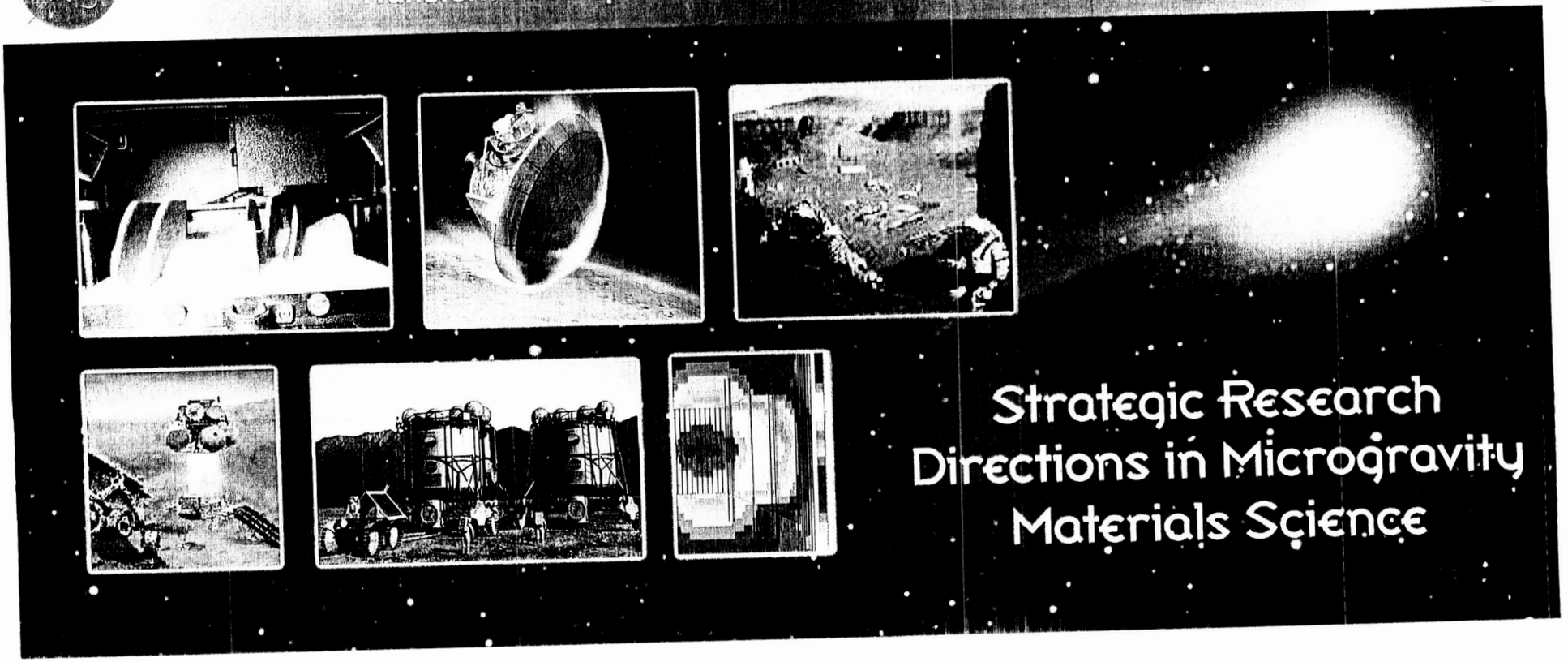
Advanced Spaceport and Range Technology Conference
Transformation Space Launch and Operations Conference



