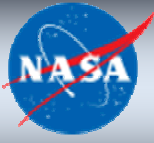


Shields-1 Preliminary Radiation Shielding Dosimetry in Polar Low Earth Orbit

Dr. D. LaurenceThomsen III (Larry)
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7 November 2019

NASA Langley Research Center



NASA Langley Research Center Hampton, Virginia

Founded in 1917 (NACA): first civil aeronautical research laboratory converted to NASA in 1958

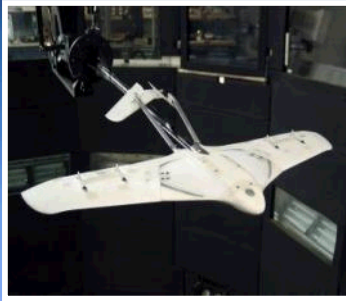
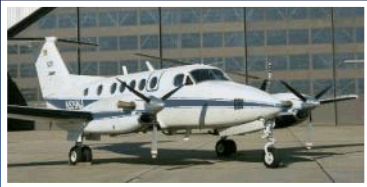
Facilities: \$3.6 billion replacement value

People: 1840 Civil Servants ; 1630 Contractors

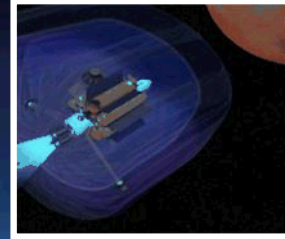
NASA Langley Core Competencies

Aerosciences

Research for Flight in All Atmospheres

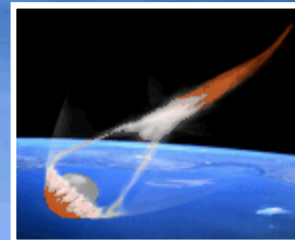


Aerospace Systems Analysis

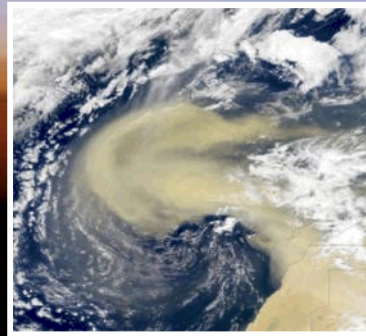


Space Exploration

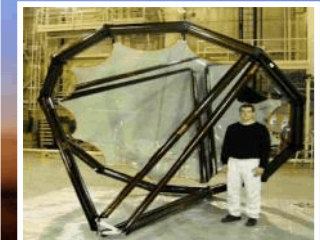
Entry, Descent & Landing



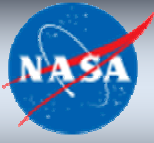
Characterization of all Atmospheres (Lasers & LIDAR)



Aerospace Structures & Materials



Materials for Extreme Environments

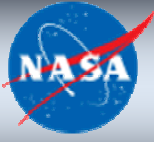


- Extreme-Use Temperature Composites
- Radiation Shielding
- Refractory Ceramics
- Materials on The International Space Station Experiment (MISSE)



MISSE
deployment
on ISS,
containing
NASA LaRC
Materials

LaRC Historical Space Materials Experiments



LDEF: Early Cargo for Space Shuttle

Near Real Time: 69 months actual (18 months planned)

Large Multimillion Project over 10 yrs from early Concepts: 1972 to Flight

Majority passive experiments, Each experimenter provided trays for the structure

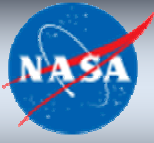


LDEF deployed on STS-41C,
Apr. 6-13, 1984, (image
credit: NASA)



LDEF retrieval on Jan. 12, 1990
(image credit: NASA/LaRC)

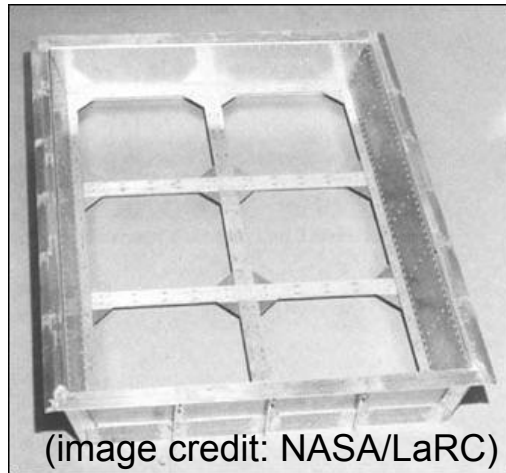
LDEF Dimensions and Mass



LDEF structure: 30 ft long x 14 ft diameter, 8000 lbs

Experiment Trays: each 34in x 50in typical
86 total (72 around cylinder, 14 on ends)

Experiment weights could be 180-200 lbs



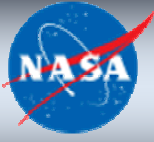
Total approximated mission weight: **21,400 lbs**



