KSC Engineering Directorate
Materials Science Division

Overview of Current Activities within NASA's Kennedy Space Center Materials Science Division

Rick Russell

November, 2014

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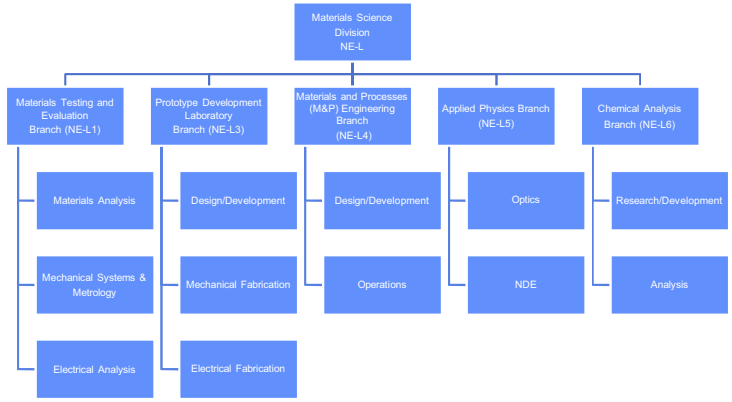
KSC Engineering Directorate
Materials Science Division

Organizational Chart



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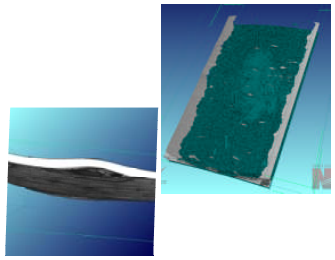
NE-L1 Materials Testing and Evaluation Services



- **Materials Testing:**
  Tensile, compression, fatigue, vibration, thermal vacuum, environmental chamber testing, materials compatibility (flammability, electrostatic discharge, hypergrowth, oxygen), exposure testing (atmospheric, see water immersion/spray/splash, tidal), accelerated corrosion, coating application, hardness, conductivity, and thermal analysis
- **Electrochemistry**
- **NDE via CT and real-time radiography and thermography**
- **Precision measurement and dimensional analysis**
- **Failure Analysis (materials, electrical, mechanical)**
- **Electrical Testing:**
  Component/board simulation, insulation resistance (IR), dielectric withstanding voltage (DWV), analog, digital, mixed-signal component, high voltage, high amperage AC/DC
- **Data acquisition instrumentation/techniques**

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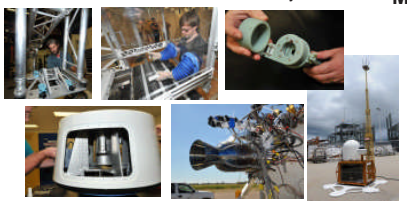
NE-L3 Prototype Development Laboratory Services

Design Engineering Services

- Mechanical engineering design
- Mechanisms and kinematics
- ProE CAD/CAM
- "Design for Manufacturability" consultation
- Structural and finite element analysis

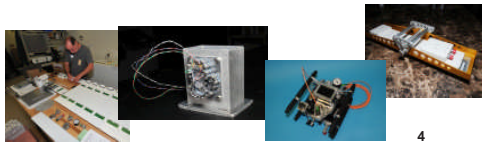


Mechanical Integration Services

- Pneumatics and hydraulics fabrication
- Rapid prototyping / additive manufacturing
- Mechanical & structural fabrication and testing
- Computer Numeric Control (CNC) machining
- Sheet metal fabrication
- Welding & soldering
- Composite materials fabrication
- COTR of 8 Mechanical IDIQ contracts

Electrical Integration Services

- Power and electrical systems
- Electrical fabrication
- Data acquisition
- LabVIEW software programming



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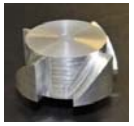
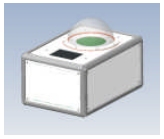
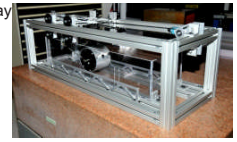
NE-L3
Prototype Development Laboratory
Surface Systems Project Support

