Space Radiation Impacts to Satellites

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Image Credit: NASA
The Threat

*Space radiation damages components causing system/mission loss or limitation*

**Surface Charging:**
Charged particles collect on satellite surfaces producing high differential voltages, damaging arcs (electrostatic discharges), and electromagnetic interference.

**Internal Charging:**
Energetic electrons accumulate in interior dielectrics (circuit boards, cable insulators) and on ungrounded metal (spot shields, connector contacts) leading to electrical breakdown and discharge in the vicinity of sensitive electronics.

**Single Event Upsets:**
Energetic ion passage through microelectronic device node causes instantaneous catastrophic device failure, latent damage, or uncommanded mode/state changes requiring ground intervention.

**Total Dose:**
Energy loss (deposited dose) from proton/electron passage through microelectronic device active region accumulates over mission (or step-wise during high dose rate events) causing device degradation and reduced performance at circuit or system level.

*NASA ASIC Guide*
The Mitigation

*Sound design may prevent some space radiation impacts*

**Surface Charging:**
NASCAP-2K, SPIS, MUSCAT can be used to model surface charging using ISO worst case environments.

**Internal Charging:**
IRENE/AE9, Novice, Numit, FASTRAD can be used to simulate electron flux internal charging over mission or for specific systems. Follow NASA-HDBK-4002 guidelines.

**Single Event Upsets:**
CREME96, CRÈME-MC, Novice, IRENE/AP9 SEE effects kernel can be used to calculate SEE upset rates for components and shielding.

**Total Dose:**
IRENE/AE9/AP9, Novice, FASTRAD.
LEO/MEO Issues

Occurrence of anomalies depends on orbit/location

- **SEUs**
- **Surface Charging**

Most Common

- **Internal Charging**
- **Total Dose**

Less Common
Anomaly Attribution/Forensics

*No single space weather indicator can explain all issues at all locations*

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<thead>
<tr>
<th><strong>SEU</strong></th>
<th><strong>Total Dose</strong></th>
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| Cause: >10 MeV protons/heavy ions  
Steady trapped population near Earth  
Sporadic events related to solar activity (flares, CMEs)  
Galactic Cosmic Rays | Cause: Long duration intensification of the radiation environment |

Each are caused by different particle populations enhanced at different times in different locations

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<th><strong>Surface Charging</strong></th>
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| • Cause: ~10s keV electrons  
Occurs during substorms (Sporadic (every ~3 hours) reconfiguration of Earth’s magnetic field) | Cause: >100 keV electrons  
Occurs during storms (Days long global change of Earth’s magnetic field structure) |
LEO/MEO SEUs

*Stably trapped proton belt*

Proton belt forms a torus shaped region around Earth

Protons reach low altitudes (<2000 km) only in South Atlantic Anomaly magnetic field distortion

Peak fluxes vary by ~2 over solar cycle

There is always some probability of an anomaly occurring in the SAA

SEUs are instantaneous

Attribution/Forensics
- Use AP9 to define location of anomaly relative to high flux along orbit
LEO/MEO SEUs

Sporadic Solar Energetic Particles

Stream from the sun and fill high latitude polar caps

Last days to weeks

Some SEPs may be trapped and form a temporary new belt

None since Sep 2017

Attribution/Forensics:
• SWPC GOES proton plots and alerts indicate event in progress
• Human in the Loop Decision Tool [O’Brien et al. 2012]
• future Solar Particle Access Model (SPAM)
LEO/MEO SEUs

*Galactic Cosmic Rays*

High energy ions from outside our solar system

Always present at high latitudes at low levels

Anti-correlated with solar cycle

**Attribution/Forensics:**
- Statistical access regions from tools such as CREME96

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Green et al, 2010
LEO/MEO Surface Charging

*Auroral electrons*

Caused by energetic electrons accelerated in high latitude auroral regions

Attribution/Forensics:

*• SEAES tool developed by Aerospace indicates likelihood of charging at LEO but is not publicly available

• Human in the Loop Decision Tool [O’Brien et al. 2012]*

![Auroral electrons](image)
Extreme Events

The US Space Weather Action Plan (SWAP) Phase 1 created an initial report on radiation benchmarks for extreme events

  
- Gives some extreme event flux values for SEPs and GCRs

Work is underway to refine the benchmarks and deliver a Phase II report
Summary

Four different issues caused by space radiation
  • Surface charging, internal charging, SEUs, and total dose

Two major concerns at LEO
  • SEUs and surface charging

SEUs
  • Stably trapped proton belt (constant, low latitude)
  • Solar Energetic Protons (sporadic, high latitude)
  • Galactic Cosmic Rays (constant, high latitude)

Surface charging
  • High latitude auroral regions