LDEF structure on a trailer (image credit: NASA/LaRC)

Ref: NASA SP-473, The Long Duration Exposure Facility (LDEF), Mission 1 Experiments

Materials International Space Station Experiment (MISSE)



Approximately 2ft x 2ft across for each half

MISSE-6, March 2008-September 2009

Post Flight Analysis, near real time 18 months

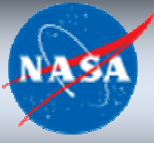
Passive experiments



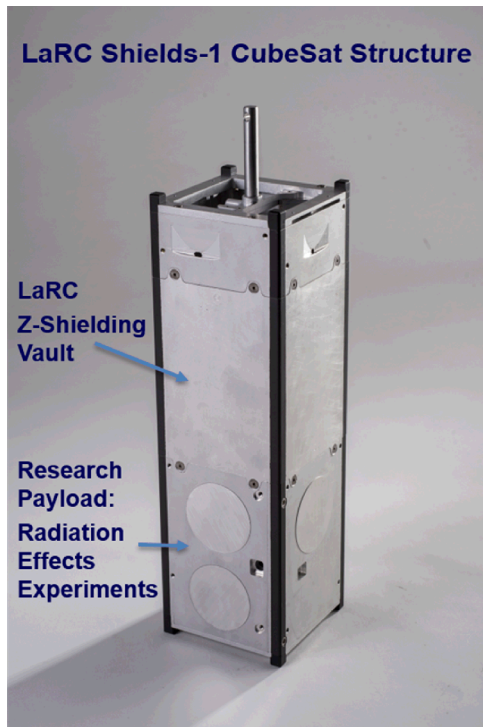
Image Credit: NASA LaRC

Shields-1, Space Radiation Effects Experiments

NORAD ID 43850



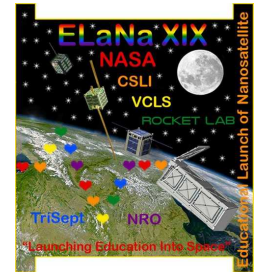
Presently, Shields-1 operates with LaRC Z-Shielding providing radiation protection for the electronics over 10 months in polar low earth orbit.



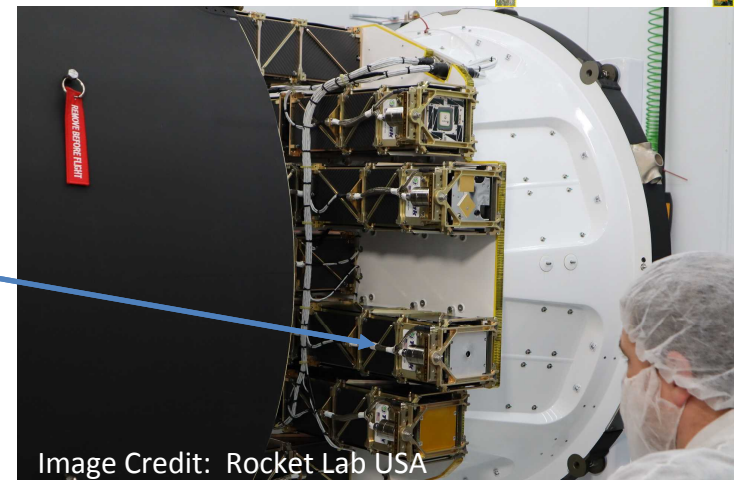
LaRC Shields-1, Preship for ELaNaXIX Mission, July 2018



Shields-1 onboard Rocket Lab USA, Electron Rocket, NASA ELaNaXIX Mission, 16 December 2018 Launch



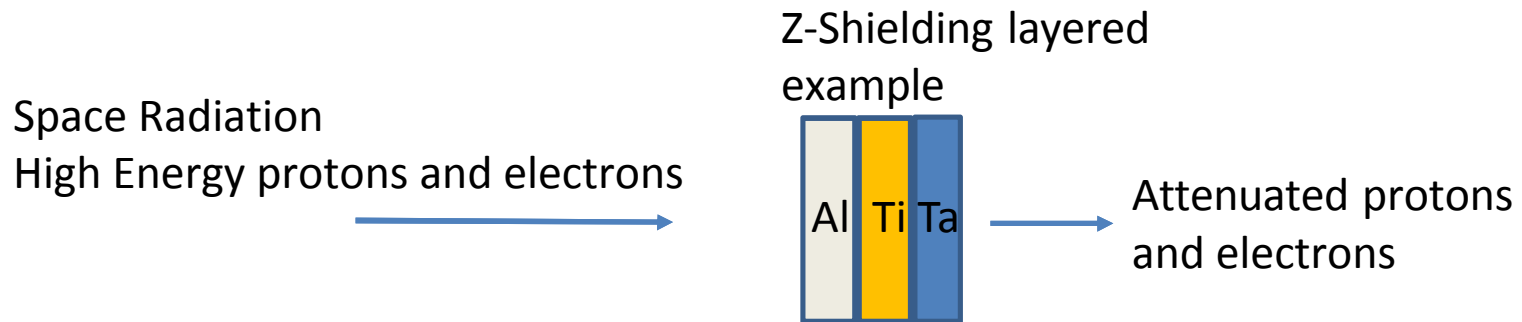
Shields-1 structure and Final Preship Picture with LaRC Z-Shielding Vault and Experiment, Solar Panels and Thermal Radiator



