NASA Shields-1, A CubeSat Platform for Testing the Effects of Space Radiation on Materials

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13 June 2018

NASA Langley Research Center

NASA Vision and Mission

NASA Mission

Drive advances in science, technology, aeronautics, and space exploration to enhance knowledge, education, innovation, economic vitality, and stewardship of Earth.

NASA Vision

We reach for new heights and reveal the unknown for the benefit of humankind..

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

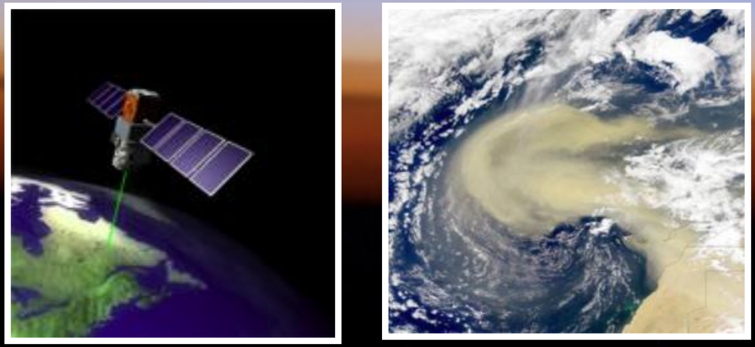
Aerospace Systems Analysis

Space Exploration

Entry, Descent & Landing

Characterization of all Atmospheres

(Lasers & LIDAR)



Aerospace Structures & Materials

Advanced Materials, Polyimide Resins and Composites

NASA LARC Advanced Materials R&D

Maturation of PETI-5:

Requirements Driven High Performance Adhesive and Composite Matrix Resin

- About 20,000 pounds of IM7/PETI-5 unidirectional tape prepared in the High Speed Research (HSR) program
- Performance at 350°F for 60,000 hrs (previously unattainable)
- Technology patented and licensed to 4 companies

PETI-5/IM7 Skin Stringer Panel (6 ft x 10 ft)

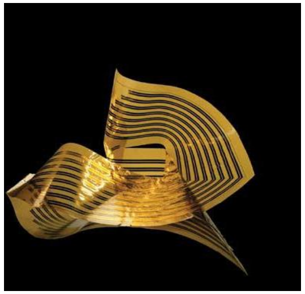
Polyimide Based R&D 100 Winners

2005
PETI-330 High
Temperature Resin

2001
TEEK
Polyimide Foam

2000
Macro Fiber
Composite Actuators

2000
Atomic Oxygen
Resistant Polymers



1996
LaRC -SI

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

(image credit: NASA/LaRC)

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

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

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: Materials Experiment Platform

CubeSat Market: $0.5B-1B over 3yrs

- Over 1700 small satellites forecasted for 2017-2023 (www.spaceworksforecast.com)

- Over 500 over next 3 yrs into polar low earth orbit (PLEO) (www.spaceworksforecast.com)

- Typical CubeSats costs $1-2M* (https://esto.nasa.gov/techval_space.html)

  **NASA ESTO Office reported it is $1-$1.5M per U at the 2017 SmallSat Conference and is updating its figure.*
- CubeSat value at risk: <u>$0.5-1B in the next three years alone</u>

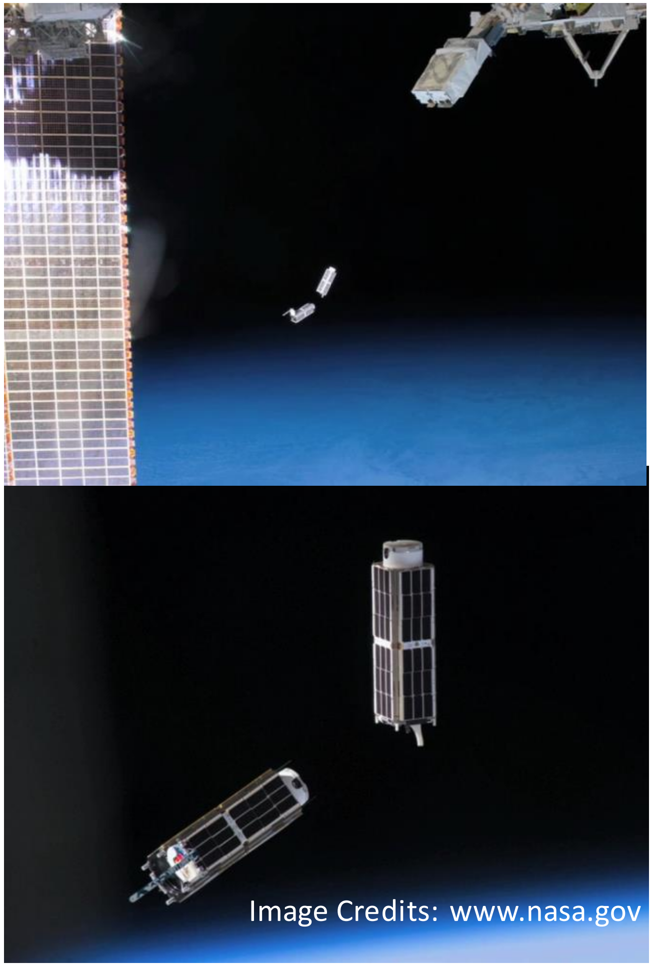


Image Credits: www.nasa.gov

LaRC Shields-1: materials experimental platform

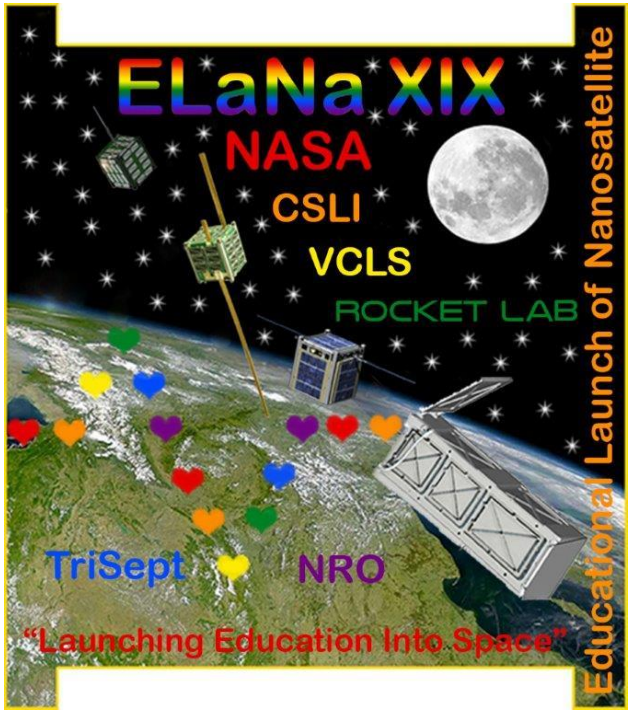
7 Kg, 10cm x 10cm x 33 cm
Near real time: 1 min data collections

Highlights

- Extends typical CubeSat missions from 3 months to years with an atomic number (Z)-grade vault.
- Demonstrates a Charge Dissipation Film designed for extreme charging environments.
- Develops and demonstrates a one-piece (Z)-grade radiation protection for electron radiation environments.
- Matures innovative μdosimeters.
- Reduces technology development schedule and associated costs by collective testing in a relevant space environment.

