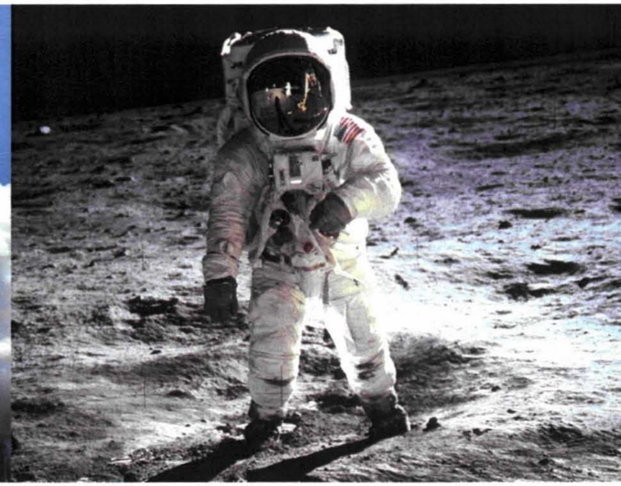
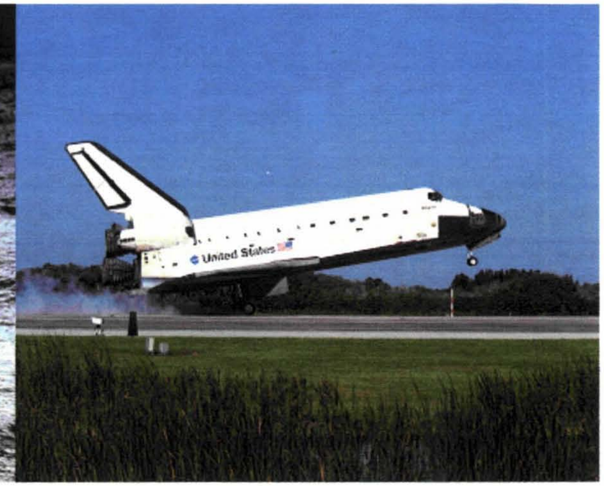
National Aeronautics and
Space Administration

John F. Kennedy Space Center

Polymer Chemistry

Chemical Analysis and Polymer Branch
Materials Science Division
Engineering and Technology Directorate
Kennedy Space Center, Florida

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Anne Caraccio (Anne.Caraccio@nasa.gov)
7/29/2010

Materials Science Division
Organizational Chart

NE-L
Murray, S.– Chief
~~**Foster, A. – Deputy**~~ Delete
Balles, A. – Technical Integration Mgr

- NE-L1 Failure Analysis & Material Eval.
- NE-L2 Mat. Testing & Corrosion Control
- NE-L3 Prototype Development
- NE-L4 Materials and Processing
- NE-L5 Applied Physics
- **NE-L6 Chemical Analysis & Polymer Branch**
  - Chemical Analysis
  - **Polymer Science & Technology Lab**

Lab Overview

Mission

To develop and apply new technologies in polymer and material chemistry that benefit NASA's programs and mission

Team

2 NASA scientists, 1 co-op, and 4 contractors

Areas of Expertise

Polymer Nanocomposites
Next Generation Wire Materials
Carbon Nanotube and Nanofiber Materials
Conductive Polymers
Polymer Processing
Fire and Polymers
Foam and Insulation Materials

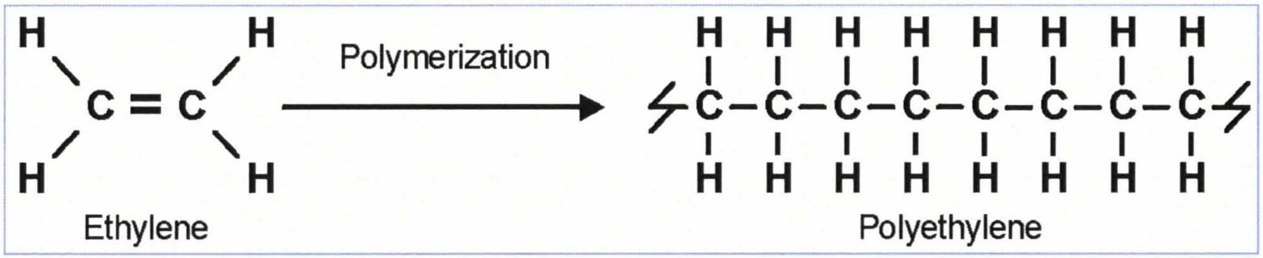
Numerous Collaborative Efforts

***NASA Centers** (JSC, LaRC, MSFC, GSFC, GRC)*
***KSC Directorates** (Shuttle, Ares, Orion, Ground support operations)*
***Academia** (Alberta, FIT, GT, Harding, Illinois-Urbana Champagne, UCF, UF, USF)*
***Industry Space Act Agreements** (Thermax, DeWAL, Sharklet, Crosslink, Sabic, Amalgam)*
***Industry Contracts** (ARCnano, Epner)*

What Are Polymers?

POLY MERS are made of many MONO MERs

↓ *Many* ↓ *Units* ↓ *One* ↓ *Unit*



Polymers: Derived from the Greek words ***poly*** and ***mers*** meaning **"*many parts*"**.

- Large molecules composed of repeated chemical units
- When you think of *POLYMER* most automatically think → *PLASTIC. However,* polymers are a wide range of *natural* and *synthetic* materials with a wide variety of properties.
- Molecular weight of the resulting synthesized polymer can range from the very lightest of molecules up to huge gels.

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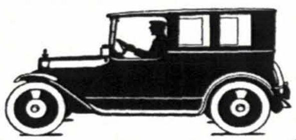
History of Polymer Chemistry

1844

Charles Goodyear patents **vulcanization** process.

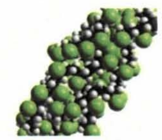


1907

Leo Bakeland created the first completely synthetic polymer, Bakelite (Phenol/formaldehy de).

1920

Vinyl Chloride resin mass production begins (Invented in 1835).



1930

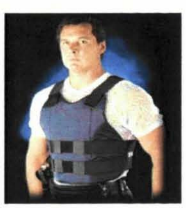
Polystyrene mass production begins (Invented in 1839 by Eduard Simon).

1930s-40s

Polyethylene mass production begins.

1960s-70s

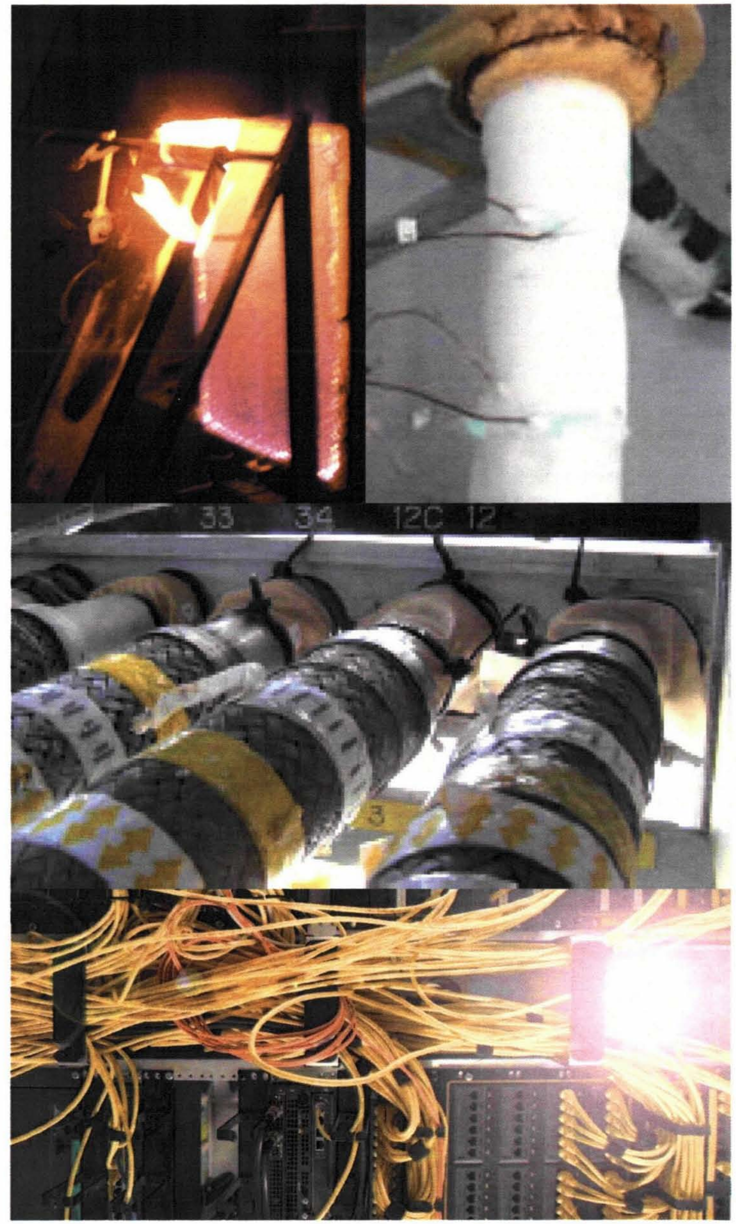
Kevlar and high performance polymer industries take off.



