



# Spacecraft Charging Material Properties Database

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***NASA, Marshall Space Flight Center, Huntsville, Alabama, USA***

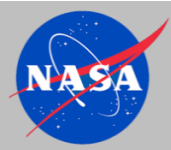
**Linda Neergaard Parker**

***USRA, Huntsville, Alabama, USA***

***14<sup>th</sup> International Symposium on Materials in the Space Environment  
(ISMSE) and 12<sup>th</sup> International Conference on Protection of Materials  
from Space Environment (ICPMSE)***

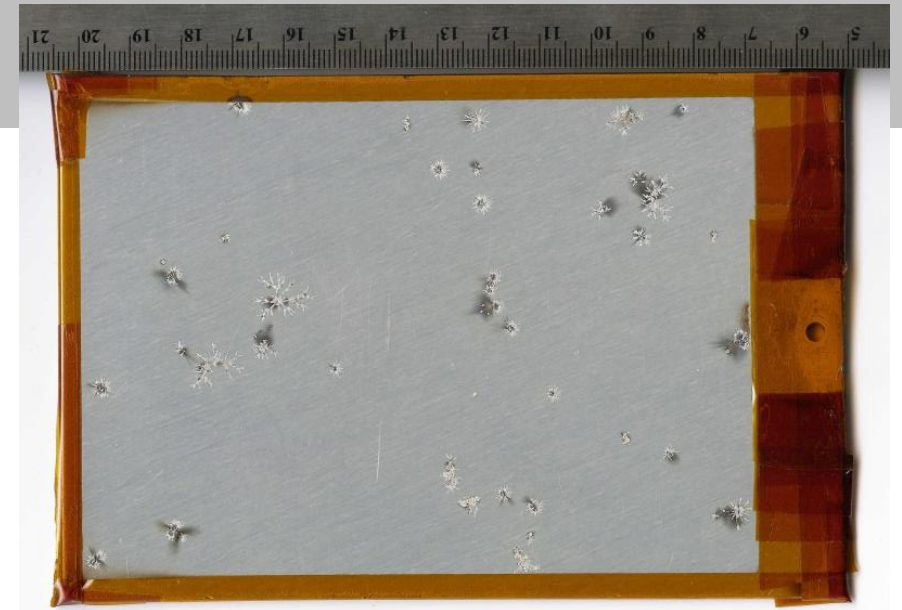
***1 – 5 October 2018, Biarritz, France***

**[Joseph.minow@nasa.gov](mailto:Joseph.minow@nasa.gov)**

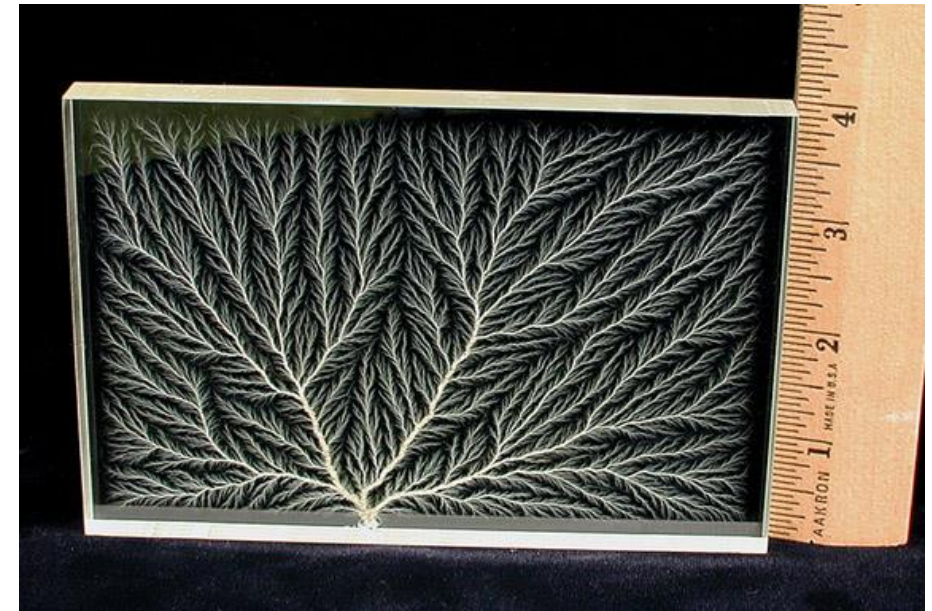


# Introduction – Spacecraft Charging

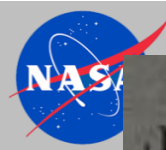
- Accumulation of excess negative charge generates potential differences between spacecraft ground and space (frame potential), between two points on the spacecraft surface or within materials (differential potential)
- An electrostatic discharge (ESD) results when electric fields associated with potential differences ( $\mathbf{E} = -\nabla\Phi$ ) exceed the dielectric breakdown strength of materials allowing charge to flow in an arc
- Magnitude of damage depends on energy available to an arc
$$E = \frac{1}{2}CV^2$$
- Charging to a potential  $V$  depends on electrical properties of materials
  - Surface and volume resistivity
  - Dielectric constant
  - Secondary and backscattered electron yields, photoemission yields
  - Dielectric breakdown strength



