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JR Dennison
Utah State University

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Of Mice and Materials: Payoffs of UNSGC Research Infrastructure Awards

J.R. Dennison

Materials Physics Group
Physics Department, Utah State University

Utah NASA Space Grant Consortium Annual Meeting
Weber State University
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To paraphrase Douglas Adams, “Space is [harsh]. You just won’t believe how vastly, hugely, mind-bogglingly [harsh] it is.” Interactions with this harsh space environment can modify materials and cause unforeseen and detrimental effects to spacecraft. If these are severe enough the spacecraft will not operate properties of surface and bulk materials as a result of prolonged exposure to the space environment has been identified as one of the critical areas of research in spacecraft design. Further, materials modifications can change the satellite environment, leading to feedback mechanisms for further spacecraft responses.
The Poster Child for Space Environment Effects

Before

After

USU MISSIE SUSpECS II Sample Tray

Ag coated Mylar with micrometeoroid impact

Logan, UT
Complex dynamic interplay between space environment, satellite motion, and materials properties

**Facilities & Capabilities**

**Sample Characterization & Preparation**
- Bulk composition (AA, IPC).
- Surface contamination (AES, AES mapping ESD).
- Surface morphology (SEM, optical microscopy).

**Conduction Related Properties:**
- Bulk & surface conductivity.
- High resistivity testing.
- Capacitance, dielectric constant, charge decay monitoring, and electrostatic discharge.

**Electron Induced Emission:**
- Total, secondary and backscattered yield vs. incident energy and angle.
- Energy-, angle-resolved emission spectra.
- Cathodoluminescence

**Ion Induced Emission:**
- Total electron and ion yield versus incident energy and angle.

**Photon Induced Emission:**
- Total electron yield vs photon energy.
- Energy-angle resolved photoelectron yield cross-sections.

**Electron Induced Arcing:**
- Four ultrahigh vacuum chambers for electron emission tests equipped with electron, ion, and photon sources, detectors, and surface analysis capabilities.
- Two high vacuum chambers for resistivity tests.
- High vacuum chamber for electrostatic breakdown tests.
- Ultrahigh vacuum chamber for pulsed electro acoustic measurements of internal charge distributions.
Measurements with many methods... \[ J = q_e n_e(z, t) \mu_e F(z, t) + q_e D \frac{dn_{tot}(z, t)}{dx} \]

Interrelated through a...
\[ \frac{\partial}{\partial z} F(z, t) = q_e n_{tot} / \varepsilon_0 \varepsilon_F \]
\[ \frac{\partial n_{tot}(z, t)}{dt} - \mu_e \frac{\partial}{\partial z} [n_e(z,t)F(z,t)] - q_e D \frac{\partial^2 n_e(z,t)}{\partial z^2} = N_{ex} - \alpha_{ev} n_e(z,t)n_{tot}(z,t) \]
\[ \frac{dn_{h}(z,t)}{dt} = N_{ex} - \alpha_{ev} n_e(z,t)n_h(z,t) \]
\[ \frac{dn_{l}(z,t)}{dt} = \alpha_{ev} n_e(z,t)[N_e(z, \varepsilon) - n_l(z, \varepsilon, t)] - \alpha_{ev} N_e \exp \left[ - \frac{\varepsilon}{k_B T} \right] n_l(z, \varepsilon, t) \]

Complete set of dynamic transport equations...written in terms of spatial and energy distribution of electron trap states
USU Space Survivability Test Chamber

Radiation Sources
- A: High Energy Electron Gun
- B: Low Energy Electron Gun
- C: UV/NIR Kapton Discharge Lamps
- D: Air Mass Zero Filter Set
- E: Flux Mask
- F: Sr90 Radiation Source

Analysis Components
- F: UV/VIS/NIR Reflectivity Spectrometers
- G: IR Emissivity Probe
- H: Integrating Sphere
- I: Photodiode UV/VIS/NIR Flux Monitor
- J: Faraday Cup Electron Flux Monitor
- K: Platinum Resistance Temperature Probe

Sample Carousel
- L: Samples
- M: Rotating Sample Carousel
- N: Reflectivity/Emissivity Calibr. Standards
- O: Resisstance Heaters
- P: Cryogen Reservoir

Chamber Components
- Q: Cryogenic Vacuum Feedthrough
- R: Electrical Vacuum Feedthrough
- S: Sample Rotational Vacuum Feedthrough
- T: Probe Translational Vacuum Feedthrough
- U: Sapphire UV/VIS Viewport
- V: MgF UV Viewport
- W: Turbomolecular/Mech. Vacuum Pump
- X: Ion Vacuum Pump
- Y: Ion/Convection Pressure Gauges
- Z: Residual Gas Analyzer

Chamber Components
- α: CubeSat
- β: CubeSat Test Fixture
- γ: Radiation Shielding
- δ: COTS Electronics
- ε: Rad Hard Breadboard
- η: COTS Test Fixture
- θ: Electron Gun

Instrumentation (Not Shown)
- Data Acquisition System
- Temperature Controller
- Electron Gun Controller
- UV/VIS/NIR Solar Simulator Controller
- FLU IR Resonance Lamp Controller
- Spectrometers and Reflectivity Source

Utah NASA Space Grant Consortium Faculty Research Infrastructure Award Program, “Space Survivability Test Facility for CubeSats, Components and Spacecraft Materials,” JR Dennison, (April 2016 to April 2017.)
Simulated Space Environment Fluxes

**Electron Radiation**
A high energy (~10-80 keV) and three lower energy (~10 eV to 5 keV) electron guns provide high electron fluxes.