Shields-1 in PPOD deployer, 2nd from bottom, inside Electron Rocket Fairing before encapsulation

Z-Shielding Characteristics

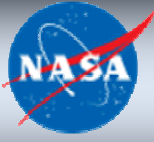
- **Low atomic number materials graded or layered to higher atomic number materials**



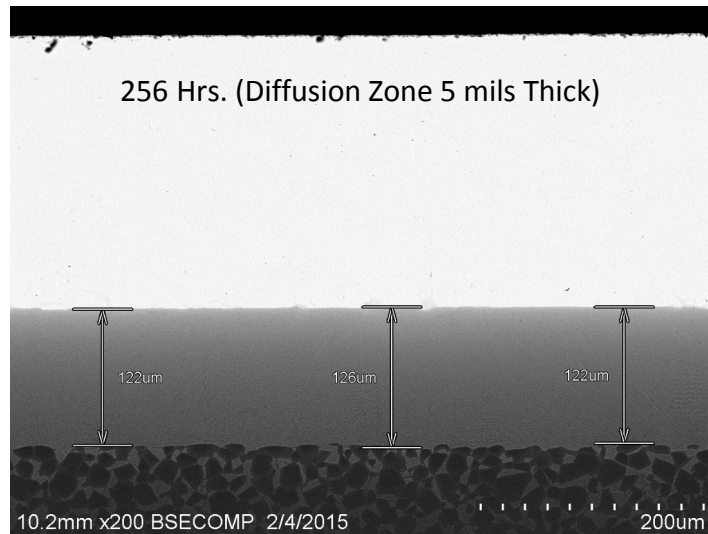
For many low earth orbits: electron radiation can be effectively shielded and the risks for internal charging substantially reduced with Z-Shielding

- **One piece structure**
 - **Continuous metallic properties: thermal and electrical continuity**
 - **Manufacturing methods: diffusion bonding, welding, plasma spray**
 - **Machining examples: milling, hot wire, and water jet**
 - **Thickness reduced by over half compared to Aluminum baselines**

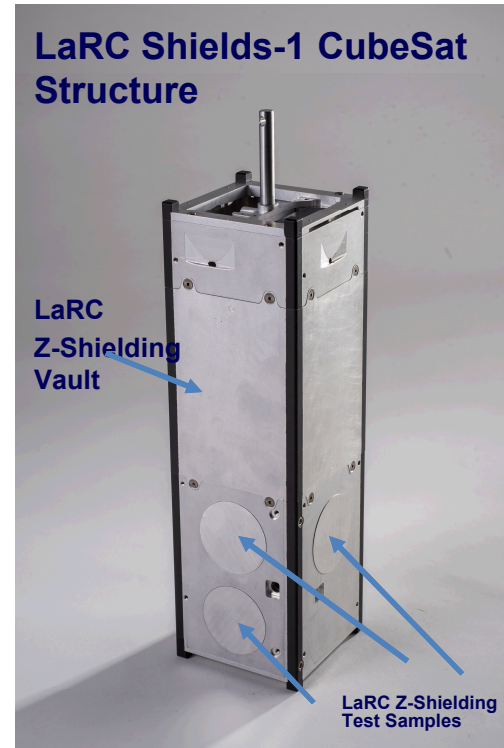
Z-Grade Shielding Materials and Technology Development



Z-Grade Shielding from Titanium and Tantalum Diffusion Bonding



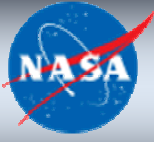
Product
→



Relevant Publications:

