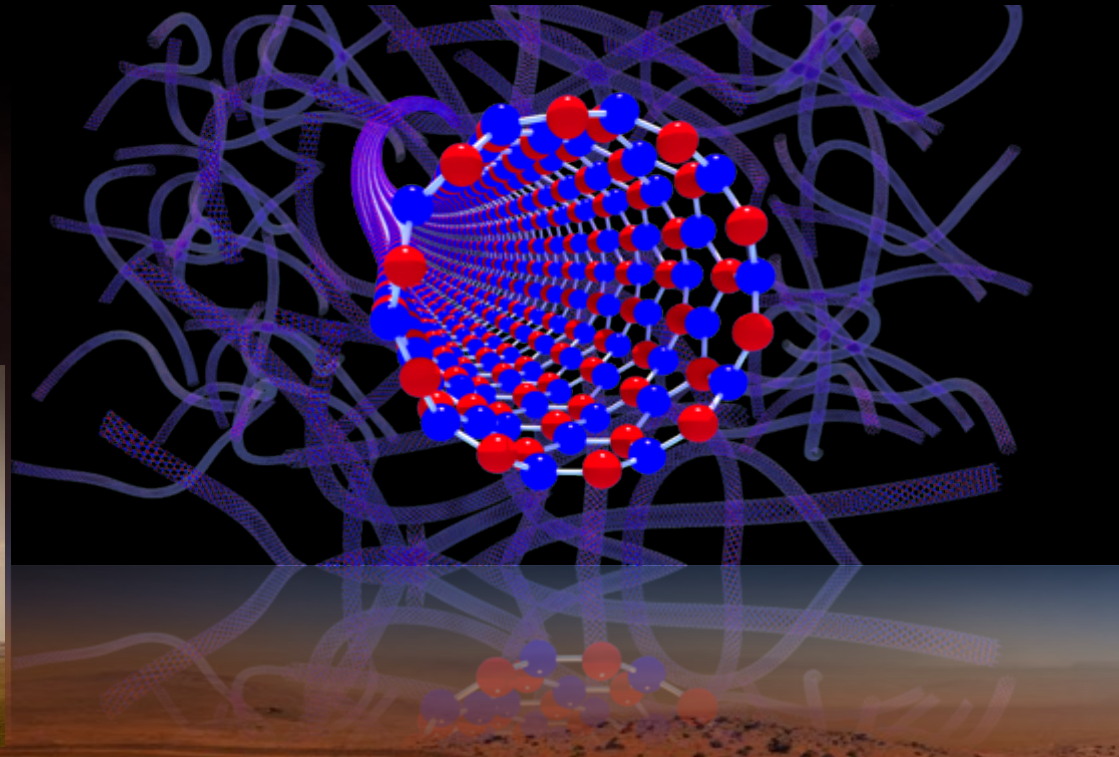
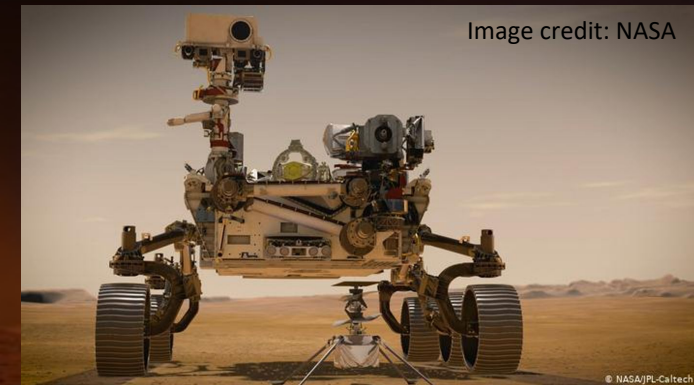




NASA Langley Research Center

Lightweight Multifunctional Structural Composites for Extreme Space Environments



Advanced Materials and Processing Branch, NASA Langley Research Center, Hampton VA USA

NASA Langley Research Center



NASA Langley Research Center Hampton, Virginia

Founded in 1917 (NACA): first civil aeronautical research laboratory converted to NASA in 1958

