Radiation Hardness Assurance (RHA): Challenges and New Considerations

Michael J. Campola
NASA Goddard Space Flight Center (GSFC)
NASA Electronic Parts and Packaging (NEPP) Program

To be presented by M. J. Campola at the Single Event Effects (SEE) Symposium coupled with the Military and Aerospace Programmable Logic Devices (MAPLD) Workshop in La Jolla, California May 22-25, 2017
### Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>COTS</td>
<td>Commercial Off The Shelf</td>
</tr>
<tr>
<td>DD</td>
<td>Displacement Damage</td>
</tr>
<tr>
<td>GEO</td>
<td>Geostationary Earth Orbit</td>
</tr>
<tr>
<td>GSFC</td>
<td>Goddard Space Flight Center</td>
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<tr>
<td>LEO</td>
<td>Low Earth Orbit</td>
</tr>
<tr>
<td>LET</td>
<td>Linear Energy Transfer</td>
</tr>
<tr>
<td>MBU</td>
<td>Multi-Bit Upset</td>
</tr>
<tr>
<td>MCU</td>
<td>Multi-Cell Upset</td>
</tr>
<tr>
<td>NEPP</td>
<td>NASA Electronic Parts and Packaging</td>
</tr>
<tr>
<td>RDM</td>
<td>Radiation Design Margin</td>
</tr>
<tr>
<td>RHA</td>
<td>Radiation Hardness Assurance</td>
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<tr>
<td>SEB</td>
<td>Single Event Burnout</td>
</tr>
<tr>
<td>SEDR</td>
<td>Single Event Dielectric Rupture</td>
</tr>
<tr>
<td>SEE</td>
<td>Single Event Effects</td>
</tr>
<tr>
<td>SEFI</td>
<td>Single Event Functional Interrupt</td>
</tr>
<tr>
<td>SEGR</td>
<td>Single Event Gate Rupture</td>
</tr>
<tr>
<td>SEL</td>
<td>Single Event Latchup</td>
</tr>
<tr>
<td>SOA</td>
<td>Safe Operating Area</td>
</tr>
<tr>
<td>TID</td>
<td>Total Ionizing Dose</td>
</tr>
</tbody>
</table>
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 dynamic 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

Risk Acceptance Will Change

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

• Part Classifications Growing
  o Mil/Aero vs. Industrial
  o Automotive vs. Commercial

Credits: NASA's Goddard Space Flight Center/Bill Hrybyk
## Summary of Environmental Hazards

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

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

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**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

- 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
<table>
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<th>Environment/Lifetime</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Dose-Depth / Worst Case SEE Rate</td>
<td>Dose-Depth evaluation at thinnest shielding / SEE Rate Calculation</td>
<td>Ray-Trace for subsystem / SEE Criticality Analysis</td>
</tr>
<tr>
<td>Medium</td>
<td>Dose-Depth / Worst Case SEE Rate</td>
<td>Dose-Depth evaluation at thinnest shielding / SEE Rate Calculation</td>
<td>Dose-Depth / Worst Case SEE Rate Calculation</td>
</tr>
<tr>
<td>Low</td>
<td>Similar mission dose, same solar cycle / SEE do no harm</td>
<td>Dose-Depth / Worst Case SEE Rate</td>
<td>Dose-Depth / SEE Rate Calculation</td>
</tr>
</tbody>
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<th>Medium</th>
<th>High</th>
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</thead>
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<tr>
<td>High</td>
<td>Ray-Trace for subsystem / SEE Criticality Analysis</td>
<td>Ray-Trace for subsystem / SEE Criticality Analysis</td>
<td>Full Ray-Trace / SEE Criticality Analysis</td>
</tr>
<tr>
<td>Medium</td>
<td>Dose-Depth evaluation at thinnest shielding / SEE Rate Calculation</td>
<td>Ray-Trace for subsystem / SEE Rate Calculation</td>
<td>Ray-Trace for subsystem / SEE Criticality Analysis</td>
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<tr>
<td>Low</td>
<td>Dose-Depth / SEE do no harm</td>
<td>Dose-Depth / Worst Case SEE Rate</td>
<td>Dose-Depth evaluation at thinnest shielding / SEE Rate Calculation</td>
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New Considerations: NEPP Efforts to Improve RHA

• Define / Evaluate the Environment
  o Inclusion of Environment Variability

• Define the Requirements
  o Requirements by Technology
    » JESD57 updates, establishes testing procedures.
    » NEPP RHA guideline & Small Mission RHA.

• Evaluate Design/Components and “Engineer” with Designers
  o Bayesian Methodologies
    » 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
  - 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:
Bayesian Methodology

• Likelihood of Schottky Diode SEE failure at 0.5 - 0.75 $V_R$ (binomial)
  o All data (110/207)
  o Manufacturer data (33/42)
  o Part family data (23/30)
  o 100V parts (19/42)

• Priors
  1. Flat prior, uninformed
  2. Beta, informed by total failing at $V_R$ (140/207)

<table>
<thead>
<tr>
<th>Likelihood:</th>
<th>All</th>
<th>Manufacture</th>
<th>Family</th>
<th>100V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Credible Set</td>
<td>95%</td>
<td>99%</td>
<td>95%</td>
<td>99%</td>
</tr>
<tr>
<td>Prior 1</td>
<td>.598</td>
<td>.618</td>
<td>.882</td>
<td>.907</td>
</tr>
<tr>
<td>Prior 2</td>
<td>.650</td>
<td>.667</td>
<td>.845</td>
<td>.864</td>
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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
Thank you.

michael.j.campola@nasa.gov