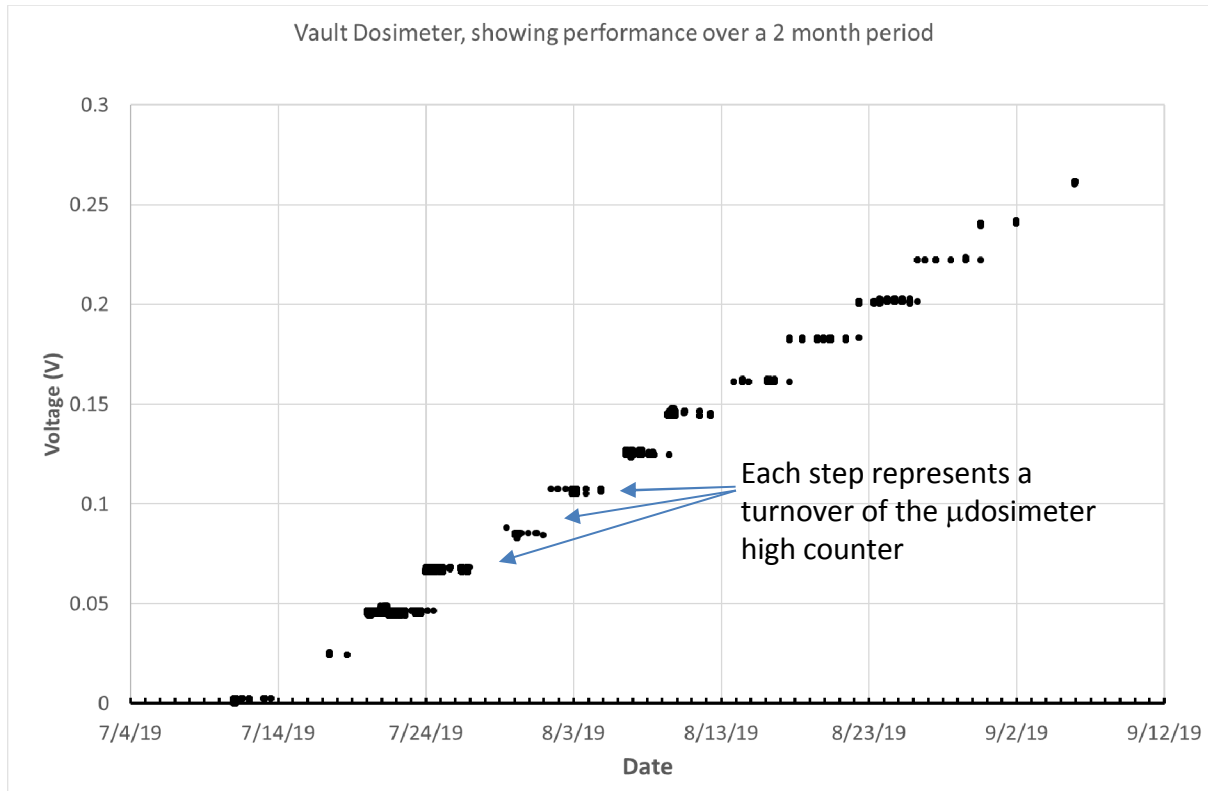
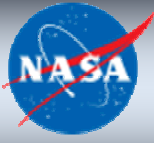
- U.S. Patent No. 10,039,217, 31 July 2018, "Methods of Making Z-Shielding." D.L. Thomsen III, R.J. Cano, B.J. Jensen, S.J. Hales, and J.A. Alexa.
- U.S. Patent Application No 15/949,644, LAR-19109, 12 April 2018, "Method of Making Thin Atomic (Z) Grade Shields", D.L. Thomsen III.
- U.S. Patent Application No. 20170032857, 2 February 2017, "Atomic Number (Z) Grade Shielding Materials and Methods of Making Atomic Number (Z) Grade Shielding." D.L. Thomsen III, S.N. Sankaran, and J.A. Alexa.
- D.L. Thomsen III, W. Kim, and J.W. Cutler. "Shields-1, A SmallSat Radiation Shielding Technology Demonstration", 29th AIAA/USU Conf. on Small Sat., SSC15-XII-9, August 2015.
- U.S. Patent No. 8,661,653, 4 March 2014, "Methods of Making Z-Shielding." D.L. Thomsen III, R.J. Cano, B.J. Jensen, S.J. Hales, and J.A. Alexa.

Shields-1: Radiation Shielding Experiments



- **Vault Electronics**
 - To measure total ionizing dose (TID) over time and monitor system electronics performance.
- **Atomic Number (Z)-Grade Radiation Shielding**
 - To measure total ionizing dose of Z-grade radiation shielding and compare to baseline aluminum for at least 3 samples each.

Shields-1 Vault Experimental Results



- Preliminary results:
estimated dose rate: 1.5 Rads/week (80 Rads/year)
- Consistent with expected results of 1.5 Rad/week
- Suggests Z-Shielding Vault behaves similarly to a spherical shielding model
- Reduces total ionizing dose on sensitive electronic parts