Strategic Research Directions in Microgravity Materials Science

Washington, D.C. ■ May 24-26, 2004

Dr. R.G. Clinton, Jr., Manager
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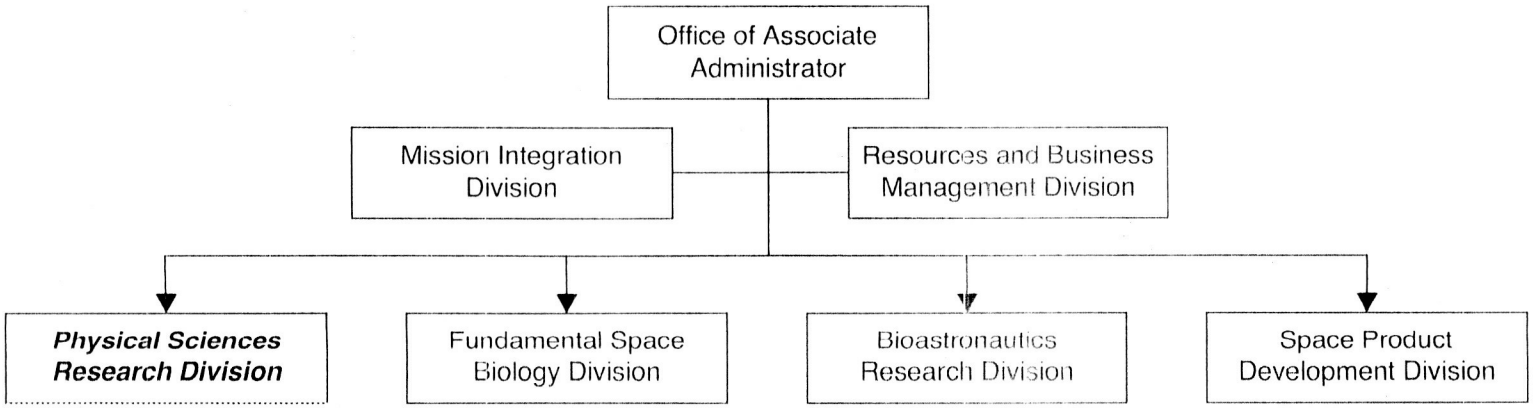
Outline

- **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**

Where We Were

Office of Biological and Physical Research

Code U



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

Microgravity Materials Science Research Program

National Aeronautics and Space Administration • Marshall Space Flight Center

MSFC Microgravity Science and Applications Department

Materials Science Research Rack-1 (MSRR-1)

Sample Ampoule Cartridge Assembly

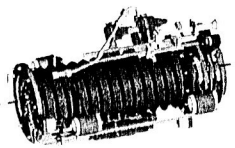
Sample Ampoule or Crucible

Cartridge

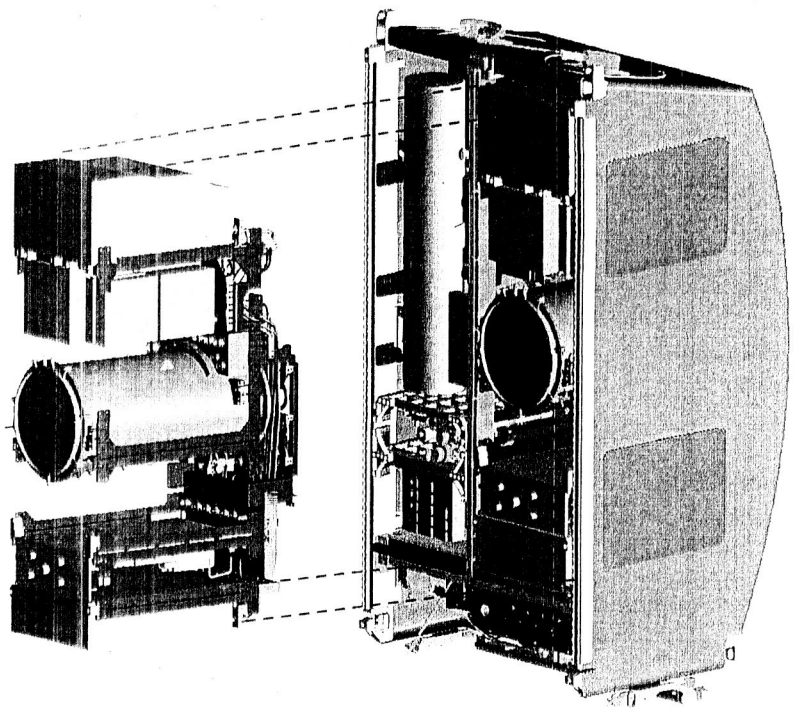
- Contains "Sample" to be processed
- Sealed
- PI provided