We now use more ***plastic*** than steel, aluminum and copper combined.

Composites/Materials Development at KSC

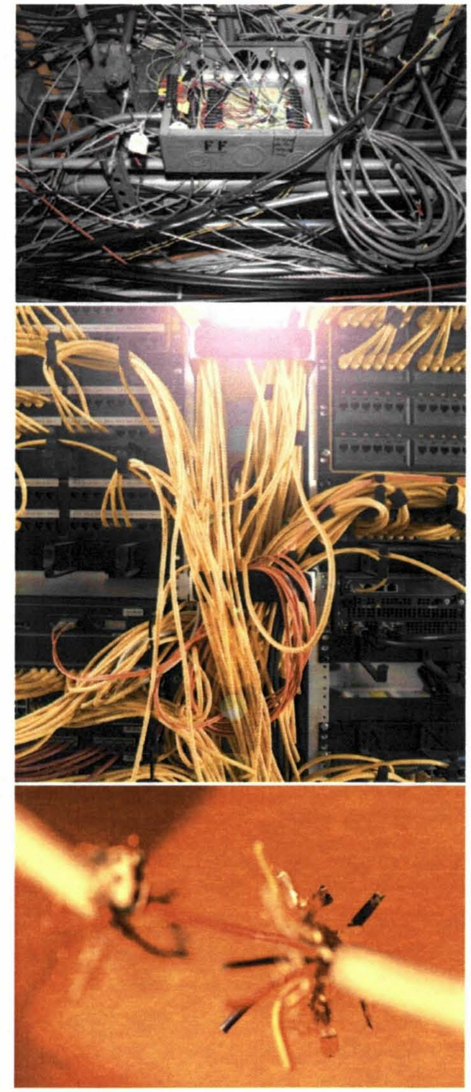
- Smart Materials and Detection Systems
- Self healing materials
- Flame retardant materials
- Aerogel composites
- Aerogel for environmental remediation
- Chemochromic hazardous gas detectors
- Antimicrobial polymers
- CNTs and conductive polymer technologies



Why Wiring?

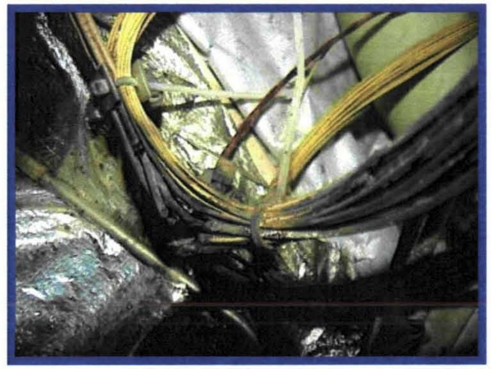
- **Aged Wire**
  - Cracks and frays over time
  - Hard to detect damage
  - Extensive maintenance related damage during ground processing work

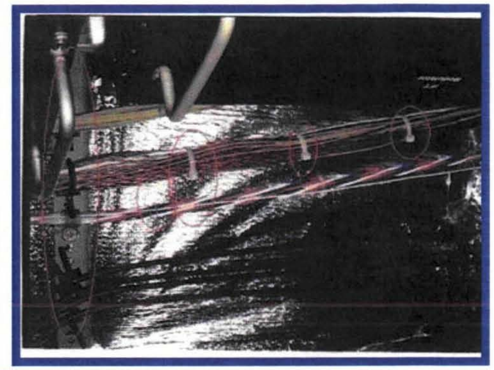
- **Space Shuttle Orbiter**
  - 183 miles of wiring buried deep within structure of vehicle
  - Difficult to manually inspect



Next Generation Wiring Materials

Wire System Failures

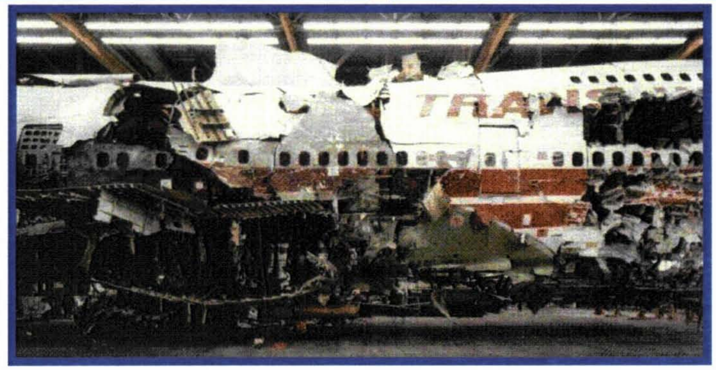




STS-93 (July 1999)
- Short circuit in 14 AWG Kapton® insulated wire

TWA 800 (July 1996)
- Frayed Kapton® wire in center tank area

SwissAir 111 (September 1998)
- Damaged wire in plane's entertainment system



Manual Repair Technologies for Kapton and Teflon wires

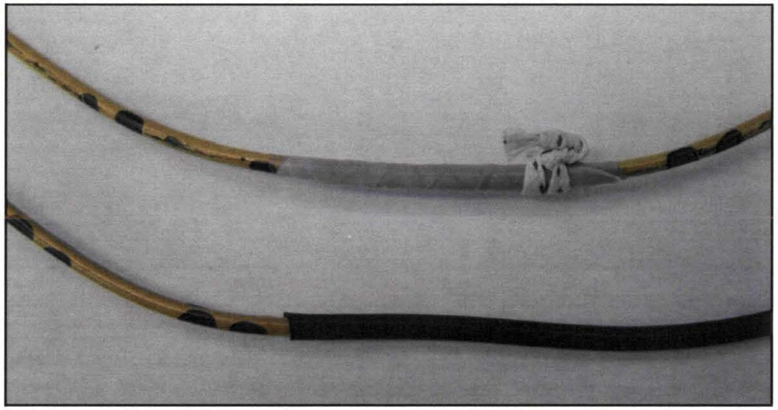
In situ Damage Detection systems for vehicle health monitoring