Shields-1 on ELaNaXIX Mission

- Shields-1 owned by NASA Langley Research Center and Co-Operated by University of Michigan
- Sun-Synchronous Orbit 85 deg inclination and 500 km altitude
- Launch Date Aboard Rocket Lab USA, Electron Rocket July 2018



Three Experiments

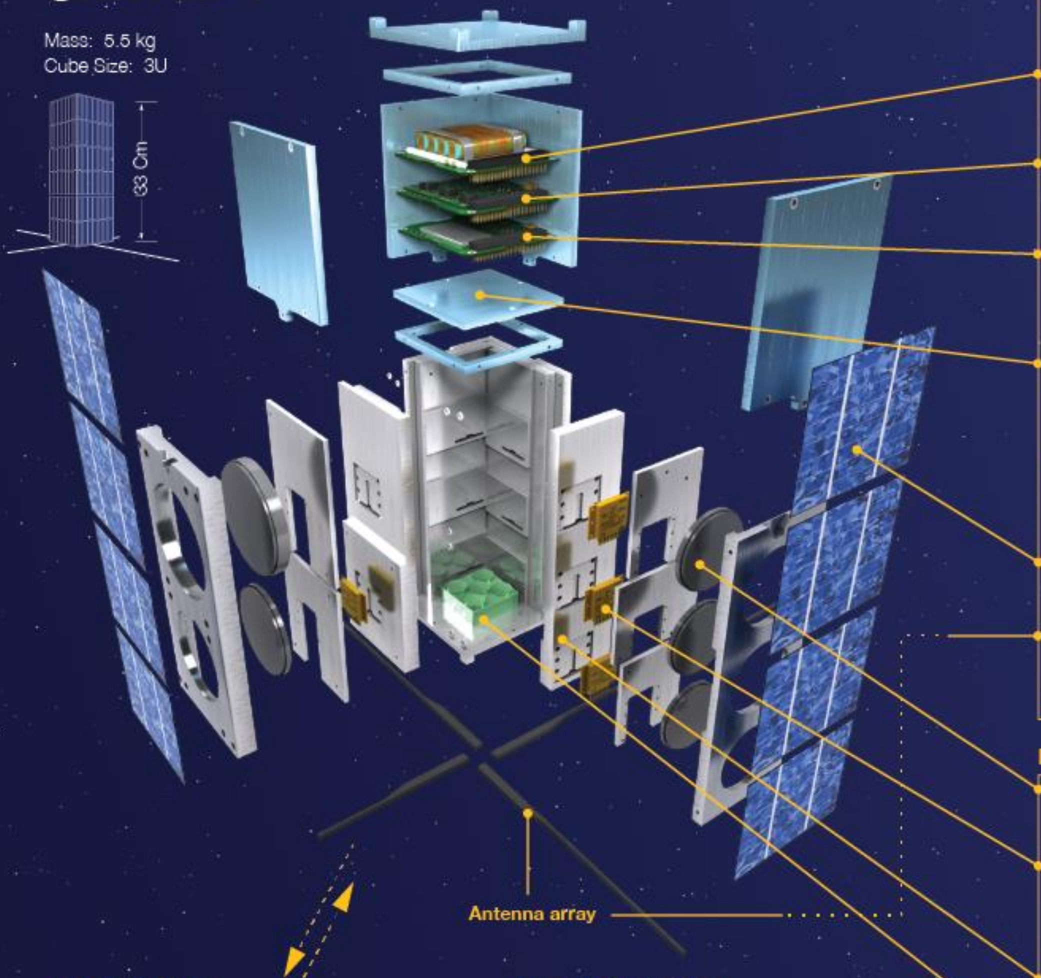
- **Atomic Number (Z)-Grade Radiation Shielding**
  - **To measure total ionizing dose of Z-grade radiation shielding and compare to baseline aluminum for at least 3 samples each.**
- **Charge Dissipation Film Resistance**
  - **To measure the resistance over time.**
- **Vault Electronics**
  - **To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

Spacecraft Overview with Experiments

Excerpt: Shields-1 Brochure, NASA NP-2015-04-608-LaRC

Shields-1

Mass: 5.5 kg
Cube Size: 3U



System

Low risk 🟩
Med risk 🟨
High risk 🟥

CubeSat Vault Electronics 🟩
TRL Advancement: 4-6, Partner: MXL, AstroDev
Redesigned board layout to fit in the inner CubeSat vault form factor.

Battery system 🟩
Partners: MXL, AstroDev
Four lithium ion cells provide power during eclipse periods and high power operational modes. The batteries provide 6800 mAh at 8.4V.

Electrical power system 🟩
Partners: MXL, AstroDev
The EPS regulates power from the solar panel and outputs three bus voltages: 3.3V, 5.0V, 8.4V. Telemetry systems monitor currents, voltages, and temperatures.

Flight computer and Communications 🟩
Partner: AstroDev
The Flight Computer provides telemetry collection and command control capabilities. It interfaces to various sensors around the spacecraft, controls the payload, and logs data to dual, redundant SD card systems. A lithium-1 radio provides half duplex communication in the UHF band.

Z-Grade Radiation Shielding Vault 🟨
TRL Advancement: 3-6, Partners: NASA Langley Research Center
Radiation shielding using Atomic Number (Z) Grade Technology for enhanced electron shielding performance with reduced volume benefits for small satellite applications.

Flight Software 🟩
TRL Advancement: 7-9, Partners: MXL, AstroDev
The flight software, written in C, provides primary spacecraft operational capability and runs on the flight computer. It gathers telemetry, monitors health, and processes commands, both in real time from the ground and scheduled for a later time. The software has flown in various forms on RAX, MCubed, and GRIFEX.

Electrostatic Discharge Cleaned CubeSat Solar Panels 🟨
TRL Advancement: 4-8, Partner: Vanguard Space Technologies, Inc, SBIR Commercial Readiness Program
CubeSat Solar Panels designed for extreme radiation environments.

Antenna array 🟩
The ISIS deployable antenna system contains up to four tape spring antennas of up to 55 cm length. The system can accommodate up to four monopole antennas, which deploy from the system after orbit insertion. The antenna system has been designed for maximum compatibility with existing COTS CubeSat components.

Research

Work Research Payload 🟨
Experimental Radiation Shielding: Experimental Z-grade or baseline shielding with varying areal densities in front of the µdosimeters.

µDosimeters 🟩
TRL Level: 9
µdosimeters tested in inner and outer proton belts with varying shielding areal densities.
Space heritage from previous missions: AeroCube 6, MARS, Van Allen Probes, Rapid Pathfinder "Deal" Mission, LRO, MISSE-7B.

Back Shield Panels 🟨
Shielding behind the µdosimeters to create a back slab. Most radiation will enter through the front Z-grade experimental sample or baseline shield.

Charge Dissipation Film 🟥 (schedule)
TRL Advancement: 3-6, Partner: LUNA Innovations, Inc.
LUNA XP-CD-B is a charge dissipation film designed for extreme internal charging environments, developed through the NASA STTR Phase I proposal award NNX11CI29P and Phase III.

Ground Systems

Proposed Ground link station 🟩
Wallops Island
18 Meter UHF parabolic dish: 401 MHz U/L and 402 MHz D/L, Government Frequency License submitted in the first half of FY2014.

Mission Operations

Flight Mission Support Center 🟩
NASA Langley Research Center
Special operations center for launch support, early orbit and payload activation, anomaly resolution, data capture and down link, payload health and monitoring.