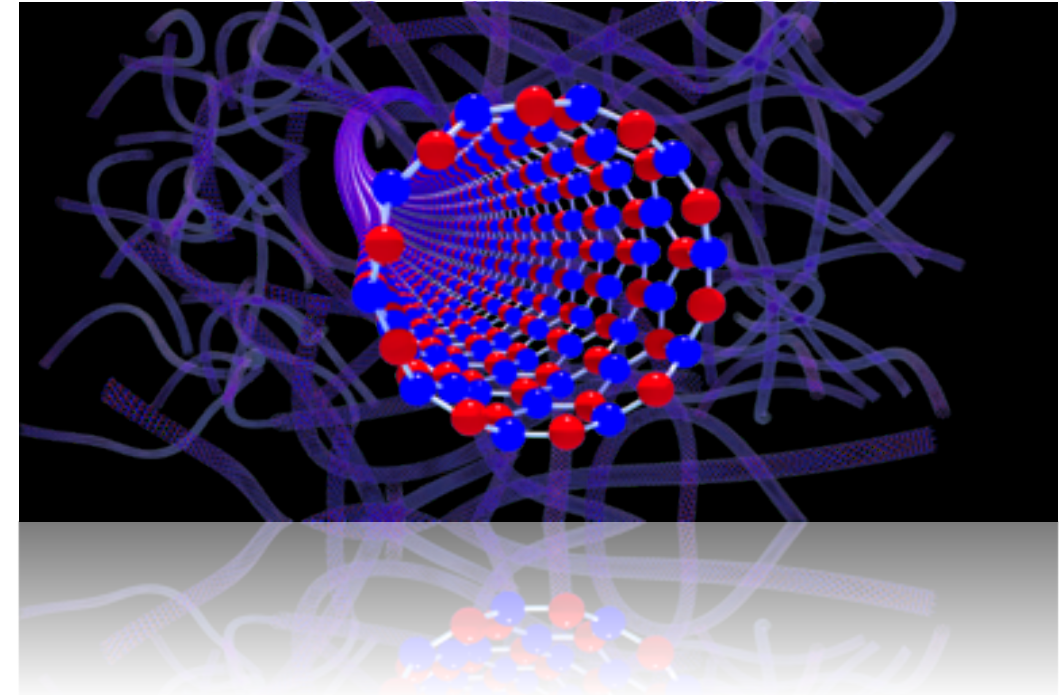
Facilities: \$4 billion value

People: 2000 Civil Servants ; 1700 Contractors

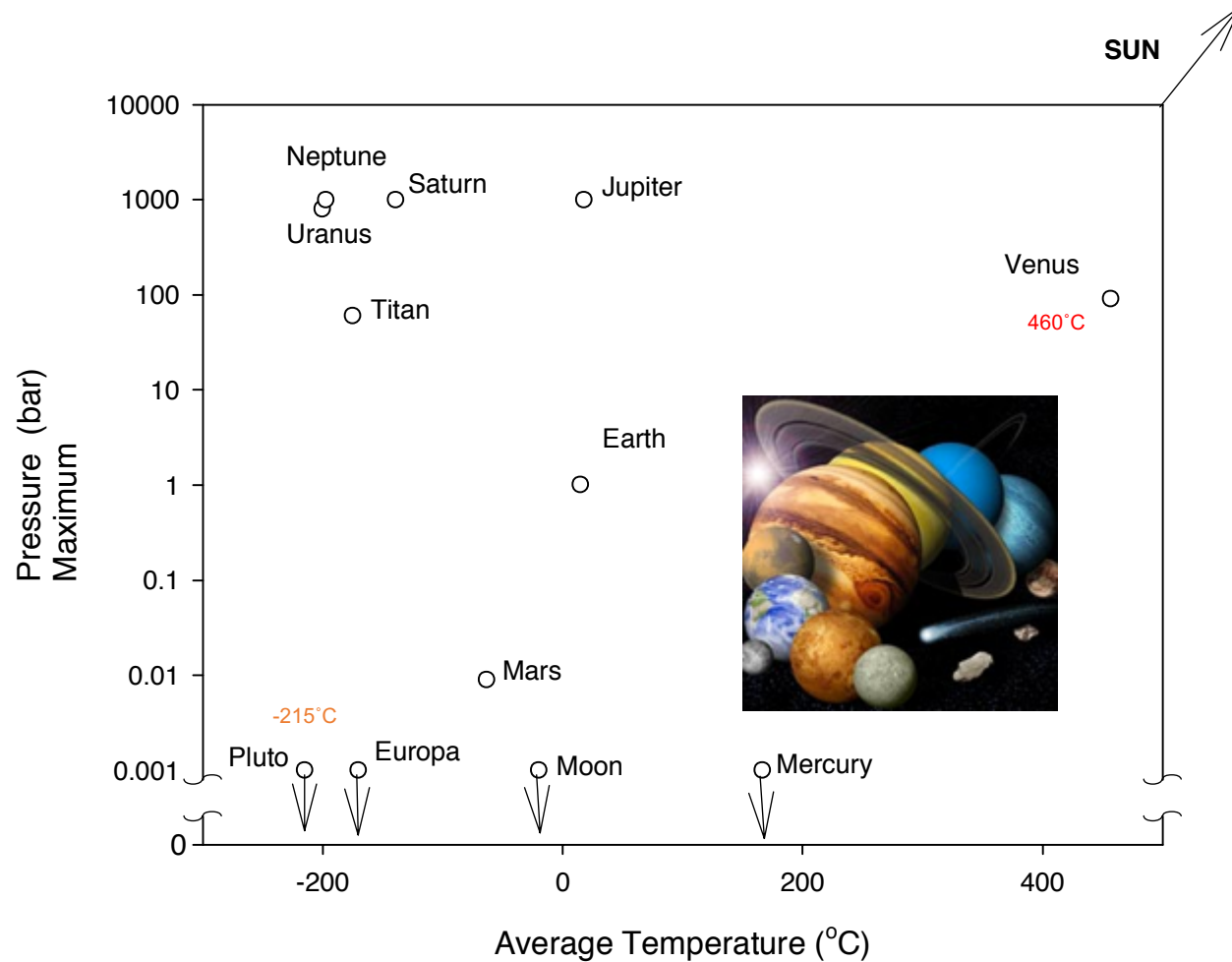
All images credit: NASA

Outline

- Motivation: Extreme Environments in Space
- Current NASA Space Projects: Artemis
- BNNT Synthesis
- BNNT and BNNT Composite Application
- Multifunctional Properties in Extreme Environments
 - Dispersion and Purification
 - Mechanical Properties
 - Thermal Properties
 - Sensor/Actuator/Energy Harvester
 - Radiation Shielding
- Summary



Extreme Environments in Space Exploration



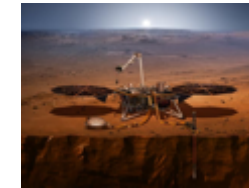
http://www.jpl.nasa.gov/solar_system/

17NASA Extreme Environments Tech Space missions Report FINAL



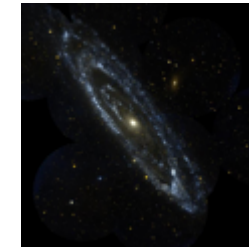
Lunar surface

-173 to 127°C
 -247°C (25K) at pole
 Sharp abrasive edge dust
 Radiation
 1/6 Earth gravity



