Recent Progress in Space Radiation Environment Models

Michael Xapsos and Janet Barth
NASA/Goddard Space Flight Center
Jean-Marie Lauenstein
Muniz Engineering, Inc.
Environments and Effects
Overview

Plasma
- Charging
  - Biasing of instrument readings
  - Pulsing
  - Power drains
  - Physical damage

Particle radiation
- Ionizing & Non-Ionizing Dose
  - Degradation of micro-electronics
  - Degradation of optical components
  - Degradation of solar cells
- Single Event Effects
  - Data corruption
  - Noise on Images
  - System shutdowns
  - Circuit damage
- Drag
  - Torques
  - Orbital decay

Neutral gas particles
- Surface Erosion
  - Degradation of thermal, electrical, optical properties
  - Degradation of structural integrity

Ultraviolet & X-ray
  - Degradation of thermal, electrical, optical properties
  - Degradation of structural integrity

Micrometeoroids & orbital debris
- Impacts
  - Structural damage
  - Decompression

Space Radiation Effects

after Barth
Deep space missions may also see neutrons from planetary background and other trapped particle belts. Earth’s atmospheric and terrestrial radiation includes secondary particles such as neutrons produced by GCR and solar particles.
Outline

- Background - Solar Activity Cycle
- Solar Particle Events
- Galactic Cosmic Rays (GCR)
- Trapped Particles
- Displacement Damage Models for Solar Cells
- Summary
The Solar Activity Cycle

- Solar cycle is typically 11 years:
  - Solar Maximum (7 years)
  - Solar Minimum (4 years)

- Solar particle event, galactic cosmic ray and trapped particle fluxes all vary throughout cycle.
The Solar Activity Cycle

- Common indicators of solar activity:
  - Sunspot numbers
  - 10.7 cm radio flux

[Graph showing sunspot numbers from 1947 to 1997, labeled Cycle 18, Cycle 19, Cycle 20, Cycle 21, and Cycle 22.]
Solar Particle Events

- Occur randomly in time, more frequently during solar maximum
- Event sizes span orders of magnitude; generally larger during solar maximum
- Radiation consists of protons, heavy ions, electrons, x-rays, etc.
- Particle energies up to ~GeV/n
- Duration: hours to days
- Large events may have:
  » Integral fluence > $10^9$ cm$^{-2}$
  » Ionizing dose > 1 krad(Si)
  » Damage equivalence > $10^{13}$ 1 MeV electrons / cm$^2$
1.4% average power loss on CLUSTER spacecraft

ANNEX 1: Evolution of the Solar Array Power from 24-Oct to 02-Nov 2003 when two solar radiation storms occurred (the time of their maximum is indicated in the plot “---”). The degradation of the panels was about 1.4% and the average power loss is shown for each spacecraft. The perigee passes are marked as "....." and labeled with “P”
Solar Proton Event Models

- Predict proton fluences during solar max for given confidence level and mission duration
  - King/Stassinopoulos
  - JPL91
  - NASA ESP
    - Based on cycles 20-22
    - 1-300 MeV protons
    - Describes complete range of event sizes
  - NASA PSYCHIC
    - Continuation of ESP to include solar min, arbitrary orbits, heavy ions; available this year
Galactic Cosmic Rays

CNO - 24 Hour Averaged Mean Exposure Flux

Energy = 25-250 MeV/n - IMP-8

Date

Trapped Particles

after Hess
Recent Developments in Trapped Proton Models

![Graph showing differential flux vs. energy for different models: TPM-1 Quiet Sol Min, TPM-1 Quiet Sol Max, PSB97 Sol Min, AP-8 Sol Min, and AP-8 Sol Max. The x-axis represents energy in MeV, ranging from 1 to 1000, and the y-axis represents differential flux in MeV$^{-1}$ cm$^{-2}$ s$^{-1}$. The graph compares the models across a range of energies, highlighting their differences in predicting trapped proton fluxes.]
Recent Developments in Trapped Electron Models

- POLE Ave Sol Max
- POLE Ave Sol Min
- AE-8 Sol Max

Energy (MeV) vs. Differential Flux (MeV$^{-1}$cm$^{-2}$s$^{-1}$)
Displacement Damage Models

- **JPL Model for radiation degradation of solar cells**
  - Based on experimental data
  - Useful for experimentally well-characterized cells

- **NRL Model for radiation degradation of solar cells**
  - Based on limited experimental data and nonionizing energy loss (NIEL) calculations
  - Useful for characterizing new technologies

- **WinNIEL Model**
  - Provides NIEL values not previously available for wide ranges of particle energies and many solar cell materials
  - Extends utility of NRL Model
Nonionizing Energy Loss in Silicon

Carbon NIEL and LET in Silicon

Incident Carbon Ion Energy (MeV) vs. NIEL or LET (MeV-cm²/g)
Summary

♦ Models covered:
  » Solar particle events
  » Galactic cosmic rays
  » Trapped particles
  » Displacement damage

♦ References:
  » MSFC SEE Program – http://see.msfc.nasa.gov
  » SPENVIS – www.spenvis.oma.be/spenvis/