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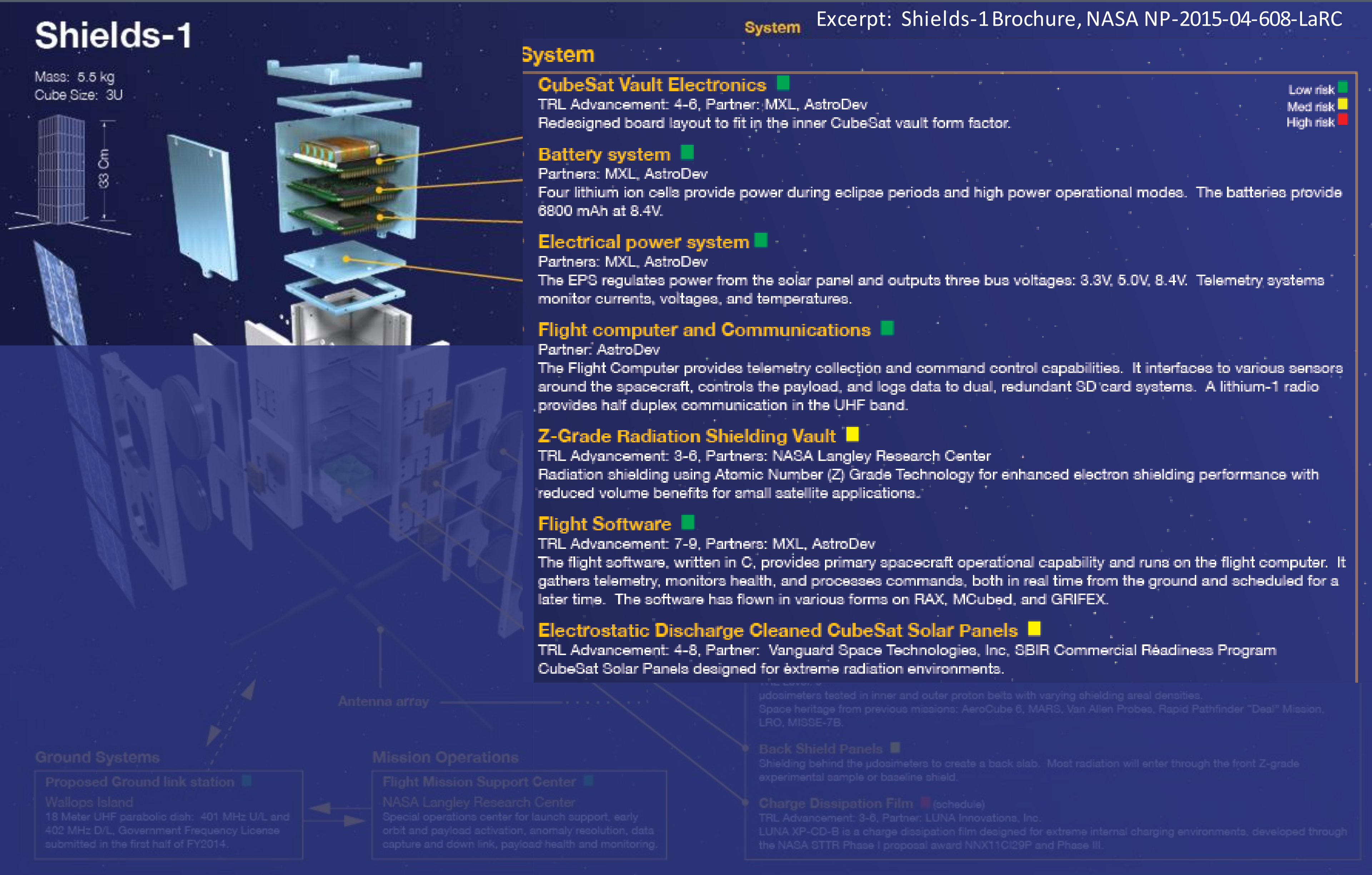

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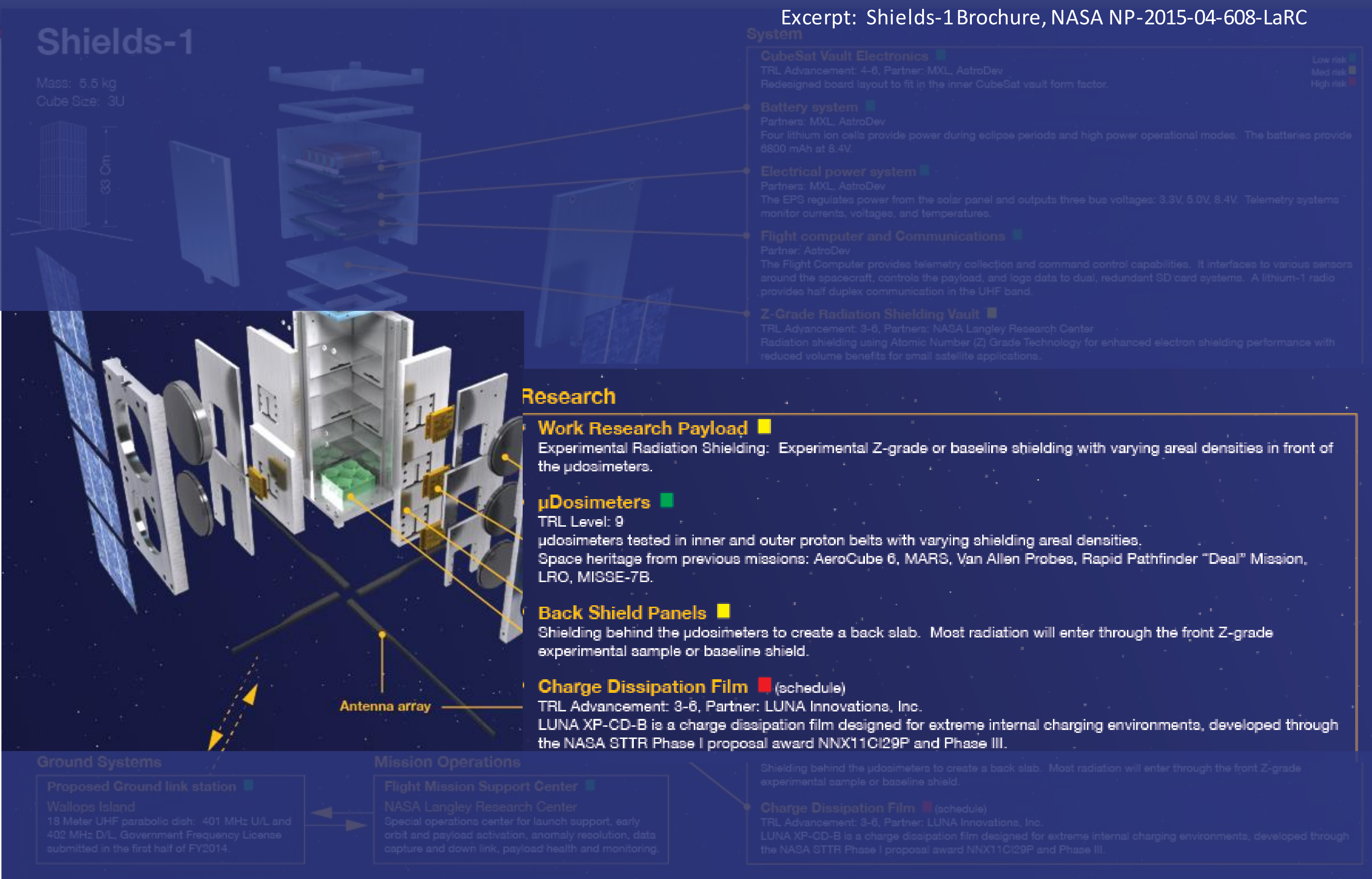

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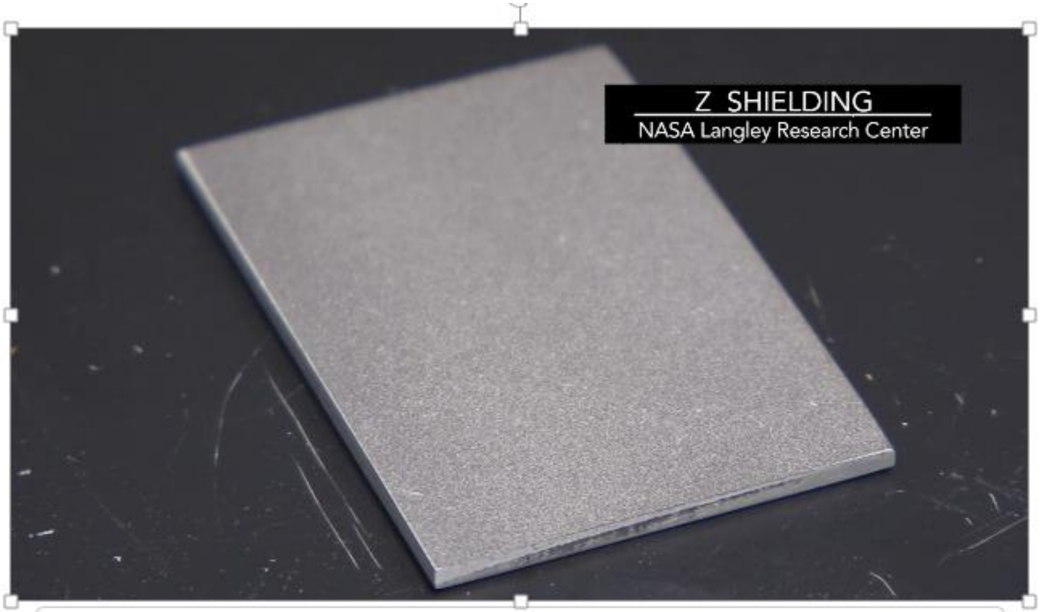
Shielding Experiment

