Applied Nanotechnology for Human Space Exploration

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NASA's Strategic Vision

Deep Space Exploration

Mars Manned

Lunar Manned

Mars Robotic

Crew Exploration Vehicle

Lunar Robotic

ISS Complete

2005

2010

2015

2020

2035
Exploration Architecture

- Lunar / Interplanetary Transfer
- Lunar Surface Operations
- Planetary Operations (Human/Robotic)
- Launch Vehicles
- Crew Exploration Vehicle (CEV)
- ISS Operations
Future Exploration Mission Requirements Cannot Be Met with Conventional Materials

**Vehicles and Habitats**
- Reduced mass and volume
- High strength
- Thermal and radiation protection
- Self-healing, self-diagnostic
- Multi-functionality
- Improved durability
- Environmental resistance (dust, atmosphere, radiation)

**EVA Suits**
- Reduced mass
- Increased functionality and mobility
- Thermal and radiation protection
- Environmental resistance

**Satellites and Rovers**
- Reduced mass and volume
- Reduced power requirements
- Increased capability, multifunctionality
Nanomaterials: Single Wall Carbon Nanotubes

**Unique Properties**
- Exceptional strength
- Interesting electrical properties (metallic, semi-conducting, semi-metal)
- High thermal conductivity
- Large aspect ratios
- Large surface areas

**Possible Applications**
- High-strength, light-weight fibers and composites
- Nano-electronics, sensors, and field emission displays
- Radiation shielding and monitoring
- Fuel cells, energy storage, capacitors
- Biotechnology
- Advanced life support materials
- Electromagnetic shielding and electrostatic discharge materials
- Multifunctional materials
- Thermal management materials

**Current Limitations**
- High cost for bulk production
- Inability to produce high quality, pure, type specific SWCNTs
- Variations in material from batch to batch
- Growth mechanisms not thoroughly understood
- Characterization tools, techniques and protocols not well developed

**Size Comparison**
C_{60}, Nanotubes, and Atoms

[C60 molecule, single wall carbon nanotube, and atoms with dimensions labeled]
## Applied Nanotechnology at JSC: Fundamentals to Applications

### Characterization
- Purity, Dispersion, Consistency, Type
- SWCNT Load Transfer
- Single Fiber Diffusivity

### Processing
- Purification
- Functionalization
- Dispersion
- Alignment

### Collaborations
- Academia, Industry, Government

<table>
<thead>
<tr>
<th>APPLICATIONS</th>
<th>PARTNERS</th>
<th>1</th>
<th>2</th>
<th>3</th>
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<tbody>
<tr>
<td>Supercapacitors</td>
<td>EP, GRC, Industry</td>
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<td>NX, Rice, PV, Ames</td>
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Technology Readiness Levels (TRL)

TRL 9
System Test, Launch & Operations

TRL 8
System/Subsystem Development

TRL 7
Technology Demonstration

TRL 6
Technology Development

TRL 5
Research to Prove Feasibility

TRL 4
Basic Technology Research

TRL 3
Basic principles observed and reported

Component and/or hardware validation in laboratory or space environment

Component and/or hardware validation in relevant environment

Component and/or hardware demonstration in a space or ground environment

System prototype demonstration in a space or ground environment

Actual system completed and "flight qualified"

Actual system "flight proven" through successful mission operations
Growth, Modeling, Diagnostics and Production

**Laser Ablation**

**Objective:** Ensure a reliable source of single wall carbon nanotubes with tailored properties (length, diameter, purity, chirality).

**High Pressure CO (HiPco)**

- Continuous process
- 10-100's g/day
- Small diameters (0.9nm)
- Company spin-off (CNI)

Modeling, Diagnostics, and Parametric Studies
Growth, Modeling, Diagnostics and Production

NASA / Rice University
3rd Single-Wall Nanotube Growth Mechanisms Workshop
April 2007
Canyon of the Eagles Ranch, Texas
Applications for Human Space Exploration

- Advanced Life Support
  - Regenerable CO₂ Removal
  - Water recovery

- Thermal Protection and Management
  - Ablators and ceramic nanofibers
  - TPS repair materials
  - Passive / active thermal management (spacesuit fabric, avionics)

- Nano-Biotechnology
  - Health monitoring (assays)
  - Countermeasures

- Multi-functional / Structural Materials
  - Primary structure (airframe)
  - Inflatables

- Power / Energy Storage Materials
  - Proton Exchange Membrane (PEM) Fuel Cells
  - Supercapacitors / batteries