- 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

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

MSRR-1

SPD EM + MSL EM

- NASA provides Rack Subsystems
- NASA integrates the Rack Payload

Transitioning to Exploration

Aligning with the Vision: OBPR Programs, Projects, and Products

RESEARCH ELEMENTS	PRODUCT LINES
• **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	***Human Health And Performance***
• **Shielding** • **Transport and modeling** • **Radioprotectants** • **Dosimetry and monitoring**	***Radiation Protection***
• **Advanced life support** • **Environmental monitoring and control** • **Contingency technologies** • **EVA Technologies and Human-Robotic Interactions** • **Space human factors** • **Low gravity & exploration (ISRU-life support)**	***Human Support System Technologies***
• **Cross-cutting low gravity/fundamental research**	

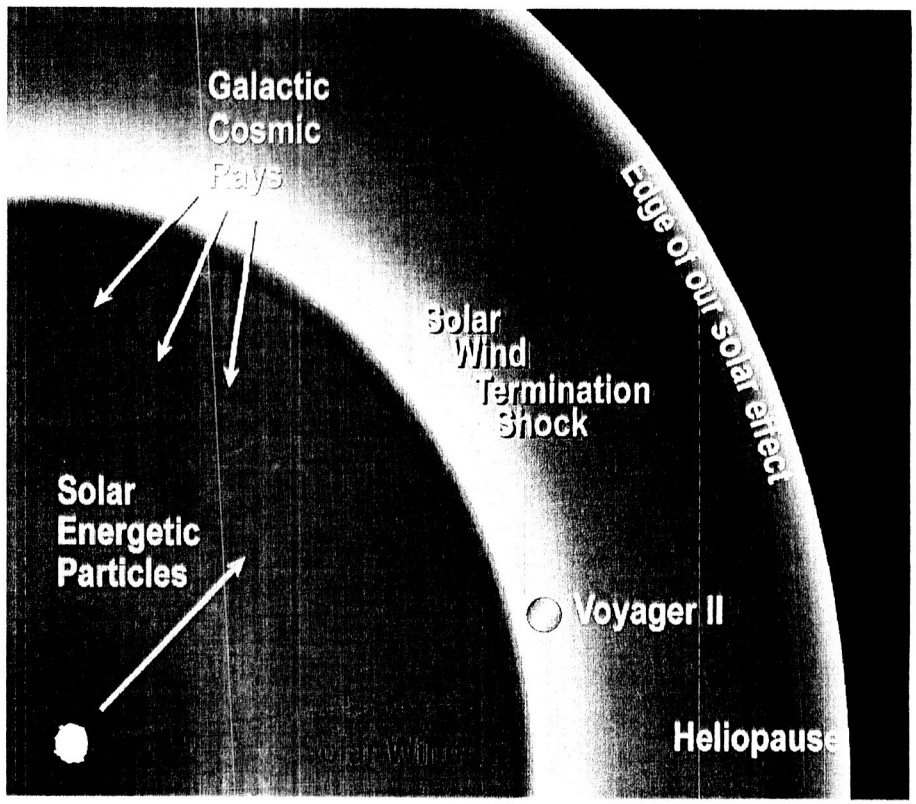
Space Radiation Shielding Program

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

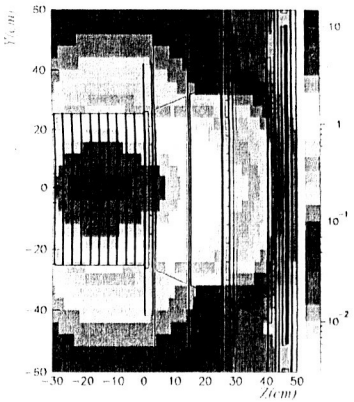


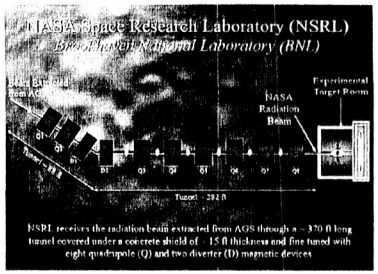
Space Radiation Shielding Program

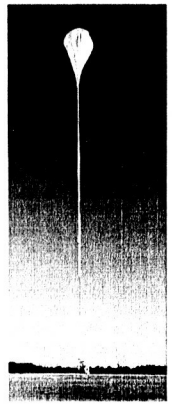
National Aeronautics and Space Administration • Marshall Space Flight Center