LaRC Z-Shielding Increases CubeSat Mission Lifetimes



NASA Tech-Transfer web releases of LaRC Z-Shielding

Z-shielding Technology pitch:
https://www.youtube.com/watch?v=oHA8j5bpFcU&t=21s
Webinar: https://www.youtube.com/watch?v=RrqDocGqawQ
https://techgatewire.larc.nasa.gov/2017/01/26/radiation-protection-material-webinar/

- **Extends typical CubeSat missions from 3 months to years**
- **A 100x reduction of total ionizing dose and removal of internal charging effects**.
- **Increases return on investment**

Shielding is not common today

- CubeSat missions have been short, mostly experimental
- There are size and material constraints in the "standard" CubeSat packaging
- Mostly in low, short-lived orbits, such as deployed from ISS
- The actual satellites have been viewed as "disposable"

But that can and will change quickly

- The satellites themselves are now more capable
- Higher orbits are now available
- Longer orbit life calls for longer functional life for the satellite
- Shielding now matters

Solution: Z-Shields

- Predicted Life 3 -18 yrs: Z-Shields LEO Light
- Predicted Life 5-27 yrs: Z-Shields LEO
- 100x or greater performance increase
- $1M CubeSat on-Orbit: $0.5 million/month (2 month lifetime)
- CubeSat with Z-Shields limited only by orbit lifetime (2-6 yrs typical LEO)

Total Ionizing Dose (TID) Environment

Polar- LEO:

- **Orbit: 102° inclination, 775 km apogee, 458 km perigee**
- **ELaNa III[1] CubeSat environment: AUBIESAT-1, RAX-2, DICE, Explorer, M-Cubed/COVE.**
- **TID environment Shielddose-2 calculation[2]: 5.0 kRad/yr total dose, 0.5 g/cm2 Al**
  - *0.5 g/cm2 ~ 0.078 in Al the typical Al Structure thickness for the CubeSat standard form factor*
  - *Commercial parts Hardness levels[3]: 2-10 Krad*
  - *Radiation Design Margin[4] of 2*

Adding shielding to commercial CubeSats reduces risk for premature failures due to total ionizing dose

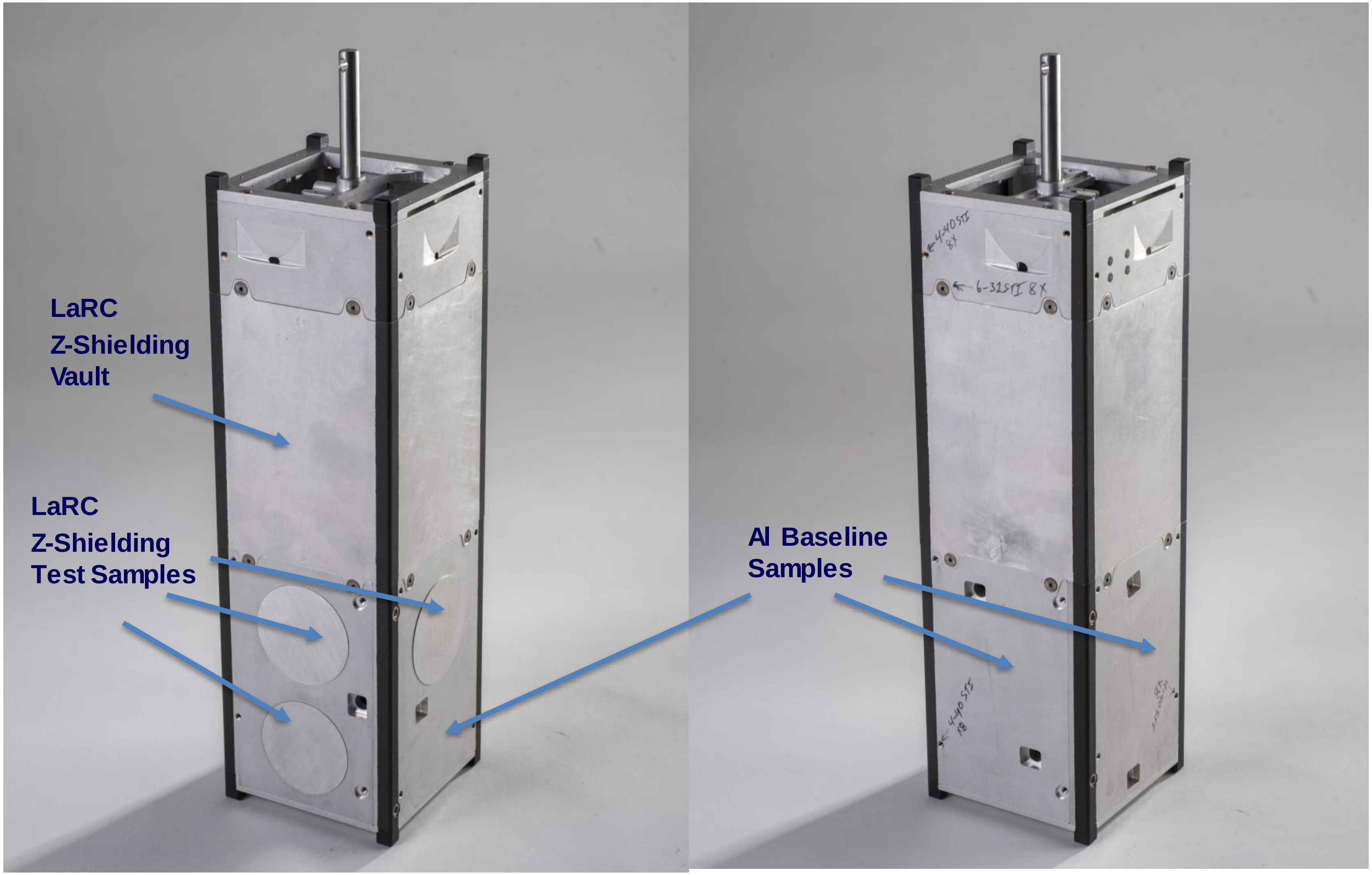
1. http://www.nasa.gov/pdf/627975main_65121-2011-CA000-NPP_CubeSat_Factsheet_FINAL.pdf
2. SPENVIS, Shielddose-2 calculation, AP8min-AE8 Max Model Environment.
3. NASA PD-ED-1258, “Space Radiation Effects on Electronic Components in Low-Earth Orbit, April 1996
4. NASA PD-ED-1260, “Radiation Design Margin Requirement”, May 1996.

LaRC Z-Shielding: 100 times performance over Al:

Shielding Material	TID (Rads/yr)	Lifetime* LEO (yr)	1U mass (Kg)	Key Features
Z-Shields LEO (80 mil)	183 (15 e)	5.5-27.5	0.91	**Excellent choice for higher altitude LEO orbiting spacecraft. Greater electron radiation shielding than Z-Shields LEO-Light.**
Z-Shields LEO-Light (80 mil)	275 (95 e)	3.6-18	0.66	**Thinnest and lightest of the Z-shields. 100 times performance over Al with respect to thickness.**
Al (78mil)	27269 (26496 e)	13-66 days	0.320	This is the commercial Al wall shielding thickness being offered in the CubeSat commercial market. It offers basically no electron radiation protection for polar LEO or GEO.