ISS MMOD shield 1.3  $\mu\text{m}$  chromic acid anodized thermal control coating (T. Schneider/NASA)

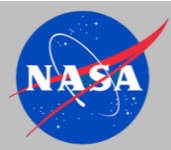


PMMA (acrylic) charged by  $\sim 2$  to 5 MeV electrons



- Ad  
di  
po  
w
- Ar  
as  
di  
flo
- M
- Ch  
m





# Surface Charging

- Surface charging models solve for surface potentials and electric fields as a function of time dependent ion and electron currents to and from surface elements

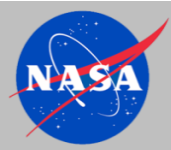
$$\frac{dQ}{dt} = \frac{d\sigma}{dt} A = C \frac{dV}{dt} = \sum_j I_k$$

where

$$\frac{dQ}{dt} = \sum_j I_k =$$

- $+I_i(V)$  **incident ions**
- $-I_e(V)$  **incident electrons**
- $+I_{bs,e}(V)$  **backscattered electrons**
- $+I_c(V)$  **conduction currents**
- $+I_{e,se}(V)$  **secondary electrons due to  $I_e$**
- $+I_{i,se}(V)$  **secondary electrons due to  $I_i$**
- $+I_{ph,e}(V)$  **photoelectrons**
- $+I_b(V)$  **active current sources including charged article beams, thrusters**

and  $J = \sigma E + k_{RIC} \left(\frac{dS}{dt}\right)^x$



# Surface Charging

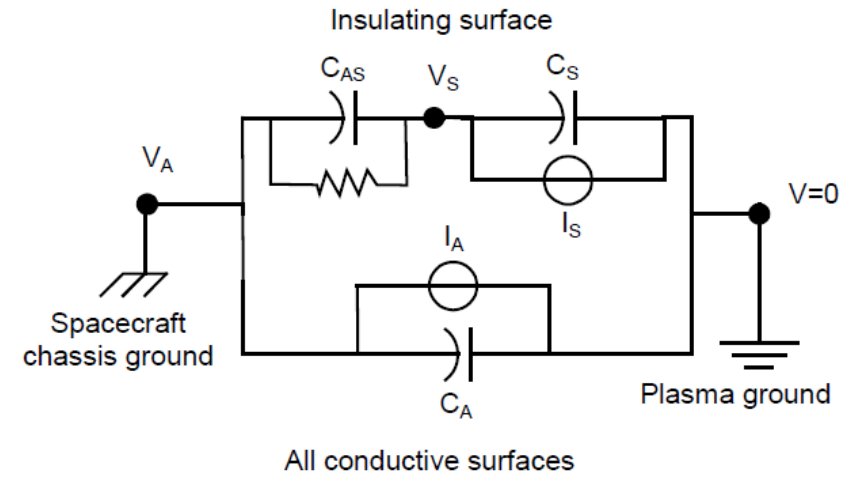
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$$\frac{dQ}{dt} = \frac{d\sigma}{dt} A = C \frac{dV}{dt} = \sum_j I_k$$

where

$$\frac{dQ}{dt} = \sum_j I_k = \begin{aligned} &+I_i(V) && \text{incident ions} \\ &-I_e(V) && \text{incident electrons} \\ &+I_{bs,e}(V) && \text{backscattered electrons} \\ &+I_c(V) && \text{conduction currents} \\ &+I_{e,se}(V) && \text{secondary electrons due to } I_e \\ &+I_{i,se}(V) && \text{secondary electrons due to } I_i \\ &+I_{ph,e}(V) && \text{photoelectrons} \\ &+I_b(V) && \text{active current sources including} \\ &&& \text{charged article beams, thrusters} \end{aligned}$$

and  $\mathbf{J} = \sigma \mathbf{E} + k_{RIC} \left(\frac{dS}{dt}\right)^x$



$$C_{AS} = \kappa \epsilon_0 \frac{S}{d} \sim S \times 10^{-6} F$$

$$C_A \sim C_S = 4\pi \epsilon_0 R \left(\frac{S}{4\pi R^2}\right) \sim \frac{S}{R} \times 10^{-11} F$$

$$\begin{aligned} C_A \dot{\Phi}_A + C_{AS}(\dot{\Phi}_A - \dot{\Phi}_S) &= I_A \\ -C_{AS}(\dot{\Phi}_A - \dot{\Phi}_S) + C_S \dot{\Phi}_A &= I_A \end{aligned}$$

$$C \dot{\Phi} = \mathbf{I}(\Phi)$$

[Davis and Mandell, 2015]