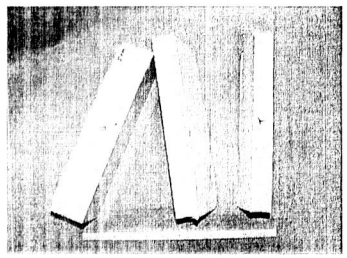
MSFC Microgravity Science and Applications Department

Radiation Transport Codes | **Cross Section Measurements** | **Deep Space Test Bed (DSTB)** | **Materials Design and Testing** | **Insertion Technologies**









Radiation Transport Codes Development:

Simulation and characterization of shielding effectiveness

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:

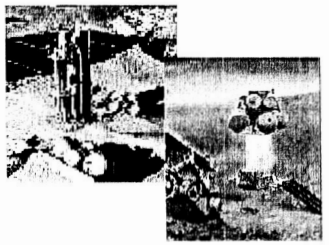
Design, fabricate, and test innovative shielding materials including multi-functional criteria for targeted applications: spacecraft structural elements; EVA suits; regolith-based shielding systems; radiation monitors

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

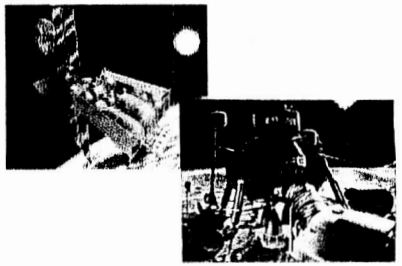


Space Resource Utilization

Mass Reduction

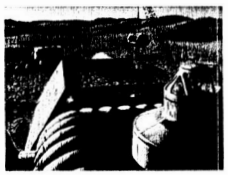
- Reduces Earth to orbit mass by 20 to 45%
- Estimated 300 MT/yr reduction in Earth logistics

Cost Reduction



- Reduces number and size of Earth launch vehicles
- Allows reuse of landers

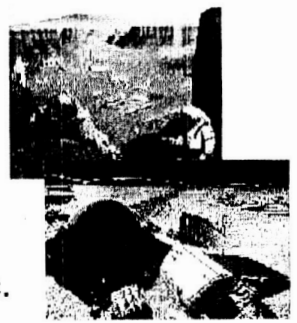
Risk Reduction



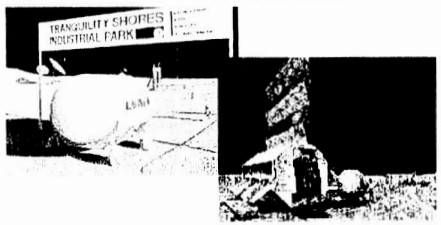
- Reduces dependence on Earth supplied logistics
- Enables self-sufficiency
- Provides backup options & flexibility
- Radiation Shielding

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

In-Situ Resource Utilization: Common Resources & Processes Support Multiple Robotic/Human Mission Destinations

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 O_2, 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
- CO_2 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
- O_2 & Fuel Low Heatleak Tanks (0-g & reduced-g)
- O_2 Feed & Transfer Lines
- O_2/Fuel Couplings

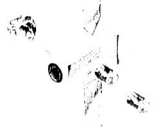
In Situ Resource Utilization: Core Technologies Enable Multiple Applications

Planetary Resource Utilization Maximizes Benefits, Flexibility, & Affordability

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


Fuel Cell Power for Rovers & EVA


0-g & Reduced-g Propellant Transfer

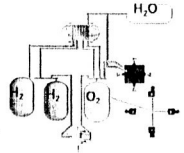


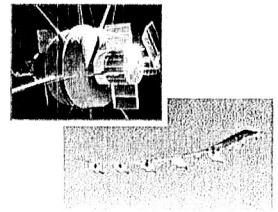

Core Technologies

- CO_2 & N_2 Acquisition & Separation
- Sabatier Reactor
- RWGS Reactor
- CO_2 Electrolysis
- Methane Reforming
- H_2O Separators
- H_2O Electrolysis
- H_2O Storage
- Heat Exchangers
- Liquid Vaporizers
- O_2 & Fuel Storage (0-g & reduced-g)
- O_2 Feed & Transfer Lines
- O_2/Fuel Couplings
- Fuel Cells
- O_2/Fuel Igniters & Thrusters