Mars surface

-126 to 21°C
 Sand storm
 Radiation
 Entry, Descent, & Landing



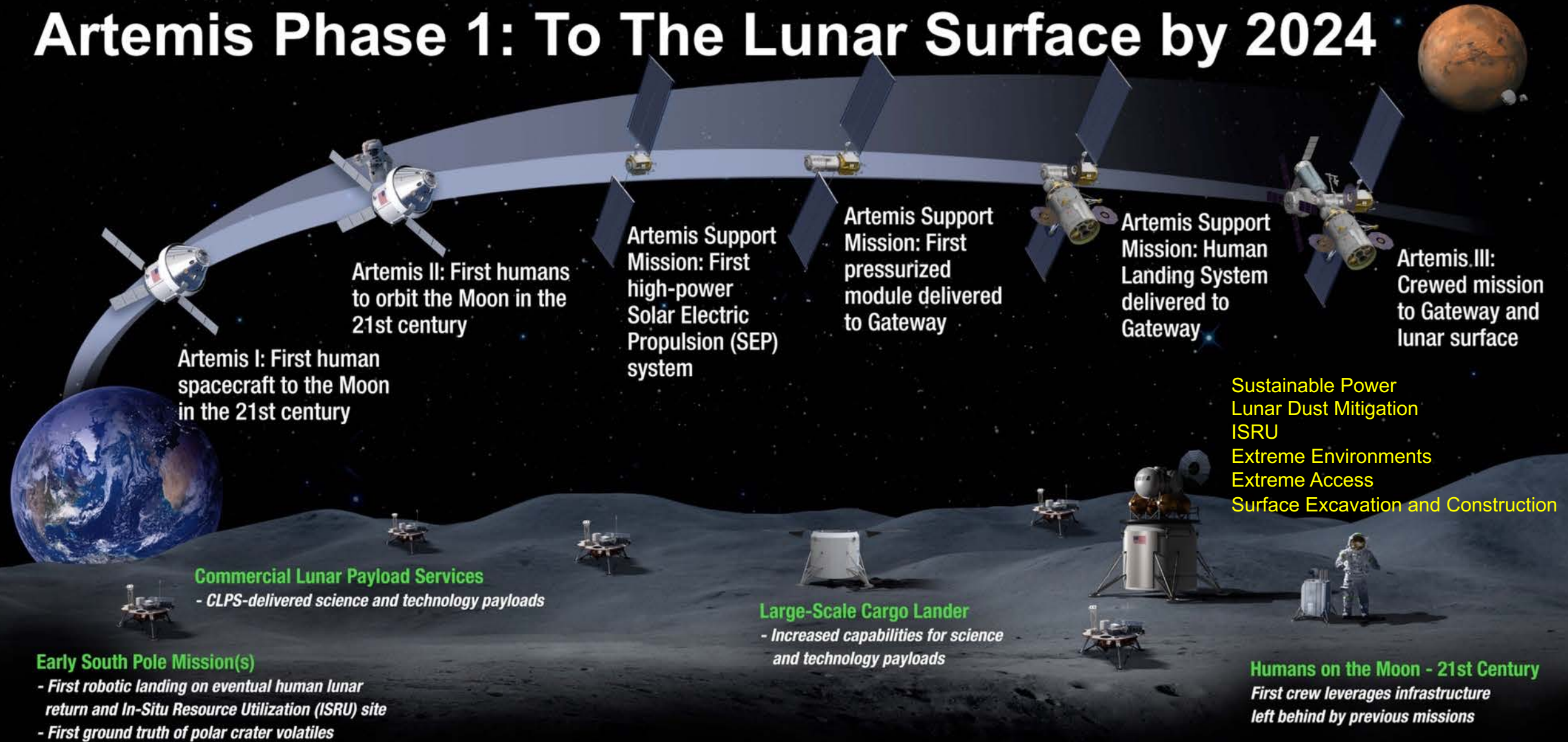
Deep space

2.7K
 Radiation
 Microgravity

Heat flux at atmospheric entry: Heat fluxes often exceeding 10's W/cm²
 Hypervelocity impact: Higher than 3 km/sec
 Low and high temperature: Lower than -55°C and Exceeding +460°C
 Thermal cycling: Cycling between temperature extremes outside of the military standard range of -55°C to +125°C
 High pressures: Exceeding 20 bars
 High radiation: Total ionizing dose (TID) exceeding 300 krad (Si), GCR, SPE, Neutron
 Low and High gravity: microgravity on comets, 2.5g on Jupiter, launch, entry, descent

Artemis Program: Send 1st Woman & next Man to the Moon by 2024 (about \$40B), and then Mars and Beyond

