Internal Charging

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NASA/MSFC
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## NASA Goddard Space Flight Center, Space Weather Research Center (SWRC)

**Message Type:** Space Weather Alert  
**Message Issue Date:** 2013-07-12T11:35:00Z  
**Message ID:** 20130712-AL-001  

**Summary:**

Significantly elevated energetic electron fluxes in the Earth's outer radiation belt. GOES 13 "greater than 0.8 MeV" integral electron flux is above $10^5$ pfu starting at 2013-07-12T11:00Z.

Spacecraft at GEO, MEO and other orbits passing through or in the vicinity of the Earth's outer radiation belt can be impacted.

**Activity ID:** 2013-07-12T11:00:00-RBE-001.

### Outline

- Internal charging  
- MeV electron fluence threat thresholds  
- NUMIT internal charging model  
- Real time GEO internal charging tool  
- LEO internal charging tool
Internal (Deep Dielectric) Charging

- High energy (>100 keV) electrons penetrate spacecraft walls and accumulate in dielectrics or isolated conductors

- Threat environment is energetic electrons with sufficient flux to charge circuit boards, cable insulation, and ungrounded metal faster than charge can dissipate

- Accumulating charge density generates electric fields in excess of material breakdown strength resulting in electrostatic discharge

- System impact is material damage, discharge currents inside of spacecraft Faraday cage on or near critical circuitry, and RF noise

PMMA (acrylic) charged by ~2 to 5 MeV electrons
MeV Electron Threat Fluence Thresholds

- **NASA-HBK-4002A:** ~MeV electron flux $\geq 9 \times 10^4$ e/cm²·sec·sr
  
  \[
  (10^{10} \text{ e/cm}^2 \text{ in 10 hours})
  \]

- **CCMC/SWRC:** > 0.8 MeV electron flux $> 1 \times 10^5$ e/cm²·sec·sr

- **NOAA/SWPC:** > 2 MeV electron flux $> 1 \times 10^3$ e/cm²·sec·sr
NUMIT Model for EVA Suit Charging

- NUMIT computes charge deposition, electric field as function of depth in insulating materials due to radiation charging by electrons
- Five material layers parameterized by electrical resistivity, radiation induced conductivity parameters, dielectric constant

![Diagram](image)

\[ \nabla \cdot \mathbf{D} = \rho \\
\mathbf{D} = \varepsilon \mathbf{E}, \quad \varepsilon = \kappa \varepsilon_0 \\
\frac{\partial \rho}{\partial t} = -\nabla \cdot \mathbf{J} \\
\mathbf{J} = J_R + J_C = J_R + \sigma \mathbf{E} \\
= J_R + \left[ \sigma_{\text{dark}} + \sigma_{\text{radiation}} \right] \mathbf{E} \\
\sigma_{\text{radiation}} = k \left( \frac{\text{d} \psi}{\text{d}t} \right)^\alpha \quad 0.5 < \alpha < 1.0 \]