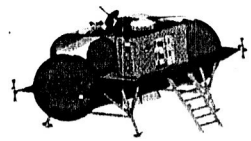
Life Support Systems for Habitats & EVA


Water – H_2/O_2 Based Propulsion/Power

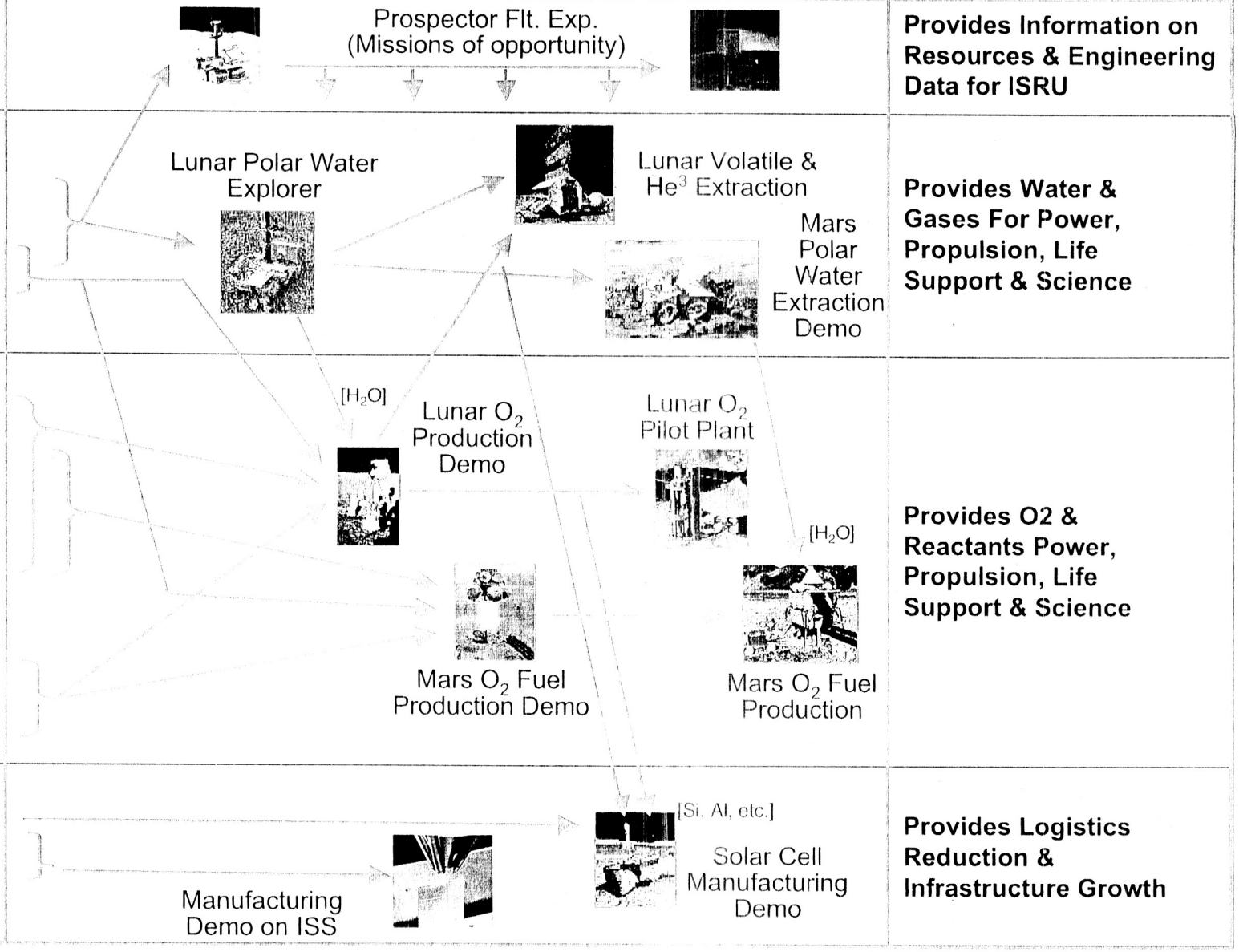




Non-Toxic O_2-Based Propulsion

