Design and “As Flown” Radiation Environments for Materials in Low Earth Orbit

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Overview

- Introduction
  - ISS materials qualified for ~10 years on orbit to design environment
  - Some materials have now been exposed to periods of ~7 years
  - Can they be used longer to save replacement cost, effort?

- ISS Design Environments

- Construction of "As Flown" reference environment

- Summary
Issue

- SSP 30512 provides a conservative proton, electron environment for use in estimating radiation dose effects on materials

- ISS has been on orbit now for ~5 years
  - How does the “as-flown” environment compare to the (conservative) design environment?
  - How are materials qualified for 10 years holding up?
  - If design environment was conservative, can space exposed materials on exterior of ISS qualified for 10 years be used for longer periods before replacement is required
    - Significant program impact if replacement activities can be reduced (or eliminated)

- Add “as-flown” radiation environment to SSP-30512 to supplement the design environment for studies of on-orbit performance of materials
30512 Design Environment

SSP-30512 Revision C
“Radiation Environment for Design”

- Electron, proton environments for dose are conservative by design
  - 500 km, 51.6 deg inclination
  - AE-8 max, AP-8 max
  - Recommend 2x dose environment to account for solar particle events, cosmic rays, secondary particles, other sources not included in environment

- Dose in Si as function of depth in Al for:
  - Sphere electronics
  - Semi-infinite slabs surface coatings
  - 

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### Table 3.1.2: Energy Spectra for Trapped Electrons

<table>
<thead>
<tr>
<th>Energy (MeV)</th>
<th>Integral Flux (electrons/cm²·day)</th>
<th>Differential Flux (electrons/cm²·day·MeV)</th>
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</thead>
<tbody>
<tr>
<td>0.01</td>
<td>1.97E+07</td>
<td>1.70E+11</td>
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### Table 3.1.3: One Year Dose in Dense-Natural Aluminum Medium (RADS 5D) Sheet 1 of 2

<table>
<thead>
<tr>
<th>Shielding (MILS)</th>
<th>Shielding (CM)</th>
<th>Shielding (GAM)</th>
<th>Electrons</th>
<th>Protons</th>
<th>Total Dose</th>
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### Table 3.1.1: APEXMAX Differential and Integral Flux

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<th>Energy (MeV)</th>
<th>Integral Flux (protons/cm²·day)</th>
<th>Differential Flux (protons/cm²·day·MeV)</th>
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<td>6.03E-08</td>
<td>3.65E-08</td>
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</tbody>
</table>
30512 Design Environment

**Differential Flux**
- **Electrons**

**Integral Flux**
- **Electrons**

**Differential Flux**
- **Protons**

**Integral Flux**
- **Protons**

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AE-8/AP-8, Mean Altitude

- Quick analysis:
  - 2 years (May 2000-May 2002) ISS radiation fluence
  - Mean 390 km altitude used to compute dose in material

- No attempt to determine dose variations due to changes in ISS altitude
ISS Design, “As-Flown” Dose

- ISS cables insulated by 7 mil to 9 mil PTFE overwrap
  - (~0.2 mm per layer)

- 2 layers
  - 0.2 to 0.4 mm PTFE depending on whether cables are wrapped once or twice

- “As flown” dose ~10X design dose in 0.2 to 0.4 mm

- Suggests that 10 year estimated life of cables could be much longer
Predicted, Measured Dose

Need additional predicted vs measured dose information for electron energies <70 keV


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ISS "As Flown" Orbit

- **ISS ephemeris data:**
  - ISS two line element sets provide orbit information

- **Satellite Tool Kit (STK) Merged Simplified General Perturbations (MSGP4) propagator used to compute orbit:**
  - *SGP4 propagators required to compute ephemeris using NORAD (USSPACECOM) TLE set format*
  - Propagator model considers secular and periodic variations in orbit parameters due to Earth oblateness, solar and lunar gravitational effects, gravitational resonance effects and drag induced orbital decay