# Surface Charging

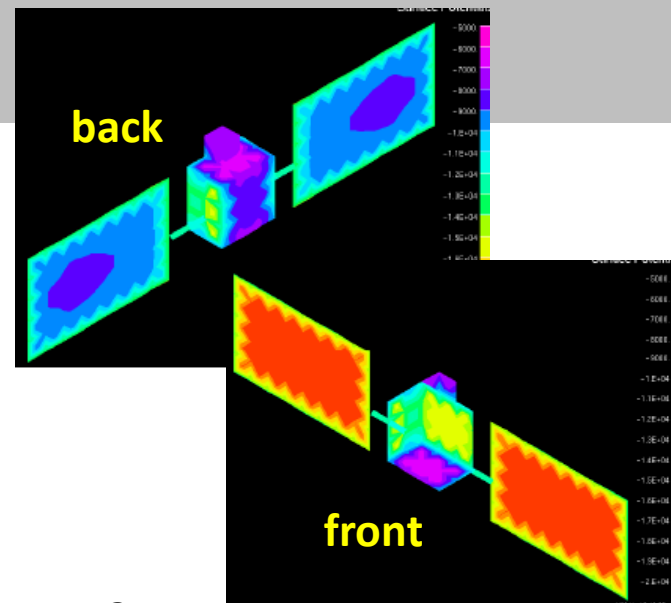
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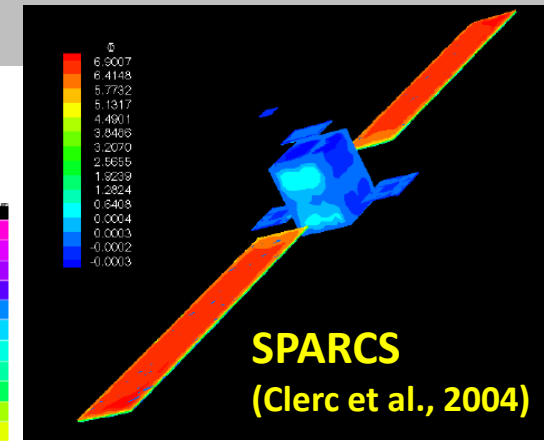
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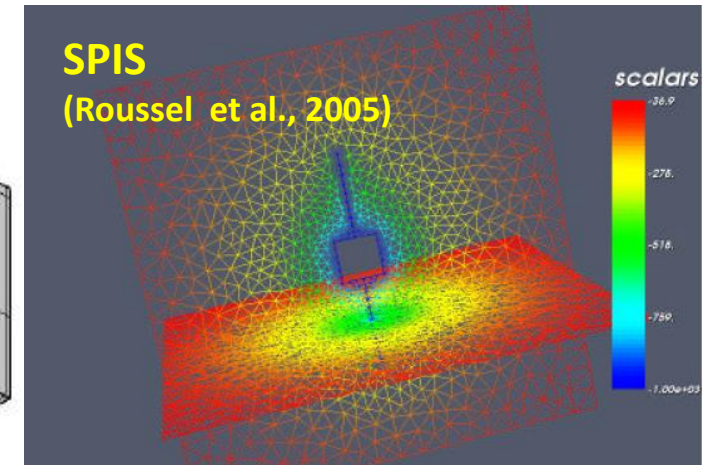
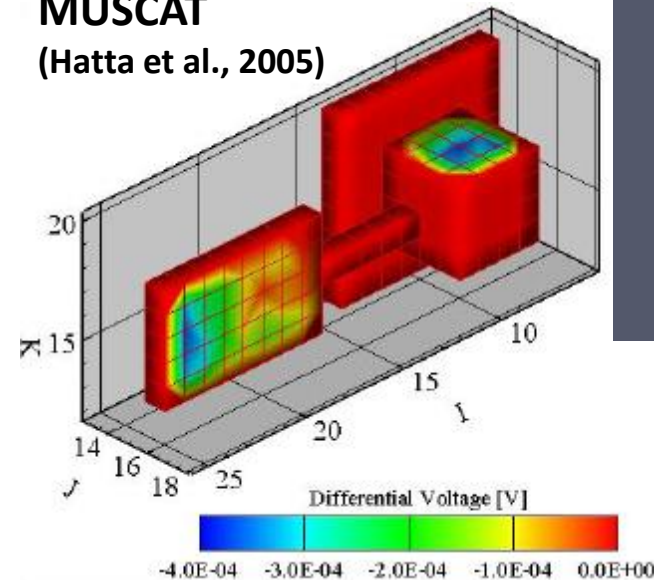
$$\text{and } \mathbf{J} = \sigma \mathbf{E} + k_{RIC} \left( \frac{dS}{dt} \right)^x$$

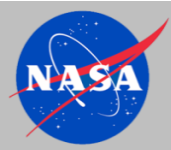


**Nascap-2K**  
(Neergaard et al., 2001)



**MUSCAT**  
(Hatta et al., 2005)





# Internal Charging

- Internal charging models solve coupled radiation transport and electrostatic equations to obtain time dependent potentials and electric fields within materials exposed to penetrating electrons
- Radiation transport depends on material properties
  - Density
  - Atomic number
  - Atomic mass