Possible ISRU Technology, Demonstration, & Mission Integration Roadmap



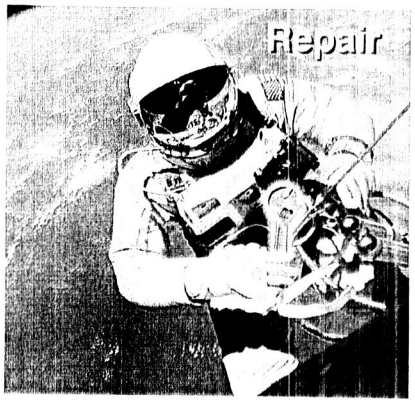
In Situ Fabrication and Repair

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

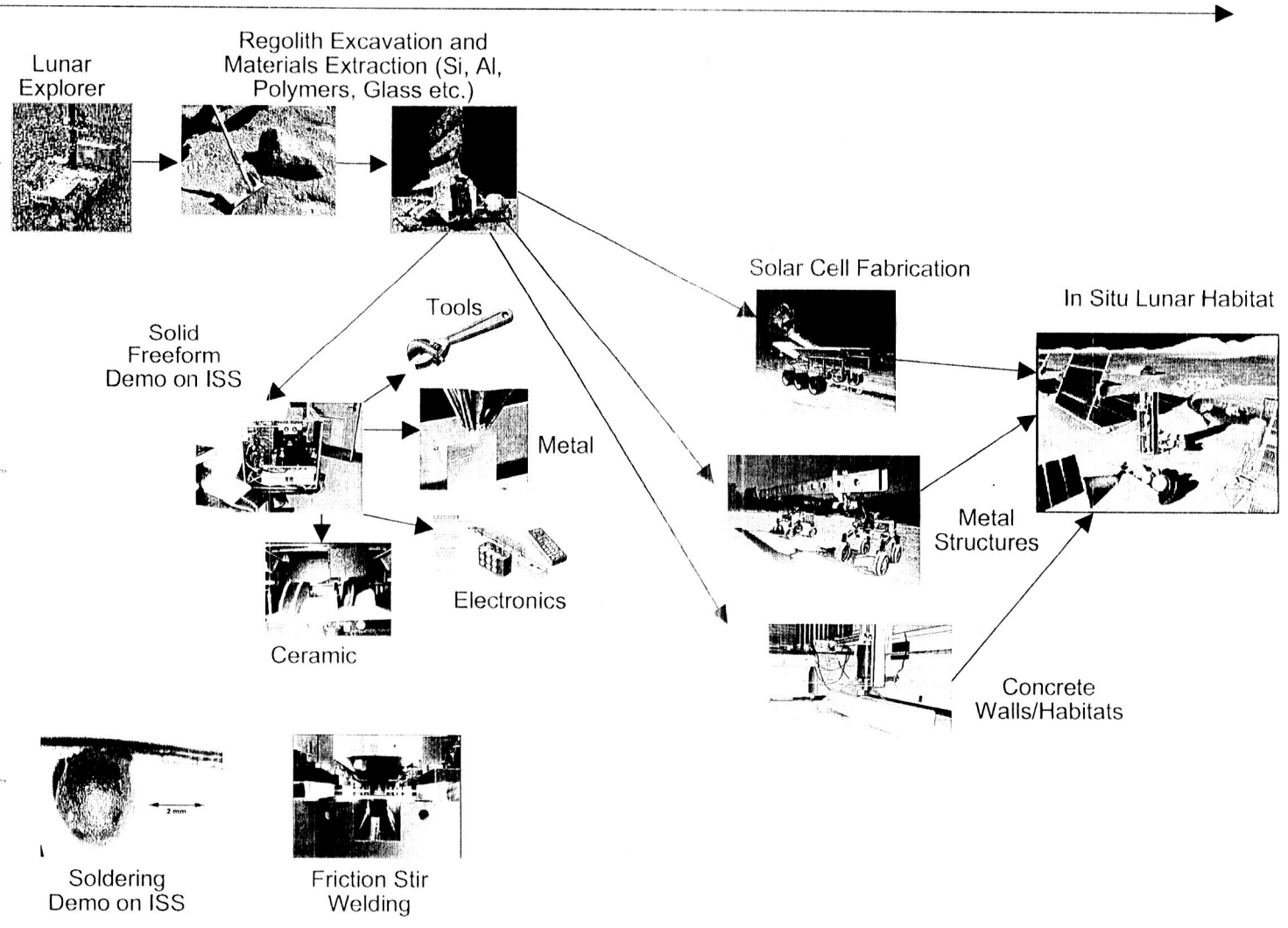