*Lifetime determined from NASA PD-ED-1258 Commercial Part Hardness and a Radiation Design Margin of 2 per NASA PD-ED-1260. SPENVIS MULASSIS Sphere AP8max-AE8min Model at 85 deg 500 km altitude orbit. www.spenvis.oma.be. e=electron RAD

Shields-1:   2 Orientations

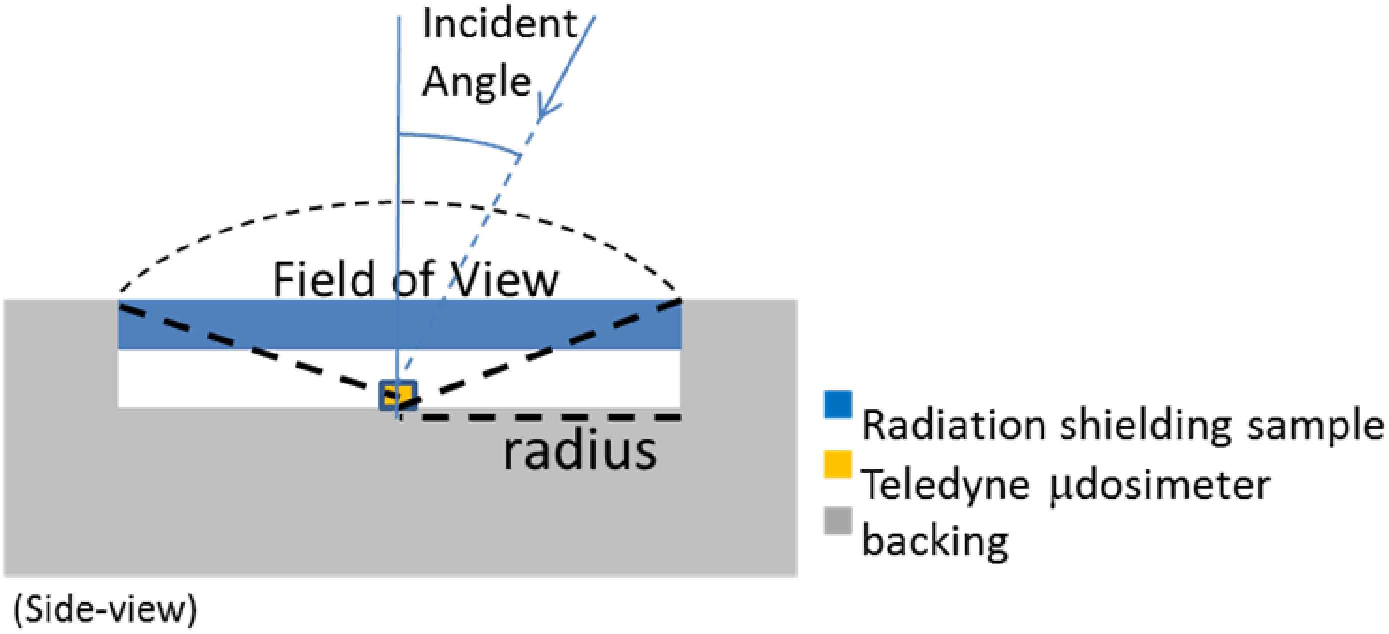


LaRC
Z-Shielding
Vault

LaRC
Z-Shielding
Test Samples

Al Baseline
Samples

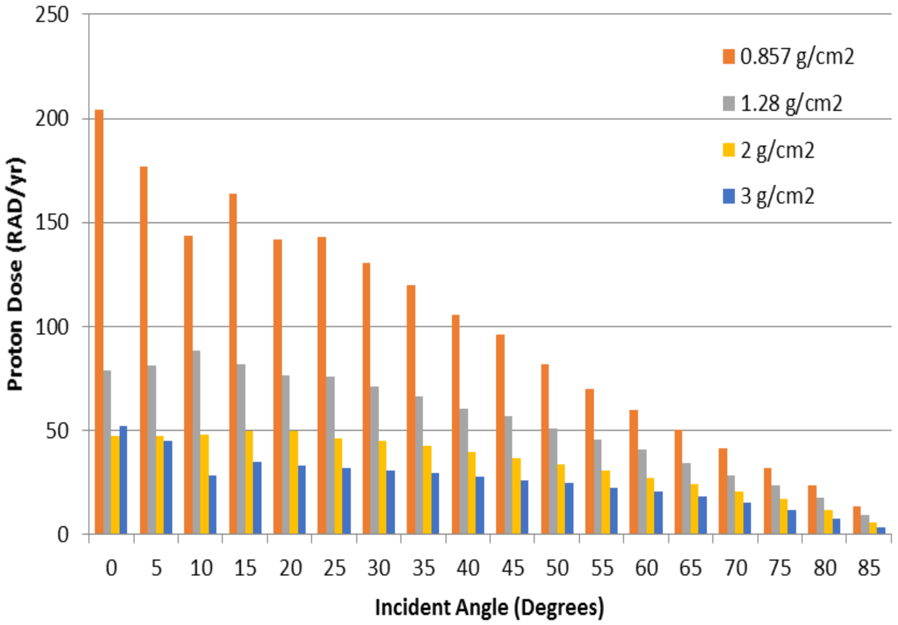
Radiation Shielding Experiment

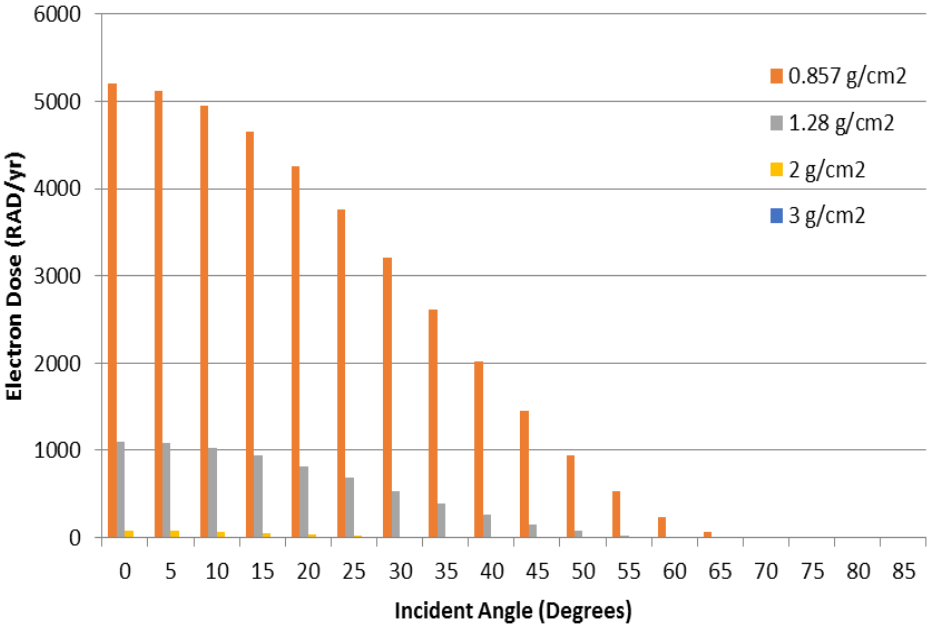


- Infinite slab, geometry approximation
- >95% incident radiation through shielding sample
- Large sample field of views, thick backing

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.

