Strategic Research Directions in Microgravity Materials Science

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• **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
    - Bioastronautics 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

NASA National Aeronautics and Space Administration • Marshall Space Flight Center
MSFC Microgravity Science and Applications Department
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

SPD + MSL
EM EM

- 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**
  - *Human Health*
  - *And Performance*

- **Radiation Protection**

- **Human Support System Technologies**
  - *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
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 multifunctional 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

**Expands Human Exploration & Presence**

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

**Enables Space Commercialization**

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

**ISRU enables “Accessible” & “Sustainable” planetary surface exploration of Moon & Mars**
Possible Destinations

- Moon
- Mars & Phobos
- Near Earth Asteroids & Extinct Comets
- Europa
- Titan

Common Resources

Water
- Moon
- Mars
- Comets
- Asteroids
- Europa
- Titan
- Triton
- Human Habitats

Carbon
- Mars (atm)
- Asteroids
- Comets
- Titan
- Human Habitats

Metals & Oxides
- Moon
- Mars
- Asteroids

Helium-3
- Moon
- Jupiter
- Saturn
- Uranus
- Neptune

Core Building Blocks

- Atmosphere & Volatile Collection & Separation
- Regolith Processing to Extract O₂, Si, Metals
- Water & Carbon Dioxide Processing
- Fine-grained Regolith Excavation & Refining
- Drilling
- Volatile Furnaces & Fluidized Beds
- 0-g & Surface Cryogenic Liquefaction, Storage, & Transfer
- In-Situ Manufacture of Parts & Solar Cells

Core Technologies

- Microchannel Adsorption
- Constituent Freezing
- Molecular Sieves
- Carbothermal Reduction
- Water Electrolysis
- CO₂ Electrolysis
- Sabatier Reactor
- RWGS Reactor
- Methane Reformer
- Microchannel Chem/thermal units
- Scoopers/buckets
- Conveyors/augers
- No fluid drilling
- Thermal/Microwave Heaters
- Heat Exchangers
- Liquid Vaporizers
- O₂ & Fuel Low Heatleak Tanks (0-g & reduced-g)
- O₂ Feed & Transfer Lines
- O₂/Fuel Couplings
Planetary Resource Utilization Maximizes
Benefits, Flexibility, & Affordability

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

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
- O₂ Feed & Transfer Lines
- O₂/Fuel Couplings
- Fuel Cells
- O₂/Fuel Igniters & Thrusters

Life Support Systems for
Habitats & EVA

Water – H₂/O₂ Based
Propulsion/Power

Non-Toxic O₂-Based
Propulsion

0-g & Reduced-g
Propellant Transfer

Fuel Cell Power for
Rovers & EVA
Possible ISRU Technology, Demonstration, & Mission Integration Roadmap

In-Situ Resource Excavation & Separation
- Regolith Excavation
- Thermal/Microwave Extraction
- H₂O Separation
- CO² & N₂ Separation

Resource Processing
- Carbothermal Regolith Processing
- CO/CO₂ Processing to Fuel
- H₂O 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.

Prospector Flt. Exp. (Missions of opportunity)

Lunar Polar Water Explorer

Lunar Volatile & He³ Extraction

Lunar O₂ Production Demo

Lunar O₂ Pilot Plant

Mars O₂ Fuel Production Demo

Mars Polar Water Extraction Demo

Provides Information on Resources & Engineering Data for ISRU

Provides Water & Gases For Power, Propulsion, Life Support & Science

Provides O₂ & Reactants Power, Propulsion, Life Support & Science

Provides Logistics Reduction & Infrastructure Growth

Manufacturing Demo on ISS

Solar Cell Manufacturing Demo
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
Possible In Situ Fabrication and Repair Technology Demonstration and Mission Integration Roadmap

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MSFC Microgravity Science and Applications Department

In-Situ Resource Excavation & Separation/Recycling
- Regolith Excavation
- Extracted Materials
- Recycled Materials

In Situ Fabrication
- Spare Parts and Tools
- Habitats
- Solar Panels
- Inflatables
- Pressure Vessels

In-Situ Repair
- Soldering
- Welding
- Materials Joining
- Self Healing

Lunar Explorer
Regolith Excavation and Materials Extraction (Si, Al, Polymers, Glass etc.)

Solid Freeform Demo on ISS

Tools

Solar Cell Fabrication

In Situ Lunar Habitat

Metal
Electronics
Ceramic

Concrete Walls/Habitats

Metal Structures

Soldering Demo on ISS
Friction Stir Welding

MG2212, Slide 16  Advanced Spaceport and Range Technologies Conference, May 2004
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
Materials Science for Spacecraft and Propulsion Systems

2001 Customer Supported Workshop
NRA01: Special Focus Propulsion 2003 Customer Supported Workshop
NRA02: Special Focus

2002 Customer Supported Workshop
High T. Low Wt. Magnets High Voltage Insulation
Lt. Wt. Thermal Insulation

HI. Durable Heat Shield
HI. T. H2 Resist Refractory Materials
Reflective, Env. Resist, Thin Films
Extended Life Cathodes
Lt. Wt. Structural Materials

Protective Coatings Deployable Structures Hi. Temp. Heat Pipes

Increased Temp. Hot Shield Extreme Temp Insulators
10 Year Life Electric Prop. Grids

Increased Nozzle Durability
Low density films
Increased Life Coatings
Low Density Structural Materials

High Priority Research Areas
Aerocapture
Chemical Propulsion
Solar Sail
Nuclear Propulsion
Electric Propulsion
Emerging Technologies
Spacecraft Structures
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.