Self-Healing insulation

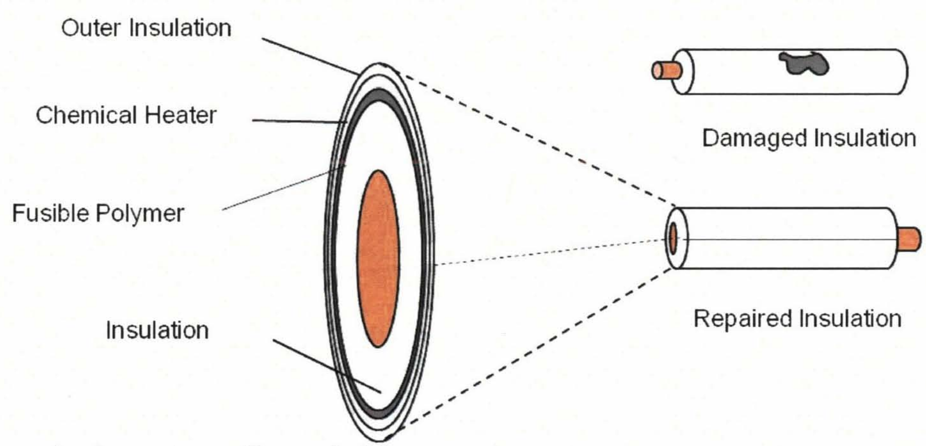
Wire System Materials

Insulation and Repair Materials

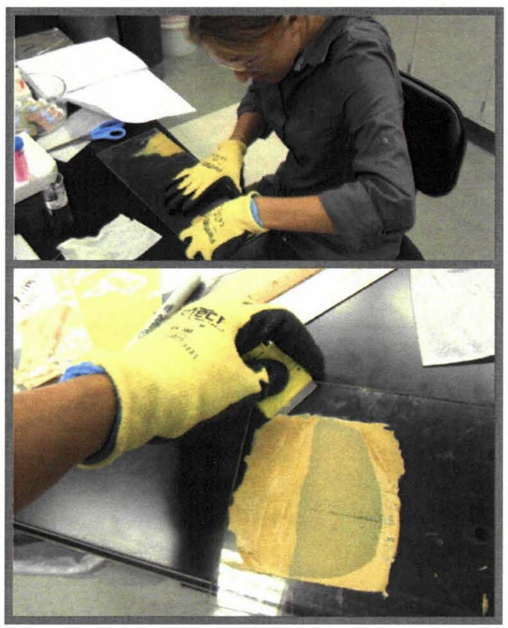
Present Wiring Repairs



Manual Repair Concept



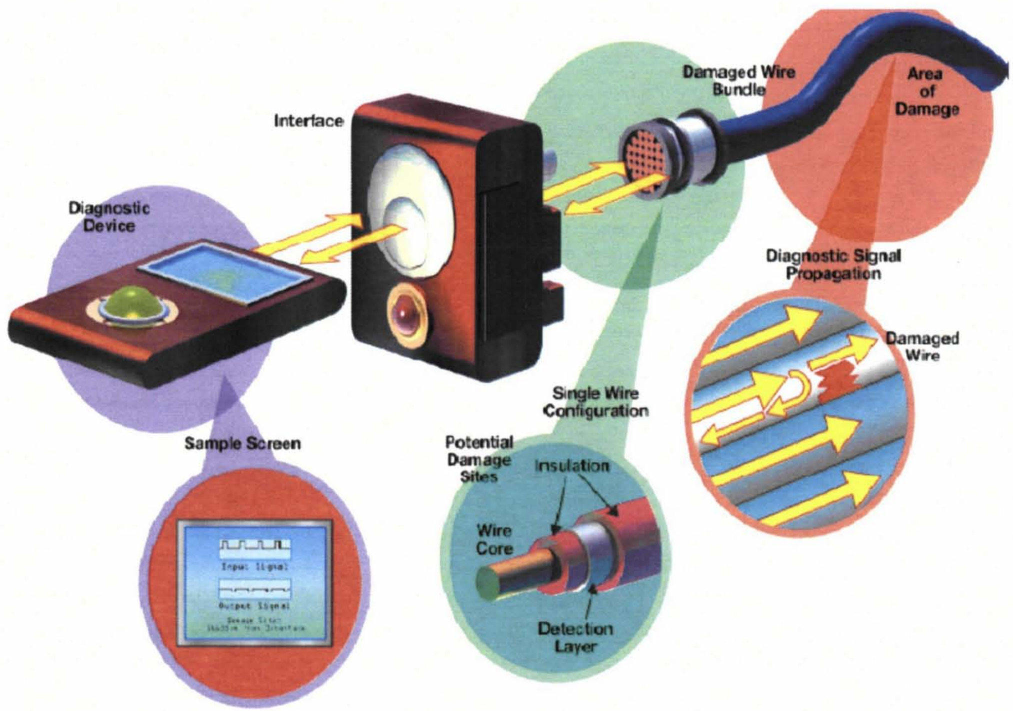
Casting of wire repair materials



Laboratory Repair Process

Wire Systems Integration

- Smart Connectors
  - Small, lightweight, ultra reliable
- In-situ wire damage detection system
  - Capable of wire damage detection "on-the-fly"
- Integrated vehicle health monitoring (IVHM)
  - System-of-systems level, providing high level of reliability

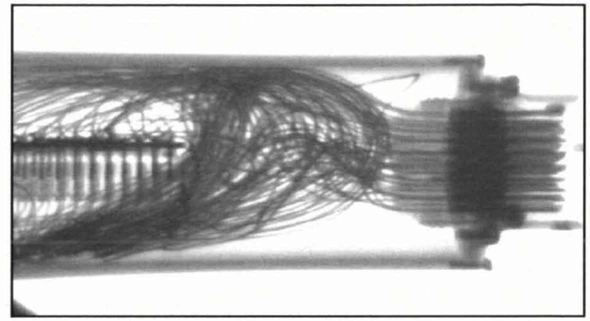


Self-Healing Wire Repair

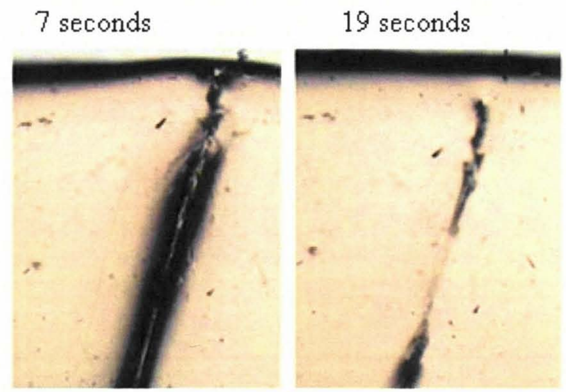
See Video

"Smart Wiring" Summary

- Early wire fault detection and self-repair includes the development of an *in situ* detection system to detect and locate an electrical compromise on an energized "live" wire.
- The *in situ* detection monitoring system uses Time Domain Reflectometry (TDR) to locate failures such as opens, shorts, and intermittent faults in existing wiring systems.
- A new wire construction that contains a conductive composite detection layer for early detection to wire insulation damage and self-healing capabilities are also included in this "Smart Wiring" system.
- Applicable to Game Changing Technologies, Cross-cutting Capabilities, Flagship Inflatable Technology Demonstrations, and 21st Century Launch Complex.
- Currently partnering with wiring industry and NAVAIR.



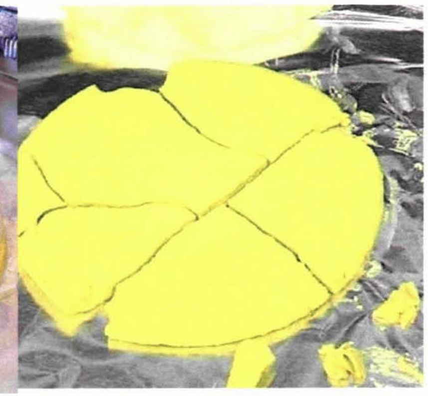
X-ray image of miniaturized TDR connector



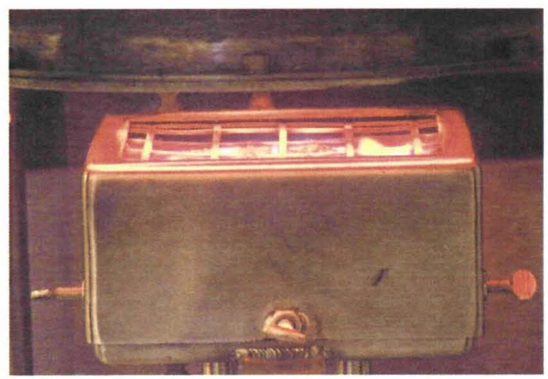
Self healing occurring in repair film in seconds after damage from left to right

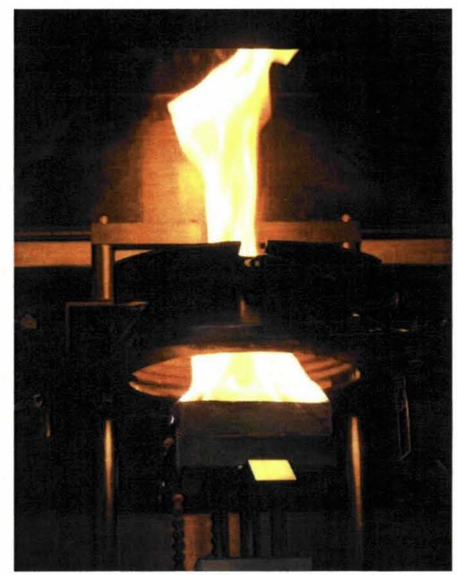
Fire and Polymers

- Flame retardant strategies
  - Polymethoxyamide derivatives for high temperature engineering polymers (patent issued)
  - Carbon nanotube synergistic FR properties
  - Polyhedral Oligomeric Silsesquioxanes (POSS) FR properties