Artemis Phase 1: To The Lunar Surface by 2024



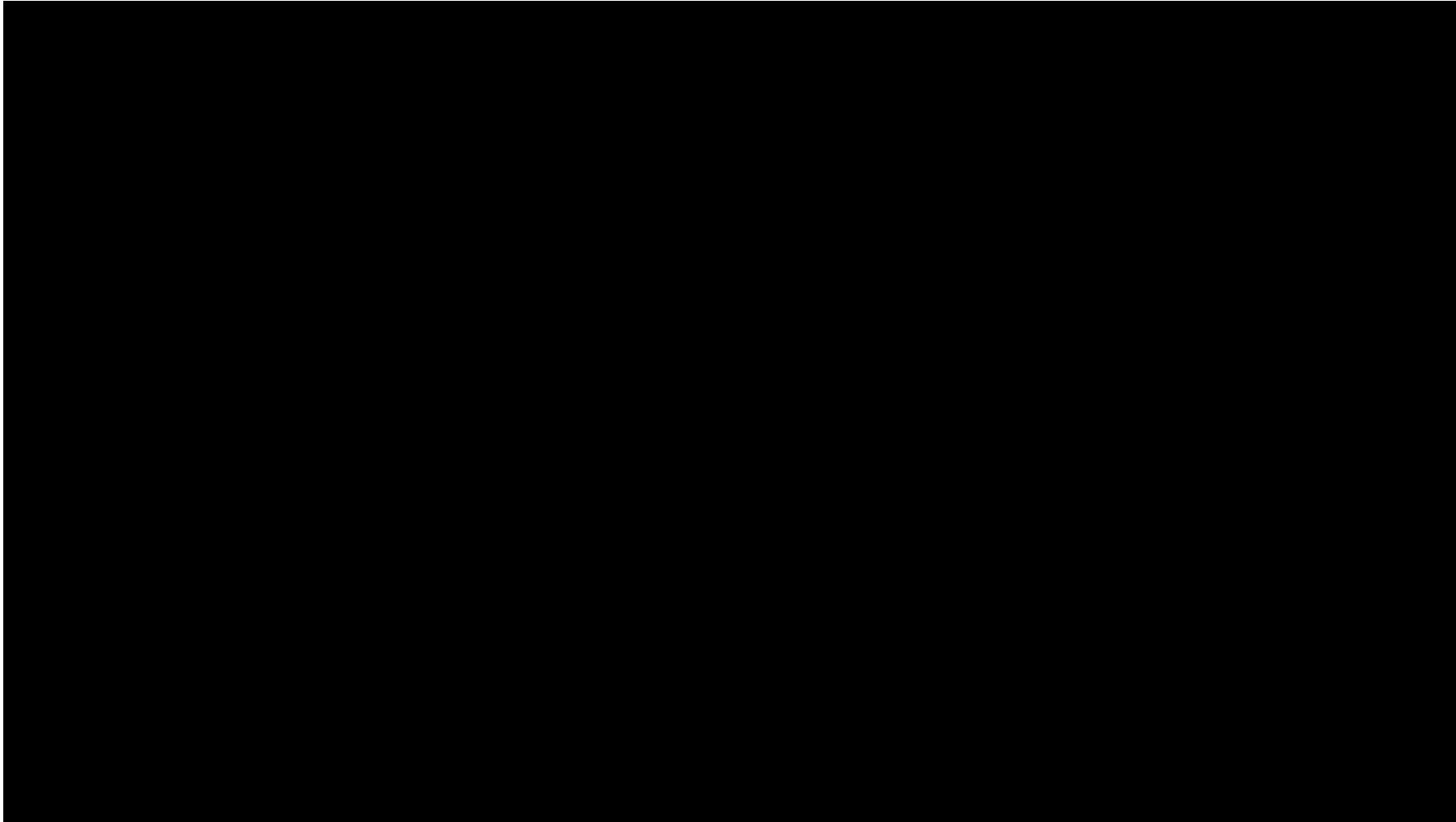
LUNAR SOUTH POLE TARGET SITE

2020

All Images Credit: NASA

2024

ISRU Landing Pad: Multipurpose Cassegrain System



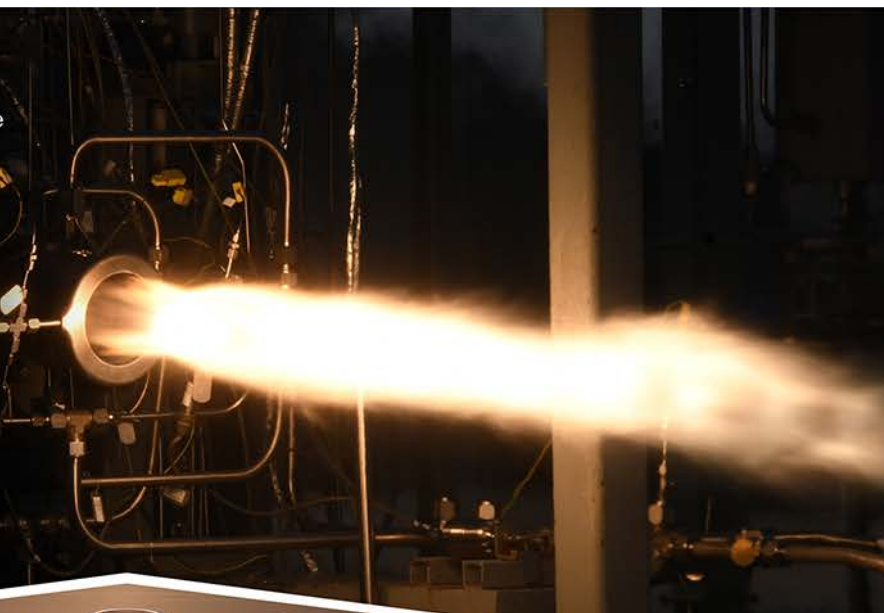
<https://www.youtube.com/watch?v=mpXdY2v5FDI&feature=youtu.be>

Rapid Analysis and Manufacturing Propulsion Technology (RAMPT)

Project Description: The RAMPT project is maturing novel design and manufacturing technologies to increase scale, significantly reduce cost, and improve performance for regeneratively-cooled thrust chamber assemblies, specifically the combustion chamber and nozzle for government and industry programs.

The high level RAMPT goals are to:

- 1) Develop additive and advanced manufacturing methods and design processes that enable new regeneratively-cooled thrust chamber assembly technology.
- 2) Identify and optimize additive manufacturing design and fabrication processes that reduce production lead times and analysis life cycle and
- 3) Engage academic, government and industry investments through public-private partnerships to facilitate infusion of technology and provide process development data and technology improvements across the propulsion and commercial industries.

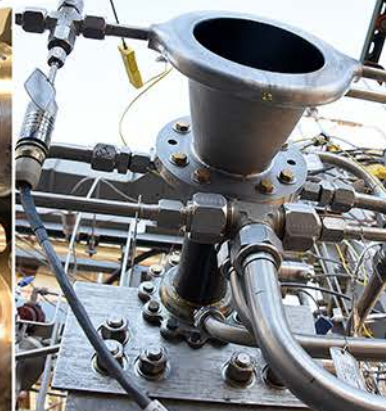
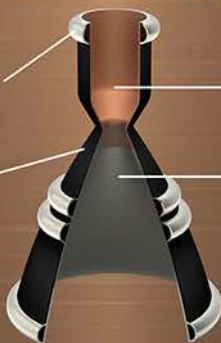


Bimetallic Deposited Manifolds

3D printed Copper Chamber

Composite Overwrap
Thrust Chamber Assembly

Integrated Large Scale Freeform
Manufacturing Freeform
Deposition Regen-Cooled Nozzle



