PSI’s Space Radiation Instrumentation

Radiation Detection & Dosimetry Workshop

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PSI Rad Sensor Experience

- PSI has developed several generations of charged particle sensors
  - Space science
  - Spacecraft & microelectronics survivability
  - Spacecraft operations support

- SDOM [JAXA] – Gen1
  - 1-200 MeV protons, 0.5-10 MeV electrons, alphas, Heavy ions - 32 particle-energy bins
  - 2 sensors currently flying (GEO & GTO), 1 awaiting launch on JEM

- LPD [USEF(Japan)] – Gen2
  - 1-150 MeV protons, 0.3-20 MeV electrons, alphas/heavy ions - 12 particle-energy bins
  - 1 sensor currently flying (1000 km polar), follow-on sensor launch 2007

- CEM [NASA LWS SET] – Gen2
  - Modified LPD
  - Launch 2009

- HIPS [AFRL] – Gen3
  - LPD derivative
  - High energy electrons and protons, Imaging sensor
  - Development started (launch 2009 on DSX)

- LIPS [AFRL]
  - 20-2000 keV protons and electrons
  - Imaging sensor, 12 particle energy bins x 8 angular bins
  - Launch 2009 on DSX

- PSI has flown >20 instrument and experiments since 1991 on satellites, shuttle and space station
PSI Rad Sensor Design Objectives & Data Quality

• PSI GEN1& GEN2 radiation sensors had several performance goals that have now been demonstrated on orbit:

  • Single sensor to detect protons, electrons, alphas, heavy ions
  • Large throughput (AΩ) – up to 0.3 cm² sr
    – Results in high count rates, efficient detection of small populations of particles, good counting statistics
  • High count rate – up to 200 kcps
    – Does not saturate during solar storms
  • Good particle discrimination
    – Cross-contamination between electrons and protons can be a significant problem
    – SDOM & LPD (GEN1&2 sensors) achieved <10⁻⁴ contamination
    – Achieved through sensor design and on-board processing
  • High accuracy calibration and validated sensor model
    – Returning fully calibrated data from sensor turn-on
  • Flight proven technology on multiple orbital missions
  • High quality, calibrated data received from turn-on
LPD – Light Particle Detector (GEN-2)

- Designed for and flying on the SERVIS-1 satellite (Japan)
  - Space Environment Reliability Verification Integrated System
  - Orbital mission Oct03-present
  - SERVIS-2 follow-on launch 2007
  - CEM for LWS-SET

- Baseline Energy Range
  - protons: 1 to 150 MeV (6 bins)
  - electrons: 0.3 to 10 MeV (4 bins)
  - alphas: >12 MeV (1 bin)
  - ions: >3 MeV/nucleon (1 bin)

- Large G-factor/high count rate
  - 0.2 cm² sr
  - 200 kcps

- FPGA-based processing

- Extensive ground calibration & modeling

- Physical parameters
  - 4 kg (fully redundant)
  - 7 W (HiRel/RadHard)
Generic Block Diagram

- Combination of multiple detectors: SSDs and scintillator
- AntiCoincidence Scintillator rejects side penetrating particles
- Collimator defines acceptance angle for low energy particles
- High-speed analog circuitry and ADC (12-bit) enables 200 kcps rate
- High-speed, FPGA-based processor reduces data volume
Modeling and Calibration

- All PSI sensors are modeled using the GEANT4 code
  - no free parameters

- The model is validated with calibration data
  - Sensors are calibrated over nearly their entire particle-energy range

- We use the model to:
  - develop and refine the sensor and algorithm design
  - interpolate/extrapolate sensor response to uncalibrated regimes
  - predict on-orbit performance
  - interpret orbital data

![Graph showing Proton Scintillator Response with data and GEANT simulations.](image)
Sensor Calibration & Modeling

- PSI extensively calibrates its radiation sensors
  - over nearly their entire particle / energy ranges
- We develop full 3D sensor models to describe performance
  - GEANT4 based models
  - No free parameters
- We validate the models with ground calibration data
- Use the models for to interpolate and extrapolate sensor performance to uncalibrated regions
  - Design phase
  - Interpretation of orbital data

<table>
<thead>
<tr>
<th>Particle</th>
<th>Energy (MeV)</th>
<th>Facility</th>
</tr>
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<tbody>
<tr>
<td>Proton</td>
<td>0.03-1.0</td>
<td>UNT</td>
</tr>
<tr>
<td></td>
<td>0.9-1.7</td>
<td>NASA GSFC</td>
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<tr>
<td></td>
<td>7.5-31</td>
<td>Yale Wright NSL</td>
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<td></td>
<td>15-225</td>
<td>NPTC</td>
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<tr>
<td></td>
<td>50-250</td>
<td>IUCF</td>
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<tr>
<td>Electron</td>
<td>0.03-0.4</td>
<td>NIST C-W</td>
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<tr>
<td></td>
<td>0.5-2.0</td>
<td>NIST VdG</td>
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<td>7-32</td>
<td>NIST MIRF</td>
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<tr>
<td>Alpha</td>
<td>10-50</td>
<td>Yale Wright NSL</td>
</tr>
<tr>
<td>Ion (C)</td>
<td>15-120</td>
<td>Yale Wright NSL</td>
</tr>
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</table>
On 2 Dec 2003, SERVIS LPD detected a sudden, spatially distinct enhancement of low-energy protons