## Electrostatics

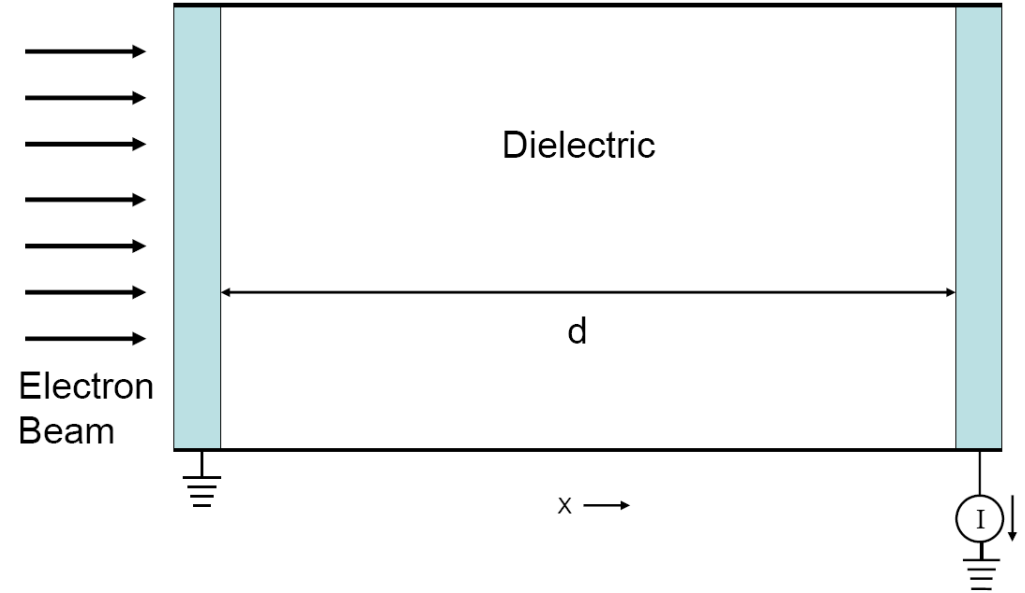
$$\vec{\nabla} \cdot \vec{D} = \vec{\nabla} \cdot \epsilon \vec{E} = \vec{\nabla} \cdot \kappa \epsilon_0 (-\vec{\nabla} \phi) = \rho$$



$$\nabla^2 \phi = -\rho / \kappa \epsilon_0$$

$$\frac{\partial \rho}{\partial t} = -\vec{\nabla} \cdot \vec{J}$$

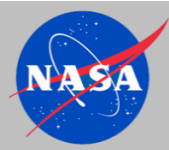
where  $J = J_{\text{conduction}} + J_{\text{radiation}}$

$$= \sigma E + k_{RIC} \left( \frac{dS}{dt} \right)^x$$



 Conductor     Ampere meter. Arrow shows positive current direction.

[Jun et al. 2007]



# Internal Charging

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- Electrostatics

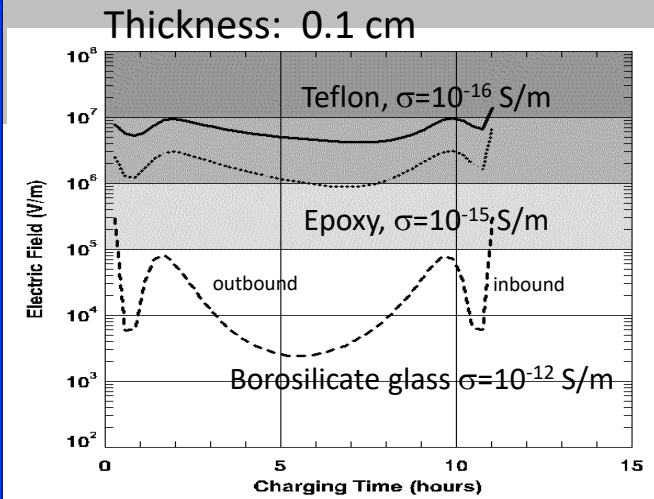
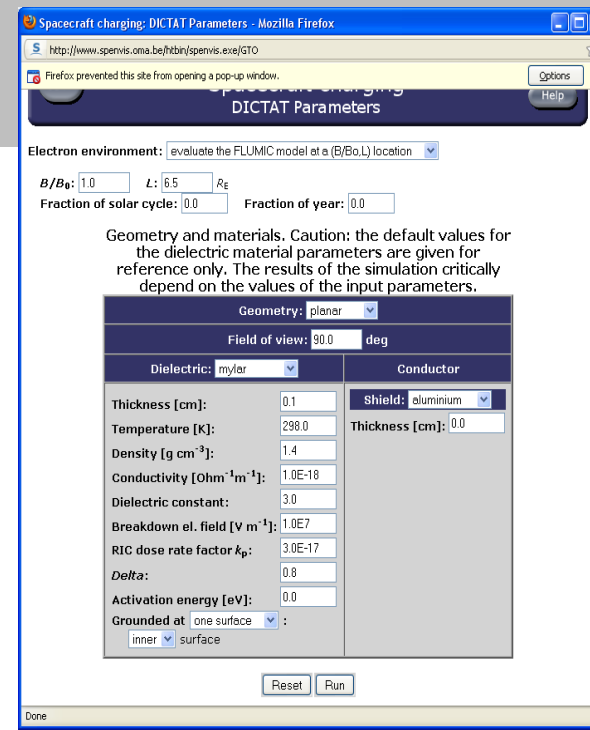
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$$\nabla^2 \phi = -\rho / \kappa \epsilon_0$$

$$\frac{\partial \rho}{\partial t} = -\vec{\nabla} \cdot \vec{j}$$

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$$= \sigma E + k_{RIC} \left( \frac{dS}{dt} \right)^x$$

