Advanced Spaceport and Range Technology Conference
Transformation Space Launch and Operations Conference

Strategic Research Directions in Microgravity Materials Science

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Ed Semmes  Space Radiation Shielding – Marshall Space Flight Center
Julie Bassler  In Situ Fabrication and Repair; Materials Science for Advanced Life Support Systems – Marshall Space Flight Center
• Where We Were - Heritage
  - Microgravity Materials Science in Office of Biological and Physical Research (OBPR) Organizational Structure
  - Microgravity Materials Science Program Overview

• Where We Are Going - Exploration
  - Low Gravity Materials Research in Realigned Office of Biological and Physical Research Product Line Structure
  - Low Gravity Materials Research Directions
    • Space Radiation Shielding
    • In Situ Resource Utilization
    • In Situ Fabrication and Repair
    • Materials Science for Spacecraft and Propulsion Systems
    • Materials for Advanced Life Support Systems

• Summary
Office of Biological and Physical Research
Code U

- Office of Associate Administrator
  - Mission Integration Division
  - Resources and Business Management Division
    - Physical Sciences Research Division
    - Fundamental Space Biology Division
    - Bioaeronautics Research Division
    - Space Product Development Division

**Physical Sciences Research Division**
- Research Elements: Fundamental Microgravity Research
  - Combustion Science
  - Fluid Physics
  - Materials Science
  - Fundamental Physics
  - Exploration Research
- Biomolecular Physics and Chemistry
- Biotechnology and Earth-Based Applications
Classes of Materials

Materials Science

Themes
Sample Ampoule Cartridge Assembly

Sample Ampoule or Crucible

- Contains "Sample" to be processed
- Sealed
- PI provided

Cartridge

- Houses PI Sample Ampoule or Crucible
- Sensors for monitoring temperature and Cartridge integrity
- Loaded into the Module Insert by crew
- Sealed to provide one-level of containment

NASA or ESA Module Insert(s)

- Module Insert designed to accommodate investigation unique processing requirements
- Replaceable on-orbit
- Provides for 'Automatic' processing
- Vacuum or inert atmosphere

MSL Experiment Module
Accommodates Various Module Inserts

MSRR-1

ESA Provides:
- Power Supply
- Avionics Control System
- Data Electronics
- Core Facility
- Gas/Vacuum distribution sub-system
- Water pump package
- Gas Supply

- NASA provides Rack Subsystems
- NASA integrates the Rack Payload
Transitioning to Exploration
### RESEARCH ELEMENTS

- **Human Adaptation and Countermeasures**
  - Exercise Systems
  - Equipment
  - Prescriptions
  - Integrative Physiology
    - Bone loss
    - Muscle alterations & atrophy
    - Neurovestibular adaptation (sensory motor)
    - Cardiovascular alterations
  - Pharmacology and nutrition
    - Immunology, infection & hematology
  - Artificial gravity prescriptions

- **Behavior and Performance**
  - Psychosocial adaptation
  - Sleep & circadian
  - Neuropsychological

- **Integrated Autonomous Medical Care**
  - Medical Prevention Systems
  - Medical Monitoring Systems
  - Medical Diagnosis Systems
  - Medical Treatment Systems
  - Medical Informatics

- **Shielding**
- Transport and modeling
- Radioprotectants
- Dosimetry and monitoring

- **Advanced life support**
- Environmental monitoring and control
- Contingency technologies
- EVA Technologies and Human-Robotic Interactions
- Space human factors
- Low gravity & exploration (ISRU-life support)

- Cross-cutting low gravity/fundamental research

### PRODUCT LINES

- **Human Health And Performance**
  - Radiation Protection
  - Human Support System Technologies
OBJECTIVES

- Safely extend the duration of crew deployment and lifetime radiation exposure
- Enable deep space missions by safeguarding the crew against expected exposure

STRATEGY

- Accurately determine the interactions of space radiation with spacecraft materials:
  - Reduce the uncertainties
- Protect crew against space radiation:
  - Develop new multi-functional materials
    - Spacecraft structural elements
    - Extra Vehicular Activity (EVA) Suits
    - Regolith-based shielding systems
    - Monitoring and Dosimetry
  - Non-materials concepts
Space Radiation Shielding Program

Radiation Transport Codes
Development:
Simulation and characterization of shielding effectiveness

Cross Section Measurements

Deep Space Test Bed (DSTB)

Materials Design and Testing

Insertion Technologies

Radiation Transport Codes

Ground-based Accelerator Cross-Section Measurements:
Nuclear cross section measurements for simulation and validation purposes

Space-based Research:
Deep Space Test Bed facility to simulate the space radiation environment
- Transport Code Validation
- Radiobiology and biomolecular-based materials validation

Materials Research:
Design, fabricate, and test innovative shielding materials including multi-functional criteria for targeted applications: spacecraft structural elements; EVA suits; regolith-based shielding systems; radiation monitors