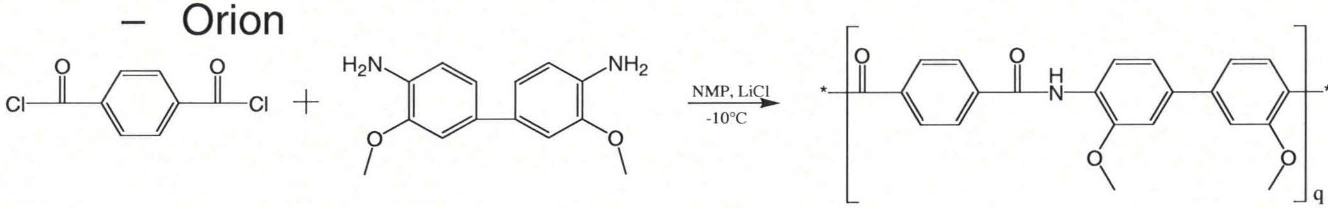


- Fire risk consultation
  - Wire insulation
  - Thermal insulation
  - Ablator





- Fire standards and risk
  - Ares I
  - Ares V
  - Orion



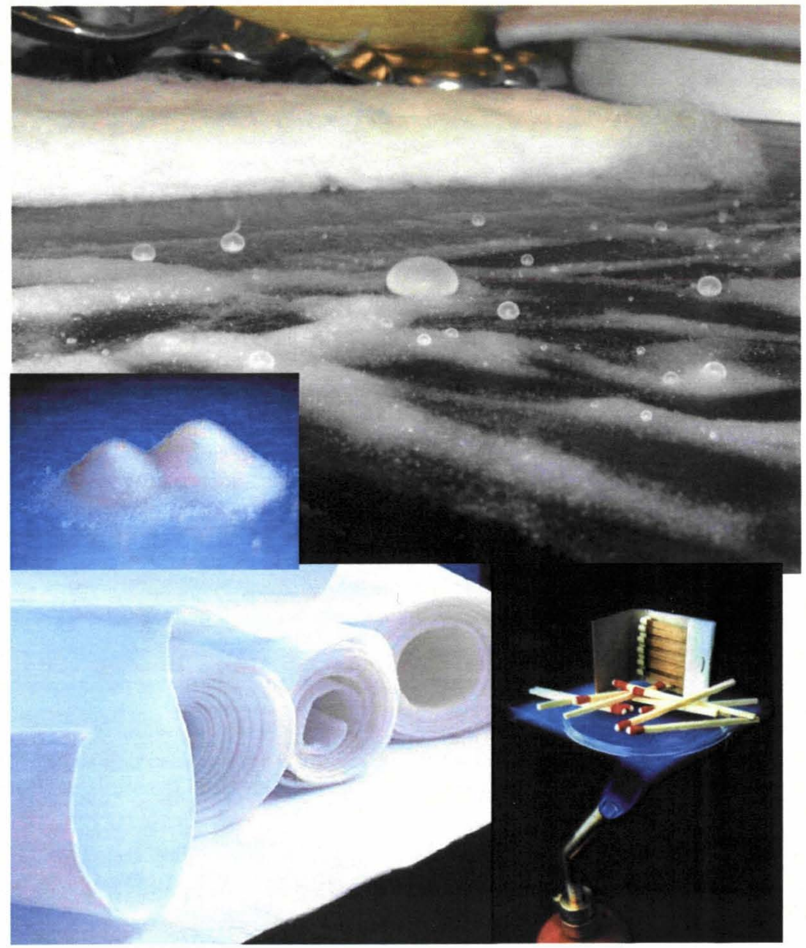
Aerogel Technology

- Aerogel materials are generally silica based, light weight materials, fully breathable, and treated to be super-hydrophobic.

- Aerogel granules are free flowing, fills small cavities, does not compact, no preconditioning required, and can be molded or formed using binders.

- Aerogel granules (Nanogel®) by Cabot Corp.:
  - 90% porous with a mean pore diameter of 20 nm.
  - Bead bulk density ≈ 80 kg/m^3 (5 lbs/ft^3).
  - Individual beads are fragile (shear), but have high elastic compression of over 50% with no damage.
  - k-value ≈18 mW/m-K @ 25°C and 760 torr.
  - *www.cabot-corp.com/nanogel*

- Aerogel blanket (Spaceloft®) manufactured by Aspen Aerogels:
  - Bulk density 6 to 8 lbs/ft^3.
  - k-value ≈12 mW/m-K @ 38°C and 760 torr.
  - Use temperature range -273°C to 650°C (-459°F to 1200°F).
  - *http://www.aerogel.com/*



Aerogel Composites

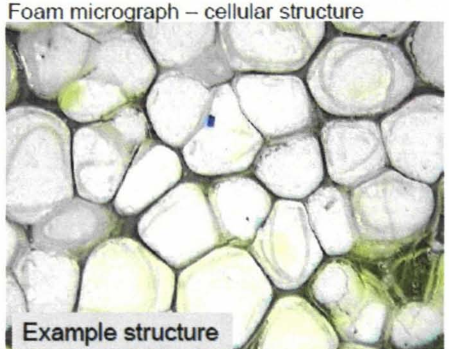
AeroFoam - polyimide foam + aerogel

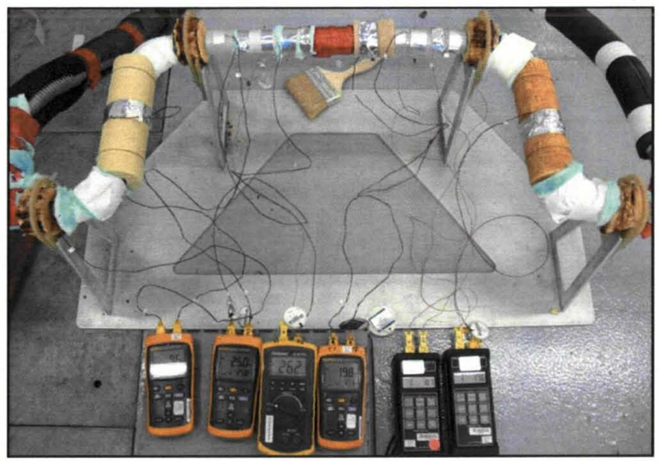
Enhanced thermal and vibration damping performance. Structural integrity to the aerogel and cryogen storage capabilities.

AeroPlastic – thermoplastic + aerogel

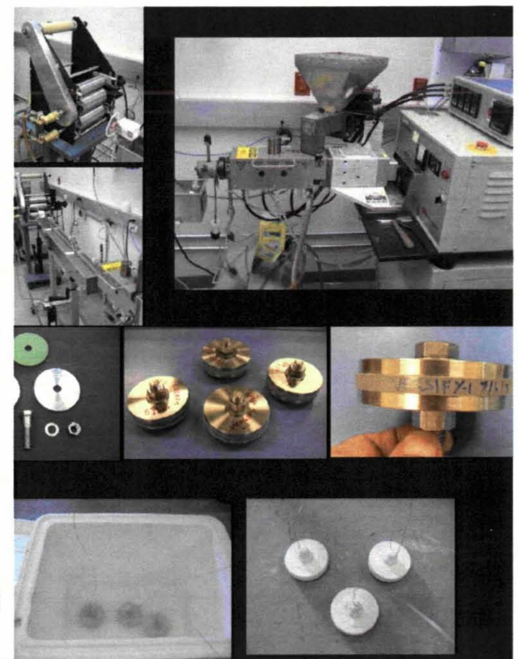
Extruded process, composite reducing heat transfer by 40-60%. Cryogen storage and transfer applications such as piping and seal.