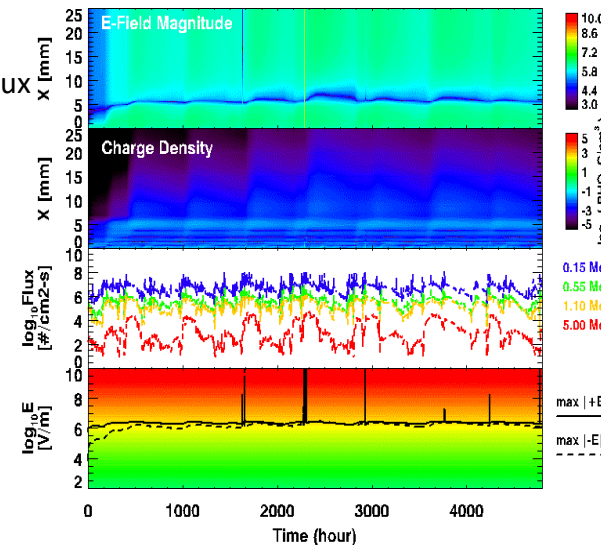


DICTAT (1-D model)

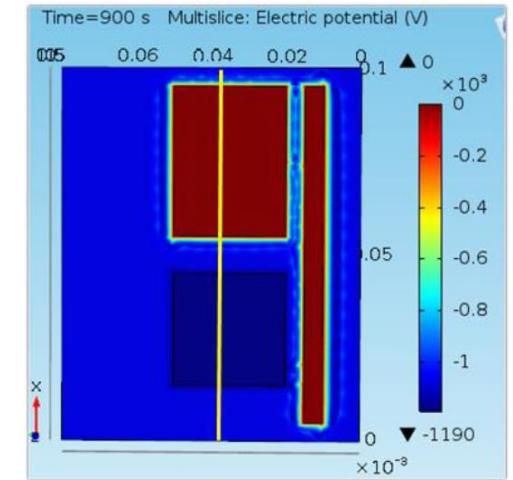
<http://www.spennis.oma.be/>

**Charging current**  
Electron energy, flux  
from LANL-01A

**Material**  
PMMA  
Z=6, A=12  
~2.5 cm thick  
 $\sigma \sim 1 \times 10^{-17}$  S/m  
 $\kappa = 2.00$   
 $\rho = 1.0$  g/cm<sup>3</sup>



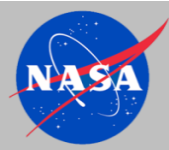
NUMIT (1-D model)



NUMIT 3-D

Kim et al., 2018





# Spacecraft Charging Materials Database (SCMD)

Electrical Properties

New Record

NOTIFICATION <sup>1</sup>



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The Spacecraft Charging Materials Database (SMDC) is a NASA sponsored repository for information on the electrical properties of materials relevant to surface charging and internal charging processes for materials exposed to charged particles and photons in the space environment. Contents of the archive are material properties obtained from laboratory testing (or space based experiments when appropriate) to support spacecraft charging modelling and analyses.

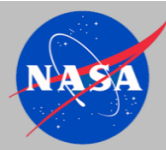
Materials exposed to the space environment will accumulate charge due to the differential collection of ion and electron currents from the space radiation and plasma environment. The magnitude of the electric fields, electric potentials, and electric potential gradients generated by an excess charge density on (or in) a material is an important consideration for space system design and operations. Accumulation of a significant localized charge density can lead to electric fields exceeding the electrostatic breakdown strengths of materials, resulting in electrostatic discharges which are responsible for a number of detrimental effects including material degradation, electromagnetic interference, and even catastrophic failure of sensitive electronic components in extreme cases.

This database contains parameters of importance to charging including volume and surface conductivity, dielectric constant, secondary electron and backscatter yields due to incident electrons and protons, photoelectric current density, material density, and radiation induced conductivity parameters. We hope the SCMD will provide a resource for the exchange of information on electrical properties of materials available to both contributors providing fundamental measurements of electrical properties of materials and the analysis community conducting quantitative modelling studies of spacecraft charging.