Insertion Technologies:
- Materials Maturation
- Integrated TPS and Shielding Materials
- Life Systems Integrated Shields
- Design Optimization and Tools
In Situ Resource Utilization (ISRU) is Enabling For Exploration

**ISRU enables mass & cost efficient Near-Earth & Solar System Space Transportation**

- Reduces Earth to orbit mass by 20 to 45%
- Estimated 300 MT/yr reduction in Earth logistics

**Space Resource Utilization**

- Reduces dependence on Earth supplied logistics
- Enables self-sufficiency
- Provides backup options & flexibility
- Radiation Shielding

- Develops material handling and processing technologies
- Provides infrastructure to support space commercialization
- Earth, Moon, & Earth-Moon space manufacturing, and product/resource development, resupply, & transportation

**Expands Human Exploration & Presence**

- Increase Surface Mobility & extends missions
- Habitat & infrastructure construction
- Propellants, life support, power, etc.

**Enables Space Commercialization**

- ISRU enables “Accessible” & “Sustainable” planetary surface exploration of Moon & Mars
<table>
<thead>
<tr>
<th>Possible Destinations</th>
<th>Common Resources</th>
<th>Core Building Blocks</th>
<th>Core Technologies</th>
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</thead>
<tbody>
<tr>
<td>Moon</td>
<td><strong>Water</strong></td>
<td>• Atmosphere &amp; Volatile Collection &amp; Separation</td>
<td>- Microchannel Adsorption</td>
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<tr>
<td>Mars &amp; Phobos</td>
<td>• Moon</td>
<td>• Regolith Processing to Extract O₂, Si, Metals</td>
<td>- Constituent Freezing</td>
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<tr>
<td></td>
<td>• Mars</td>
<td>• Water &amp; Carbon Dioxide Processing</td>
<td>- Molecular Sieves</td>
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<td></td>
<td>• Comets</td>
<td>• Fine-grained Regolith Excavation &amp; Refining</td>
<td>- Carbothermal Reduction</td>
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<td></td>
<td>• Asteroids</td>
<td>• Drilling</td>
<td>- Water Electrolysis</td>
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<tr>
<td></td>
<td>• Europa</td>
<td>• Volatile Furnaces &amp; Fluidized Beds</td>
<td>- CO₂ Electrolysis</td>
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<td></td>
<td>• Titan</td>
<td>• 0-g &amp; Surface Cryogenic</td>
<td>- Sabatier Reactor</td>
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<td></td>
<td>• Triton</td>
<td>• Liquefaction, Storage, &amp; Transfer</td>
<td>- RWGS Reactor</td>
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<td></td>
<td>• Human Habitats</td>
<td>• In-Situ Manufacture of Parts &amp; Solar Cells</td>
<td>- Methane Reformer</td>
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<tr>
<td>Near Earth Asteroids &amp; Extinct Comets</td>
<td></td>
<td></td>
<td>- Microchannel Chem/thermal units</td>
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<td></td>
<td><strong>Carbon</strong></td>
<td></td>
<td>- Scoopers/buckets</td>
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<tr>
<td></td>
<td>• Mars (atm)</td>
<td></td>
<td>- Conveyors/augers</td>
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<tr>
<td></td>
<td>• Asteroids</td>
<td></td>
<td>- No fluid drilling</td>
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<td></td>
<td>• Comets</td>
<td></td>
<td>- Thermal/Microwave Heaters</td>
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<tr>
<td></td>
<td>• Titan</td>
<td></td>
<td>- Heat Exchangers</td>
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<tr>
<td></td>
<td>• Human Habitats</td>
<td></td>
<td>- Liquid Vaporizers</td>
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<tr>
<td></td>
<td><strong>Metals &amp; Oxides</strong></td>
<td></td>
<td>- O₂ &amp; Fuel Low Heatleak Tanks (0-g &amp; reduced-g)</td>
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<tr>
<td></td>
<td>• Moon</td>
<td></td>
<td>- O₂ Feed &amp; Transfer Lines</td>
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<tr>
<td></td>
<td>• Mars</td>
<td></td>
<td>- O₂/Fuel Couplings</td>
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Planetary Resource Utilization Maximizes
Benefits, Flexibility, & Affordability

In-Situ Production Of Consumables for Propulsion, Power, & ECLSS

Life Support Systems for Habitats & EVA

Core Technologies
- CO₂ & N₂ Acquisition & Separation
- Sabatier Reactor
- RWGS Reactor
- CO₂ Electrolysis
- Methane Reforming
- H₂O Separators
- H₂O Electrolysis
- H₂O Storage
- Heat Exchangers
- Liquid Vaporizers
- O₂ & Fuel Storage (0-g & reduced-g)
- O₂ Feed & Transfer Lines
- O₂/Fuel Couplings
- Fuel Cells
- O₂/Fuel Igniters & Thrusters

Fuel Cell Power for Rovers & EVA

Water – H₂/O₂ Based Propulsion/Power

Non-Toxic O₂-Based Propulsion

0-g & Reduced-g Propellant Transfer

MG2212, Slide 13  Advanced Spaceport and Range Technologies Conference, May 2004
### Possible ISRU Technology, Demonstration, & Mission Integration Roadmap

