Radiation Environment Modeling for Spacecraft Design: New Model Developments

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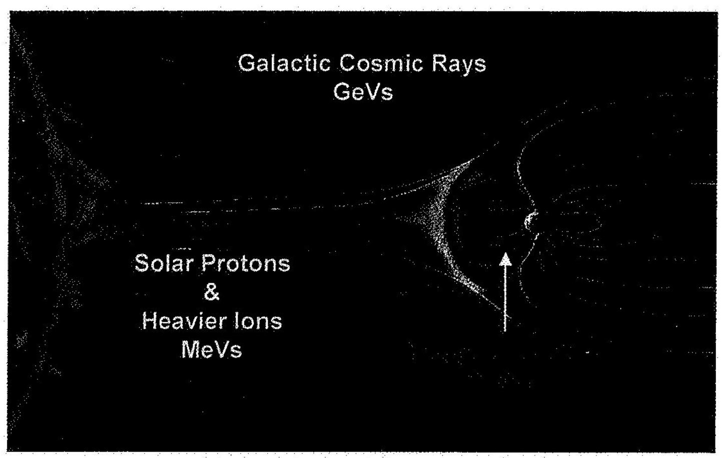
NASA/GSFC

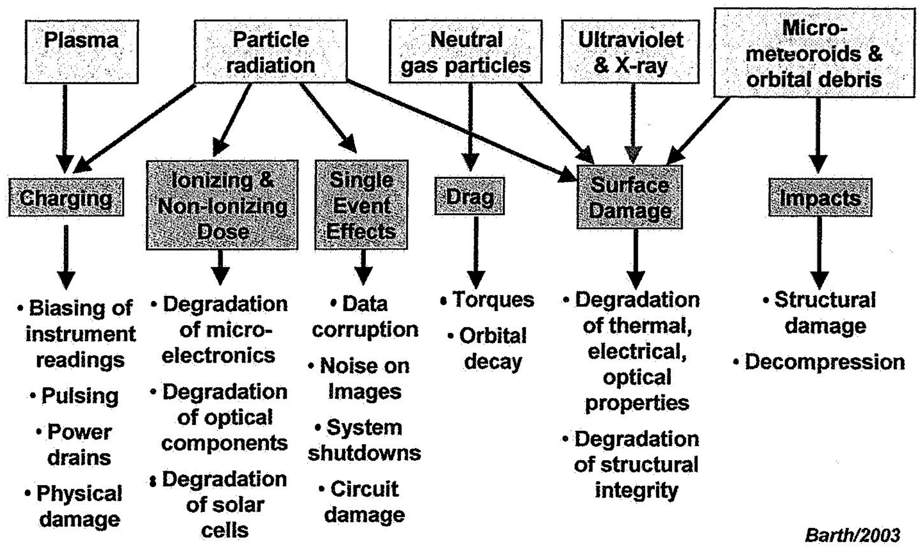
RADECS Workshop
28 September 2006
Athens, Greece

The Space Radiation Environment



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

Effects of Space Environments on Systems



Barth/2003

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Space Radiation Environment Model Use During Space Mission Development and Operations

- ***Mission Concept***
  - Observation requirements & observation vantage points
  - Development and validation of primary technologies
- ***Mission Planning***
  - Mission success criteria, e.g., data acquisition time line
  - Architecture trade studies, e.g., downlink budget, recorder size
  - Risk acceptance criteria – include assessment of Space Weather forecasting capabilities
- ***Design***
  - Component screening, redundancy, shielding requirements, grounding, error detection and correction methods
- ***Launch & Operations***
  - Asset protection
    - Shut down systems
    - Avoid risky operations, such as, maneuvers, system reconfiguration, data download, or re-entry
  - Anomaly Resolution
    - Apply lessons learned to operations and modeling

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Space Radiation Hazards for Humans

Golightly – AMS 2004

- Failure of life support systems
- Failure of space systems operational infrastructure
- The exposure received by humans from space radiation is an important occupational health risk.
  - Major concern is increased risk of cancer morbidity/mortality
  - Other possible health risks
    - Cataracts
    - Coronary disease
    - Damage to neurologic system (e.g., aging)
    - Genetic damage to offspring
  - The probability is *very small* of death during or immediately following a mission due to space radiation exposure

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"Standard" Space Radiation Environment Models

"Standard" Space Radiation Environment Models

- Lacking a standardization process, *de facto* model standards have been adopted by the space community for space radiation environment models
- The following models have been "generally" accepted as *de facto* standards:
  - AP-8 and AE-8 for radiation belt protons and electrons and plasma
  - JPL91 for solar protons
  - CREME86 for galactic cosmic rays and solar heavy ions

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Concerns about Standard Models

- The space system design and radiation health communities have identified three concerns related to *de facto* standard models:
  - The models are not adequate for modern applications;
  - Data that have become available since the creation of the models are not being fully exploited for modeling purposes;
  - When new models are produced, there is no authorizing organization identified to evaluate the models or their datasets for accuracy and robustness.