Surface Systems Project Support

- Excavation Test Stand (ETS)
- Badger Cams
- Badger Bucket
- Hummer Quick Attach Mounting Interface mechanism
- Automated Umbilical Arm (AUB) components
- Dust Tolerant Automated Umbilical (DTAU)
- Badger Cover
- Badger Impact Test Stand
- Wheel Electrostatic Spectrometer (WES) Rolling Mechanism
- Extreme Access Airframe and Mold Fabrication
- Extreme Rassor
- Electrodynamic Dust Shield Demo
- Regolith Box for Jet Plume experiment
- Fabrication of Electrodes for EDS MISSIE-X Pay
- Fabricate and build the Big Bin at the GMRO
- Morpheus Flame Trench-Cut Eyebolts
- Composite Bucket Drum
- 3D Hand Print
- Feed System Screen

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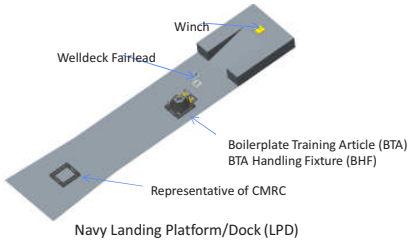
NE-L3
Prototype Development Laboratory
Surface Systems Project Support

EFT-1 Landing and Recovery Operations Support and Testing Hardware



Navy Landing Platform/Dock (LPD)
Class Welldeck

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NE-L4 Materials and Processes (M&P) Engineering Services

- Provide M&P support to both design/development & operations activities at KSC:
  - M&P selection for design (e.g. metallic & nonmetallic materials, welding, corrosion control)
  - Design review support for M&P
  - Oxygen system compatibility analysis
  - Administer KSC M&P Control Program (review/approval of Material Usage Agreements [MUAs])
  - Specifications and standards
  - MRB/PRB support
  - Nondestructive Examination (NDE)
  - Contamination Control
  - Coordinate/integrate failure analyses
- Provide coordinated KSC M&P support to Agency-wide activities:
  - Constellation M&P requirements development (NASA-STD-6016)
  - M&P Requirements for GSE Design (NASA-STD-5005)
  - Materials testing requirements (NASA-STD-6001)
  - NASA M&P Working Group
  - NASA NDE Working Group

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NE-L4 Materials and Processes (M&P) Engineering Support

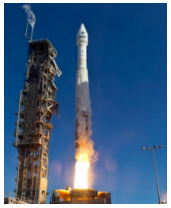
Launch Sevices Program (LSP):
M&P Support to Mission Integration Teams and Engineering Review Boards

Atlas V (KSC and VAFB)
Delta II (VAFB)
Pegasus (VAFB)
Falcon 9 (VAFB)

Past Missions:	Upcoming Missions:
NuSTAR	JPSS-1
NPP	MAVEN
RPSP	GOES-R
Juno	OSIRIS-Rex
GRAIL	Solar Orbiter
IRIS	Jason-3
LDCM	SMAP
MSL	MMS
TDRS-K	TDRS-L


Delta II/GRAIL, 9-10-11


Pegasus XL/IRIS, 6-27-13


Atlas V/LDCM, 2-11-13

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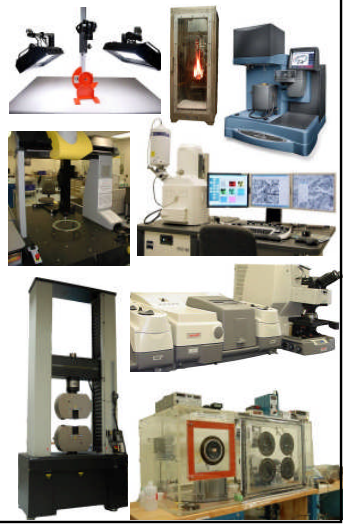
Failure Analysis