**Ionizing Radiation**
A 100 mCi encapsulated Sr$^{90}$ β-radiation source (~200 keV to >2.5 MeV) mimics high energy (~500 keV to 2.5 MeV) geostationary electron flux [2].

**Infrared/Visible/Ultraviolet Flux**
A commercial Class AAA solar simulator provides NIR/Vis/UVA/UVB electromagnetic radiation (from 200 nm to 1700 nm) at up to 4 times sun equivalent intensity.

**Far Ultraviolet Flux**
Kr resonance lamps provide FUV radiation flux (ranging from 10 to 200 nm) at 4X sun equivalent intensity. Kr bulbs have ~3 month lifetimes for long duration studies.

**Temperature Control**
Temperature range from 60 K [4] to 450 K is maintained to ±2 K [3]. This is achieved through cartridge heaters, and chilled fluid pumped through a cold plate.

**Controlled Atmosphere and Vacuum**
Ultrahigh vacuum chamber allows for pressures <10$^{-7}$ Pa to simulate LEO.

**Video Discharge Monitoring**
Using custom developed software, live video capture and processing of electrostatic discharge events allows for visual identification of discharge location and frequency.

**Flexible Sample Mounting**
A rotating graphite carousel, ensures uniform irradiation and allows for custom mounting of samples. Or a flange mounted fixture allows for electrostatic discharge testing. Radiation source to sample distance is adjustable.

**Biological Testing**
Biological samples, which are vacuum incompatible, can use a custom designed chamber with controlled atmosphere and temperature.
SST Chamber Components Developed Under UNSGC Infrastructure Award

Biological Test Chamber

Custom Designed SST Sr$^{90}$ Radiation Source

Radiation Absorbent Sample Mount
High frequency RF antenna dielectric components used on telecommunications satellites were tested in orbital conditions. Electrostatic discharge events induced by β-radiation were monitored and characterized using both video and current monitoring to identify the frequency, location, and magnitude of discharges. Effect of temperature (~10 °C to 60 °C) on discharge characteristics was tested over a full orbital cycles of several days.  

Funded by ViaSat.

Irradiation tests of electron transport properties of PEEK materials for NASA Europa Clipper Mission. Funded--NASA JPL

VUV degradation of communications satellite antennas and thermal control coatings. Funded--Proprietary space industry funding.
High performance RF communications cabling underwent accelerated testing simulating the duration of a full multi-year mission. In-Situ permittivity characterization was performed to understand the long-term cumulative effects of $\beta$-radiation on cable properties including frequency response and power loss. Additionally, electrostatic discharge was monitored and characterized using video and current monitoring. This provided understanding of charge accumulation and discharge induced by $\beta$-radiation within the samples.

*Funded by Times Microwave.*

Testing of New Spacecraft Propulsion Engineering Designs Equipment to be flown on a Terrier Malamute rocket to test hybrid thruster designs. *Proposed by USU Engineering Department in conjuncture with a NASA Undergraduate Student Instrument Project (USIP).*
Microcontrollers are essential satellite components, but radiation hardened electronics can be prohibitively expensive for CubeSat missions. Testing of economical Commercial-Off-The-Shelf (COTS) electronic components is necessary to determine their viability for replacing radiation hardened electronics. Tests showed that the Arduino ceased to function properly functioning after ~250 Gy exposure.

**USU Physics Senior Project.**

β radiation TID effects on electronic components.
*Funded-- Space Dynamics Lab.*
*Funds Pending--Proprietary Space Flight Industry.*
*Project Proposed--SparkFun*

Radiation induced conductivity (RIC) of perovskite dielectric materials by total ionizing dose (TID).
*Funding pending from DOE Sandia National Labs.*
Viability of Plant Growth in Space

Radish seeds flown on the Russian BION-M1 mission were observed by Logan High School students to have faster germination rates than control, ground based radish seeds. Seeds were tested in the SST to test if radiation was the cause of this change in germination rate. A biological test chamber, designed by University Tsukuba students, housed the seeds in a controlled atmosphere for safe testing in the SST vacuum.

Partial funding through the DoEd USUStars Gear Up Program. Partial funding through the Japan Tsukuba University Student Space Collaboration Program.