- Electromagnetic / Radiation Shielding and Monitoring
  - ESD/EMI coatings
  - Radiation monitoring
Exploration Life Support

CHALLENGE:

Supply the daily needs of humans for long duration missions

- Air Revitalization
- Food Management
- Solid Waste Management
- Thermal Control
- Water Reclamation

Human consumable and throughput values in kg/crewmember/day  Klaus et al, 2005
**Exploration Life Support:**
**Atmosphere Revitalization System**

**MISSION:**
- Vehicle cabin atmospheric pressure & quality
- Atmospheric gas storage, supply and distribution
- Carbon dioxide partial pressure control
- Trace contaminant & particulate control
- Resource recovery, storage and distribution
- Lower spacecraft complexity = Lower risk
- Lower risk = Greater safety

**Timeline and Milestones:**

<table>
<thead>
<tr>
<th>Year</th>
<th>Crew Exploration Vehicle</th>
<th>Lunar Sortie</th>
<th>Lunar Outpost</th>
<th>Systems Engineering</th>
<th>Air Revitalization Systems</th>
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<tbody>
<tr>
<td>2006</td>
<td>PDR▲</td>
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<td>Systems Analysis</td>
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<td>Testing</td>
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<td>Pressure Systems</td>
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<td>Closed Loop Regenerative</td>
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Advanced Life Support: Regenerable CO₂ Removal

**CHALLENGE:**
- Long duration space flight requires a regenerable system for air revitalization
- NASA need: lower mass, higher performance, reduced volume

**SOLUTION:**
- Carbon Nanotubes: superior surface area & thermal conductivity
- Functionalized with CO₂ scrubbing chemistry – less volatile
- Suitable for both EVA and vehicle applications
- Applicability to smokestack applications on Earth

**COLLABORATION:**
- Rice University: Nanotube functionalization
- UTA: Primary amine chemistry
- JSC (EC): Requirements for space systems
- NASA Ames: Nanomaterials for trace contaminant control system & CO₂ Sensors
- Energy industry participation interest

Current RCRS materials: Zeolites and amine-coated polymer beads.

To be replaced by Single Wall Carbon Nanotube (SWCNT) Structure

Micro-scale testing with thermo-gravimetric analysis
NanoMaterial Solution:

- Use SWCNT functionalized with CO₂/H₂O scavenging amines
- Amines require lower energy for regeneration than present molecular sieve
- Higher surface area reduces system size/weight

Functionalized SWCNT CO₂ Receptor + CO₂

Functionalized SWCNT + CO₂

Nanotube functionalization chemistry
(Chattopadhyay et al, 2005)

CO₂ Gas

Absorbent Material

Bubbler

CO₂ Sensor

CO₂ capacity testing
Transport and storage of wastewater from human interfaces

Primary processing: organic and nitrogenous contaminant reduction

Secondary processing: inorganic contaminant reduction

Brine dewatering: water removal from highly concentrated brine

Post-processing and disinfection: polishing to meet potability standards

Storage and transport of potable water prior to consumption

Secondary Treatment
Inorganic Removal

Primary Treatment
Organic Removal

Brine Dewatering

Post-processing

Disinfection

Wastewater Storage

Potable Water Storage
**Advanced Life Support: Water Disinfection / Recovery**

**CHALLENGE:**
- NASA requires renewable chemical-free systems to purify water in space
- Current solution: Iodine – toxic to astronauts and non-regenerable

**SOLUTION:**
- C$_{60}$/fullerene enhances disinfection property of UV light
- Singlet oxygen production enhances the rate at which bacteria are killed
- Chemical-free system for closed loop water purification
- Commercial Potential - Portable water disinfection devices

**COLLABORATION:**
- NASA JSC Advanced Life Support (EC)
- Rice University: C$_{60}$ deposition

UV light energizes fullerenes. Upon relaxation, photons are emitted and the excited fullerenes interact with oxygen molecules in water to produce singlet oxygen.

*Singlet oxygen kills bacteria.*
Power & Energy: Supercapacitors

**Challenges:**
- NASA requires reliable, robust power sources suitable for both EVA and vehicle applications.
- NASA requires increased power & energy densities, increased cycle life, reduced mass.

**Solution:**
- Carbon nanotube surface area and nanoporosity superior to current materials for electrolyte ion support.
- Carbon nanotube electrolyte supports: enhanced electrical and thermal conductivity.
- Potential for enhanced performance and longer cycle life.