Foam micrograph – cellular structure





AeroPlastic demo testing on cryo-piping system



Fiber/Textile+ aerogel structural composites

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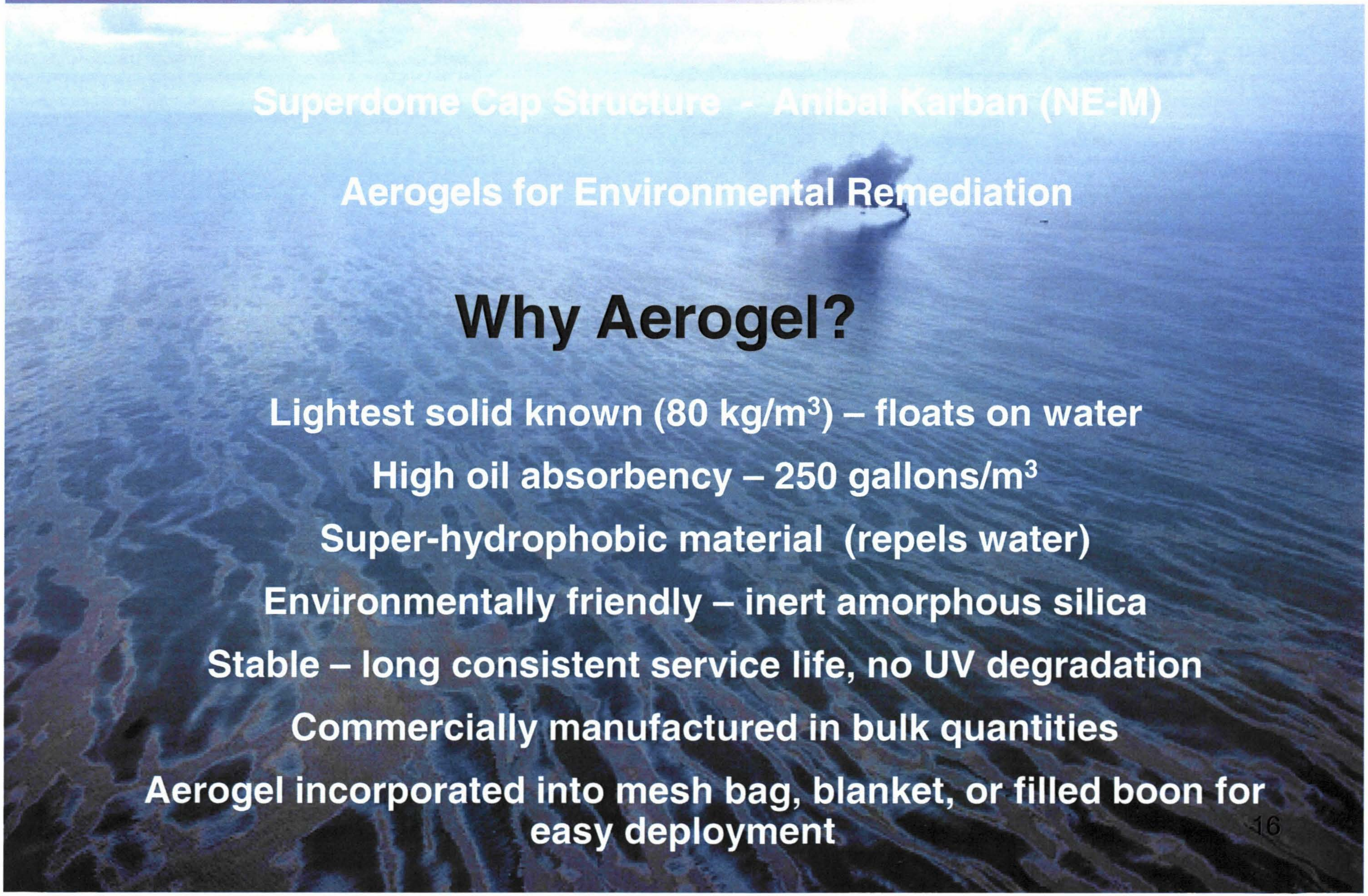
Aerogels for Oil Remediation



Superdome Cap Structure - Anibal Karban (NE-M)

Aerogels for Environmental Remediation

Why Aerogel?

Lightest solid known (80 kg/m^3) – floats on water

High oil absorbency – 250 $gallons/m^3$

Super-hydrophobic material (repels water)

Environmentally friendly – inert amorphous silica

Stable – long consistent service life, no UV degradation

Commercially manufactured in bulk quantities

Aerogel incorporated into mesh bag, blanket, or filled boon for easy deployment

KSC's Solution

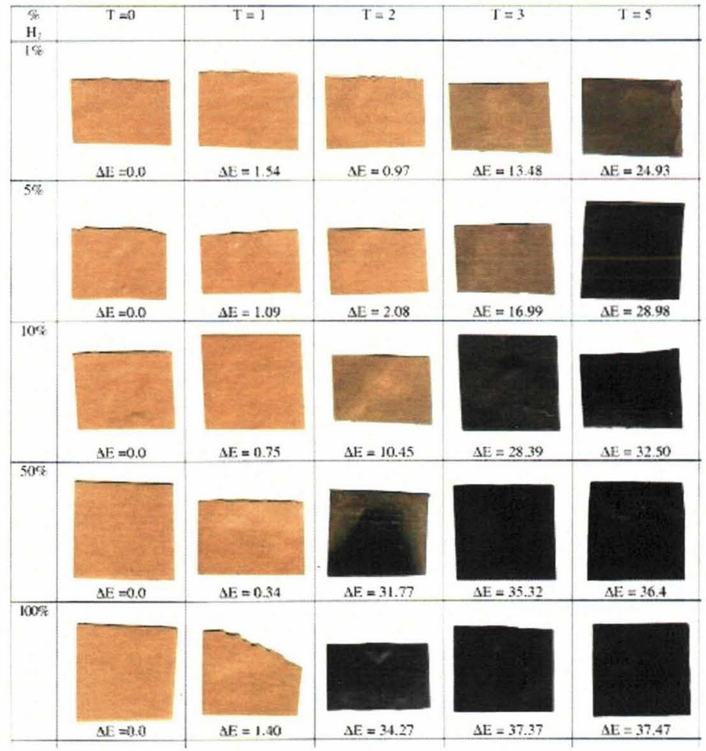
- Cabot Nanogel: Commercial small business collaboration through existing SAA with NASA KSC
- $2800 per m^3 = 250 gallons oil
- 60,000 barrels of oil released per day
- 480,000 miles of boons to be deployed off Florida coast
- Inventory of aerogel for oil recovery

Domestic inventory	Europe inventory	Sustainable capacity per month
100 m^3	2000 m^3	600 m^3
25,000 gallons equivalency	500,000 gallons equivalency	150,000 gallons equivalency

Chemochromic Hydrogen Sensors

In collaboration with UCF

Irreversible Sensor



A patent-pending irreversible color changing H_2 gas sensor was developed at KSC in partnership with UCF and ASRC.

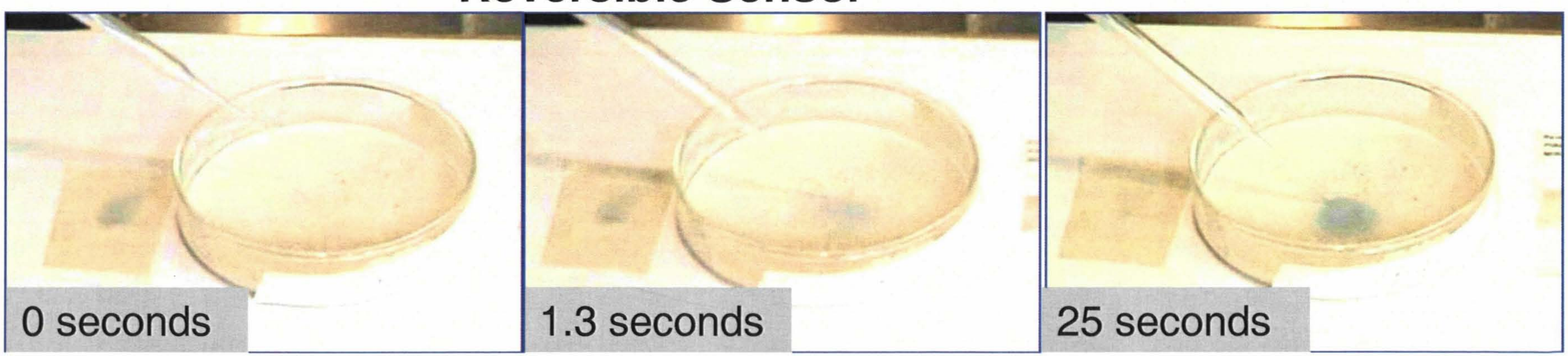
Changes color from a light tan to black in the presence of H_2.

Can be manufactured into any polymer part, tape, fiber, or fabric material for unlimited potential uses.

- **Paint, Gloves, Coveralls, PPE**

Operates under ambient and cryogenic temperatures.