- **Generated ephemeris with MSGP4 propagator**
  - Period: 20 November 1998 to 1 June 2006
  - Time step: 60 seconds
  - Orbit file exported from STK as a geodetic longitude, latitude, and altitude text file for input to AE-8, AP-8
ISS “As flown”

AE-8/AP-8
Min
ISS “As flown”

AE-8/AP-8
Max
Objective Assignment of Solar Min or Max Models

- AE/AP models for solar maximum, minimum only

- Strategies typically adopted for use include
  - Most severe model for conservative design use
  - 7 yrs max, 5 yrs min for 11 year solar cycle
Solar Min/Max Weighting

- Objective technique used for determining when to use solar minimum or solar maximum version of AE-8/AP-8 models [Watts et al., 1996]

- \( \Phi = \alpha \Phi_{\text{max}} + (1-\alpha)\Phi_{\text{min}} \)
  where \( \Phi_{\text{max}} = \) AE-8, AP-8 max
  \( \Phi_{\text{min}} = \) AE-8, AP-8 min
  \( \alpha = \) F107 weighting factor
  = 0 for solar min
  = 1 for solar max

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25%/75%
ISS “As flown”

AE-8/AP-8
Min
Max
ISS “As flown”

AE-8/AP-8
Min
Max
Modules
"As-flown" Fluences

- Trapped electrons
- 30512 Design Environment

- Trapped protons
- GOES solar protons (GEO)
- GOES solar protons (LEO)
- 30512 Design Environment
Solar Protons

Event | >30 MeV fluence (#/cm²)
---|---
2000/07/12 | 4.3 x 10⁹
2000/08/00 | 3.2 x 10⁹
2001/09/24 | 1.2 x 10⁹
2001/11/04 | 3.4 x 10⁹
2003/10/28 | 3.4 x 10⁹
2005/01/15 | 1.0 x 10⁹

Total | 16.5 x 10⁹

Sources: Reedy, 2006
“As-flown” Dose

Zarya Dose Evaluation

- As-flown Environment
  - Trapped $\varepsilon^+$ + bremsstrahlung
  - Trapped $p^+$
  - Solar $p^+$
  - Total Dose

- SSP-30512 Design Environment
  - Trapped $\varepsilon^+$ + bremsstrahlung
  - Trapped $p^+$
  - Total Dose

Dose in Silicon (rads)

Aluminum Shielding Thickness (mm)
"As-flown" Dose Ratios

Zarya Dose Evaluation

SSP-30512/As-flown
- Trapped e\(^{-}\) + bremsstrahlung
- Trapped + Solar p\(^+\)
- Total Dose
- 2x Total Dose

Aluminum Shielding Thickness (mm)

SSP 30512 (rads-SI) / As-Flown (rads-SI)

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NOAA MEPED Data vs AE-8 Model

- NOAA 0 deg
- NOAA 90 deg
- AE-8
NOAA Data vs AE-8

0 deg

90deg
Daily Fluence Example

NOAA/MEPED vs AE-8 Fluence

Mean AE-8 Annual Fluence

Mean AE-8 Daily Fluence

AE-8
90 deg
0 deg

# / cm² sr

Date

1.0 1.2 1.4 1.6 1.8 2.0
NOAA Electrons

AE-8 omnidirectional flux
NOAA electrons measured in two orthogonal directions
-- 0 deg in zenith on zenith-nadir line
--90 deg perpendicular to velocity
Summary

- SSP 30512 design environment for dose over estimates actual flight dose
  - SSP 30512/as flown reference environment
    - ~2x to 4x for 0.01 mm to 100 mm
    - ~2x at minimum between 2 to 8 mm over qualification
  - 2x SSP 30512/as flown reference environment
    - ~4x to 8x for 0.01 mm to 100 mm
    - ~4x at minimum between 2 to 8 mm over qualification

- Dose includes
  - Trapped electrons, bremsstrahlung x-rays
  - Trapped protons, solar protons

- Materials originally qualified for ~10 to 15 years anticipated to be acceptable for use for periods of up
  - 20 to 30 years based on SSP-30512
  - 40 to 60 years based on 2x SSP-30512