### Table 1-2 NUMIT Model, Existing Suit

<table>
<thead>
<tr>
<th>Layer</th>
<th>( Z_{\text{eff}} )</th>
<th>( A_{\text{eff}} )</th>
<th>Density (g/cm³)</th>
<th>Vol. Resis. (S/m)</th>
<th>( \kappa )</th>
<th>RIC (S/m)</th>
<th>RIC Exp</th>
<th>Depth (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8.25</td>
<td>17.19</td>
<td>0.429</td>
<td>1.00E+16</td>
<td>2</td>
<td>1.00E+14</td>
<td>0.7</td>
<td>0.114</td>
</tr>
<tr>
<td>2</td>
<td>5.484</td>
<td>10.008</td>
<td>1.225</td>
<td>1.00E+12</td>
<td>2</td>
<td>1.00E+14</td>
<td>0.7</td>
<td>0.137</td>
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<tr>
<td>3</td>
<td>6.24</td>
<td>11.99</td>
<td>0.752</td>
<td>1.00E+17</td>
<td>2</td>
<td>1.00E+14</td>
<td>0.7</td>
<td>0.165</td>
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<tr>
<td>4</td>
<td>6.083</td>
<td>11.291</td>
<td>0.501</td>
<td>1.00E+15</td>
<td>4</td>
<td>1.00E+14</td>
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<td>0.193</td>
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<tr>
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<td>1.00E+14</td>
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<td>0.244</td>
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<td>31.541</td>
<td>60.487</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Average</td>
<td></td>
<td></td>
<td>6.3082</td>
<td>12.0974</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wt Ave</td>
<td></td>
<td></td>
<td>6.0847</td>
<td>11.555</td>
<td></td>
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<td></td>
<td></td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Layer Number</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>---</td>
<td>space (outside of suit)</td>
</tr>
<tr>
<td>1</td>
<td>Teflon/Nomex/Kevlar</td>
</tr>
<tr>
<td>2</td>
<td>Neoprene coated Nylon</td>
</tr>
<tr>
<td>3</td>
<td>Dacron polyester</td>
</tr>
<tr>
<td>4</td>
<td>Urethane coated Nylon</td>
</tr>
<tr>
<td>5</td>
<td>Nylon chiffon, Nylon Spandex,</td>
</tr>
<tr>
<td></td>
<td>water cooling tubes</td>
</tr>
<tr>
<td>---</td>
<td>skin (inside suit)</td>
</tr>
</tbody>
</table>
EVA Suit Study Environment

geo_flux_ts_215.11186.txt → test_env.txt

8 hours  16 hours
Interpolation records for filling data gaps

3/30/2014
## Arms and Lower Torso

### Current Design*

<table>
<thead>
<tr>
<th>Layer</th>
<th>$\kappa$</th>
<th>$\sigma$ (S/m)</th>
<th>Depth (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.0</td>
<td>$10^{-16}$</td>
<td>1.14</td>
</tr>
<tr>
<td>2</td>
<td>2.0</td>
<td>$10^{-12}$</td>
<td>1.37</td>
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<td>3</td>
<td>2.0</td>
<td>$10^{-17}$</td>
<td>1.65</td>
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<tr>
<td>4</td>
<td>4.0</td>
<td>$10^{-15}$</td>
<td>1.93</td>
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<tr>
<td>5</td>
<td>2.0</td>
<td>$10^{-12}$</td>
<td>2.44</td>
</tr>
</tbody>
</table>

$Z_{\text{eff}} = 6$

$A_{\text{eff}} = 12$

2.04 g/cm$^3$

$K_p = 10^{-14}$ S·sec/m·rad

$\Delta = 0.7$

$\Delta T = 1.0$ sec

*Using material spec for nylon conductivity $\sigma = 10^{-12}$ S/m

geo_flux_ts_215.11186.txt $\rightarrow$ test_env.txt

3/30/2014
30 mm
0.14 g/cm³
κ=1.13
$10^{-13}$ S/m
τ≈100 sec

Simulated:
30 days
(720 hours)

Δt=30 sec

LANL-01 2003
text: geo_flux_ts_1.0017361.txt
30 days
Case 2a

60 mm
0.14 g/cm³
κ=1.13
10⁻¹⁹ S/m
τ~1157 days

Simulated:
30 days
(720 hours)

Δt=300 sec

LANL-01 2003
geo_flux_ts_1.0017361.txt
30 days
Time constant for charge decay through conduction: \( \tau = \kappa \varepsilon_0 / \sigma \)

<table>
<thead>
<tr>
<th>( \kappa )</th>
<th>( \sigma ) (S/m)</th>
<th>( \tau )</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>( 10^{-12} )</td>
<td>( \sim 18 \text{ sec} )</td>
</tr>
<tr>
<td>2</td>
<td>( 10^{-13} )</td>
<td>( \sim 3 \text{ min} )</td>
</tr>
<tr>
<td>2</td>
<td>( 10^{-14} )</td>
<td>( \sim 30 \text{ min} )</td>
</tr>
<tr>
<td>2</td>
<td>( 10^{-15} )</td>
<td>( \sim 5 \text{ hr} )</td>
</tr>
<tr>
<td>2</td>
<td>( 10^{-16} )</td>
<td>( \sim 2 \text{ days} )</td>
</tr>
</tbody>
</table>