Reversible Sensor

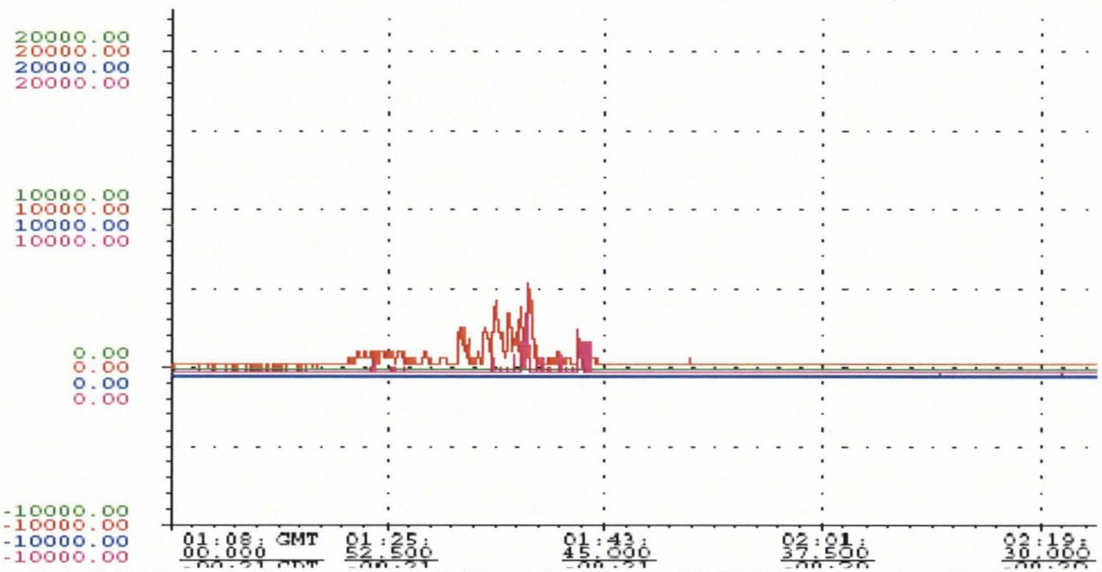


Chemochromic Hydrogen Sensors

STS-129 Transfer Line

LPA OMBUU Deployment for STS 117, 118, 120, 122, 123

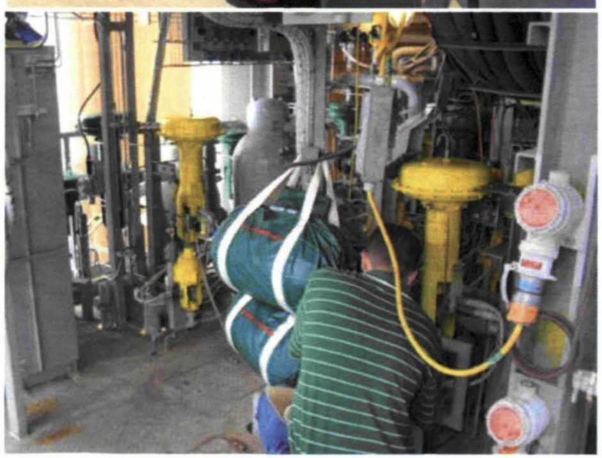
STS-118 LOAD-1 HP SKID (H2CONC-B)



ST: 01:08:00.000 SD: 080707 ET: 03:31:00.000 ED: 080707 GRID INTERVAL: 00:17:52.500 PLOTTED: 23:41:57 08/06/07

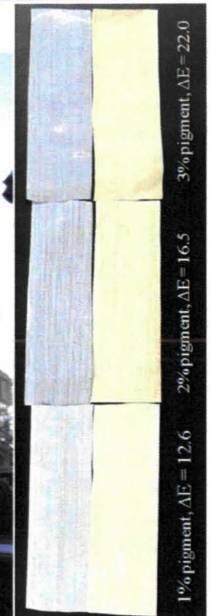
FD	DESCRIPTION	TCID	UNITS	ER	FD	DESCRIPTION	TCID	UNITS	ER
GFHR4145A	OMBUU LH2 VLV CK PRI H2 CONC	SA118C	PPM		GFHR4165A	OMBUU HOSE I/F PL VNT PRI H2 CONC	SA118C	PPM	
GFHR4175A	OMBUU HOSE I/F PL FILL PRI H2 CONC	SA118C	PPM		GFHR4185A	OMBUU LH2 HP SAMPL PNLS PRI H2 CON	SA118C	PPM	

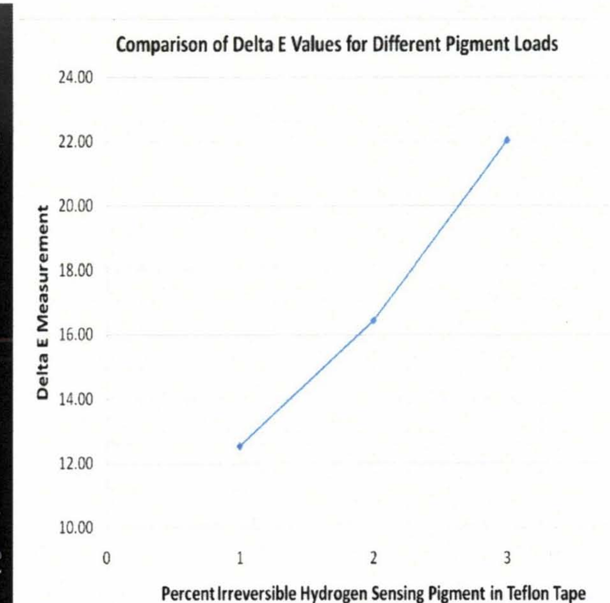
TITLE: STS-118 LOAD-1 HP SKID (H2CONC-B) OPT: -INDIV RANGE

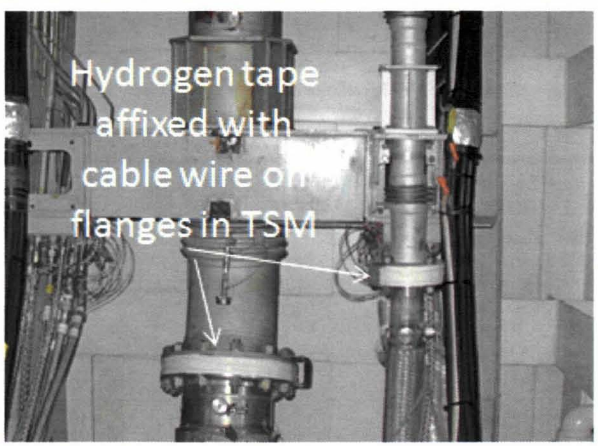


STS-130 and 131 Operations

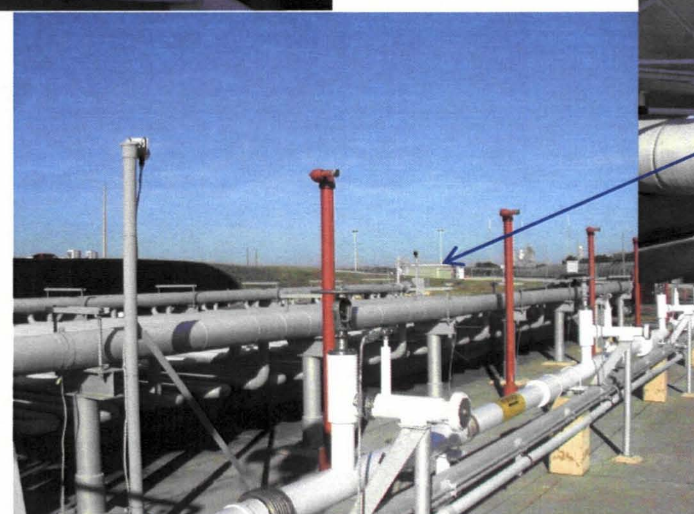
Hydrogen vent lines on Pad A slope.