[SCMD Template](#)

[NASA-HDBK-4002](#)

[NASA-HDBK-4002A](#)



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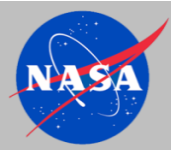
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[SCMD Template](#)

[NASA-HDBK-4002](#)

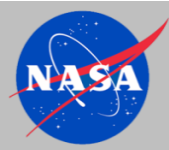
[NASA-HDBK-4002A](#)



# SCMD – Electrical Properties of Materials

- Database currently holds information on 49 materials
  - NASCAP default materials
  - Utah State University test results

The screenshot shows a web application interface for the SCMD Electrical Properties database. At the top, there are two buttons: "Electrical Properties" and "New Record". Below these is a header bar with a hamburger menu icon and the text "ELECTRICAL PROPERTIES". The main content area includes a "starts with:" dropdown menu set to "All", a "Filter By" dropdown, and a "Select All" button with a green checkmark. A list of materials is displayed, each with a checkbox and a blue link to its details. The materials listed are: 12 micron Teflon (FEP) on Al, Aluminum, Annealed Amorphous Carbon1, Annealed Amorphous Carbon2, Annealed Amorphous Carbon3, Annealed Amorphous Carbon4, Black Kapton, Carbon Nanotube H19, Carbon Nanotube H24, and Carbon Nanotube L19. At the bottom, there is a pagination bar showing "page 1 of 5 (49 Records)" and navigation buttons for first, previous, next, and last, with page numbers 1, 2, 3, 4, and 5.



# SCMD – Electrical Properties of Materials

- Database currently holds information on 49 materials
  - NASCAP default materials
  - Utah State University test results
- Electrical properties of materials

The screenshot displays the SCMD web application interface. The main content area shows the electrical properties for Aluminum. The interface includes a search bar at the top, a navigation menu, and a list of materials on the left. The right panel displays the detailed properties for Aluminum, including common name, dielectric constant, thickness, bulk conductivity, atomic number, photocurrent, surface resistivity, atomic weight, density, material classification, secondary electron yield, primary electron energy, first coefficient range, exponent 1, 2nd coefficient range, exponent 2, secondary yield due to protons, proton yield, proton max, radiation induced conductivity (RIC), and RIC (power of).

**Aluminum**

Properties

- Common Name: Aluminum
- Dielectric Constant: 1
- Thickness: 0.001 m
- Bulk Conductivity:  $-1 \text{ } 1/\Omega \text{ m}$
- Atomic Number: 13
- Photocurrent:  $4\text{E-}05 \text{ A/m}^2$
- Surface Resistivity:  $-1 \text{ } \Omega/\text{sq}$
- Atomic Weight: 26.98 AMU
- Density:  $2699 \text{ kg/m}^3$
- Material Classification: Conductor

Secondary Electron Yield

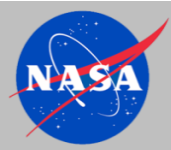
- Max yield (delta max): 0.97
- Primary electron energy (Emax): 0.3 keV
- First coefficient Range 1: 154 Å
- Exponent 1: 0.8
- 2nd Coefficient Range 2: 220 Å
- Exponent 2: 1.76

Secondary Yield Due To Protons

- Proton Yield: 0.244
- Proton Max: 230 keV

Radiation Induced Conductivity (RIC)

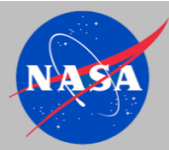
- RIC (power of):  $1\text{E-}16 \text{ } 1/\Omega \text{ m}$



# SCMD – Test Information

- Database currently holds information on 49 materials
  - NASCAP default materials
  - Utah State University test results
- Electrical properties of materials
- Information on test conditions and links to test reports

The screenshot displays the SCMD web application interface. At the top, there is a search bar and a menu icon. The main content area is divided into two sections: a list of materials on the left and a detailed view for 'Aluminum' on the right. The 'Aluminum' view shows tabs for 'Properties' and 'Test Info', with the 'Test Info' tab selected. The 'Test Information' section includes fields for 'Data Source' (Nascap-2k v4.2), 'Contact Name' (unknown), and 'Tested in Vacuum' (Unknown). Below the 'Test Information' section, there is a section for 'ELECTRICAL PROPERTIES'. The list of materials on the left includes '12 micron Teflon (FEP)', 'Aluminum', 'Annealed Amorphous Carbon1', 'Annealed Amorphous Carbon2', 'Annealed Amorphous Carbon3', 'Annealed Amorphous Carbon4', 'Black Kapton', 'Carbon Nanotube H19', 'Carbon Nanotube H24', and 'Carbon Nanotube L19'. A yellow callout box highlights the text: 'Information on test conditions and link to test reports (when available)'. The bottom of the interface shows pagination information: 'page 1 of 5 (49 Records)' and navigation buttons for 'first', 'prev', '1', '2', '3', '4', '5', 'next', and 'last'.



# SCMD – Search Option

- Database currently holds information on 49 materials
  - NASCAP default materials
  - Utah State University test results
- Electrical properties of materials
- Information on test conditions and links to test reports
- Search options
  - Exact search match
  - Checking to see if can be “part” of word

The screenshot shows the SCMD web application interface. At the top, there is a search bar with the text "search here.. searches all records and documents." and a "MENU" button. Below the search bar, there are two buttons: "Electrical Properties" and "New Record". The main content area is titled "ELECTRICAL PROPERTIES" and features a "starts with:" dropdown menu set to "All". To the right of this menu are "Select All" and "Generate Report" buttons. A "Filter By" dropdown menu is open, displaying a list of filter options with checkboxes: "Most Popular Filters", "2nd Coefficient Range 2", "Additional Information", "Atomic Number", "Atomic Weight", "Bulk Conductivity", "Common Name", "Contact Name", "Data Source", "Density", "Dielectric Constant", "Exponent (power of) RIC", and "Exponent 1". At the bottom of the page, there are pagination controls: "<< first", "< prev", "1", "2", "3", "4", "5", "next >", and "last >>".