**Collaboration:**
- NASA Glenn: Separator materials
- JSC (EP): Requirements
- Georgia Tech: Functionalized nanomaterials
- ReyTech Corp.: Improved fabrication & packaging
**Power & Energy: Fuel Cells**

**CHALLENGE:**
- NASA requires reliable, robust power sources suitable for both EVA and vehicle applications.
- NASA requires increased power & energy densities, increased cycle life, reduced mass.

**SOLUTION:**
- Novel carbon nanotube high surface area, high thermal & high gas diffusivity catalyst support.
- Reduced activation polarization – increased reliability.
- Higher power density from more efficient utilization of platinum catalysts.

**COLLABORATION:**
- NASA Glenn: High temperature membranes.
NanoMaterials for EMI Shielding

**CHALLENGE:**
- Control of electromagnetic emission and susceptibility characteristics of electronic, electrical, and electromechanical equipment and subsystems for space exploration

**SOLUTION:**
- Single-wall carbon nanotubes (SWCNT) offer low material density and high electrical conductivity
- Can be integrated into polymer matrices as thin transparent conductive coatings
- Cheap and easy to fabricate for application to off-the-shelf products: Laptops, PDAs, etc.

**COLLABORATION:**
- UTD
- UTPA
- Rice
- U of Florida
- JSC (EV)

Translucent Appliqués: Potential coatings for LCD screens

EMI testing in collaboration with UTPA

Nanotube materials

Nanomaterials functionalization

EMI testing & test development

Testing, requirements
Active Radiation Dosimeter

**CHALLENGE:**
- Acute radiation sickness poses a risk to astronaut health for interplanetary travel
- Currently no "real-time" personal radiation detecting sensor for extravehicular activity
- Current technologies lack desired sensitivity

**SOLUTION:**
- Use radiation sensitive functionalized SWCNTs to measure radiation dose rates and total dose.
- High surface area nanomaterials can increase sensitivity

**COLLABORATION:**
- JSC (SF) Dosimeter
- JSC (EB) Sensors
- JSC (EC) Advanced EVA
- NASA Ames Gas sensors
- Rice Univ. Nanotube functionalization
- PVAM Radiation Testing
**Advanced Thermal Protection System (TPS) Repair**

**CHALLENGE:**
- Improve and expedite curing and repair processes for current missions
- Long duration missions need more effective repair processes: On Orbit/En Route/On the surface

**SOLUTION:**
- Use microwave energy to heat nanotubes in polymer and ceramic matrices for localized heating, curing & bonding
- Repair of RCC and tiles, CEV materials
- Potential commercial applications including composite curing

**COLLABORATION:**
- Rice: Nanotube microwave research (Tour) Functionalized nanomaterials

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~ 1:1 Energy transfer in nanotubes
Microwaves:Heat
**CHALLENGE:**
- Thermal protection system with impact and radiation protection
- Lower weight = Greater performance
- Lower spacecraft complexity = Lower risk
- Lower risk = Greater safety

**SOLUTION:**
- Use SWCNT impregnated into Phenolic Impregnated Carbon Ablator (PICA) Thermal Protection System (TPS) – additional strength
- Enhanced radiation protection via integration of polyethylene
- Nextel and/or Kevlar fabric incorporated for impact protection

**COLLABORATION:**
- NASA Ames: TPS Lead
- JSC (ES3): Composites, Arc Jet Testing

- Carbon Fiberform
- Vacuum Impregnation
- Gelling cycle
- Drying Cycle

- Carbon nanotubes for char strength
- Polyethylene for radiation protection

- PICA with phenolic resin impregnated
- PICA - Fiberform before impregnation
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<th>Major Medical Operations</th>
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<tr>
<td>The role that forces play on cell mechanisms</td>
<td>Contrast agents to target specific sites for surgery</td>
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<td>(gravitational forces)</td>
<td>Bio-mimetic or engineered compounds to help wound healing</td>
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<td>Molecular machines (ATPase, Kinesin, Microtubules,</td>
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<td>Polymerase, etc.)</td>
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<th>Life Support</th>
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<td>Identification of molecular indicators for onset</td>
<td>High surface area materials for CO₂ removal</td>
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<td>Inorganic coatings that catalyze the revitalization of air and</td>
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<td>Ethical use of information from nanotech devices</td>
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<td>Indicators for drugs effectiveness</td>
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| Systems Integration                              |                                                                  |
|--------------------------------------------------|                                                                  |
| Develop 'common toolkit' for bio-nano chemistry  |                                                                  |
| and assembly processes                           |                                                                  |
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Questions?

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