Comprehensive suite of FA capability including:

- *Non-Destructive Evaluation* (CT/x-ray, borescopes, photodocumentation, dimensional analysis).
- *Microscopy* (optical, digital, laser confocal, scanning electron, polarized light).
- *Metallography* (dissection equipment, grinding/polishing wheels, metallographs).
- *Mechanical Test* (hardness, tensile/compression, fatigue, vibration, charpy impact, .).
- *Physical Test* (thermal analysis, electrostatic discharge, corrosion, flammability, offgas, compatibility, conductivity, thermal vacuum, environmental).
- *Chemistry (energy dispersive spectroscopy, wavelength dispersive spectroscopy, Fourier-Transform Infra-Red, X-ray fluorescence, X-ray diffraction, optical emission spectroscopy, inductively coupled plasma, GC/MS, ion chromatography)*



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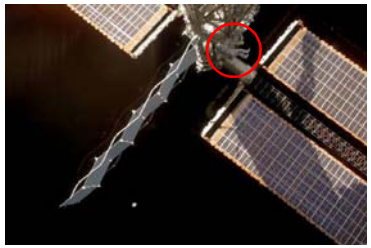
FA in Low Earth Orbit

- **When failure occurs to hardware in the vacuum of space, a series of new problems arise:**
  - Accessibility to hardware.
  - Inadequate sampling techniques.
  - Tight schedules.
  - Lack of FA equipment.
  - Delivery of samples to laboratory.
- **Astronauts become the eyes, ears, and hands of the laboratory.**



Astronaut Dan Tani performing spacewalk during Solar Alpha Rotary Joint (SARJ) failure investigation

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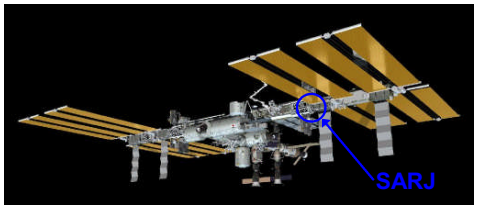
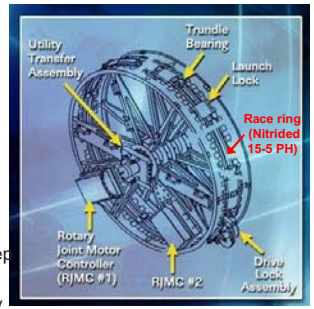
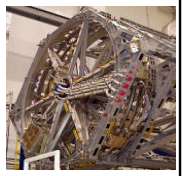
ISS Assembly





- **Solar Alpha Rotary Joint failure**
  - 10-Foot diameter joint rotates 360º in order to keep the solar arrays facing the sun.
  - Installed June 2007, drawing high current draw by August 2007.
  - Spacewalk in October 2007 revealed "metal shavings" in vicinity, did not know origin.
  - Samples brought to KSC October 2008
    - Initial FA performed overnight on 3 pieces of Kapton tape with "shavings"



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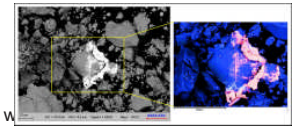
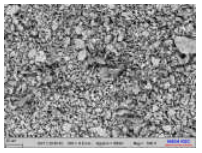
Root Cause

- **"Metal shavings" were originating from the nitrided 15-5 Precipitation Hardened SARJ race ring surfaces that were spalling**
  - Failure was due to contact stress fatigue
    - Sub-surface initiation at Nb carbides
  - Lubrication problem led to spalling:
    - Minimal lubricant on race surfaces
    - 440C roller bearing surfaces had oxide formation, w prevented adequate gold plating (meant to lubricate).
    - Resulted in metal-to-metal contact (440C to nitrided 15-5PH) which led to high frictional forces and incipient spalling.
  - The fix:
    - Cleaned debris from all race surfaces
    - Replaced all trundle bearing assemblies
    - Continued use until need of redundant race was necessary
  - Team:
    - Over 100 personnel across most NASA centers
    - Complete investigation and repair took about 1 year