Possible In Situ Fabrication and Repair Technology Demonstration and Mission Integration Roadmap

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



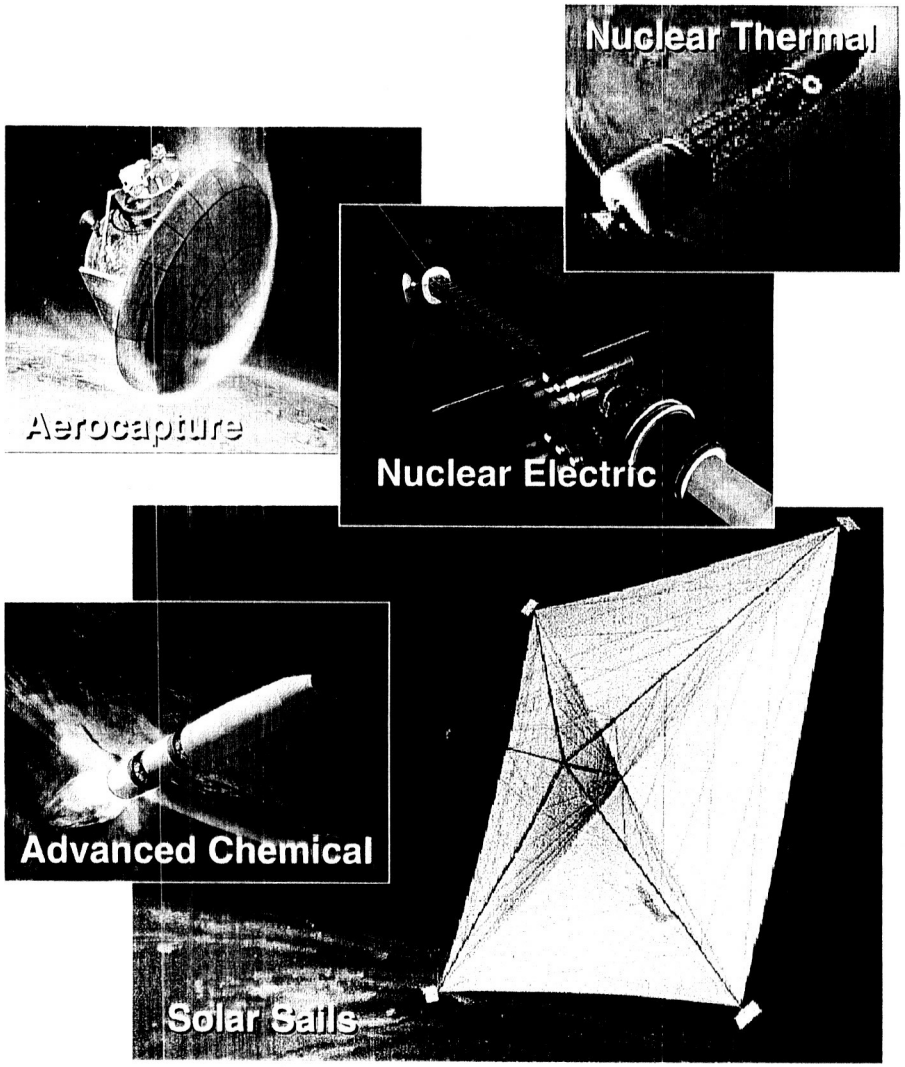
Materials Science for Spacecraft and Propulsion Systems