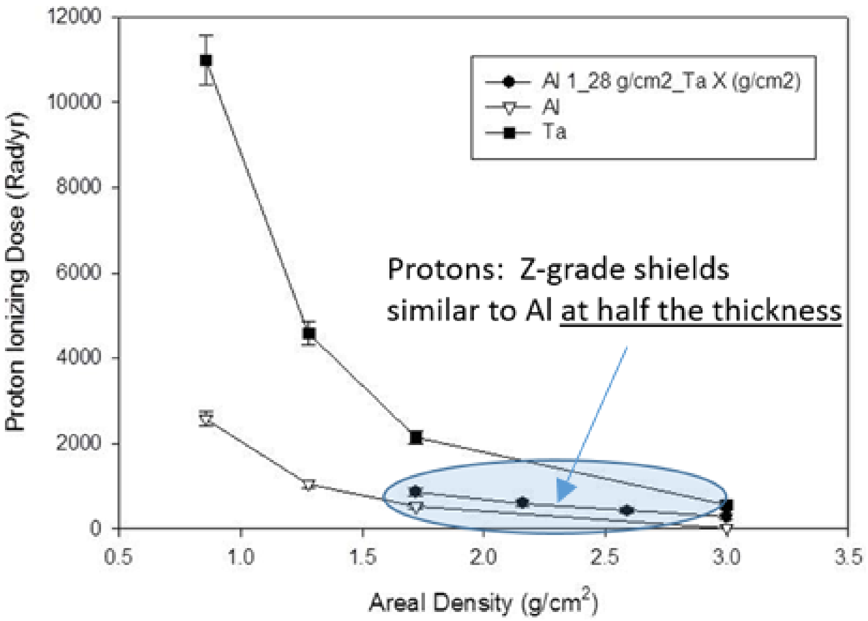




- Incident angle dependence used to determine shielding field of view slab diameters.
- In order to receive greater than 95% of the proton radiation through a shielding slab the incident angles need to be at least 75 degrees.
- No electrons contribute to dose from incident angles greater than 70 degrees.

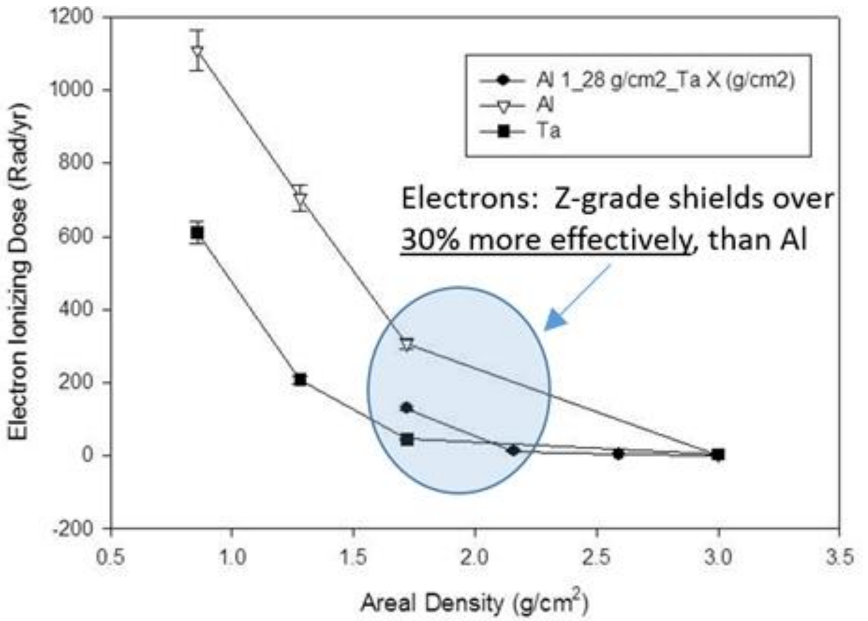
Expected Dose Results for Various Shielding Areal Densities in GTO

SPENVIS: Ionizing dose from AP8min-AP8Max Model for GTO using MULASSIS with propagated integration error from the μdosimeter as a function of areal density.



Proton Dose

Protons: Z-grade shields similar to Al <u>at half the thickness</u>



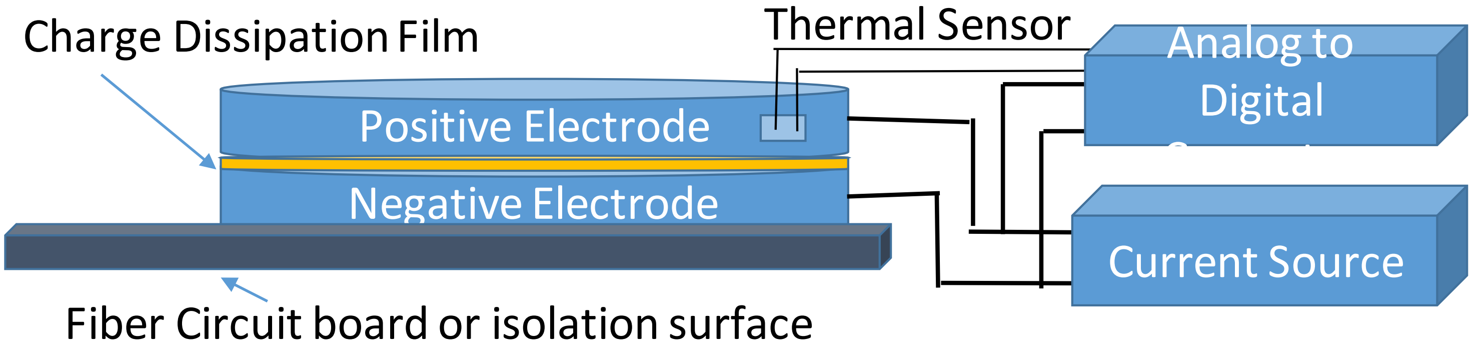
Electron Dose

Electrons: Z-grade shields over <u>30% more effectively</u>, than Al

Aluminum/ Tantalum Z-Grade Shielding Samples (Al_Ta)
Baseline: Aluminum (Al) and Tantalum (Ta)

Charge Dissipation Film Experiment

Charge Dissipation Film Experiment



Charge Dissipation Film

Thermal Sensor

Analog to
Digital

Positive Electrode

Negative Electrode

Current Source

Fiber Circuit board or isolation surface

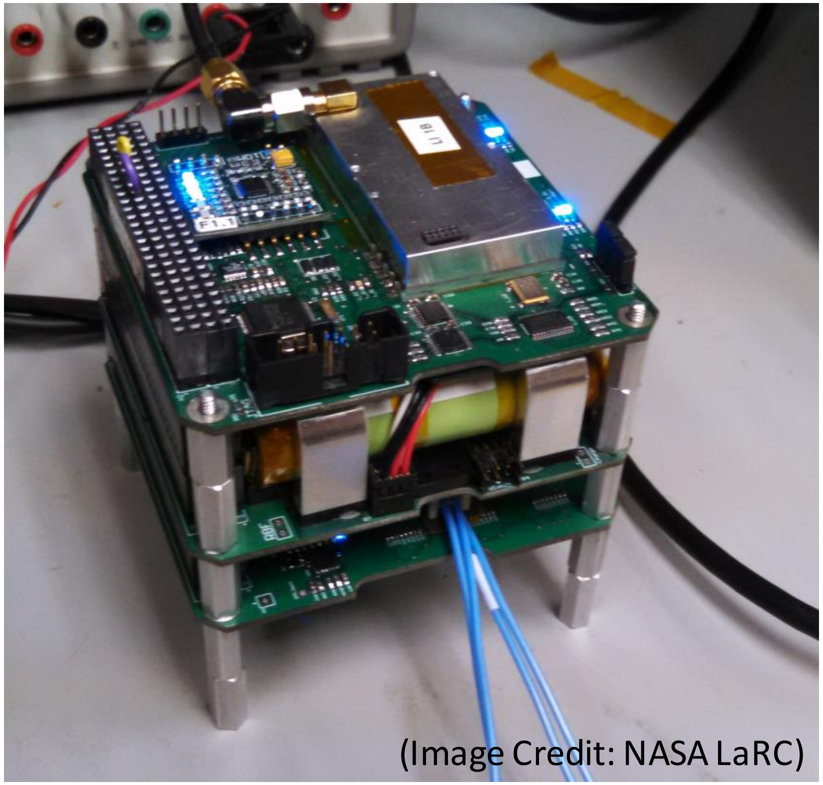
LUNA XP-CD-B Volume Resistivity	Specimen Dimensions	Expected Resistance
4.7 x 10e^9 ohm cm at 25°C	Area 5 cm^2	2.3 MOhm
	Thickness 0.0025 cm	

Measure Resistance of a known thickness and area charge dissipation Film, using an approach in ASTM 257-14, “Standard Test Methods for DC Resistance or Conductance of Insulating Materials”.

