Exploration Architecture

Lunar / Interplanetary Transfer

Launch Vehicles

Crew Exploration Vehicle (CEV)

ISS Operations

Planetary Operations
(Human/Robotic)

Lunar Surface 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
# 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

## Applications Table

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<th>APPLICATIONS</th>
<th>PARTNERS</th>
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## TRL
- 1: Initial Concept
- 2: Feasibility Demonstrated
- 3: Feasibility Demonstrated
- 4: Feasibility Demonstrated
- 5: Qualified for Engineering Development

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Technology Readiness Levels (TRL)

TRL 9
- Actual system “flight proven” through successful mission operations

TRL 8
- Actual system completed and “flight qualified” through test and demonstration (Ground or Flight)

TRL 7
- System prototype demonstration in a space environment

TRL 6
- System/subsystem model or prototype demonstration in a relevant environment (Ground or Space)

TRL 5
- Component and/or breadboard validation in relevant environment

TRL 4
- Component and/or breadboard validation in laboratory environment

TRL 3
- Analytical and experimental critical function and/or characteristic proof-of-concept

TRL 2
- Technology concept and/or application formulated

TRL 1
- Basic principles observed and reported
**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)

**Growth, Modeling, Diagnostics and Production**

**Laser Ablation**
- Batch process
- ~1g/day
- Large diameters (~1.4nm)
- Graphite Co, Ni Catalysts
- Fullerences + SWCNT + Impurities
- Argon gas
Characterization: Purity, Dispersion & Consistency

Standard Nanotube Characterization Protocol

SEM

TEM

UV-Vis Spectroscopy

Optical Dispersion Analysis

Raman

TGA

New Purity Reference Standard

NIST ANSI ISO

Areppalli, et al., Carbon, 2004
Applications for Human Space Exploration

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

Advanced Life Support
- Regenerable CO₂ Removal
- Water recovery

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

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

Electromagnetic / Radiation Shielding and Monitoring
- ESD/EMI coatings
- Radiation monitoring

Nano-Biotechnology
- Health monitoring (assays)
- Countermeasures
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

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Experimental Regenerable System

LiOH Canisters
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 CO$_2$/H$_2$O scavenging amines
- Amines require lower energy for regeneration than present molecular sieve
- Higher surface area reduces system size/weight

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**Nanotube functionalization chemistry**
(Chattopadhyay et al, 2005)

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**Diagram:**

- **Functionalized SWCNT CO$_2$ Receptor**
- **CO$_2$ Gas**
- **Absorbent Material**
- **Bubbler**
- **CO$_2$ Sensor**
- **CO$_2$ 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
**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

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.*

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

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Water purifier cell  UV Light source
**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:**
- 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
- JSC (EP): Testing, requirements
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 coatings
- Cheap & easy of fabrication for application to off-the-shelf products: Laptops, PDAs etc.

**COLLABORATION:**
- UTD
- UTPA
- U of Florida
- Rice
- JSC (EV)
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)
- JSC (EB)
- JSC (EC)
- NASA Ames
- Rice Univ.
- PVAM

**Radiation Testing**
- Device Under Test (DUT) Board
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
Nanotechnology: Astronaut Health Management

Basic Biomedical Research
- The role that forces play on cell mechanisms (gravitational forces)
- Molecular machines (ATPase, Kinesin, Microtubules, Polymerase, etc.)
- In vivo monitoring of ultra-low concentration proteins and biomolecules

Major Medical Operations
- Contrast agents to target specific sites for surgery
- Bio-mimetic or engineered compounds to help wound healing
- Miniaturized electron microscopes for biopsies

Personal Biomedical Monitoring
- Identification of molecular indicators for onset of conditions
- High sensitivity assays
- Short prep-time assays, no prep-time assays and in vivo monitoring
- Multiple simultaneous assays

Life Support
- High surface area materials for CO$_2$ removal
- Inorganic coatings that catalyze the revitalization of air and water
- Sensors to monitor harmful vapor/gases

Personal Countermeasures
- Timed drug release
- Targeted drug therapy
- Triggered drug release
- Indicators for drugs effectiveness

Toxicology & Ethics
- Biodistribution of nanoparticles
- Toxicology of nanoparticles
- Ethical use of information from nanotech devices

Systems Integration
- Develop ‘common toolkit’ for bio-nano chemistry and assembly processes
Applied Nanotechnology for Human Space Exploration

Questions?

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