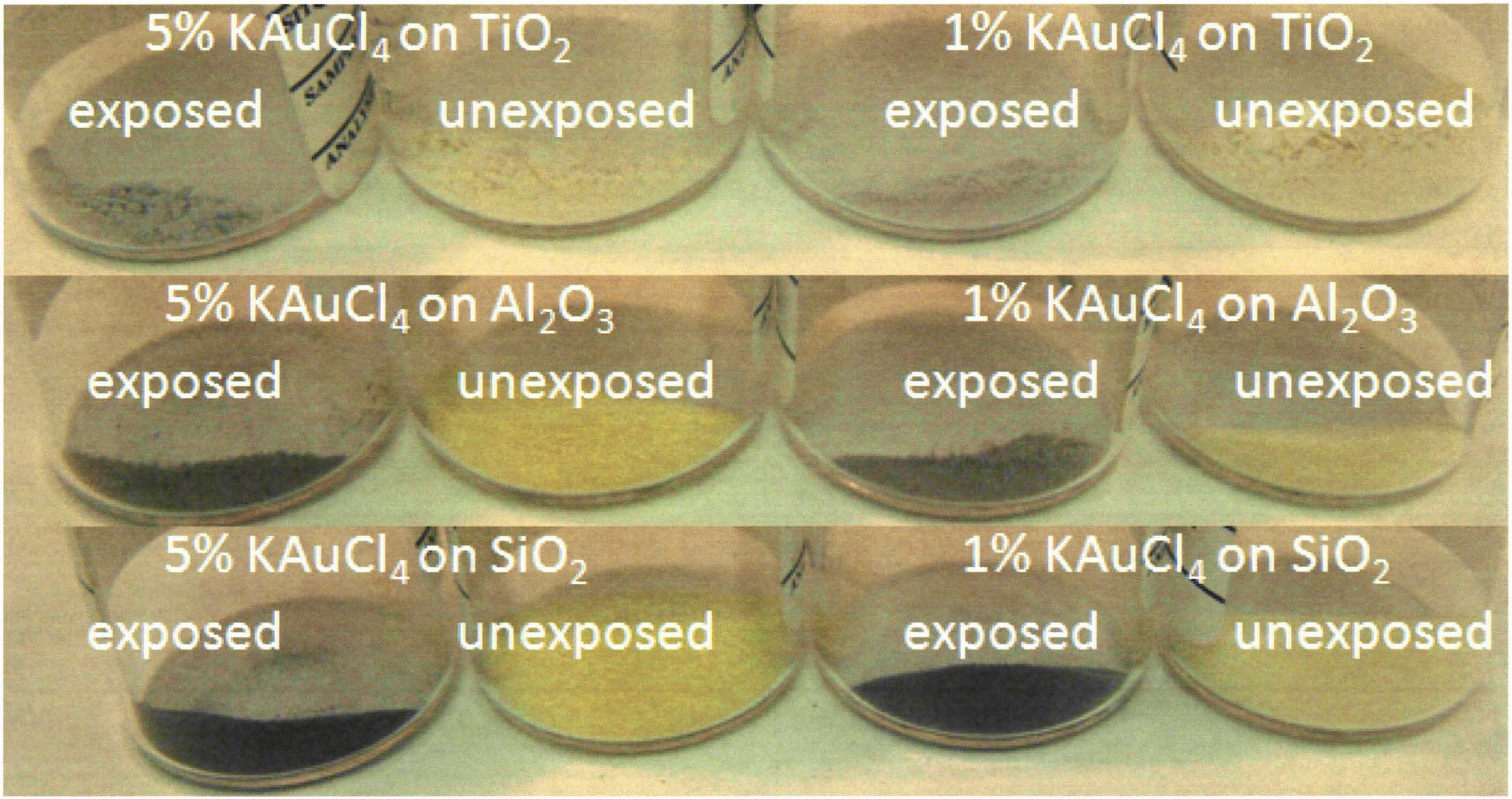


TSM for STS-131



STS-130 H2 Pressure Flange A3362

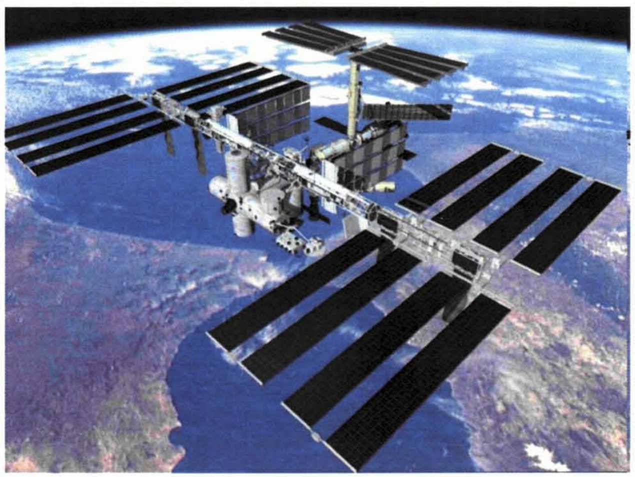
HyperPigment



Comparison of 1% and 5% by weight $KAuCl_4$ on different substrates.

Antimicrobial Materials

Shuttle Potable Water
(4) 170 lb Inconel bellow tanks
Iodine (3-4 mg/L)



ISS Potable Water
Stainless tubing
Ionic Silver Biocide

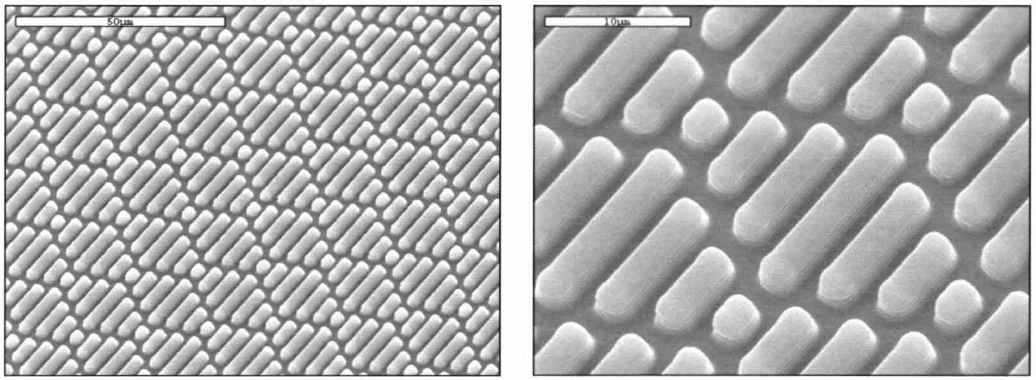
Orion Potable Water

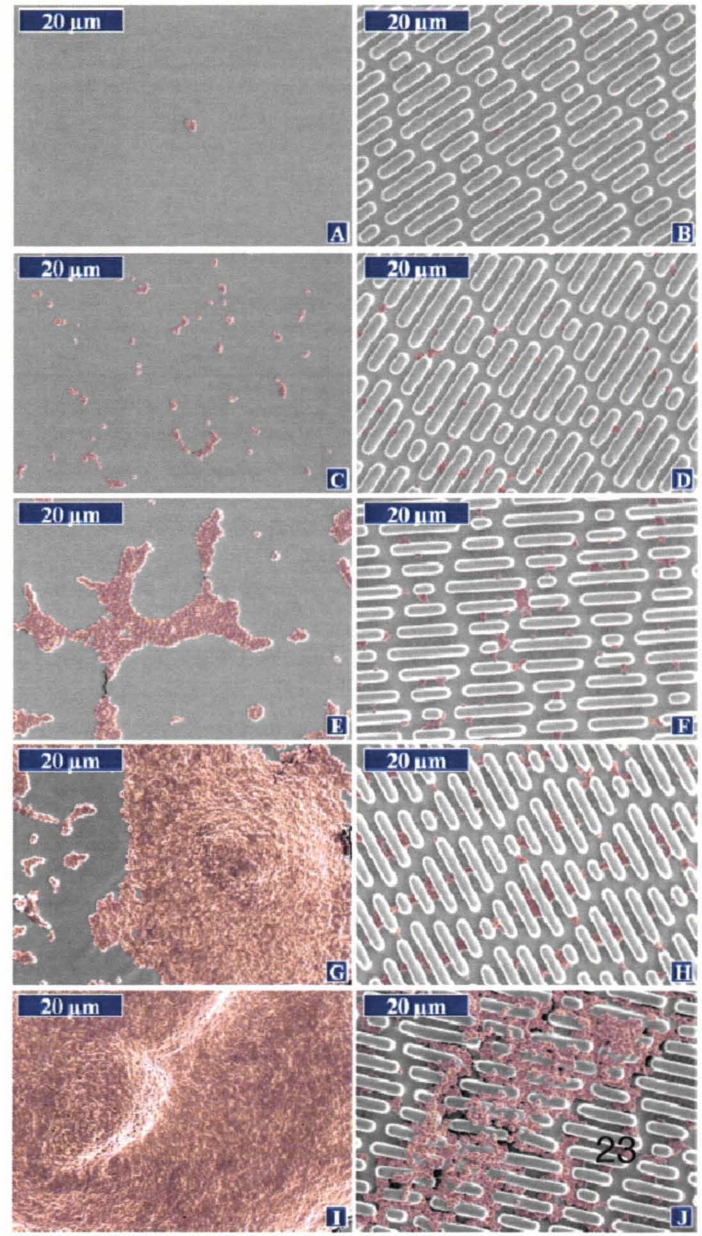
(5) Inconel 718 Tanks (14.3 gal)
Miles of Titanium water lines

Antimicrobial Materials

In collaboration with Sharklet Technologies and UF

Surface Morphology and Surface Chemistry





- Efficacy studies after 21 days decreases biofilm formation
- Easy to imprint during manufacture of polymer articles through a coining process
- Can be used in conjunction with antimicrobial polymers