Electric fields resulting from internal (deep dielectric) charging as function of depth in dielectric material and electrical conductivity. Fields are updated at 5 minute intervals using NOAA GOES >0.8 MeV, >2.0 MeV electron data.
Geostationary Orbit Internal Charging Tool

GEO Internal Charging Model using GOES-13 e- Flux Data
Data Extracted: 2013 08 26 0000 GMT

GOES Electron Flux (5 minute data)
Begin: 2013 Aug 26 0000 UTC

Updated 2013 Aug 28 23:56:03 UTC
NOAA/SWPC Boulder, CO USA
Geostationary Orbit Internal Charging Tool

GEO Internal Charging Model using GOES-13 e- Flux Data
Data Extracted: 2013 08 26 1800 GMT

GOES Electron Flux (5 minute data) Begin: 2013 Aug 26 0000 UTC

Updated 2013 Aug 28 23:56:03 UTC
NOAA/SWPC Boulder, CO USA
Geostationary Orbit Internal Charging Tool

GEO Internal Charging Model using GOES-13 e- Flux Data
Data Extracted: 2013 08 27 0300 GMT

GOES Electron Flux (5 minute data)
Begin: 2013 Aug 26 0000 UTC

Updated 2013 Aug 28 23:56:03 UTC
NOAA/SWPC Boulder, CO USA
Geostationary Orbit Internal Charging Tool

GEO Internal Charging Model using GOES-13 e- Flux Data
Data Extracted: 2013 08 27 1200 GMT
Geostationary Orbit Internal Charging Tool

GEO Internal Charging Model using GOES-13 e- Flux Data
Data Extracted: 2013 08 27 2100 GMT

GOES Electron Flux (5 minute data)
Begin: 2013 Aug 26 0000 UTC

Updated 2013 Aug 28 23:56:03 UTC
NOAA/SWPC Boulder, CO USA
Geostationary Orbit Internal Charging Tool

GEO Internal Charging Model using GOES-13 e- Flux Data
Data Extracted: 2013 08 28 0600 GMT

GOES Electron Flux (5 minute data)
Begin: 2013 Aug 26 0000 UTC

Updated 2013 Aug 28 23:56:03 UTC
NOAA/SWPC Boulder, CO USA
Geostationary Orbit Internal Charging Tool

GEO Internal Charging Model using GOES-13 e- Flux Data
Data Extracted: 2013 08 28 1500 GMT

LOG Conductivity (S/m) vs. Depth (cm)

GOES Electron Flux (5 minute data)
Begin: 2013 Aug 26 0000 UTC

Updated 2013 Aug 28 23:56:03 UTC
NOAA/SWPC Boulder, CO USA
Radiation Shielding Option

0.069 g/cm² Al shielding  
(0.256 mm)  

no shielding
Input Data Options

GOES Electron Flux (5 minute data)

Begin: 2011 Jun 18 0000 UTC

Updated 2011 Jun 20 17:36:02 UTC  NOAA/SWPC Boulder, CO USA

Fok Radiation Belt Model
[iswa.ccmc.gsfc.nasa.gov]

0.425 MeV

2.00 MeV
LEO Internal Charging Model

- 1-D internal charging simulation treating electron flux responsible for charging dielectric materials (or isolated conductors) covered by thin shielding (e.g., MLI):

\[ \kappa \varepsilon_0 \frac{dE}{dt} + \sigma E = J_p \]

where \( J_p \) is the integral electron current density penetrating the MLI shielding, \( \kappa \) is the dielectric constant, \( \varepsilon_0 \) the permittivity of free space, and \( \sigma \) the electrical conductivity of the dielectric material

