tailoring conservatism for TID/DD.

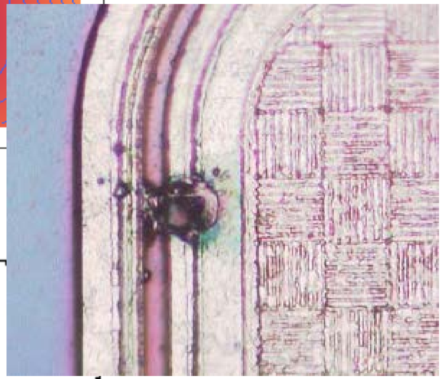


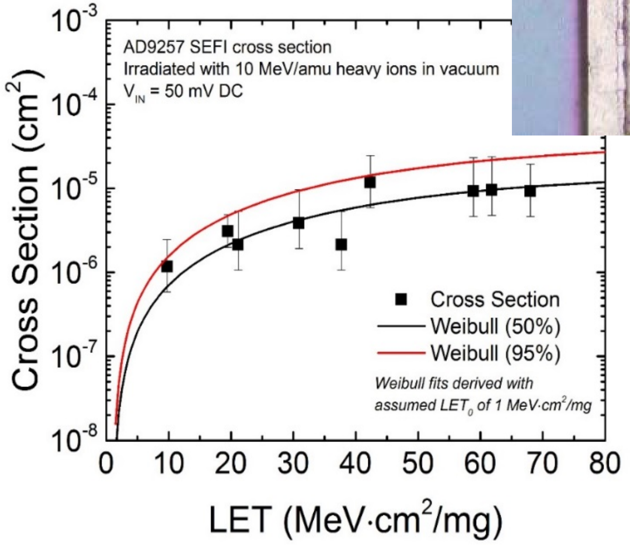


Requirements by Technology

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

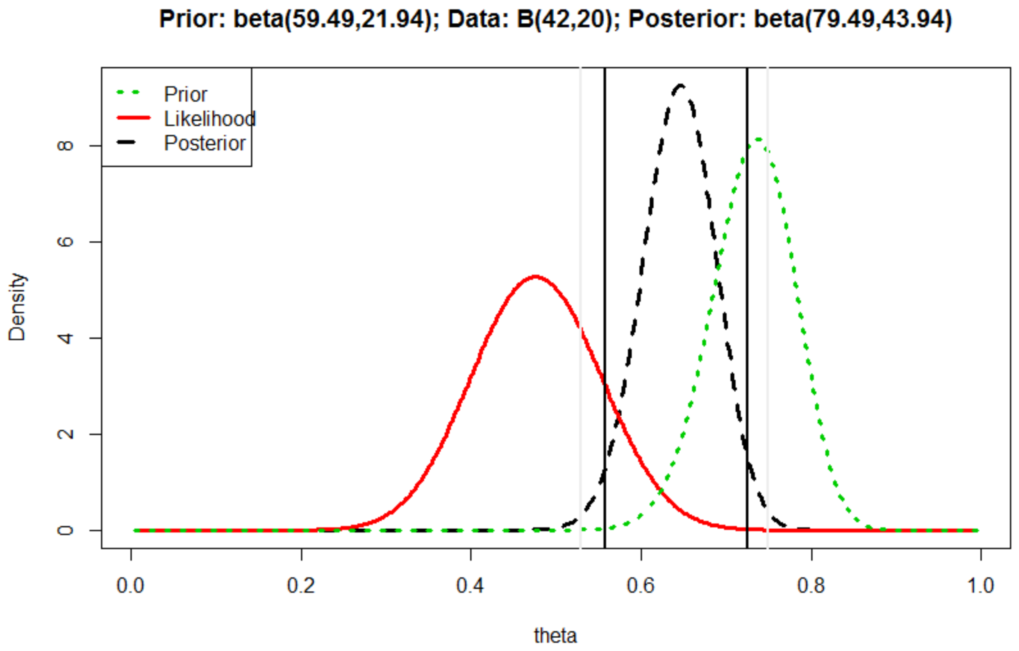






Bayesian Methodology

- Likelihood of Schottky Diode SEE failure at 0.5 -0.75 V_R (binomial)
  - All data (110/207)
  - Manufacturer data (33/42)
  - Part family data (23/30)
  - 100V parts (19/42)
- Priors
  1. Flat prior, uninformed
  2. Beta, informed by total failing at V_R (140/207)



Likelihood:	All		Manufacture		Family		100V	
Credible Set	95%	99%	95%	99%	95%	99%	95%	99%
Prior 1	.598	.618	.882	.907	.881	.909	.601	.645
Prior 2	.650	.667	.845	.864	.843	.864	.737	.761

Summary

- Challenges identified in the past are here to stay
- RHA flow doesn't change, risk acceptance needs to be tailored
- Varied missions profiles and environments don't necessarily benefit from the same risk reduction efforts or cost reduction attempts
- We need data with statistical methods in mind
- Risks versus rewards can have big impact on mission enabling technologies

- Sponsor: NASA Electronic Parts and Packaging (NEPP) Program

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THANK YOU