In-Vitro tests of muscles cells irradiated in the SST and biological test chamber have been. The effects of radiation on muscle cells will progress work in cardiovascular disease and degenerative tissue risks from space radiation. *Partially Funded by UNSGC Graduate Fellowship.*

A collaborative follow-on will support further development of the physiological effects of ionizing radiation. *2017 UNSGC Infrastructure award for Elizabeth Vargas in USU Bioengineering.*

RESEARCH FUNDING
Pending Funding

Current and Recent Funding
Utah NASA Space Grant Consortium Faculty Research Infrastructure Award Program, “Effects of Space Ionizing Radiation on Cell Viability,” Elizabeth Vargoss with JR Dennison, ($20,000, April 2017 to April 2018).
Utah NASA Space Grant Consortium Faculty Research Infrastructure Award Program, “Space Survivability Test Facility for CubeSats, Components and Spacecraft Materials,” JR Dennison, ($20,931, April 2016 to April 2017).

STUDENT FUNDING:
USU Undergraduate Research and Creative Opportunities (URCO), ”Temperature Dependence of Electrostatic Breakdown in Highly Disordered Polymers,” ($2,000, January 2017 to June 2017) [for Trevor Kippen with Allen Andersen and J.R. Dennison].
NASA Utah Space Grant Consortium Graduate Student Fellowship, “Multilayer Models of Electron Emission and Charge Transport with Spacecraft Charging Applications.” ($30,000, September 2015 to August 2016) [for Greg Wilson with J.R. Dennison].

Past Funding
NASA Utah Space Grant Consortium Graduate Student Fellowship, “Electron Yield Measurements of High-Yield Low Conductivity Dielectric Materials,” ($15,000, September 2015 to August 2016) [for Justin Christensen with J.R. Dennison].
USU Physics Department Undergraduate Summer Research Internship, “Development and Applications for the Space Survivability Test Chamber.” ($2,000, May 2015 to August 2015) [for Heather Tippets with J.R. Dennison].

RELATED PUBLICATIONS
Related Presentations

**Accepted**


Alex Souvall, Ben Russon, Greg Wilson, Brian Wood and JR Dennison, “Myriad Investigations Using the USU Space Survivability Tests Facility,” Utah NASA Space Grant Consortium Research Symposium, May 8, 2017, Weber State University, Ogden, UT.

**Presented**


David King and JR Dennison, “Temperature Dependent Conductivity of Polymers,” USU Student Research Symposium, April 13, 2017, Logan, UT.


Alexandra Hughlett, Tyler Kippen, and JR Dennison, “Relaxation of Radiation Effects on the Optical Transmission of Polymers,” American Physical Society Four Corner Section Meeting, New Mexico State University, Las Cruces, New Mexico State University, Las Cruces, NM, October 21-22, 2016.

**Presentation received award for outstanding Undergraduate Talk**

**Alex Souvall, Gregory Wilson, Ben Russon, Katie Gamaunt, and JR Dennison**, “CubeSat Space Environments Effects Studied in the Space Survivability Test Chamber,” USU Fall Undergraduate Research Orientation, Logan, UT, September 9, 2016.


Alex Souvall, Greg Wilson, Katie Gamaunt, Ben Russon, Heather Tippett and JR Dennison, “Properties of Spacecraft Materials Exposed to Ionizing Radiation,” American Physical Society Four Corner Section Meeting, Arizona State University, Tempe, AZ, October 16-17, 2015.


Katie Gamaunt, Heather Tippett, Alex Souvall, Ben Russon and JR Dennison, “The Space Survivability Test Chamber,” American Physical Society Four Corner Section Meeting, Arizona State University, Tempe, AZ, October 16-17, 2015.

**Presentation received award for outstanding Undergraduate Poster**


USU Materials Physics Group

(Back row Left to Right) Ben Russon, Heather Zollinger, Zack Gibson, Matthew Robertson, Jordan Lee, David King

(Front row Left to Right) Justin Christensen, Alexandra Hughlett, Alex Souvall, Greg Wilson, Allen Andersen, JR Dennison, Windy Olsen

(Not pictured) Brian Wood, Vladimir Zavyalov, Jodie Gillespie, Jonh Mojica Decena, Katie Gamaunt, Davis Muhwezi, Tyler Kippen

(UNSGC Supported)

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J. R. Dennison received the B.S. degree in physics from Appalachian State University, Boone, NC, in 1980, and the M.S. and Ph.D. degrees in physics from Virginia Tech, Blacksburg, in 1983 and 1985, respectively. He was a Research Associate with the University of Missouri—Columbia before moving to Utah State University (USU), Logan, in 1988. He is currently a Professor of physics at USU, where he leads the Materials Physics Group. He has worked in the area of electron scattering for his entire career and has focused on the electron emission and conductivity of materials related to spacecraft charging for the last two decades.