High Count = 256 counts (steps) of Medium

Med Count = 256 counts (steps) of Low

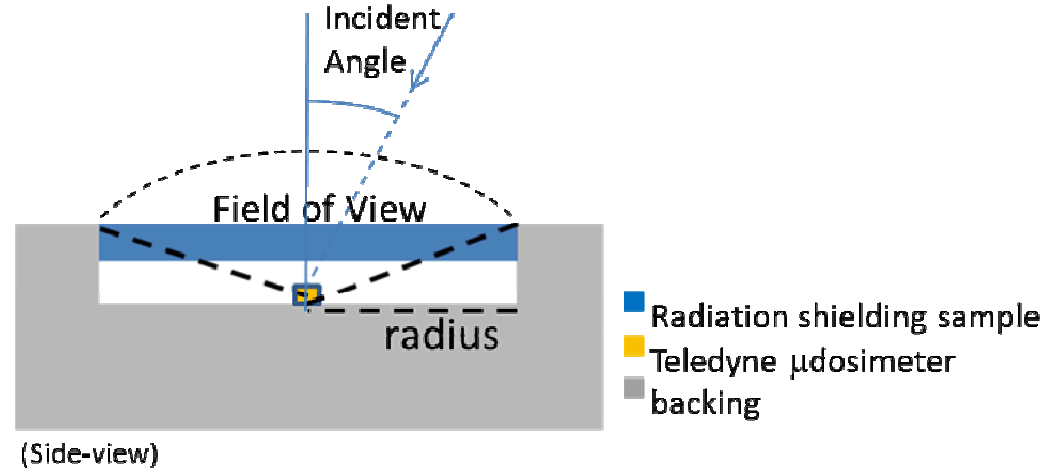
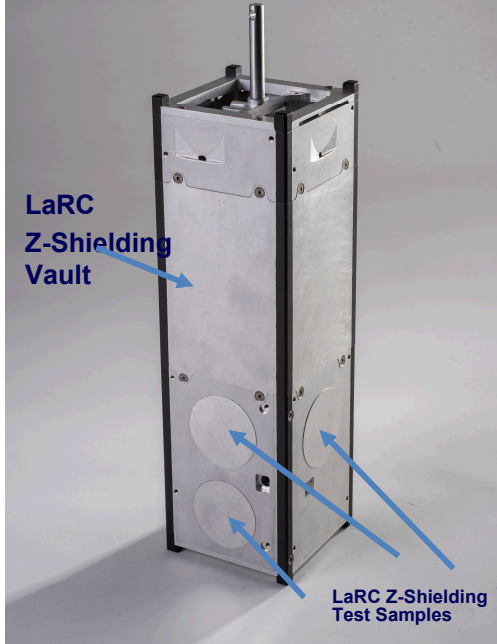
High count step = $256 \times 256 \times \sim 14.4 \mu\text{Rad/step} = 0.94 \text{ Rad/step}$

Reference: Donald Thomsen, Kevin Somervill, Mark Jones, Raymond T. Lueg, William G. Girard, Alexander D. Scammell, Jing Pei, James W. Cutler, Robert G. Bryant, "Shields-1 Initial Space Operations, a NASA CubeSat Launch Initiative ELaNaXIX Mission", SmallSat Conference, 2019, Logan, Utah, 7 August 2019.

Teledyne μdosimeter: <http://www.teledynemicro.com/product/radiation-dosimeter>

Z-Grade Radiation Shielding Experiment

LaRC Shields-1 CubeSat Structure

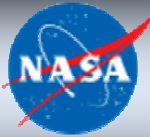


Shielding Samples Behind μ Dosimeters (UDOS)s

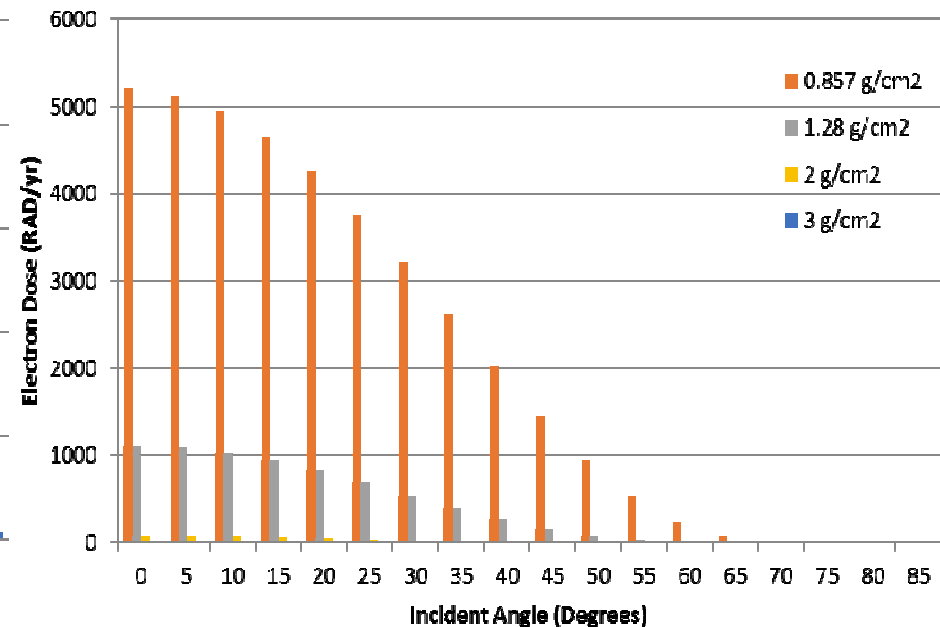
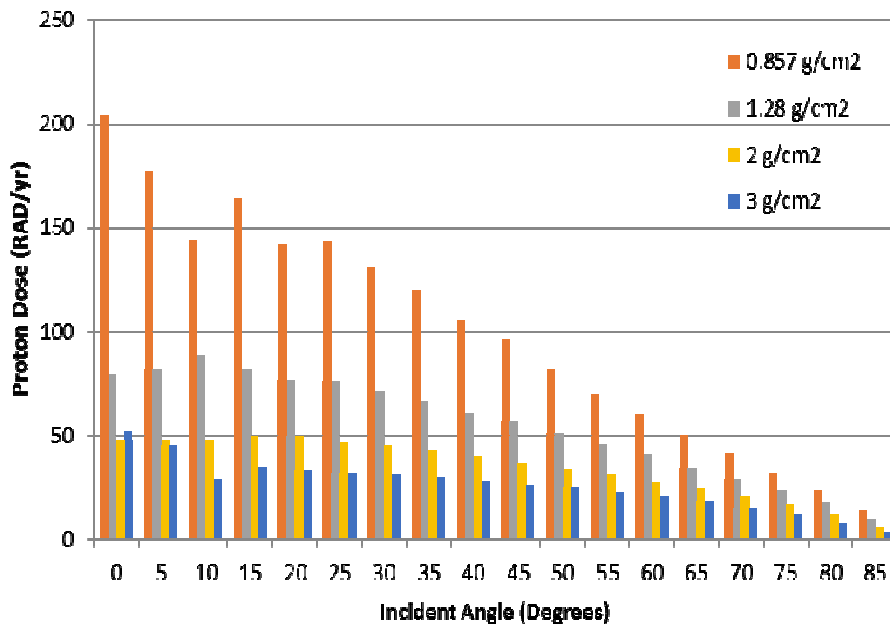
UDOS	Shielding	Areal Density (g/cm ²)
1	Al	6.00
2	Al	3.00
3	AlTiTa	3.02
4	AlTiTa	1.76
5	AlTi	1.33
6	Al	1.29
7	Al	2.00