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Orion

- **The Orion vehicle is being assembled at Kennedy Space Center by Lockheed Martin.**
- **KSC is providing M&P support to the program by assisting with failure analysis, materials usage, materials testing, material design, process control, contamination control, contamination investigation, and vehicle closeout procedures.**
- **NASA M&P works closely with Lockheed Martin M&P in vehicle processing activities to ensure that all flight hardware requirements are satisfied.**
- **Program support often is in corroboration with other branches within NE-L like the Chemical Analysis group and mechanical testing.**

Orion Crew Module after heat shield install in the O&C High Bay.

Orion Crew and Service Module shortly after completion of contamination and cleanliness closeout inspections by LM and NASA M&P for the outer Thermal Protection System panels install.

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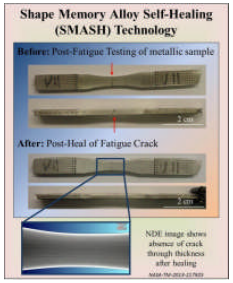
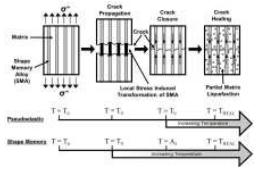
Shape Memory Alloy Self-Healing (SMASH) Technology for Repairing Fatigue Cracks

Purpose:
The purpose of the Aeronautics Research Mission Directorate (ARMD) Phase I and II Seedling research work on Shape Memory Alloy Self-Healing (SMASH) is to design and demonstrate the feasibility of an **aeronautical lightweight structural alloy** with **self-repairing** capabilities.



Applications:
The technology can be applied to the aeronautics world as well as long-duration and deep space flight missions. Success of this ARMD project would provide an alternative to common repair techniques of fatigued structures. This new option would utilize a heating source to drive the material to repair itself by forcing crack closure and affording liquid-assisted crack healing at the crack front. The implications of a successful materials system could revolutionize the industry and NASA programs.



Technology uses liquid-assisted and SMA crack closure repair phenomena.
Patent-pending composition, microstructure and fabrication technique.

Successes:
The team has developed a metal-matrix composite that has the ability to self-repair large fatigue cracks using liquid-assisted self-healing. Phase I work has proven very successful, with the team being able to attain **full healing** of **fatigue cracks** on an aluminum alloy matrix.

The team is developing other binary and ternary matrix materials that have the ability to self-repair using liquid-assisted healing, testing various processing and heat treatment techniques, and using finite element modeling to obtain the ideal reinforcement architecture.

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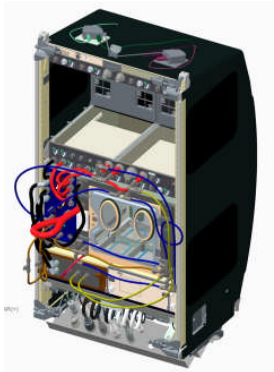
NE-L4 Materials and Processes (M&P)
Engineering Support

International Space Station Research

M&P engineering is providing support to payloads developed at KSC by ensuring that all ISS M&P requirements are satisfied and certifying the hardware for flight. The Materials Science Division laboratories can support verification testing and also provide rapid response to hardware issues encountered during processing. M&P engineering is a member of the design team currently developing the next generation of plant growth payloads.

The Vegetable Production System (Veggie) is an open-air, deployable unit for growing plants with the goal to provide fresh food for the ISS crew. The Veggie payload recently passed the Phase III safety review and will launch on Spacex-3 in early 2014.



The Advanced Plant Habitat (APH) is a quad-locker EXPRESS rack payload for plant experiments requiring active environment control. The APH project is at the 30% design level and the Critical Design Review will be in July 2014.