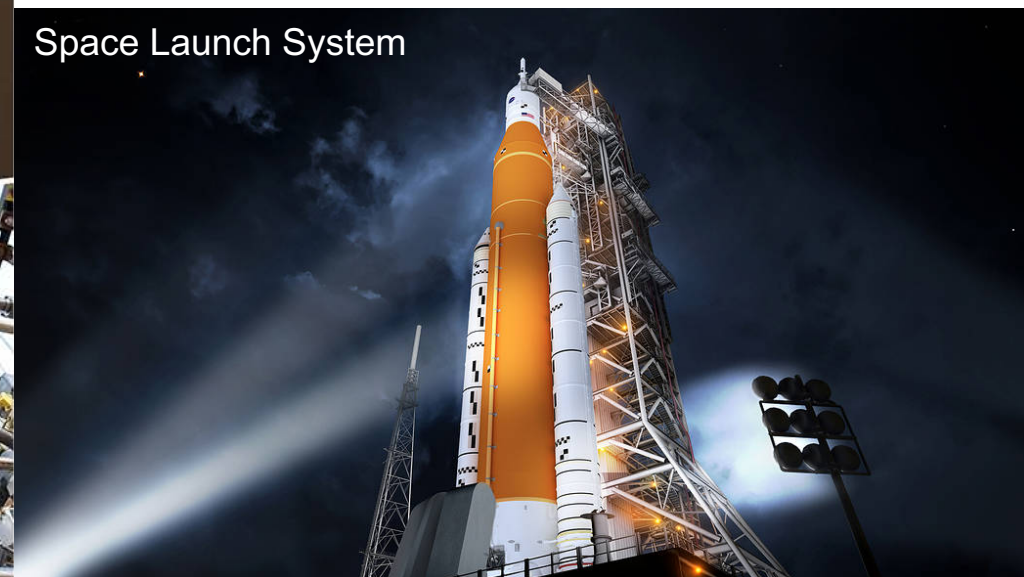
PUBLIC AND PRIVATE
PARTNERSHIPS



Large-Scale 3D Printing for Rocket Engines

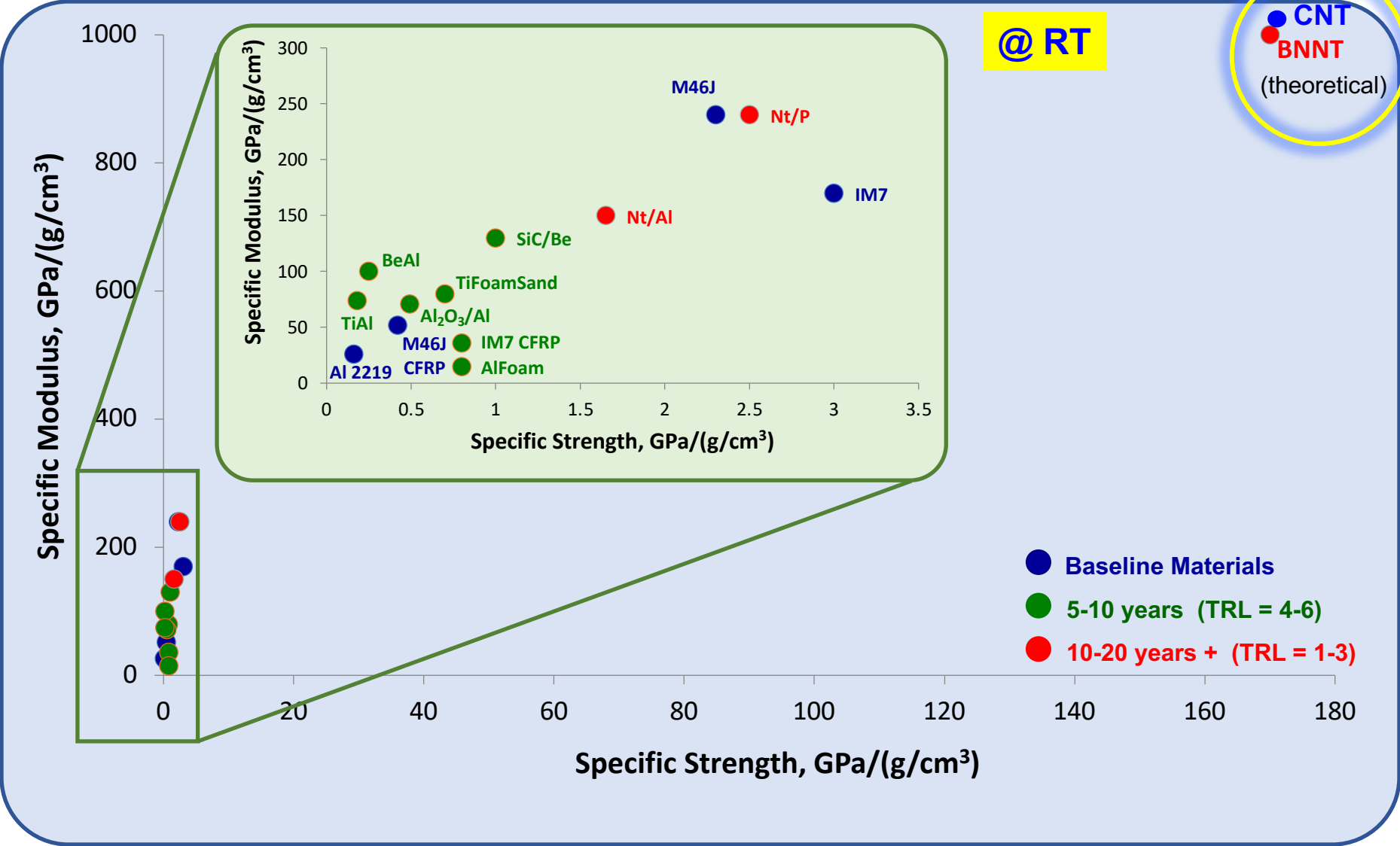
<https://www.youtube.com/watch?v=JHqdVU9Ebo&t=3s>