- **Infinite slab, geometry approximation**
- **>95% incident radiation through shielding sample**
- **Large sample field of views, thick backing**

Aluminum (Al) Incidence Angle Dependence on Total Ionizing Dose (TID)



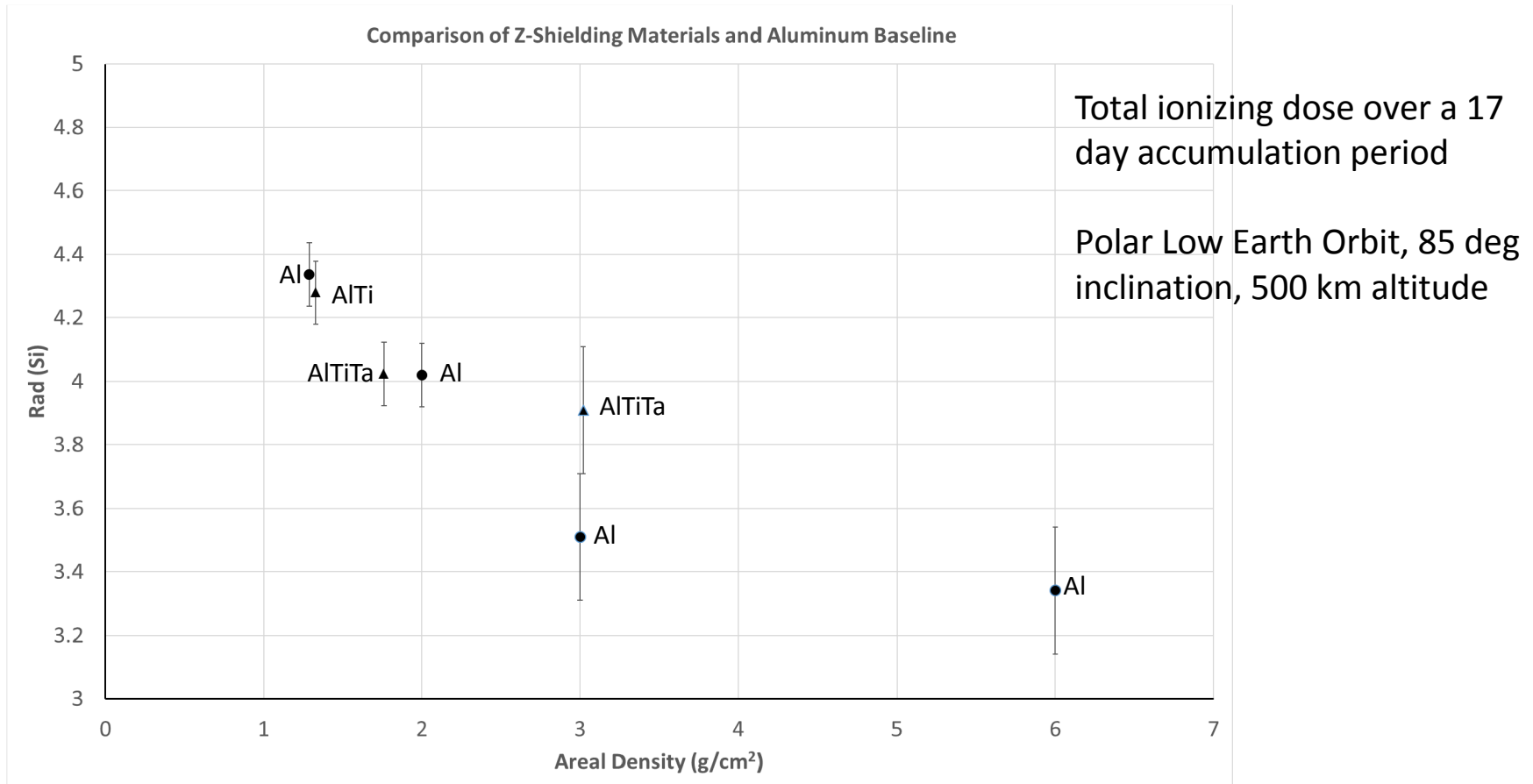
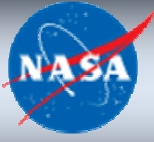
SPENVIS: Shieldose-2 from AP8min-AP8Max Model Al half-sphere results with trigonometric determined incident angle dependencies of areal density in a slab geometry for GTO.