Vault Electronics Experiment

Vault Electronics Experiment

- **Total Ionizing Dose**
- **Telemetry: Temperature and Power**
- **Power on: resets**
- **Memory Checks**

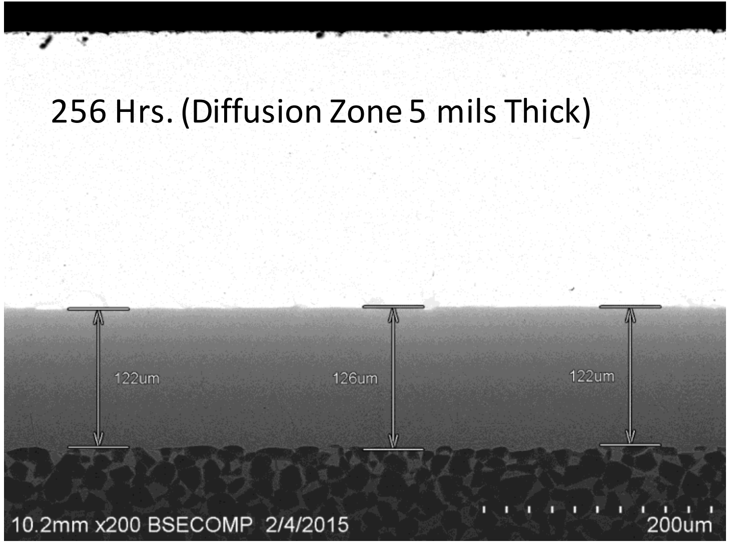

(Image Credit: NASA LaRC)

Shields-1: Astrodev vault electronics, flight stack spare

LaRC Z-Shielding Technologies

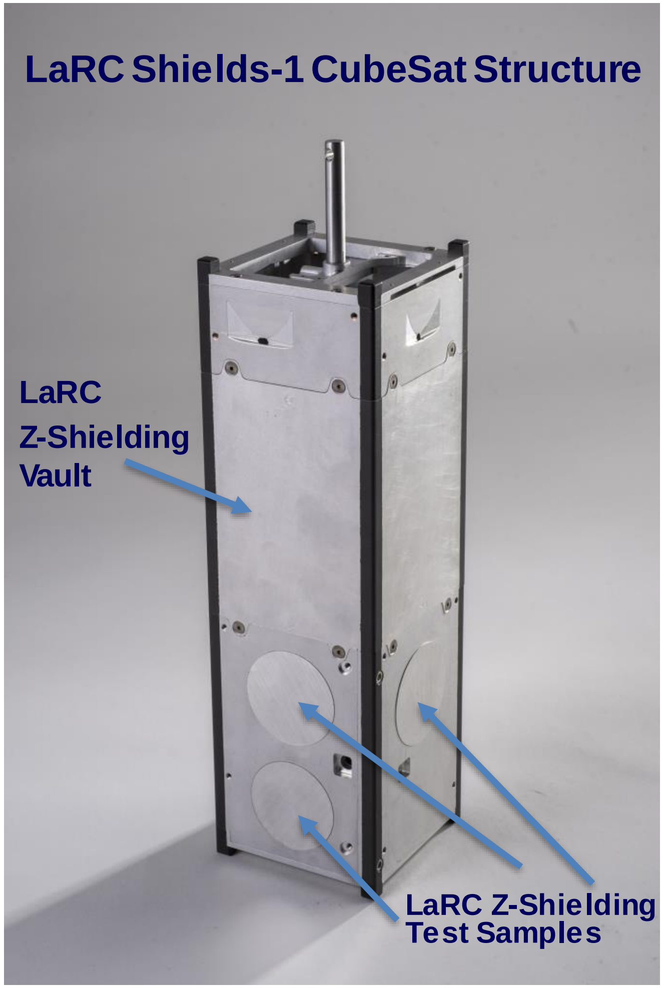
Z-Grade Shielding Materials and Technology Development

Z-Grade Shielding from Titanium and Tantalum Diffusion Bonding

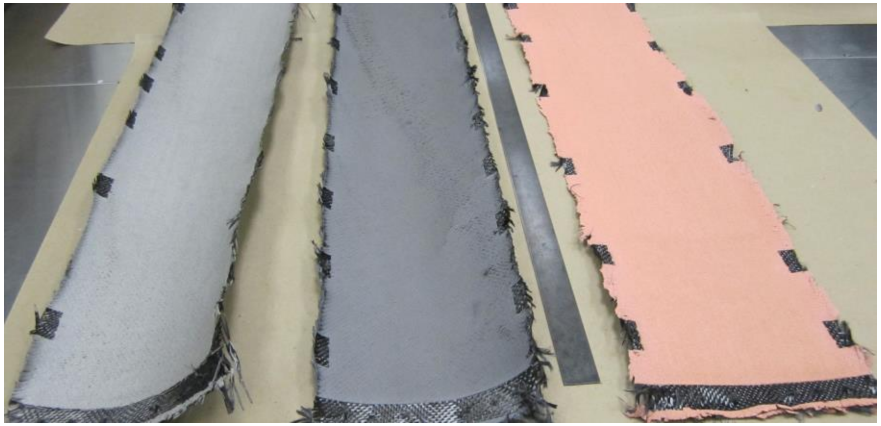


U.S. Patent Application No. 20170032857, 2 February 2017, “Atomic Number (Z) Grade Shielding Materials and Methods of Making Atomic Number (Z) Grade Shielding.” D.L. Thomsen III, S.N. Sankaran, and J.A. Alexa.

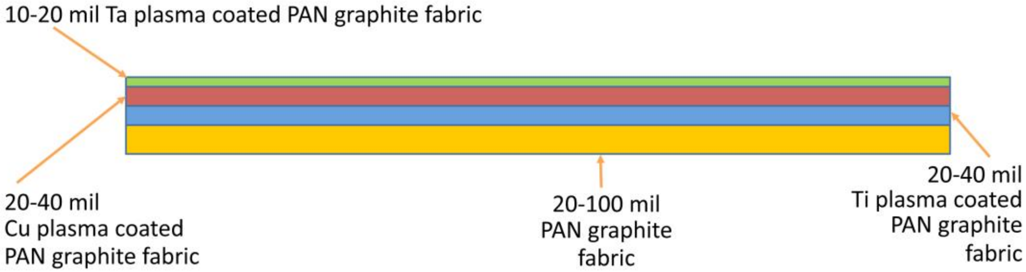
Product →



Methods of Making Atomic Number Z-grade Radiation Shielding



Metal Plasma Sprayed Carbon Fiber Fabrics



10-20 mil Ta plasma coated PAN graphite fabric

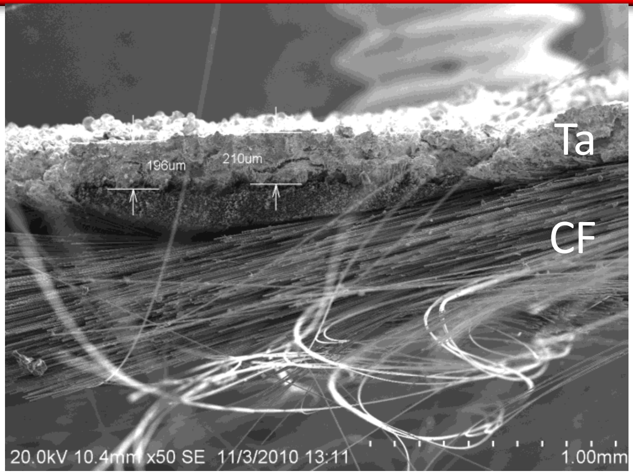
20-40 mil Cu plasma coated PAN graphite fabric

20-100 mil PAN graphite fabric

20-40 mil Ti plasma coated PAN graphite fabric

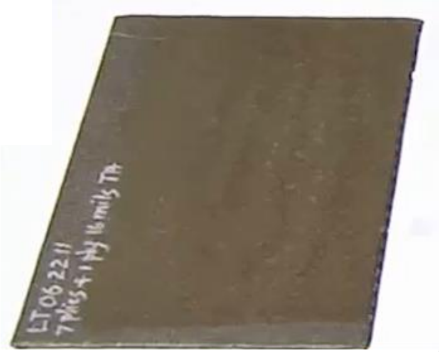
Schematic of Z-grade Lay-up with Fiber Metal Laminate

U.S. Patent 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.