Low energy protons (1 to 12 MeV) enhanced first

Enhancement in higher energy protons (12 to 25 MeV; 25 to 50 MeV) occurred after a delay

Small changes in electron activity

SAA proton flux was also enhanced
**Electron / Proton contamination**

- LPD and SDOM both exhibit very small amounts of contamination by low energy electrons

![Graph showing electron and proton counts over time]

- $<10^{-4}$ contamination of low-energy protons by electrons
SDOM – Standard Dose Monitor (GEN-1)

- PSI and MELCO developed a charged particle spectrometer
- Delivered 3 flight units for NASDA (Japan) satellites
  - MDS1: GTO
  - DRTS: GEO
  - JEM: LEO
- Characterizes the higher energy orbital radiation environment
  - protons: 1 to 200 MeV, 12 bins
  - electrons: 0.4 to 20 MeV, 5 bins
  - alphas: 7 to 150 MeV, 4 bins
  - ions: >1.5 MeV/nucleon
- High count rate
- Excellent rejection of Lo-E electrons
MDS1 SDOM Data

- Two SDOM units currently on orbit
  - MDS1: GTO
  - DRTS: GEO
- PSI involved in orbital data analysis
- Currently 3 years of DRTS data; 27 months of MDS1 data
DRTS SDOM – GOES Intercomparison

- Compared DRTS-SDOM data to GOES data for complete Oct/Nov 2003 Flare
  - End time: 13 Nov 2003 15:27:42

- Mapped SDOM bins onto GOES bins
  - Sum over SDOM energy bins
  - Time average SDOM data

- Quantitative comparison between GOES and SDOM is quite good
- SDOM not saturated during flare
- SDOM low-energy electron bins not contaminated by high energy protons
- SDOM provides better energy and temporal resolution
**DSX HIPS (GEN-3)**

- **High-energy Imaging Particle Spectrometer**
  - Under development for AFRL – DSX mission (COTR: M. Golightly)
  - Currently in EM phase
  - 2007 delivery; 2009 launch

- **Energy Range**
  - Protons 10 - 300 MeV (8 bins)
  - Electrons 0.5 - 30 MeV (12 bins)

- **Pitch angle distribution measurement**
  - 7 x 90 deg FOV
  - 16 pixels

- **Physical**
  - 200 x 210 x 120 mm$^3$
  - 10.5 W
  - 5 kg
  - 740 bytes/sec
Modular Configuration

- LPD is designed around flight-proven detector and electronics modules

- Modular design enables rapid development of new sensors
  - alter energy ranges by changing detectors
  - alter bin configuration

- Working bench model enables rapid prototyping, calibration and validation of new designs

- Redundant and non-redundant configurations available

- Easily configure redundant systems
LPD Modules
Reconfiguration of Redundant Systems

- EM modular processors available for rapid prototyping
- We create a sensor with greater capability by reconfiguring the basic redundant system
- 2 detectors → 3 detectors
- 1 processor → 2 processors
Advanced Radiation Shielding Materials SBIR

• Develop composites that provide more shielding per gram than Al
• Tailor composition to enhance $\varepsilon$ or $\rho$ shielding for specific mission
• 20-30% improvement in shielding
• thermal & mechanical properties
• Sponsor: AFRL Materials

• Commercial partner: Space Systems Loral
• Phase 3 Flight Validation
• Geosynchronous telecom satellite: Estrela Do Sul (2003-present)
• 6 material samples, Al standards, 13 RadFET dosimeters
Radiation Shielding Composites

The Goal:
Replace Al, Ti and Be alloys with composite structures that:
- Provide enhanced shielding to x-rays and neutrons.
- Provide comparable strength for direct replacement in structural applications with no weight penalty.
- Can be integrated into multifunctional structures.

Advantages
- Light weight/High strength
- High temperature performance
- High volume fraction of radiation absorbing materials
- Composite architecture
- Economical production process

Neutron shielding

PSI enriched B4C

Standard refractory
Summary

- PSI has several generations of charged particle instrumentation with flight pedigree

- PSI’s radiation instrumentation may be able to support the human exploration requirements

- Modular design and redundancy enable easy reconfiguration of LPD to serve multiple measurement requirements
  - energy range & particle types
  - G-factor & count rate
  - number of bins
  - Processing algorithms
  - multiple-axis

- LPD test model (-TM) at PSI enables rapid and efficient breadboarding test and calibration of new configurations

- PSI’s advanced shielding materials may be relevant for human exploration applications