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

- Constructin 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
  - Surface materials
### 30512 Design Environment

#### Table 3.1.3-1 AERMAX DIFFERENTIAL AND INTEGRAL FLUX

<table>
<thead>
<tr>
<th>Energy (MeV)</th>
<th>Integral Flux (electrons/cm²·day)</th>
<th>Differential Flux (electrons/cm²·MeV·day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.01</td>
<td>1.97E+10</td>
<td>1.70E+11</td>
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<tr>
<td>0.04</td>
<td>1.51E+10</td>
<td>1.31E+11</td>
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<td>0.07</td>
<td>1.17E+10</td>
<td>1.00E+11</td>
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<td>1.47E+10</td>
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<tr>
<td>0.90</td>
<td>1.60E+08</td>
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<tr>
<td>6.00</td>
<td>1.26E+07</td>
<td>1.00E+09</td>
</tr>
</tbody>
</table>

#### Table 3.1.3-2 ONE YEAR DOSE IN SEMICONDUCTOR ALUMINIUM MEDIUM

<table>
<thead>
<tr>
<th>Shielding (MILS)</th>
<th>Shielding (GAMMA)</th>
<th>Protons</th>
<th>Total Dose</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00E-01</td>
<td>0.08E+00</td>
<td>8.08E+00</td>
<td>1.91E+00</td>
</tr>
<tr>
<td>2.00E-01</td>
<td>0.16E+00</td>
<td>8.16E+00</td>
<td>3.60E+00</td>
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<tr>
<td>3.00E-01</td>
<td>0.24E+00</td>
<td>8.24E+00</td>
<td>5.30E+00</td>
</tr>
<tr>
<td>4.00E-01</td>
<td>0.32E+00</td>
<td>8.32E+00</td>
<td>7.00E+00</td>
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<tr>
<td>5.00E-01</td>
<td>0.40E+00</td>
<td>8.40E+00</td>
<td>8.70E+00</td>
</tr>
</tbody>
</table>

**Note:** The above tables provide the integral and differential fluxes for trapped electrons and protons, along with the corresponding one-year dose in a semiconducting aluminum medium. These values are critical for the design of radiation-hardened electronic systems in space environments.
30512 Design Environment

Differential Flux
Electrons

Integral Flux
Electrons

Differential Flux
Protons

Integral Flux
Protons

Electron Energy (MeV)

Proton Energy (MeV)

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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

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

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

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ISS “As flown”

AE-8/AP-8
Min


Time (UT)
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

\( \alpha = 0 \) for solar min

\( \alpha = 1 \) for solar max
20%/80%
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

<table>
<thead>
<tr>
<th>Event</th>
<th>&gt;30 MeV fluence (#/cm^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000/07/12</td>
<td>4.3 x 10^9</td>
</tr>
<tr>
<td>2000/08/00</td>
<td>3.2 x 10^9</td>
</tr>
<tr>
<td>2001/09/24</td>
<td>1.2 x 10^9</td>
</tr>
<tr>
<td>2001/11/04</td>
<td>3.4 x 10^9</td>
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<tr>
<td>2003/10/28</td>
<td>3.4 x 10^9</td>
</tr>
<tr>
<td>2005/01/15</td>
<td>1.0 x 10^9</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>16.5 x 10^9</strong></td>
</tr>
</tbody>
</table>

Sources: Reedy, 2006

![Graph showing proton rigidity vs. transmission](graph.png)
"As-flown" Dose

Zarya Dose Evaluation

As-flown Environment
- Trapped $\gamma$ + brem
- Trapped $p^+$
- Solar $p^+$
- Total Dose

SSP-30512 Design Environment
- Trapped $\gamma$ + brem
- 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
- $2 \times$ Total Dose

Graph showing the relationship between aluminum shielding thickness (mm) and dose ratios for Zarya Dose Evaluation.
NOAA MEPED Data vs AE-8 Model

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

0 deg

90 deg
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

Date

1.0 1.2 1.4 1.6 1.8 2.0

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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