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Inadequacies of Current Models

- AE-8 and AP-8 models of the radiation belts
  - Very poor time resolution
  - Large uncertainties in some regions
  - Environment definitions do not exist for some energy ranges
  - Contemporary applications require descriptions for a wider range of climatological conditions, averages and worst case are insufficient
- Interplanetary models
  - Galactic cosmic ray model in CREME86 does not represent solar modulation accurately
  - JPL91 has limited energy spectrum definition in the high energy regime
  - Solar heavy ion models in CREME86 overestimate worst case fluences

Development of New Models

For additional information, please attend
the RADECS 2007 Short Course Presentation
by Mike Xapsos

New Model Developments: Proton Belt Models

De facto standard is AP-8

- Combined Release and Radiation Effects Satellite PROton Model (CRRESPRO)
  - Brautigam et al. sponsored by US Air Force Research Laboratory (AFRL)
- Low Altitude Trapped Radiation Model (LATRM)
  - Huston et al. sponsored by NASA
- Trapped Proton Model-1 (TPM-1)
  - Huston et al. sponsored by NASA and AFRL
- SAMPEX/PET Model (PSB97)
  - Heynderickx et al. sponsored by ESA

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Coverage of New Proton Models

Model Name	# of Years of Data	Spatial Coverage	Energy Range (MeV)	Data Source
CRRESPRO	1.2	1.15 < L < 5.5	1 < E < 100	CRRES
LATRM	17	< 1000 km	16 < E < 80	TIROS/NOAA
TPM-1	Depends on Region	1.15 < L < 5.5	1 < E < 100	CRRES, TIROS/NOAA
PSB97	4	1.1< L< 2.0	18.5 < E < 500	SAMPEX

- Note that combining the TPM and PSB97 models with an update of data taken with the SAMPEX/PET instrument would result in a fairly complete trapped proton model.

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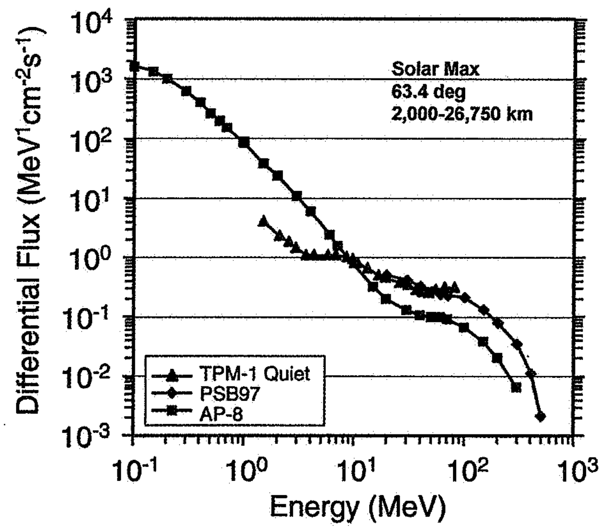
Comparison of TPM-1, PSB97, AP-8



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New Model Developments: Electron Belt Models

***De facto* standard is AE-8**

- **Combined Release and Radiation Effects Satellite ELEctron Model (CRRESELE)**
  - **Gussonhoven et al. sponsored by Air Force Research Laboratory (AFRL)**
- **FLUx Model for Internal Charging (FLUMIC)**
  - **Wrenn et al. sponsored by ESA**
- **Particle ONERA-LANL Environment Model (POLE)**
  - **Bourdarie et al. sponsored by ONERA, Los Alamos National Laboratory (LANL), and NASA**

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Coverage of New Electron Models

Model Name	# of Years of Data	Spatial Coverage	Energy Range (MeV)	Data Source
CRRESELE	1.2	2.5 < L < 6.8	0.5 < E < 6.6	CRRES
FLUMIC	11	Outer Zone	0.2 < E < 5.9	Various
POLE	25	Geostationary	0.03 < E < 6.0	LANL Instruments

- Volatile nature of the outer zone electron regions suggests that probabilistic models may be useful, but they are relatively unexplored
- Worst case approaches are used to define severe electron environments