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NE-L4 Materials and Processes (M&P)
Engineering Support

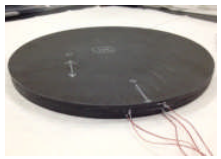
Composite Cryotank

Interagency project to advance the technologies for composite cryogenic propellant tanks at diameters suitable for future heavy lift vehicles and other in-space applications with a goal of reducing weight and cost

Thermal Conductivity Testing at Cryogenic Temperatures:

- Thermal conductivity testing of 3 inch composite disks has been completed
- Temperatures ranged from ambient to cryogenic
- Testing will be performed on a sandwich structure, representing the actual configuration

3-inch disks

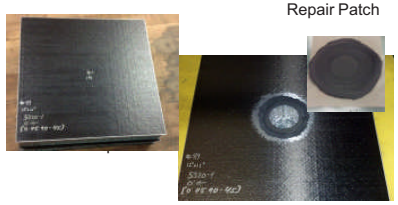


Stack of 6 disks with thermocouples

Nondestructive Evaluation and Repair Development:

- Sandwich panels have been fabricated for impact and repair
- Nondestructive evaluation will be performed on as-built, damaged and repaired panels
- Repaired panels will then undergo edgewise compression testing

Repair Patch



Panel During Repair Process

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NE-L4 Materials and Processes (M&P) Engineering Support

Corrosion Research

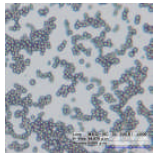
Cost of Corrosion

Corrosion is a serious problem that has enormous costs (4.2%GDP in 2007) and can cause catastrophic failures. KSC is located in one of the most naturally corrosive areas in the world. Acidic exhaust from the solid rocket boosters aggravates these natural conditions. Cost of corrosion control at KSC launch pads alone estimated as $1.6M/year.

Example of hidden corrosion: Pad 39B MLP-1: Bolt

Smart Coating

KSC's Corrosion Technology Laboratory is developing a smart, self-healing coating that can detect and repair corrosion at an early stage. This coating is being developed using microcapsules specifically designed to deliver the contents of their core when corrosion starts.



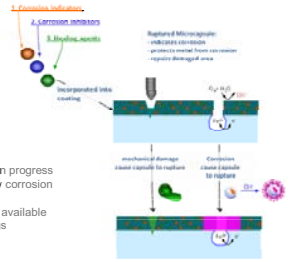


illustration of smart coating used to detect hidden corrosion

Technology Status:

- 1 patent awarded, 3 patents pending, and several in progress
- Corrosion indication function demonstrated for early corrosion indication and hidden corrosion detection
- Corrosion inhibition function tested in commercially available coatings and being developed for automotive coatings
- Self healing function tested for proof-of-concept

Research Partnerships

Government, Industry, and Academia

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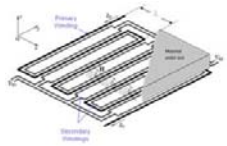
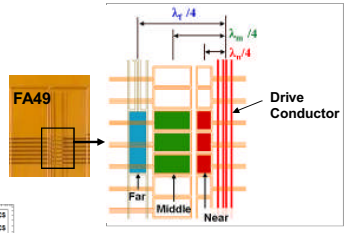
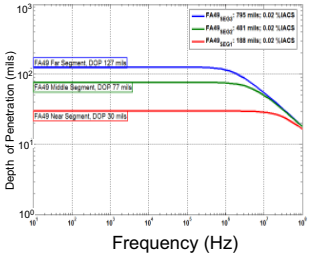
Meandering Winding Magnetometer (MWG) for COPVs







KSC Engineering Directorate
Materials Science Division

NE-L5
Applied Physics Capabilities

Laboratory Services

- Applying physics technology and concepts to solve specific flight hardware processing problems
- Developing technology for future programs
- Routing technical issues throughout the KSC engineering and scientific community to seek solutions to spaceport problems
- Technical review of concepts in support of future and current spaceport upgrades