Ta on IM-7 Carbon Fiber (CF) Fabric SEM cross-sectional image

Thickness ~196 - 210μm

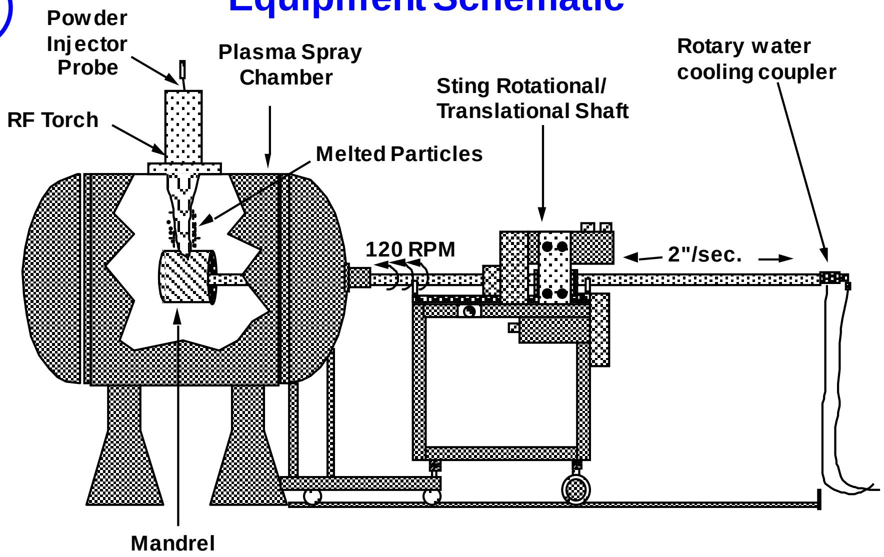


LaRC Ta Carbon Fiber Laminate, prepared by Vacuum Assisted Resin Transfer Molding (VARTM)

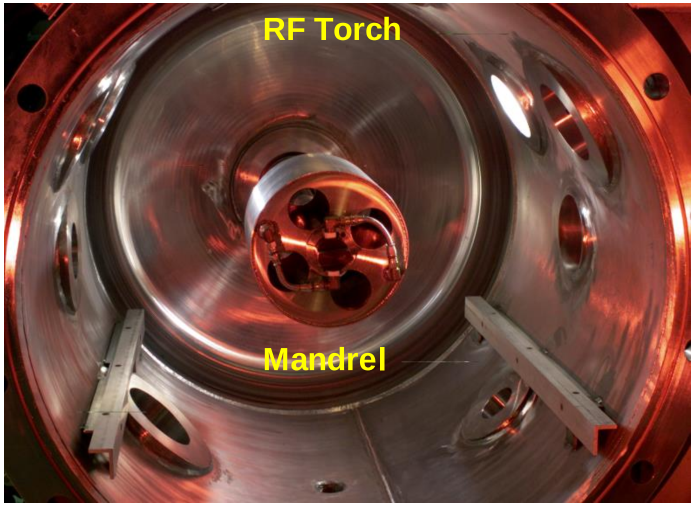
Metal Deposition via RF Plasma Spray

① NASA-LaRC RF Plasma Spray Facility

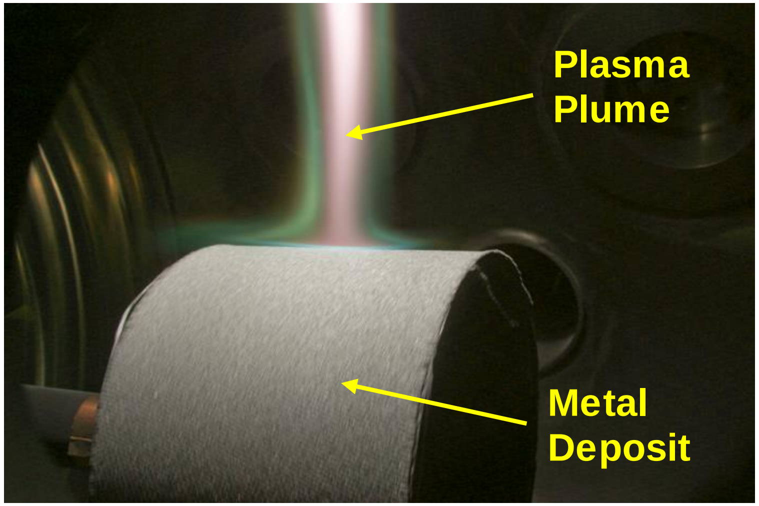
② Equipment Schematic



③ Chamber Interior



④ Metal Deposition on Rotating Substrate



Rf Plasma Spray Ta Foil Properties

Tantalum Material Properties	Density (g/cm^3)	Volume Resistivity (μ ohms-cm)	Crystal Structure	Reference
Rf Plasma Spray Ta (Z=73)	**16.02 +/- 0.02**	**49 +/- 6**	**bcc**	
Bulk Ta	16.6	13	bcc	1.
Thin Film Ta	15.6	25-50	bcc	1.

1. Maissel and Glang, Handbook of Thin Film Technology, McGraw Hill Publishing, 1970.

Shielding and Mechanical Properties

Table 1. Modulus and Strength Comparison.

Materials	Z-Number	Density (g/cm3)	Modulus (GPa)	Strength (MPa)	Reference
Tantalum	73	16.6	186	650	http://www.eaglealloys.com
Aluminum 6061	13	2.79	68.9	310	http://asm.matweb.com
Cyanate M55J	6	1.60	324	2303	Hexply 954-3

Table 2. Stiffness Comparison of 0.686 g/cm2 materials (100 mils Equivalent Al)

Materials	Thickness cm (mil)	Stiffness (MN/m)
Ta	0.0630 (16)	117
Al	0.254 (100)	175
Cyanate Composite	0.429 (169)	1390
Ta/Cyanate Composite	0.0138 (15/20)	110 + 164 =274

Use of Ta/Cyanate composite is predicted to raise stiffness and reduce thickness with respect to Al.

Ideal Applications

- **Space-Radiation Shielding CubeSats**
- **Aircraft Avionics and Crew Protection**
- **Health Care**
  - **Radiation Equipment**
  - **Facilities**
  - **Personnel Protective Gear**

Aircraft Avionics

Applications

- **High Altitude Vehicles**
- **Polar Flights**

Image Credit: https://pixabay.com/en/cockpit-avionics-flight-cargo-2671082/

Health Care

Health Care

- Radiation Equipment
- Facilities
- Personnel Protective Gear

Image credit: Pixabay.com/TheShiv76

url: https://pixabay.com/en/eye-surgery-female-medical-young-766166/

Image credit: Pixabay.com/Taokinesis

url: https://pixabay.com/en/ankle-fracture-foot-medical-2253057/

Conclusion

- Z-Grade Shielding offers reduction of total ionizing dose on sensitive electronics.
- Internal charging effects are greatly reduced.
- Extends typical CubeSat missions from 3 months to years
- Increases return on investment

LaRC Z-Shielding Publications

- 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.
- U.S. Patent Application No. 20120023737, 2 February 2012, "Methods of Making Z-Shielding." D.L. Thomsen III, R.J. Cano, B.J. Jensen, S.J. Hales, and J.A. Alexa.

LaRC Z-Shielding Licenses

- SpaceBoosters, LLC
- Z-Rated, LLC
- Burlington Medical

Acknowledgements

LaRC Z-Shielding

- Joel Alexa
- Bill Girard
- Sankara Sankaran
- Steve Hales
- Bert Cano
- Brian Jensen

Shields-1

- Ray Lueg
- Mark Jones
- Kevin Somervill
- Jamie Cutler
- Alex Scammell
- Yuan Chen
- Robert Bryant
- Arthur Bradley
- Catharine Fay

Questions?