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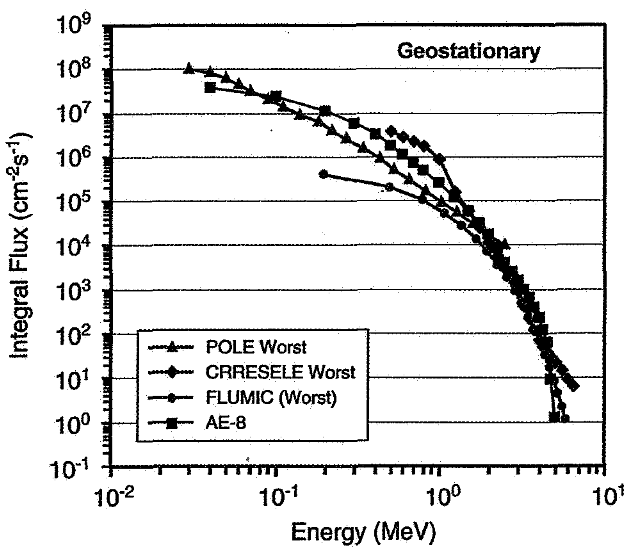
Comparison of "Worst Case" POLE, CRRESELE, and FLUMIC Models with the AE-8 Model



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New Model Developments: Galactic Cosmic Ray Model

De facto standard is CREME86

- Galactic Cosmic Ray (GCR) Model from Moscow State University (MSU)
  - Solar variation is modeled with diffusion-convection theory of solar modulation
- Cosmic Ray Effects in MicroElectronics (CREME96)
  - CREME86 was updated with the GCR MSU Model
- NASA GCR Model from Badhwar and O'Neill
  - Similar approach to GCR MSU model with different implementation of the solar modulation theory
- New approach by Davis et al. at the California Institute of Technology (CIT)
  - Uses transport model for the GCRs through the galaxy preceding the penetration and subsequent transport in the heliosphere

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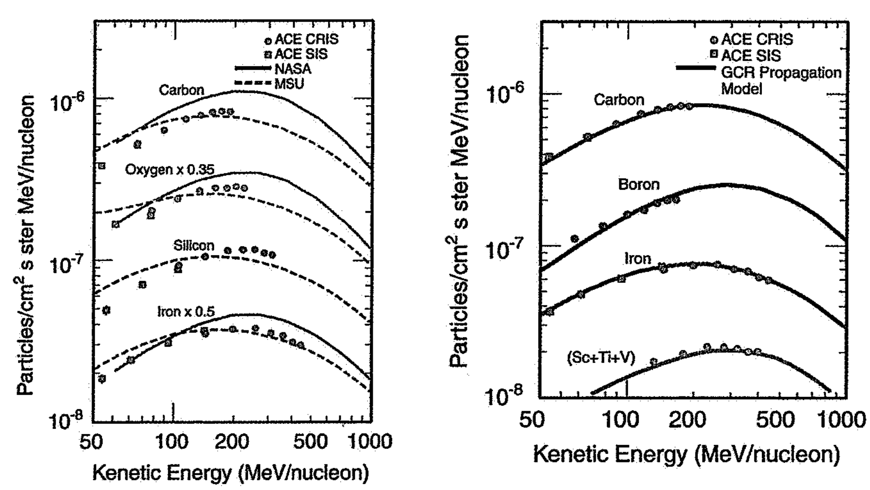
Comparison of NASA, MSU, CIT Models with ACE Instrument Data



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New Model Developments: Solar Proton Model

De facto standard is JP91 for cumulative fluence, CREME86/96 for worst case event fluence

- Solar Particle Event Fluence Model (SPE Fluence Model)
  - Nymmik et al. sponsored by Moscow State University
  - Based on power function distributions of event fluences
- Emission of Solar Proton Model (ESP)
  - Xapsos et al. sponsored by NASA
  - Based on satellite data from the 21 solar maximum years during solar cycles 20-22
  - Uses Maximum Entropy Principle to generate an optimal selection of a probability distribution, and Extreme Value theory to estimate worst case
  - Calculates cumulative and worst case solar proton fluences
- PSYCHIC
  - Xapsos et al. sponsored by NASA
  - ESP Model with satellite data set extended to cover the time period of 1966 – 2001
  - Energy range extended to over 300 MeV
  - Includes estimates for solar minimum spectra

