Small Mission Radiation Hardness Assurance (RHA)

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NASA Electronic Parts and Packaging (NEPP) Program
Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</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>
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<tr>
<td>GSFC</td>
<td>Goddard Space Flight Center</td>
</tr>
<tr>
<td>LEO</td>
<td>Low Earth Orbit</td>
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<tr>
<td>LET</td>
<td>Linear Energy Transfer</td>
</tr>
<tr>
<td>MBU</td>
<td>Multi-Bit Upset</td>
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<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>
</tr>
<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>
NEPP - Small Mission Efforts

Reliable Small Missions

- COTS and Non-Mil Data
- SEE Reliability Analysis
- CubeSat Mission Success Analysis
- CubeSat Databases
- Working Groups

Best Practices and Guidelines

Model-Based Mission Assurance (MBMA)
- W NASA R&M Program

COTS and Non-Mil Data

SEE Reliability Analysis

CubeSat Mission Success Analysis

CubeSat Databases

Working Groups

To be presented by M. J. Campola at the NASA Electrical Parts and Packaging (NEPP) Electrical, Electronic, and Electromechanical (EEE) Parts for Electronics and Technology Workshop (ETW) June 2017

* 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**

• 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 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)
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

Define and Evaluate the Hazard

- Define the Environment
  - External to the spacecraft
- Evaluate the Environment
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### Environment Severity/Mission Lifetime

<table>
<thead>
<tr>
<th></th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Manageable Dose / SEE impact to survivability or availability</td>
<td>Moderate Dose / SEE impact to survivability or availability</td>
<td>High Dose / SEE impact to survivability or availability</td>
</tr>
<tr>
<td>Medium</td>
<td>Manageable Dose / SEE needs mitigation</td>
<td>Moderate Dose / SEE needs mitigation</td>
<td>High Dose / SEE needs mitigation</td>
</tr>
<tr>
<td>Low</td>
<td>Manageable Dose / SEE do no harm</td>
<td>Moderate Dose / SEE do no harm</td>
<td>High Dose / SEE do no harm</td>
</tr>
</tbody>
</table>
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

Free-Field Environment Definition → Shielding → Internal Environment Definition → System → Sub-system → Parts → Known Hazard
## Summary of Environmental Hazards

<table>
<thead>
<tr>
<th>Environment</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>No</td>
<td>Not usual</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>International Space Station</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>
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[https://radhome.gsfc.nasa.gov/radhome/papers/SSPVSE05_LaBel.pdf](https://radhome.gsfc.nasa.gov/radhome/papers/SSPVSE05_LaBel.pdf)
Derive Smart Requirements

- **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

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<th>Medium</th>
<th>High</th>
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</thead>
<tbody>
<tr>
<td><strong>High</strong></td>
<td>Dose-Depth / GCR and Proton Spectra for typical conditions</td>
<td>Dose-Depth evaluation at shielding / GCR and proton Spectra for all conditions</td>
<td>Ray-Trace for subsystem / GCR and proton Spectra for all conditions</td>
</tr>
<tr>
<td><strong>Medium</strong></td>
<td>Dose-Depth / GCR and proton spectra for background</td>
<td>Dose-Depth / GCR and Proton Spectra For background</td>
<td>Dose-Depth evaluation at shielding / All spectra conditions</td>
</tr>
<tr>
<td><strong>Low</strong></td>
<td>Similar mission dose, same solar cycle / GCR spectra</td>
<td>Dose-Depth / GCR spectra</td>
<td>Dose-Depth / GCR and Proton Spectra For background</td>
</tr>
</tbody>
</table>
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

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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:
  
Engineering Trades / Parts Evaluation

- Define the Environment
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- Evaluate the Environment
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<tr>
<td><strong>High</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mitigate parameter drift / design to have upsets or resets occur</td>
<td>Add Shielding/ Mitigation to have upsets or resets occurring</td>
<td>Add Shielding/ Mitigation if known response</td>
<td></td>
</tr>
<tr>
<td><strong>Medium</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accept change in precision parameters / allow upsets</td>
<td>Accept change in precision parameters / mitigate upsets allow for reset</td>
<td>Add Shielding/ mitigation to have upsets or resets occurring</td>
<td></td>
</tr>
<tr>
<td><strong>Low</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carry High Risk</td>
<td></td>
<td>Accept change in precision parameters / allow upsets</td>
<td>Mitigate parameter drift / design to have upsets or resets occur</td>
</tr>
</tbody>
</table>
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
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Single Strain vs. Allowable Losses

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

- 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
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- Iterate Process
  - Review parts list based on updated knowledge
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
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
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THANK YOU