- Incident angle dependence used to determine shielding FOV slab diameters.
- In order to receive greater than 95% of the proton radiation through a shielding slab the incident angles need to be at least 75 degrees.
- No electrons contribute to dose from incident angles greater than 70 degrees.

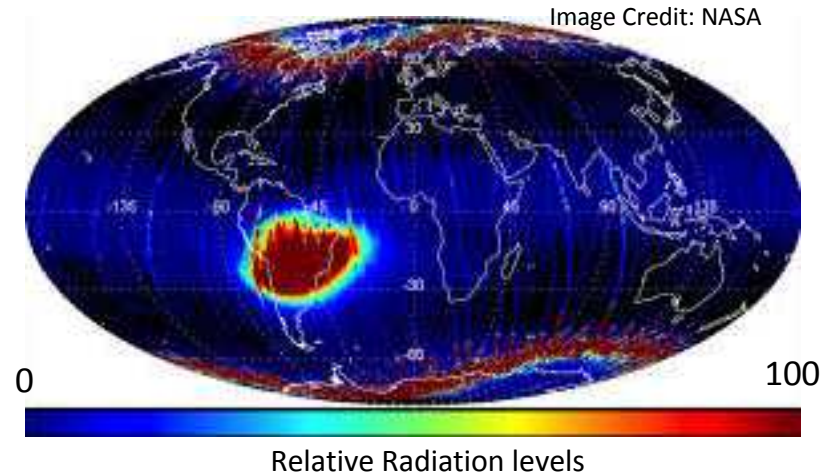
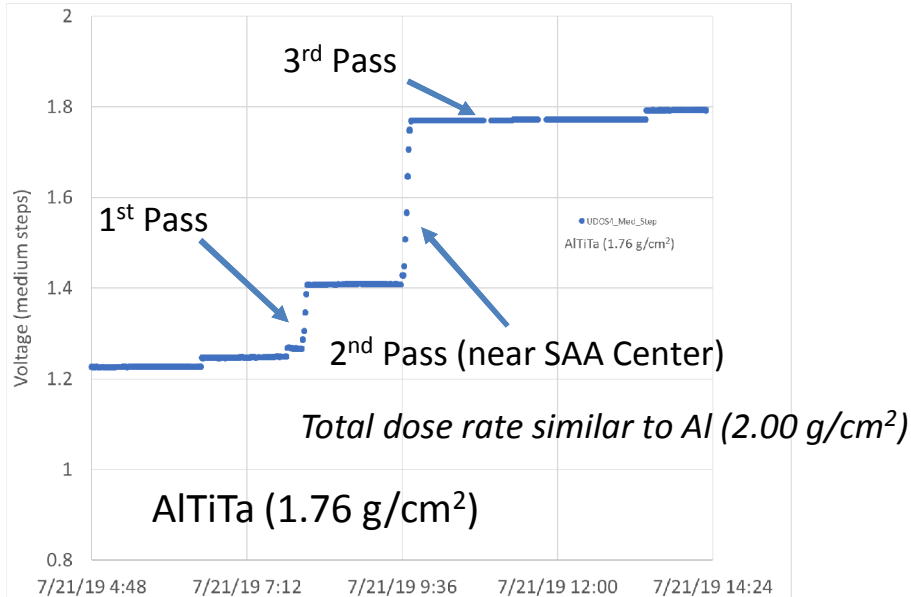
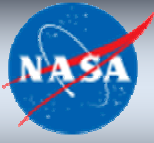
Reference: D.L. Thomsen III, W. Kim, and J.W. Cutler. "Shields-1, A SmallSat Radiation Shielding Technology Demonstration", 29th AIAA/USU Conf. on Small Sat., SSC15-XII-9, August 2015.