**National Aeronautics and Space Administration • Marshall Space Flight Center**

**MSFC Microgravity Science and Applications Department**

#### In-Situ Resource Excavation & Separation
- Regolith Excavation
- Thermal/Microwave Extraction
- H$_2$O Separation
- CO$_2$ & N$_2$ Separation

#### Resource Processing
- Carbothermal Regolith Processing
- CO/CO$_2$ Processing to Fuel
- H$_2$O Electrolysis
- Microchannel Chemical/Thermal Processing

#### Consumable Storage & Distribution
- Cryocoolers
- Light Weight Tanks
- Disconnects/pumps

#### In-Situ Manufacturing
- Solar cell production
- Metallic part fab
- Polymer part fab.

<table>
<thead>
<tr>
<th>Process</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prospector Flt. Exp.</td>
<td>(Missions of opportunity)</td>
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<tr>
<td>Lunar Polar Water Explorer</td>
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<tr>
<td>Lunar Volatile &amp; He\textsuperscript{3} Extraction</td>
<td>Mars Polar Water Extraction Demo</td>
</tr>
<tr>
<td>Resource Processing</td>
<td>Provides Information on Resources &amp; Engineering Data for ISRU</td>
</tr>
<tr>
<td>Lunar O\textsubscript{2} Production Demo</td>
<td>Provides Water &amp; Gases For Power, Propulsion, Life Support &amp; Science</td>
</tr>
<tr>
<td>Mars O\textsubscript{2} Fuel Production Demo</td>
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<td>Mars O\textsubscript{2} Fuel Production</td>
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</tr>
<tr>
<td>In-Situ Manufacturing</td>
<td>Provides Logistics Reduction &amp; Infrastructure Growth</td>
</tr>
<tr>
<td>Manufacturing Demo on ISS</td>
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<tr>
<td>Solar Cell Manufacturing Demo</td>
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</tbody>
</table>
OBJECTIVES

- Enable space exploration missions through development of autonomous, self reliant space-based assets, minimizing up mass needs.

STRATEGY

- Pursue research advancing three critical space-based capability themes:
  - **In Situ Fabrication**
    - Spare Parts and Tools
      - Valves, quick disconnects, filters, embedded electronics, medical instruments, wrenches, etc.
    - Structures
      - Solar panels from Lunar regolith
      - Habitats built from Lunar regolith
      - Thin film inflatable structures
      - Pressurized vessels
  - **In Situ Repair Techniques**
    - Soldering
    - Welding
    - Materials Joining
    - Self-healing Materials
  - **Recycling**
    - Cellulose to polymers
    - Human waste to bricks
OBJECTIVE

- Enable Spacecraft and Propulsion advancements through materials science research directed towards identified high-priority technology gaps.

STRATEGY

- Initiate research addressing key materials issues relating to the following in-space propulsion:
  - Advanced Chemical Propulsion
  - Electric Propulsion
  - Nuclear Electric Propulsion
  - Nuclear Thermal Propulsion
  - Propellantless Propulsion
    - Solar Sails
    - Aerocapture
    - Tethers
- Involve customers in identification of technology gaps that benefit from advancements in materials science.
- Cross-cutting research elements:
  - Advanced Materials for Space Propulsion Systems
  - Environmental Protection Materials
  - Vehicle Health Monitoring Materials
  - Spacecraft Materials
• **Human life support systems provide the basic functions to sustain life:**
  - Controlling pressure, temperature, and humidity; provide usable water and breathable air; supply food; and manage wastes.

• **Advanced Life Support element, of the Human Support Systems Technologies Product Line, must reduce dependence on resupply in space, by being more reliable and self-sufficient than life support systems for LEO missions.**

• **Technical challenges include:**
  - Heat transport
  - Heat rejection
  - Waste monitoring and control
  - Habitat monitoring

• **Materials Research focal areas include:**
  - Lightweight piping for heat management systems
  - Coatings for heat management systems
  - Enhanced flex-hoses
  - Hydrogen embrittlement control
  - Inflatable habitats
  - Environment monitoring utilizing Lab-on-a-Chip Applications Development (LOCAD) technologies
The Office of Biological and Physical Research (OBPR) is moving aggressively to align programs, projects and products with the vision for space exploration.

- Research in advanced materials is a critical element in meeting exploration goals
  - Crew health, safety, and life support systems
  - Significant reduction in mass to/beyond orbit
  - Commensurate cost reduction
  - Enables sustainable planetary surface exploration
  - Risk reduction

- Research in low gravity materials science in OBPR is being focused on top priority needs in support of exploration
  - Space Radiation Shielding
  - In Situ Resource Utilization
  - In Situ Fabrication and Repair
  - Materials Science for Spacecraft and Propulsion Systems
  - Materials Science for Advanced Life Support Systems

- Roles and responsibilities in low gravity materials research for exploration between OBPR and the Office of Exploration Systems are evolving.