OBJECTIVE

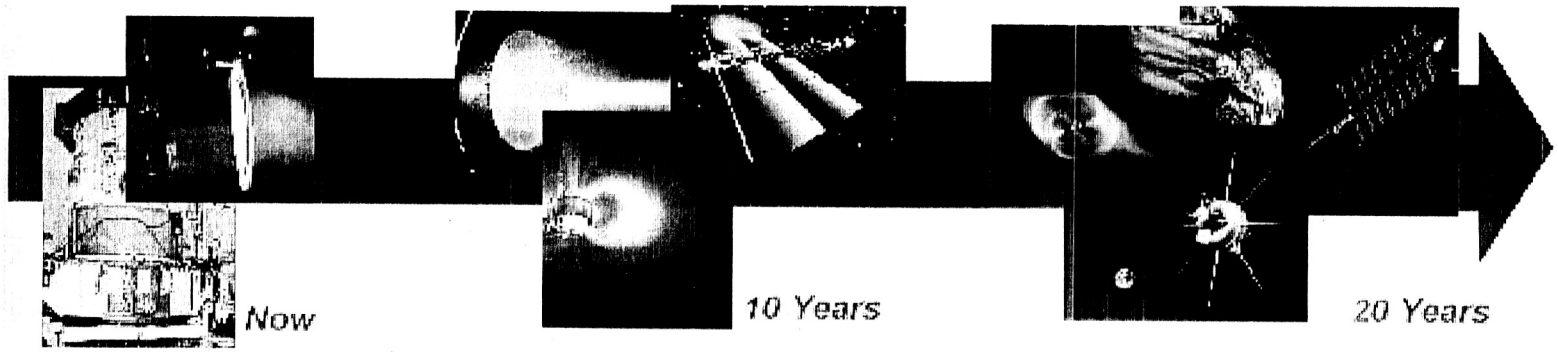
- **Enable Spacecraft and Propulsion advancements through materials science research directed towards identified high-priority technology gaps.**

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



FY04 & Prior | **FY05-06** | **FY07-08** | **FY09-10** | **FY11-12** | **FY13-14**

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

High T, Low Wt. Magnets
High Voltage Insulation
Lt. Wt. Thermal Insulation

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

Protective Coatings
Hi Strength Conductive
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

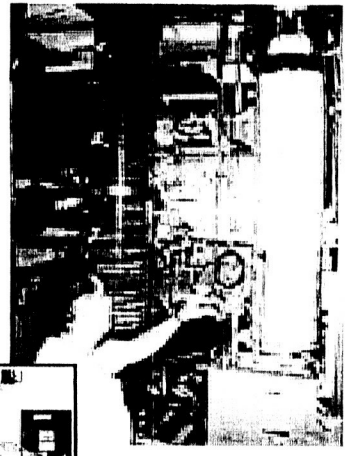
Emerging Technologies

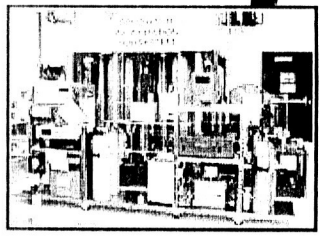
Spacecraft Structures

Materials Science for Advanced Life Support Systems

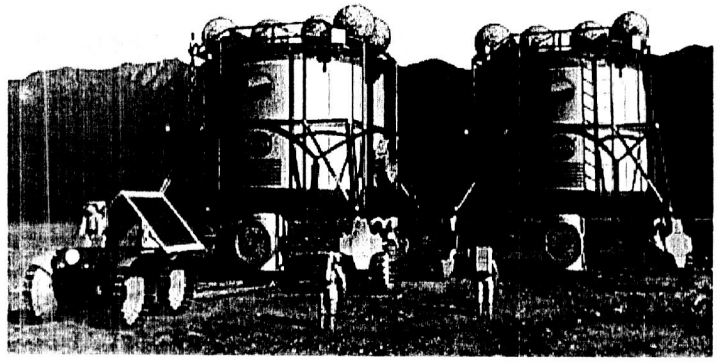
- **Human life support systems provide the basic functions to sustain life:**
  - Controlling pressure, temperature, and humidity; provide usable water and breathable air; supply food; and manage wastes.
- **Advanced Life Support element, of the Human Support Systems Technologies Product Line, must reduce 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

Biological Water Recovery System





Solid Waste Incinerator



Mars Habitat Concept

Summary

- **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.**