Space Launch System

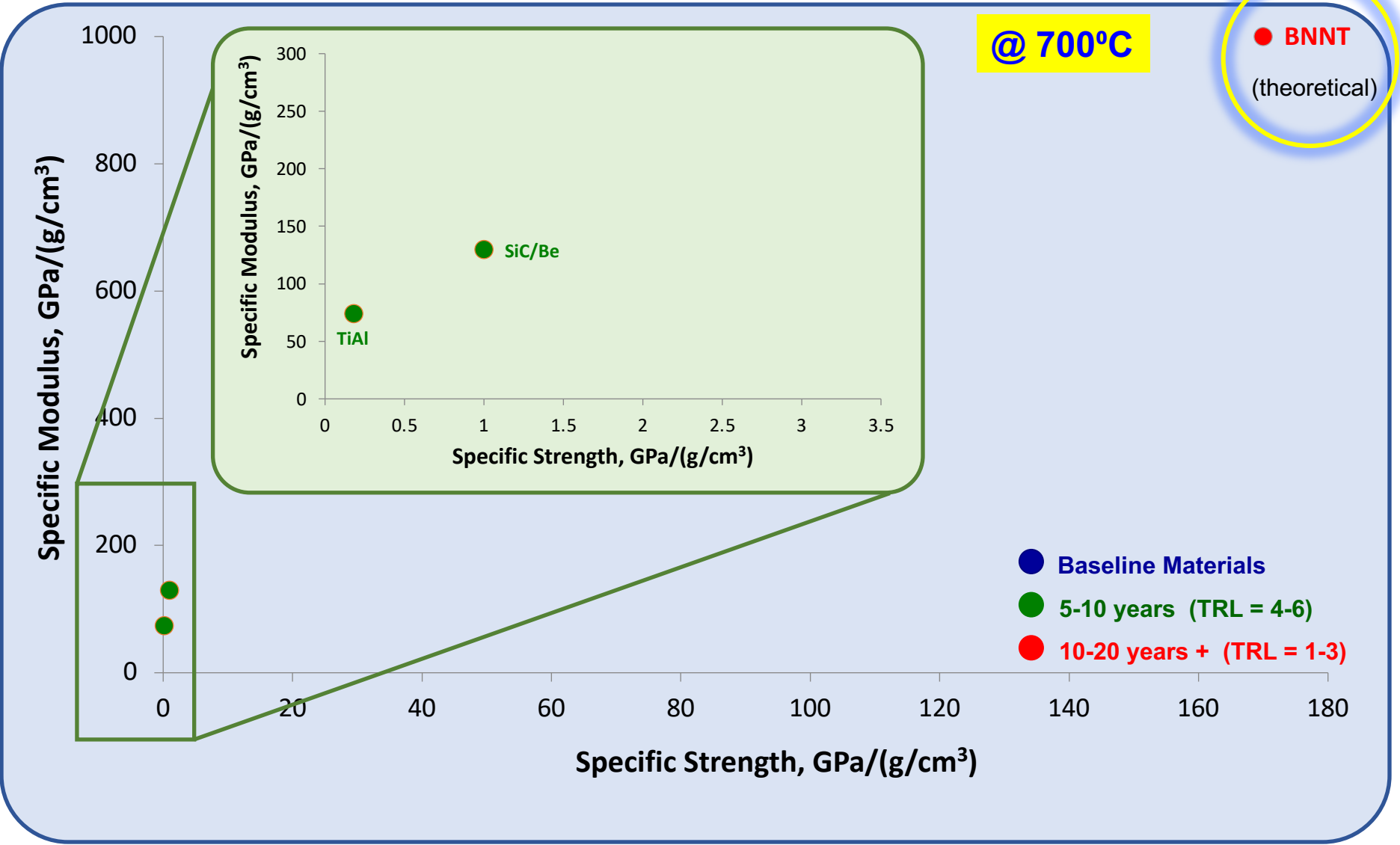


All Images Video Credit: NASA

Motivation: Properties of Materials for Vehicle Structure



Motivation: Properties of Materials for Vehicle Structure

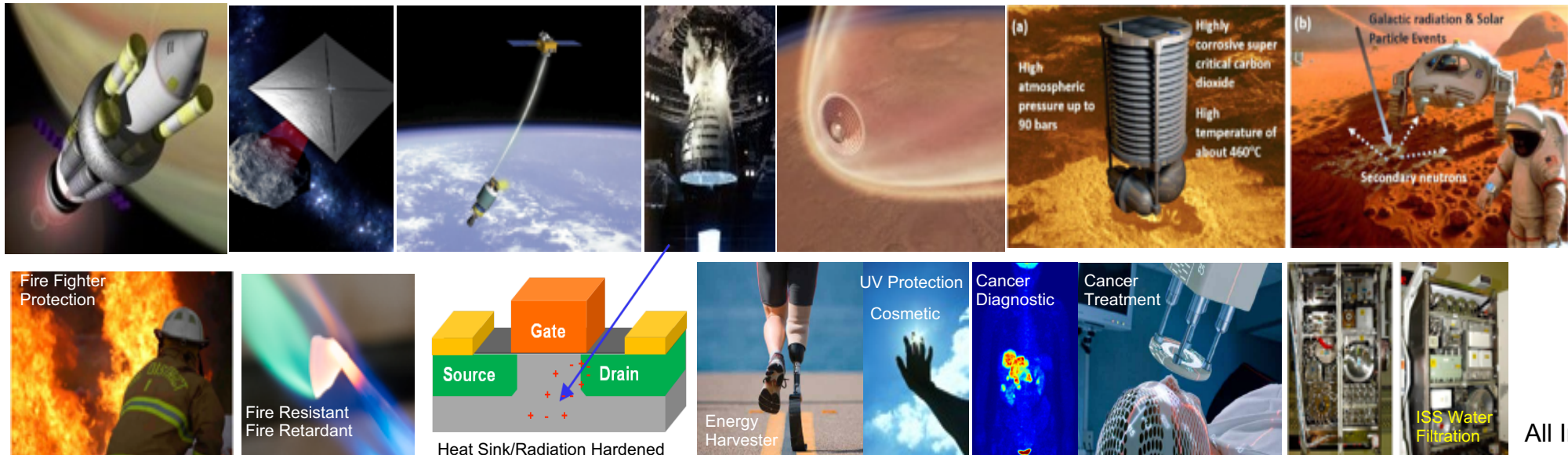


Nanotube Comparison (Theoretical)

	Carbon Nanotubes	Boron Nitride Nanotubes
Electric Properties	Metallic or semiconducting	Wide band gap (about 6.0 eV) Insulation, corrosion resistant
Mechanical Properties (Young's Modulus)	1.33 TPa (very stiff)	1.18 TPa (very stiff)
Thermal Conductivity	>3000 W/mK (highly conductive)	~300–3000 W/mK (highly conductive)
Thermal Oxidation Resistance	Stable up to 300-400 °C in air	Stable to over 900 °C in air
Neutron Absorption Cross-Section	C = 0.0035 barn	B = 767 barn (B ¹⁰ ~3800 barn) N = 1.9 barn Excellent radiation shielding
Polarity	No dipole	Permanent dipole Piezoelectric (0.25-0.4 C/m ²)
Surface Morphology	Smooth	Corrugated Better interfacial strength for composites, ionic bonding
Color	Black	White (can be colored)
Coefficient of Thermal Expansion	-1 x10 ⁻⁶ K ⁻¹ (very low)	-1 x 10 ⁻⁶ K ⁻¹ (very low)

Significance of the BNNT Innovation

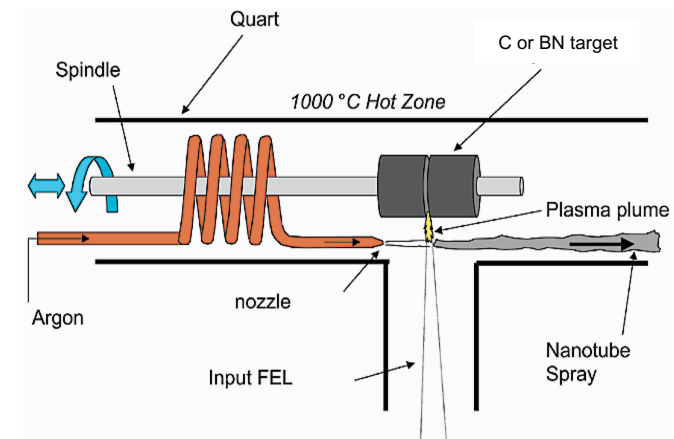
- **Structural/Mechanical: lightweight** composite armor, thermal protection, engine components, and radiation shielding materials for **extreme environments**.
- **High stiffness as well as high toughness** for spacecraft and space suits, ultrastrong tethers, meteorite impact protection layers, protective gear for astronauts.
- **Space lubricants** without moisture.
- **High temperature** thermal protection systems (TPS) used in the **nose cap**, wing **leading edges**, **engine parts**, lubricants, and planetary **Entry, Descent, & Landing (EDL)** TPS.
- **Fire resistant and retardant**.
- **High temperature sensor, actuator, energy harvesting devices** in extreme environments.
- **Radiation shielding, UV (ultraviolet) protection**, and electromagnetic transparency while decreasing aircraft weight.
- **Radar transparency** mitigates Electromagnetic Interference (EMI) and Radio Frequency (RF) blackout.
- **Efficient zero-energy water filter and desalination membrane in microgravity**.