Laboratory Assets & Specialized Equipment

- Class 4 Integra Laser
- Variety of lasers and light sources
- Optical table, mounting equipment, and a range of optics, as well as a spectrometer
- Wide assortment of electronics and mechanical components used to fabricate prototype systems to meet field problems
- Mathematica, Fortran, LabVIEW, and other software packages used to perform modeling and system analysis

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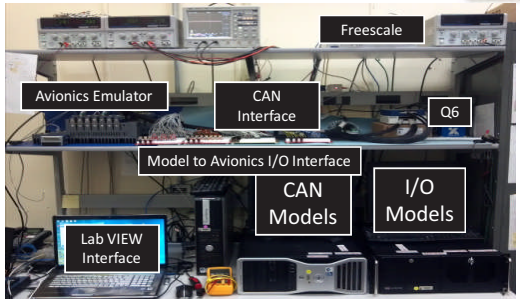
NE-L5 Applied Physics
RESOLVE

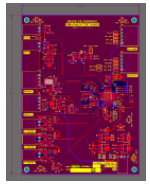
The Applied Physics Lab is leading the design and building of the RESOLVE lunar ice prospector payload instruments, avionics and software.

On Canadian Rover in 2012 Field test, Hawaii

Avionics Integration Lab



Custom avionics board



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NE-L5 Applied Physics
Surface Acoustic Wave Sensors

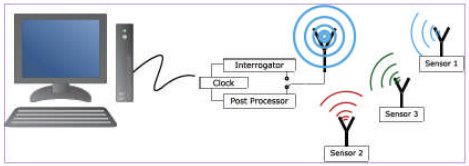
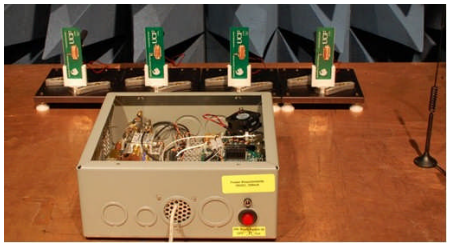
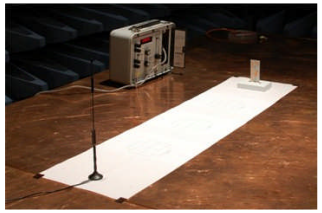


Fig.1 A multiplexed sensor system would have an interrogator that sends out RF pulses to echo based sensors. The return signals from these sensors are picked up by the interrogator and processed to determine which sensor is which and the value of the sensed parameter.

A 10 year collaboration with UCF has produced practical unpowered SAW sensor systems to operate simultaneous sensors in extremely harsh environments (e.g. cryogenics, H2)





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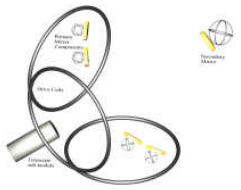
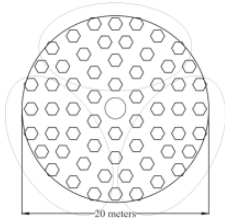
NE-L5 Applied Physics
Satellite Formation Flying: Propelling, Tracking, and Powering

By utilizing coupled coil concepts we believe we can generate forces on free flying satellites, determine their positions, and deliver power to them.

This concept provides both forces and position feedback allowing the accurate positioning and orientation of a large number of satellites, a technology that no other approach we have seen comes close to meeting.



A space telescope concept with individually controllable mirror satellites.