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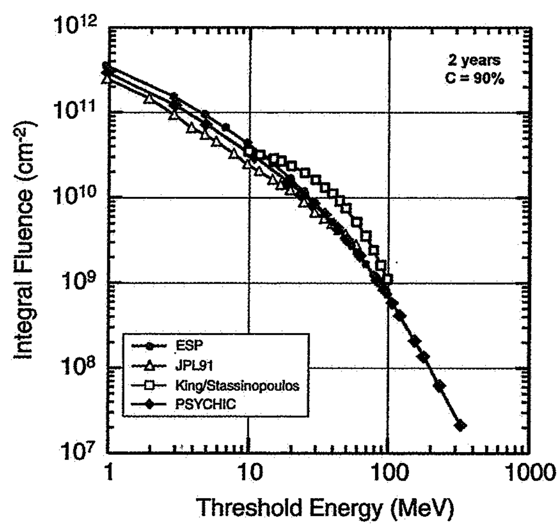
Comparison of ESP, JPL91, King/Stassinopoulos, and PSYCHIC Models



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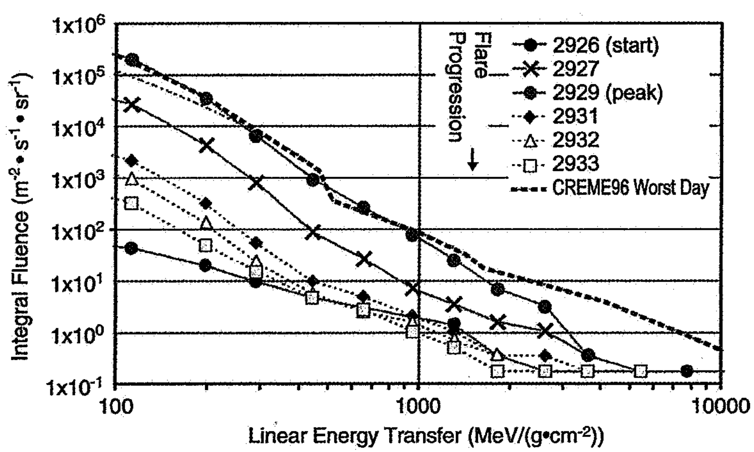
New Model Developments: Solar Heavy Ion Model

***De facto* standard is CREME86/96 for worst case event fluences**

- **CRRES/SPACERAD Heavy Ion Model of the Environment (CHIME) – Chenette et al. sponsored by US AFRL**
  - **Heavy ion abundances scaled to protons results in overestimates**
- **Modeling and Analysis of Cosmic Ray Effects in Electronics MACREE) – Majewski at al. sponsored by Boeing**
  - **Heavy ion abundances scaled to alphas results in less conservative estimates**
- **CREME96**
  - **Uses the October 1989 event as a worst case**
  - **Most extensive heavy ion measurements are for C, O, and Fe, and remaining elemental fluences are determined from a combination of measurements in 1 or 2 energy bins and abundance ratios**

Comparison of CREME96 to CREDO Measurements During 2000 and 2002



Data Courtesy of C. Dyer/QinetiQ

PSYCHIC Heavy Ion Model
Xapsos et al.

Model Name	Measurement Period	Energy Range (MeV/n)	Data Source
Alpha Particles	1973-2001	1 < E < 200	IMP-8, GOES
C, N, O, Ne, Mg, Si, S, Fe	1997-2005	0.2 < E < 5.9	ACE/SIS
Less prevalent elements	-	-	Abundance model

- **Model is published**
- **Looking for funding to develop interface**

Model Standardization

For additional information, please see
http://www.oma.be/ISO/
http://www.oma.be/PSRB/

Working Group Meeting on New Standard Radiation Belt and Space Plasma Models

- Workshop was held on 5-8 October 2004 to address concerns related to radiation belt models
- Representatives from international science, modeling, and user communities
- Three agreements were reached related to model standardization
  - Use the existing capability of the COSPAR Panel on Standard Radiation Belts (PSRB) for preparing AE-8 and AP-8 model updates for submission for ISO standards
  - Propose POLE as an update to AE-8 in the geostationary region
  - Propose to combine TPM-1 and PSB97 as an update to AP-8 in the <1000 km altitude region

Summary

- POLE (Particle ONERA-LANL Environment) Electron Model for geostationary orbits and the Low Altitude Proton (LAP) Model based on TPM-1/SAIC and PSB97/ESA were accepted by PSRB for standardization
- Recommend that a similar process be followed for standardization of interplanetary models
- Areas for model improvements
  - Need better definition in low energy regime for materials
  - Radiation belts
    - Need to understand source and loss mechanisms
    - Need to exploit data from new missions and newer modeling techniques
  - Galactic Cosmic Rays
    - Impelement physical models of cosmic ray transport to model solar modulation
  - Solar Particle Events
    - Need to understand storage and release processes in the solar structure to gain insight into statistical characteristics

Contact Information and WEB Sites

- Janet Barth
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  - 301-286-5966
- October Model Workshop
  - http://lws.gsfc.nasa.gov/news/workshop_10_5_04.htm