BNNT Synthesis

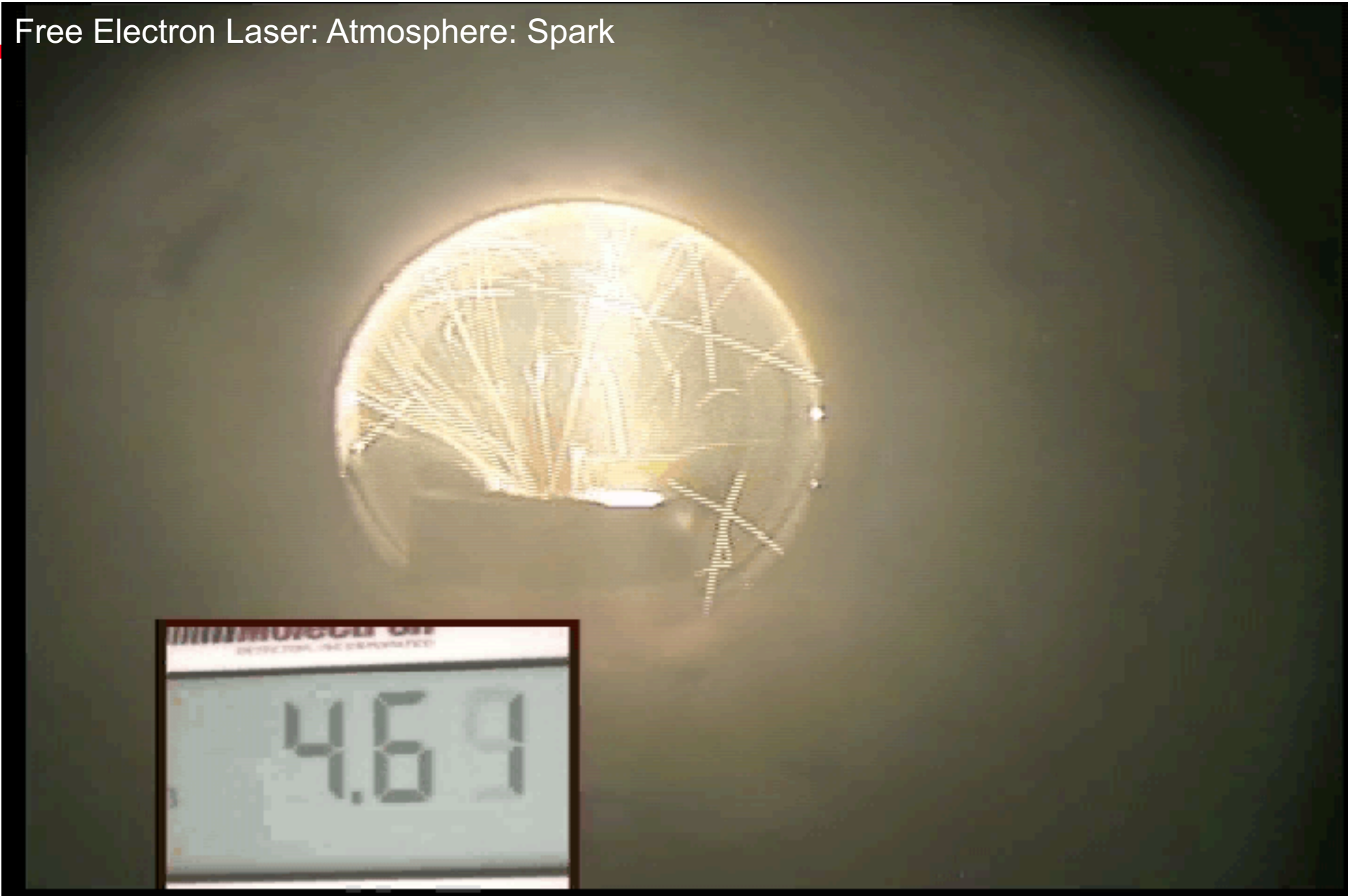
High Temperature-Pressure (HTP) BNNT

- Free Electron Laser (FEL) or CO₂ laser
- **No Catalyst, only B and N resource**
- Very long, small diameter, highly crystalline BNNT



