Model for Cumulative Solar Heavy Ion Energy and LET Spectra

Mike Xapsos and Janet Barth
NASA Goddard Space Flight Center
Craig Stauffer
Muniz Engineering, Inc.
Tom Jordan
EMPC Consultants
Richard Mewaldt
California Institute of Technology

Outline

- Introduction to PSYCHIC* Model
- Solar Protons
  - Data
  - Results
  - Summary
- Solar Heavy Ions
  - Data
  - Results
  - Summary

*Prediction of Solar particle Yields to Characterize Integrated Circuits

To be presented by Mike Xapsos at the IEEE Nuclear and Space Radiation Effects Conference (NSREC) Technical Session, July 23-27, 2007 and to be published on http://rahome.gsfc.nasa.gov
Introduction

- It is especially important to have predictive models for solar particle event fluences and fluxes for missions away from Earth’s magnetic field.
  - Geosynchronous
  - Polar
  - Interplanetary
- Current solar heavy ion models:
  - CREME96 uses October 1989 event as a worst-case event
  - Cumulative fluence models not well developed
- This work is based on advanced statistical methods so that risk/cost/performance tradeoffs can be evaluated during design phase.

Solar Proton Model

To be presented by Mike Xapsos at the IEEE Nuclear and Space Radiation Effects Conference (NSREC) Technical Session, July 23-27, 2007 and to be published on http://rahome.gsfc.nasa.gov
Solar Proton Data

- Based on the IMP and GOES series of satellite data spanning time period from 1966 to 2001
  - Energy range from 1 to 330 MeV
  - Solar maximum and solar minimum time periods treated separately

Distribution of Event Magnitudes

- Solar particle events appear to be probabilistic in nature so it is important to accurately model the distribution of event magnitudes.
- However, the data are limited
  - Can make selecting a distribution difficult and arbitrary
- Maximum Entropy Principle
  - Method for making arguably the best selection of a probability distribution compatible with known information
Distribution of Event Magnitudes

- Resulting solution using maximum entropy approach is a truncated power law function in the event magnitude during solar max
- Describes essential features of the distribution
  - Smaller event sizes follow power law function
  - Larger event sizes fall off much more rapidly

Cumulative Fluence During Solar Maximum

- Once the distribution of event fluence magnitudes is known, the cumulative fluence during a mission can be calculated.
Model Comparisons for Solar Maximum

Cumulative Fluence During Solar Minimum

- Solar minimum model is important for missions planned mostly or entirely for this time period.
- PSYCHIC model contains 3 solar minimum flux levels to allow varying degrees of conservatism to be used in design process.
Summary – Solar Proton Model

- A complete solar proton model has been developed
  - Cumulative fluences and worst case events
  - Energy range 1 to 330 MeV
  - Covers entire solar cycle
- Used at GSFC for spacecraft design
- Implemented in SPENVIS and OMERE 3.1
- Validated with measurements by CREDO instrument on MPTB*


Solar Heavy Ion Model

To be presented by Mike Xapsos at the IEEE Nuclear and Space Radiation Effects Conference (NSREC) Technical Session, July 23-27, 2007 and to be published on http://rahome.gsfc.nasa.gov
Heavy Ion Data

<table>
<thead>
<tr>
<th>Predominant Elements:</th>
<th>Measurement Period:</th>
<th>Energy Range (MeV/n):</th>
<th>Data Source:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alpha Particles</td>
<td>1973 - 2001</td>
<td>1 - 200</td>
<td>IMP-8, GOES</td>
</tr>
<tr>
<td>C, N, O, Ne, Mg, Si, S, Fe</td>
<td>1997 - 2005</td>
<td>7 – 140 (element dependent)</td>
<td>ACE/SIS</td>
</tr>
</tbody>
</table>

Less prevalent elements are scaled to above energy spectra using either ISEE-3 satellite data or a photospheric abundance model corrected for the first ionization potential effect.

Heavy Ion Energy Spectra

To be presented by Mike Xapsos at the IEEE Nuclear and Space Radiation Effects Conference (NSREC) Technical Session, July 23-27, 2007 and to be published on http://rahome.gsfc.nasa.gov