# SCMD – Other Features

- Database currently holds information on 49 materials
  - NASCAP default materials
  - Utah State University test results
- Electrical properties of materials
- Information on test conditions and links to test reports
- Search options
  - Exact search match
  - Checking to see if can be “part” of word
- Other features include
  - Export records of selected materials to a variety of external file formats
  - Generate reports on user selected material properties
  - Generate plots

MENU search here.. searches all records and documents. Q

Electrical Properties New Record

ELECTRICAL PROPERTIES

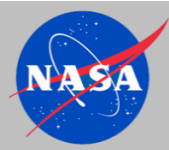
starts with: All Select All Generate Re

Filter By

<input type="checkbox"/>	12 micron Teflon (FEP) on Al
<input checked="" type="checkbox"/>	Aluminum
<input type="checkbox"/>	Annealed Amorphous Carbon1
<input type="checkbox"/>	Annealed Amorphous Carbon2
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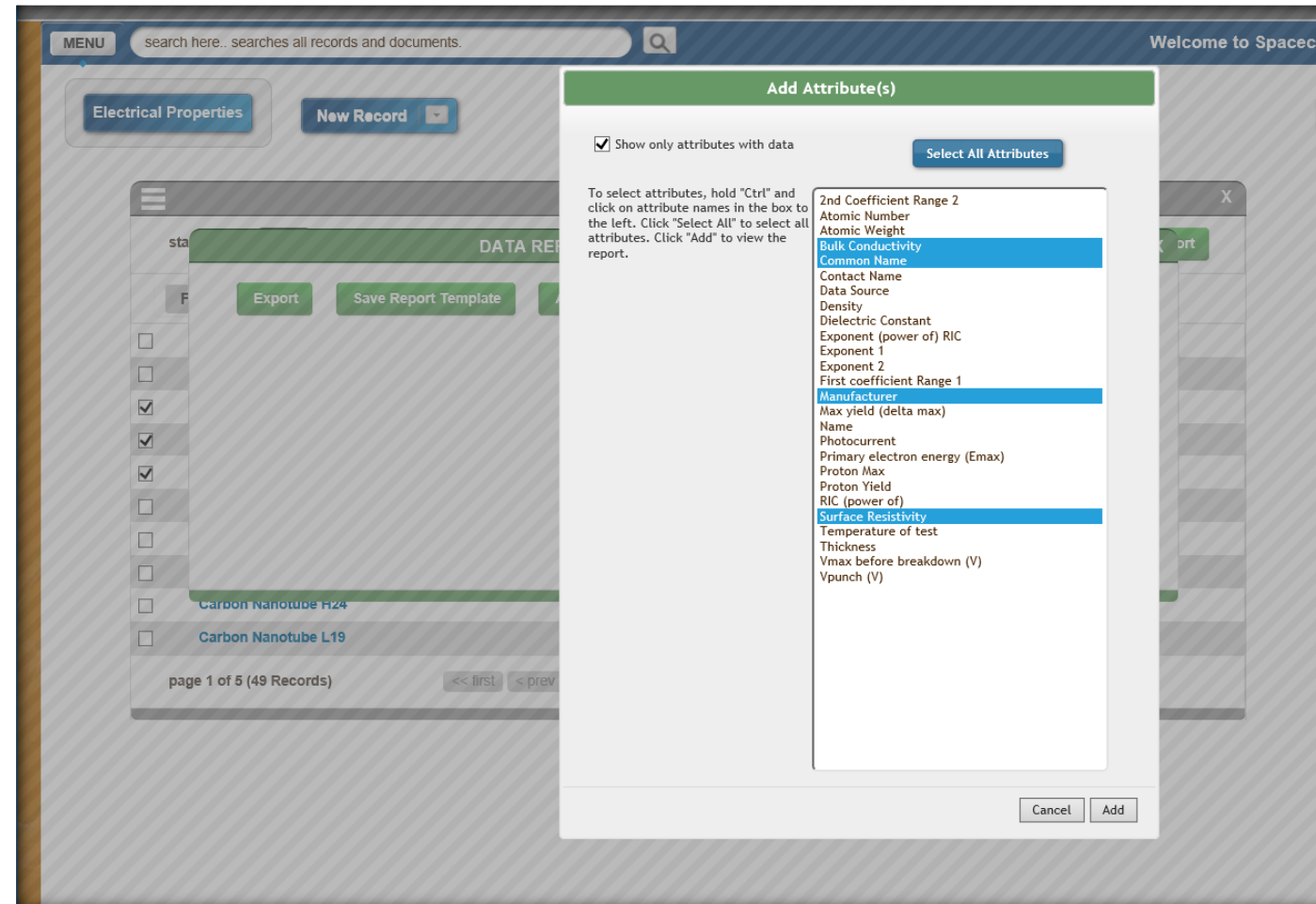
page 1 of 5 (49 Records) << first < prev 1 2 3 4 5 next > last >>