Z-Grade Radiation Shielding Compared to Baseline Aluminum

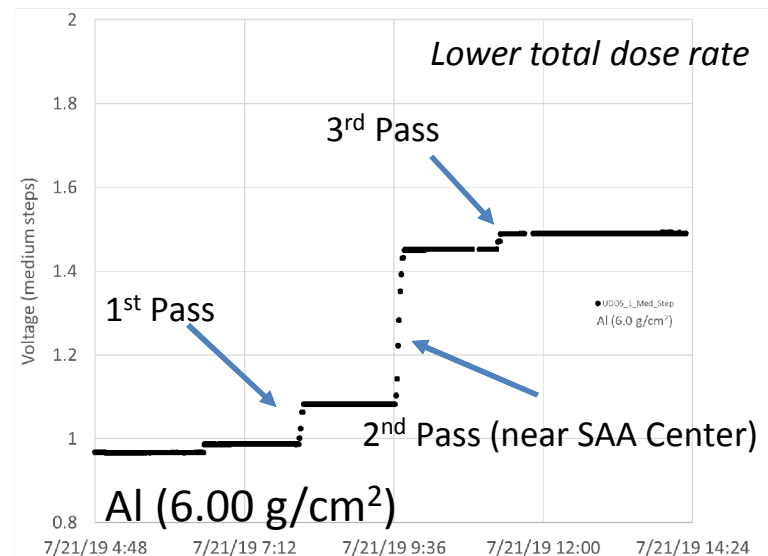
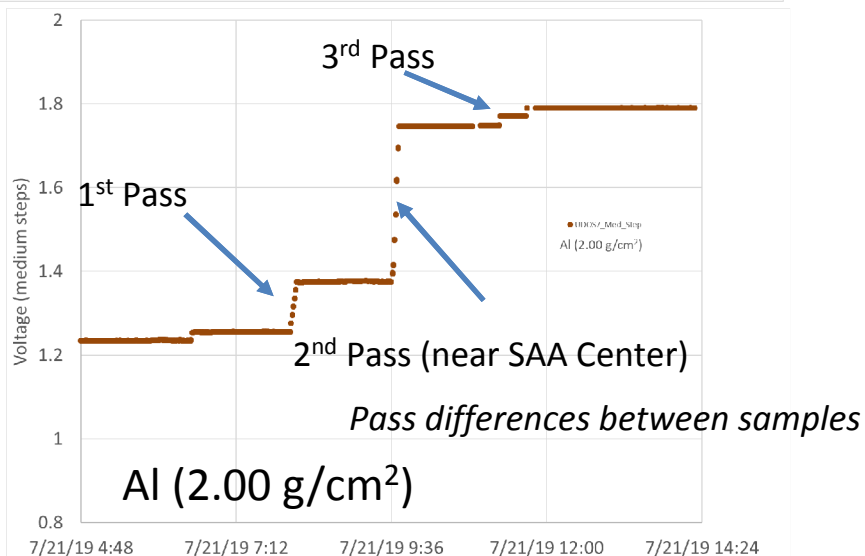


AlTiTa at lower areal density shields more effectively
Al shields more effectively at higher areal densities

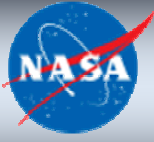
Dosimetry with the South Atlantic Anomaly (SAA)



Shielding Samples Behind μ Dosimeters (μ DOS)s

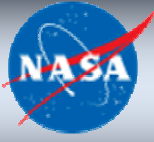


Conclusion

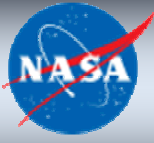


- **Z-Grade Shielding offers reduction of total ionizing dose on sensitive electronics**
- **Internal charging effects are greatly reduced by removal of electron radiation dose**
- **Extends typical CubeSat missions from months to years**
- **Slab Radiation Shielding Arrangement enables additional radiation dosimetry science, such as monitoring SAA behind different shielding thicknesses**

Acknowledgements



- R. Bryant (LaRC)
- M. Jones
- R. Lueg
- K. Somervill
- W. Girard
- T. Burns
- C. Rhoades
- M. Cooney
- N. Miller
- B. Seufzer
- V. Stewart
- H. Soto
- S. Thibeault
- A. Thornton
- S. Gayle
- C. Fay
- M Banchy
- D. Keck
- J. Applin
- J Cutler (UMich)
- W Kim (JPL)
- B. Blake (Aerospace Corp.)
- B. Crain
- A. Goff (Luna Innovations)
- S. Princiotta (Teledyne)
- M. Wrosch (Vanguard Space)
- ELaNaXIX Mission NASA CubeSat Launch Initiative
- NASA Wallops Flight Facility CubeSat Ground Operations



Back-ups