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NE-L6
Chemistry Capabilities

Chemistry Laboratory
Provides support in the investigation of unknown materials (solid, liquid, or gas) and chemical technology development. This support includes performing in-depth chemical analysis of contamination; and development of new chemical technology processes and materials

- Converting trash-to-gas
- Self healing polymeric materials
- Gas Chromatography development
- Mass Spectrometry development
- Replacement of hazardous solvents for clean space flight hardware
- In situ resource utilization process monitoring

Characterization of Unknown Materials Using Scanning Electron Microscopy with Energy Dispersive Spectroscopy

Chemical Identification and Characterization of Unknown Materials

- Fourier Transform Infrared Spectroscopy (FTIR)
- Wavelength Dispersive Spectroscopy (WDS)
- Inductively Coupled Plasma (ICP) Spectroscopy
- Optical Emission Metal (OEM) Analyzer
- Direct Analysis in Real Time (DART) High Resolution Mass Spectrometry
- Gas Chromatography/ Mass Spectrometry (GC/MS)
- Headspace and Pyrolysis Gas Chromatography/ Mass Spectrometry
- Ion Chromatography
- Polarized Light Microscopy
- Cone Calorimeter

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KSC Engineering Directorate
Materials Science Division

NE-L6 Chemistry
Green Solvents

Description:

- Historically, solvents such as 1,1,1-trichloroethane (TCE) and 1,1,2-trichloro-1,2,2-trifluoroethane (Freon) have been used by the aerospace industry for precision cleaning applications. Although these chemicals were regulated out of use decades ago due to health and environmental concerns, KSC is still spending millions of dollars for their remediation.
- The current solvent of choice, Vertrel MCA, is a fluorinated chemical that had been detected in groundwater and may face similar regulations and future clean up costs .
- The goal of this project is to identify and evaluate environmentally benign cleaning technologies for space and aviation systems that require precision-level cleanliness.

Completed Tasks:

- Literature review of state of the art cleaning solvents and technologies and visits to precision cleaning facilities
- 23 candidate solvents and three alternative technologies selected for initial evaluation
- Developed suitable laboratory protocols and testing methodologies
- Down selection to 8 solvents and 2 solvent-free processes

Current Work:

- Evaluate cleaning efficiency of co-solvent blends, supercritical carbon dioxide, and multi-gas plasma system
- Determine effect of cleaning solvents and processes on soft goods
- Build modular solvent cleaning cabinets to test effectiveness on components with complex geometries.

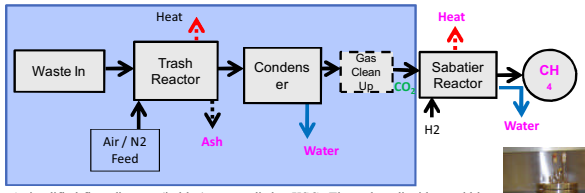
Helix supercritical system

Pico low pressure plasma system

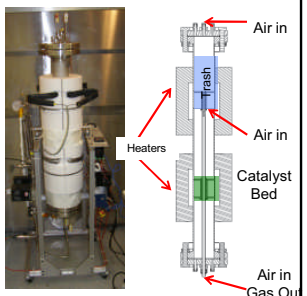
Coupons being cleaned by Argon plasma

KSC Engineering Directorate
Materials Science Division

NE-L6 Chemistry Trash to Gas Converting Space Trash Into Useful Products



- A simplified flow diagram (in blue) was studied at KSC. The carbon dioxide would be fed into a separate Sabatier reactor with hydrogen to produce methane and water.
- High fidelity waste simulant included items like food packaging, clothing, cotton, hygiene products, food, fecal and urine simulant.
- Parameters from studies performed conclude a 10 slm air flow, split equally between top and bottom inlets and 600 ˚C temperature were found to be optimal. Approximately 100% conversion of carbon in the simulant was performed for conversion into useful carbon containing gasses. ~77 minutes is needed to process 100 g of trash under these conditions. This results in a waste processing rate of about 420kg/year. This reactor would need to be scaled up by a factor of 5 or 6 to process the 2500 kg of waste generated by a crew of four.
- Tar challenges exists and we are therefore studying catalytic mechanisms for gas cleanup.
- The FY13 down select determined that FY14 will focus on the steam reforming reactor. Time will be focuses on optimizing the technology for power, mass and microgravity conditions.



KSC 2nd Generation Gasification Reactor