**Select materials of interest**



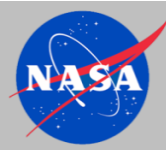
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**Select material properties of interest**





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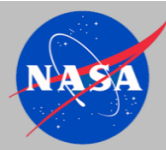
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[SCMD Template](#)

[NASA-HDBK-4002](#)

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**SCMD Template**

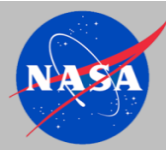
**NASA-HDBK-4002**

**NASA-HDBK-4002A**

- Template required to submit information to SCMD administrators
  - Excel<sup>®</sup> spreadsheet format
  - Input parameters must be in units given in spreadsheet
  - -9999 for no information or missing data

						Secondary Electron Yield			
Common Name	Manufacturer	Dielectric Constant	Thickness (m)	Bulk Conductivity (1/Ohm m)	Atomic Number	Max Yield (delta max)	Primary electron energy (Emax (keV))	First coefficient Range (A)	Exponent 1

- Input parameters
  - Dielectric constant
  - Secondary electron yield coefficients due to incident electrons and ions
  - Bulk conductivity
  - Surface resistivity
  - Test reports and information on testing parameters



# Spacecraft Charging Materials Database (SCMD)

Electrical Properties

New Record

NOTIFICATION <sup>1</sup>

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help



The Spacecraft Charging Materials Database (SMDC) is a NASA sponsored repository for information on the electrical properties of materials relevant to surface charging and internal charging processes for materials exposed to charged particles and photons in the space environment. Contents of the archive are material properties obtained from laboratory testing (or space based experiments when appropriate) to support spacecraft charging modelling and analyses.

Materials exposed to the space environment will accumulate charge due to the differential collection of ion and electron currents from the space radiation and plasma environment. The magnitude of the electric fields, electric potentials, and electric potential gradients generated by an excess charge density on (or in) a material is an important consideration for space system design and operations. Accumulation of a significant localized charge density can lead to electric fields exceeding the electrostatic breakdown strengths of materials, resulting in electrostatic discharges which are responsible for a number of detrimental effects including material degradation, electromagnetic interference, and even catastrophic failure of sensitive electronic components in extreme cases.

This database contains parameters of importance to charging including volume and surface conductivity, dielectric constant, secondary electron and backscatter yields due to incident electrons and protons, photoelectric current density, material density, and radiation induced conductivity parameters. We hope the SCMD will provide a resource for the exchange of information on electrical properties of materials available to both contributors providing fundamental measurements of electrical properties of materials and the analysis community conducting quantitative modelling studies of spacecraft charging.

SCMD Template

NASA-HDBK-4002

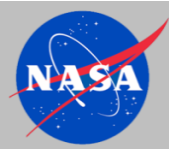
NASA-HDBK-4002A

## NASA

- Purvis et al., Design Guidelines for Assessing and Controlling Spacecraft Charging Effects, NASA-TP-2361, 1984.
- NASA-HDBK-4002 – Avoiding Problems Caused by Spacecraft On-Orbit Internal Charging Effects, 1999
- NASA-HDBK-4002A, Mitigating In-Space Charging Effects – A Guideline, 2017
- NASA-STD-4005A, Low Earth orbit Spacecraft Charging Design Standard, 2016
- NASA-HDBK-4006A, Low Earth Orbit Spacecraft Charging Design Handbook, 2007
- NASA-HDBK-4007, Spacecraft High-Voltage Paschen and Corona Design Handbook, 2016
- SLS-SPEC-159, Cross-Program Design Specification for Natural Environments (DSNE), Revision E, 2017

## Other? (TBD)

- MIL-STD-1809, Handbook for the USAF Space Environment Standard, PL-TR-93-2010, 1993
- ECSS-E-ST-20-06C, Space Engineering: Spacecraft Charging, ESA, 2008
- JERG-2-211A, Design Standard, Spacecraft Charging and Discharging, JAXA, 2012



# Spacecraft Charging Material Database Access

- Database is available on-line at the address <https://maptis.ndc.nasa.gov/scmd>
- SCMD is open to public use with free registration
  - Contact POCs for access request form
  - No export controlled or proprietary information allowed in the database
- Adding new materials
  - Material property contributions from the community are welcome and requested!
  - Template required to add materials, forward to POCs
- Please provide comments and suggestions for improvements to POCs!
- Point of contact (POC):
  - Linda Parker [lparker@usra.edu](mailto:lparker@usra.edu)
  - Joseph Minow [joseph.minow@nasa.gov](mailto:joseph.minow@nasa.gov)



# Questions?

**URL:** <https://maptis.ndc.nasa.gov/scmd>

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