- Compute electric field \( E \) and potential \( \Phi \) as function of time using electron flux measurements from NOAA-19 for the incident electron current density, \( J_p \)

- Conductivity \( \sigma \) due only to “dark” conductivity, neglect radiation induced conductivity
  - Charge loss process due to conduction to ground slows charge accumulation rate and limits ESD events in lower flux environments
  - Charge, electric field will establishes an equilibrium \( E \sim J/\sigma \) if charging time constant \( \tau = \kappa \varepsilon_0 / \sigma \) for charge loss through conduction is short compared to exposure time
  - Finite amount of time required for charge to decay through conduction after exposure to electrons

- Electric field enhancement factor included to account for sharp edges
LEO Internal Charging Model

\[ J_e(>150.0 \text{ keV}) - J_e(>300.0 \text{ keV}) \text{ electrons} \]

Simulated: 0 discharges
Inf days/event
NOAA-19: \( \pi(0\text{deg} + 90\text{deg}) \)
Model 2, \( \tau = 40.97 \text{ days} \)

10,000 cm \times 3,000 cm \times 0.200 mm
\( k = 4.00 \)
Dielectric strength = 2.50e+007 V/m
0.10 < fract. discharged < 0.30
1.0x field enhancement
1.00e+017 ohm-m

Flux \#/cm^2-sec-sr
Electric Field (V/m)

2011.8 2012.0 2012.2 2012.4 2012.6 2012.8 2013.0

Time (UT)
**LEO Internal Charging Model**

**J_e(> 150.0 keV) - J_e(> 300.0 keV) electrons**

- Simulated: 65 discharges
- 6.6 days/event
- NOAA-19: π*(90° + 90°)
- Model 2, $\tau = 409.72$ days

**Dimensions:**
- 10,000 cm x 3,000 cm x 0.200 mm
- $k = 4.00$

**Dielectric strength:**
- $2.50 \times 10^7$ V/m
- $0.10 < \text{fract. discharged} < 0.30$
- 10.0x field enhancement
- $1.00 \times 10^8$ ohm-m

**Graph Details:**
- Flux: #/cm²-sr
- Electric Field: V/m
- Time (UT): 2011.8 to 2013.0

The graph shows the flux and electric field over the period 2011.8 to 2013.0 with time intervals marked for each year.
Dimensions (LxWxD): 10.000 cm x 3.000 cm x 0.200 mm
Volume resistivity: 1.000e+018 ohm-m
Kappa: 4.0000
Dielectric strength: 2.500e+007 V/m
Efield enhancement: 10.0x
Capacitance: 5.310e-010 Farads
Conduction time constant: 409.7222 days

Fraction (f) discharged: 0.100 < f < 0.300

NOAA-19 electrons: π*(0deg + 90deg)
Electron energy: 150.0000 keV – 300.0000 keV

<table>
<thead>
<tr>
<th>Arc</th>
<th>Decimal</th>
<th>Day of Year (UT)</th>
<th>Fraction Discharged</th>
<th>Surface Voltage (Volts) Before and After Arc</th>
<th>Arc Energy (mJoule)</th>
<th>Arc Current (Amp) 0.10 us</th>
<th>Arc Current (Amp) 1.00 us</th>
<th>Arc Current (Amp) 10.00 us</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2012.0710</td>
<td>26.9785</td>
<td>0.2283</td>
<td>500.0</td>
<td>385.9</td>
<td>0.0268</td>
<td>6.06e-001</td>
<td>6.06e-002</td>
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<tr>
<td>1</td>
<td>2012.1039</td>
<td>39.0314</td>
<td>0.2004</td>
<td>500.0</td>
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<tr>
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<td>6.73e-002</td>
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<td>6.40e-002</td>
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<td>0.0259</td>
<td>5.82e-001</td>
<td>5.82e-002</td>
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Questions?