Single Event Effects: 
Space and Atmospheric Environments

Janet L. Barth 
NASA/GSFC 
Flight Data Systems & Radiation Effects

Single Event Upsets 
in Future Computing Systems 
Jet Propulsion Laboratory 
May 20, 2003

Outline

- Sun-Earth Connections
- Heavy Ions
  - Galactic Cosmic Rays
  - Solar Particle Events
- Protons
  - Solar Particle Events
  - Trapped
- Atmospheric Neutrons
- Summary
The Radiation Environment

Nikkei Science, Inc. of Japan, by K. Endo

The 11-Year Solar Activity Cycle

Sunspot cycle discovered by Schwab in 1844

Little Ice Age in 1645 to 1715

Length varies from 9 - 13 years
7 Years Solar Maximum, 4 Years Solar Minimum
**Solar Flare & Particles**
SOHO Instruments/EIT & LASCO

Solar flares are observed as sudden brightening near sunspots.
The solar system's largest explosive events.
Particles are accelerated directly by event.

**Coronal Mass Ejections**
- Bubble of gas & magnetic field
- Ejects billions of tons of matter.
- Shock wave accelerates particles to millions of km/hr throughout the Solar System.
CME Movies – SOHO/LASCO

Heavy Ions – Galactic Cosmic Ray & Solar
**Galactic Cosmic Ray Ions – Relative Abundance**

Energy = 2 GeV/n, Normalized to Silicon = $10^6$

**Heavy Ion Measurements**

CNO - 24 Hour Averaged Mean Exposure Flux

Date 10

J. Barth/551 – 5/03
Heavy Ion LET Spectra
Transient Particles Unattenuated by the Magnetosphere

LET (MeV·cm²/mg)

GCR Heavy Ions as a Function of Orbit
CREME 96, Solar Minimum, 100 mils (2.54 mm) Al

LET Fluence (#/cm²/day)

LET (MeV·cm²/mg)

Protons – Solar & Trapped

Solar Proton Events
Proton Event Fluences

Year

J. Barth/561 – 5/03
TIROS – Proton Detector

Day Before Coronal Mass Ejection

TIROS – Proton Detector

November 6, 1997 Coronal Mass Ejection
TIROS – Proton Detector

November 7, 1997 Coronal Mass Ejection

TIROS – Proton Detector

Day After Coronal Mass Ejection
**Trapped Particle Motions**

Spiral, Bounce, Drift

- Flux Tube
- Trapped Particle Trajectory
- Mirror Point
- Electron Drift
- Magnetic Field Line
- Conjugate Mirror Point

*after Hess*

J. Barth/561 - 5/03

---

**Van Allen Belts**

- High Latitude Horns

*J. Barth/561 - 5/03*
**Trapped Protons – AP-8**

$E > 30$ MeV ($\#/cm^2/s$) - Solar Minimum

**Trapped Proton Predictions**

$l=90$ deg, $H=1000/1000$ km, Solar Minimum
**Seastar - Single Event Upsets**

Single Event Upsets on Flight Data Recorder
January 1 - December 25, 1999 - 705 km

No science data lost

**Trapped Protons – Solar Cycle**

Solar Cycle Variation: 80-215 MeV Protons

Date: Huston et al.24

J. Barth/561 - 5/03
CRRES - Proton Storm Belt

Planetary Magnetospheres/Trapping
**Atmospheric Neutrons**

**Neutrons**

- **Source - Secondary products of particle cascades**
  - Spacecraft materials
  - Galactic cosmic ray collisions with atmospheric O & N
- **Single event upset (latch-up?) hazard**
  - Ground level
  - Avionics
  - Low Earth Orbits - Shuttle
- **First recognized as problem in 1980s**
3 Models

- Boeing
  » Function of Latitude, Altitude, and Energy
  » Based on Studies by Mendall, Korff, and Armstrong
  » Easy to Use
  » Accurate

- Wilson-Nealy
  » Function of Magnetic Rigidity & Atmospheric Depth
  » More Accurate
  » Includes Solar Cycle Modulation

- Wilson
  » AIR model
  » New model funded by NASA's Living With a Star Program

Neutron Models: Flux vs. Altitude

1-10 MeV Atmospheric Neutron Flux

Altitude (Thousands of feet)
Neutron Model: Flux vs. Latitude

1-10 MeV Atmospheric Neutron Flux

Latitude (deg N)

Neutron Model: Flux vs. Energy

Differential Neutron Flux - Atmospheric

Energy (MeV)
Variations in Neutron Levels

- Magnetic rigidity determines distribution
- Solar cycle modulation
  - Function of Galactic Cosmic Ray levels
    - Solar minimum - Higher
    - Solar maximum - Lower
  - Measured difference ~ 25%
  - Levels increase with solar events - Dyer et al.
- Dependent on atmospheric conditions
- Very penetrating - Aircraft shielding reduces levels by ~ 10%

Summary
**Solar Cycle Effects**

- **Solar Maximum**
  - Trapped proton levels lower
  - Background GCR levels lower
  - Solar events more frequent & greater intensity
  - Background neutrons levels lower but can increase suddenly from solar events

- **Solar Minimum**
  - Trapped protons higher
  - GCR levels higher
  - Solar proton events are rare
  - Background neutrons levels are higher

**Space Environment Models**

- Mission Concept
- Mission Planning
- Design
- Launch
- Operations

- Space Climate
  - Minimize Risk

- Space Weather
  - Manage Residual Risk

- Both

J. Barth/561 – 5/03

J. Barth/561 – 5/03

18