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Antimicrobial Materials

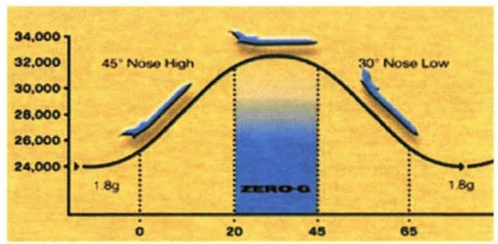
In collaboration with University of Alberta and Sharklet

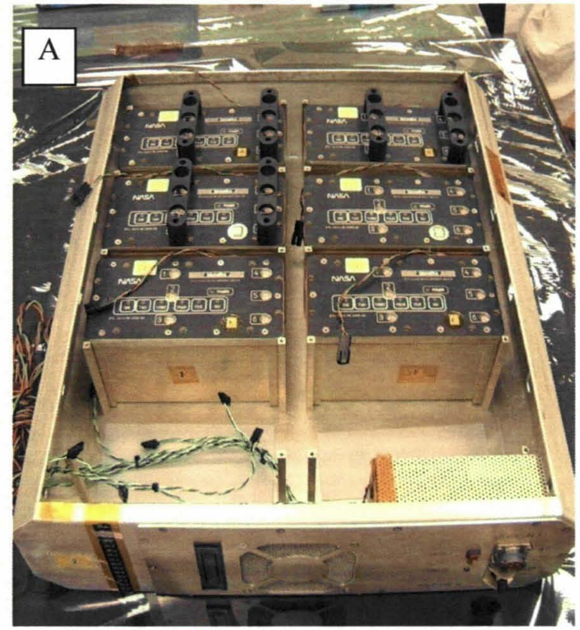
Microgravity Flight Experiments

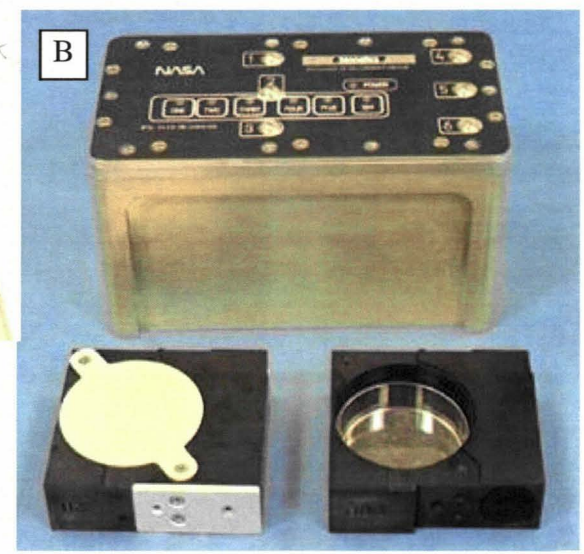
BIOLOGICAL ANALYSIS

Confirm efficacy of *Pseudomonas fluorescents* bacteria species with Sharklet® topography coupons and different surface treatments

- *How well does it work in μG and lunar G compared to 1G?*







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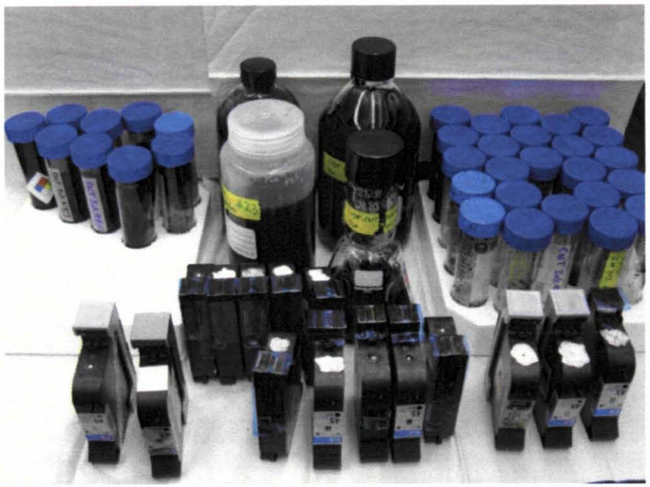
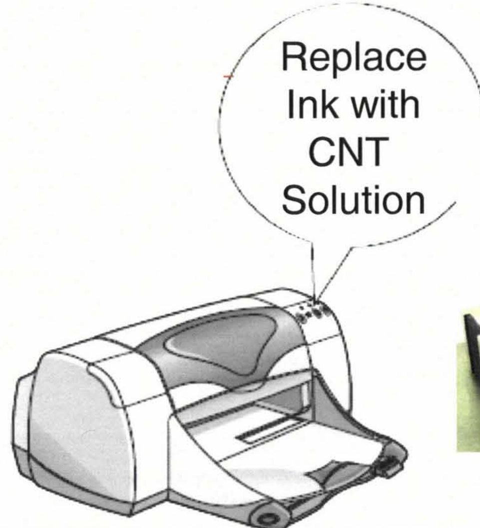
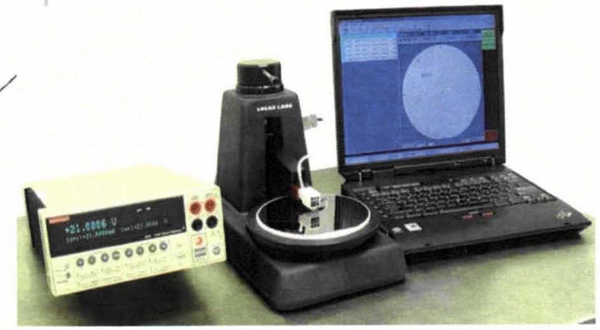
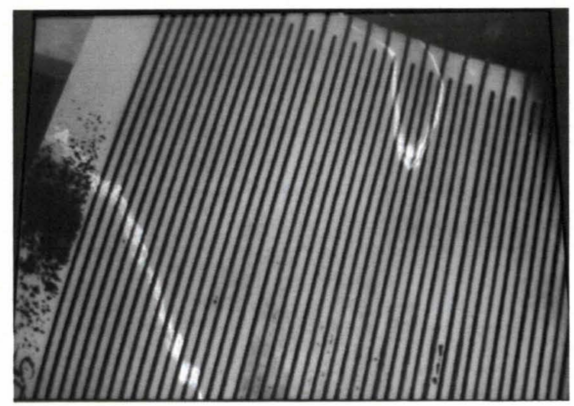
Conductive Inks Formulations for Multiple Applications









- Uses standard Inkjet printing technology
- 4pt probe used to measure resistivity or conductivity
- Formulations are solution blends; including carbon nanotubes, polymers and nanometallics. Patent application in work.
- Printing on multiple types of flat surfaces, including fabrics for dust screen technology
- Printing on curved surfaces for detection in process

Testing and Processing Equipment

- Fire Testing
  - Cone Calorimeter
  - Oxygen Index**
  - UL94 fire test
  - NASA Std 6001 fire test
  - Radiant Panel*
  - NBS Smoke Chamber*
  - Two foot tunnel*
  - Glow wire ignition*
- Cryogenic Materials Testing
  - Cryogenic moisture uptake (CMU)**
  - Brittleness/Impact test **
  - Liquid helium cold finger test**
  - Single Pin-Socket Krytox Contamination Electrical Characterization under Cryogenic Conditions**
- Specialty Test Equipment

*in collaboration with Cryogenics Test Laboratory
**in collaboration with Florida Tech

- Cellular Solid Analysis
  - Pycnometer (closed/open cell)**
  - Surface area measurement**
- Thermal Analysis
  - Thermogravimetric analysis (TGA)
  - Differential Scanning Calorimetry (DSC)
  - Dynamic Mechanical Analysis (DMA)
- Physical Testing
  - Tensile Test
  - Compressive Test
  - Pull/Peel Test
- Electrical Testing
  - 4-point probe
  - Surface /Volume resistance
- Polymer Processing capabilities
  - Extrusion
  - Injection molder
  - Fiber spinning equipment
  - Melt, ball, and high intensity mixers

National Aeronautics and Space Administration

John F. Kennedy Space Center

Acknowledgements

Polymer Science and Technology

Dr. Martha Williams, Lead
*Dr. LaNetra Tate**
*Trent Smith**
Anne Caraccio

ASRC Applied Chemistry Lab

Dr. Pedro Medelius
Dr. Tracy Gibson
Dr. Mary Whitten
Dr. Scott Jolley
Dr. Robert Devor
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QUESTIONS?