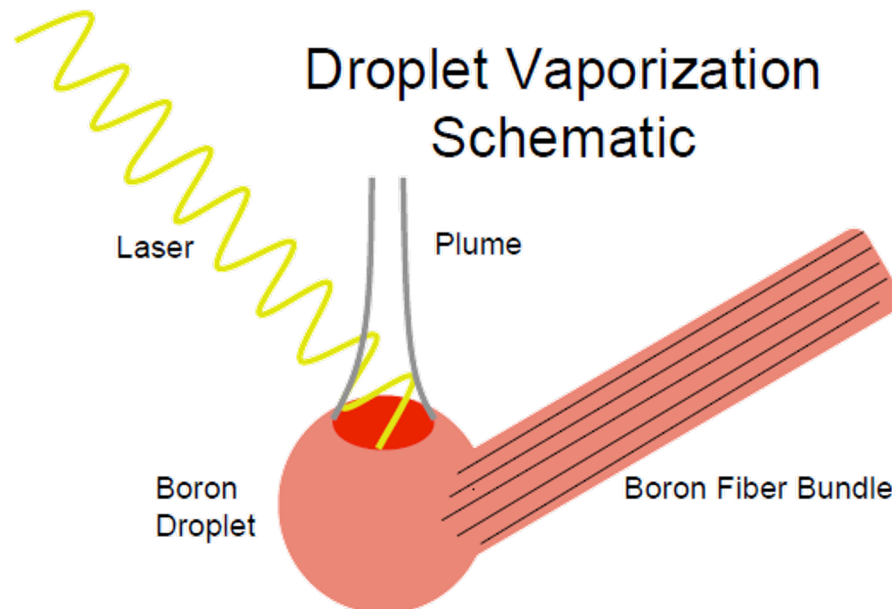
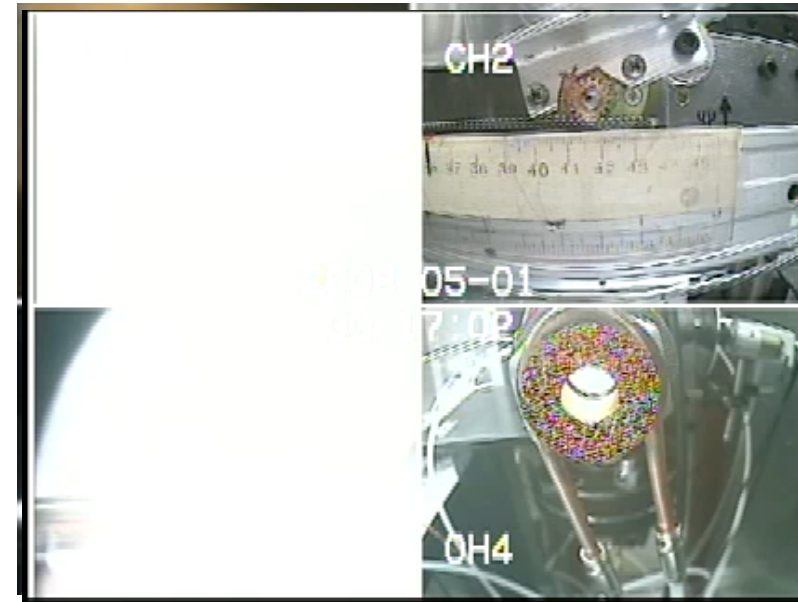
Nanotechnology, **20** 505604 (2009)
US Patent 8206674 B2 (2012)

Free Electron Laser: Atmosphere: Spark





BNNT Synthesis Lab: NASA Langley (1st Gen)

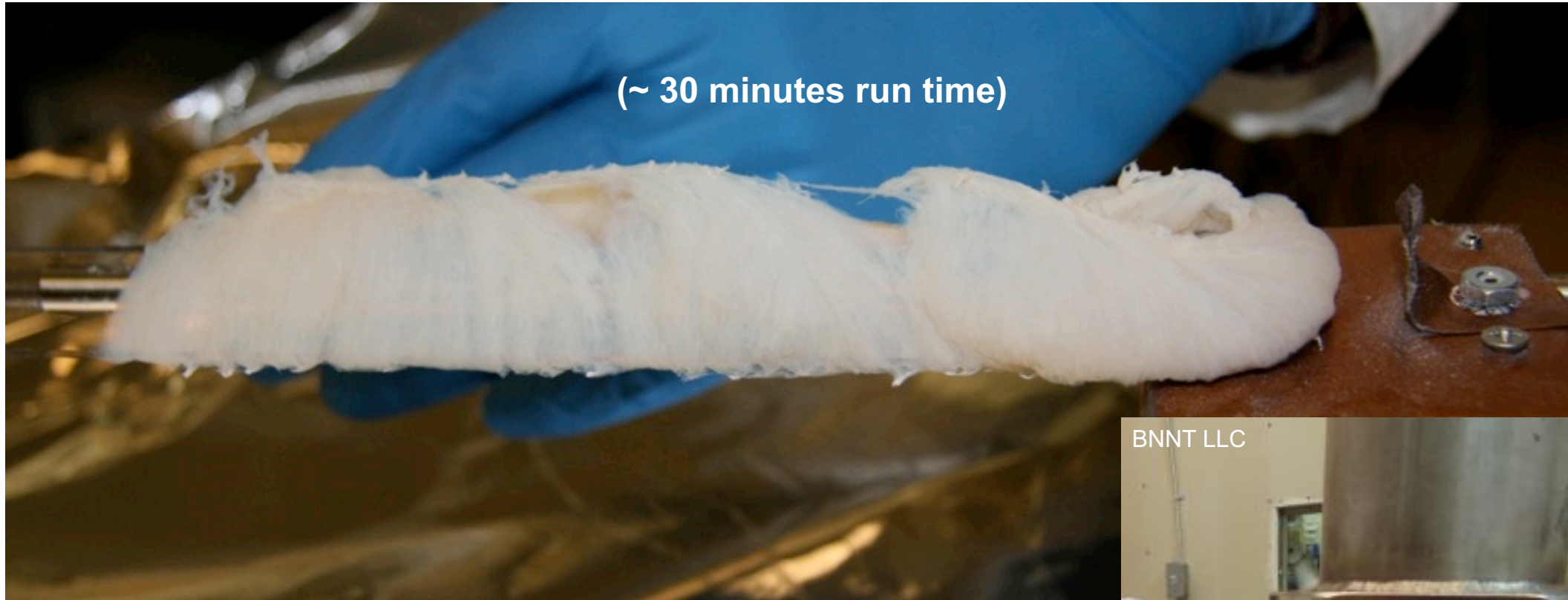


High Temperature Pressure (HTP) BNNT

- 5 kW of infrared radiation @ 10.6 μ m
- Heat source for vaporizing Boron feed stock above 3500°C
- Pressurized with Nitrogen to 13.6 atm (200 psi)

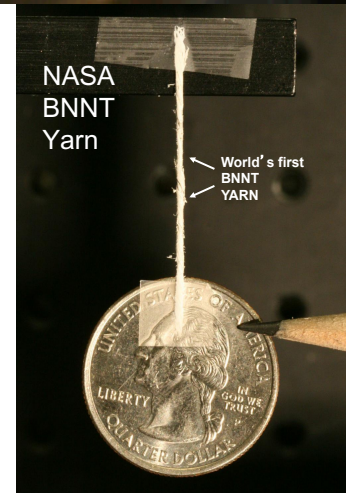
Nanotechnology, **20** 505604 (2009)
J. Thermophysics and Heat Transfer **27** 369 (2013)
Proc. SPIE **9060** 906006 (2014)

Cotton-like High Pressure and Temperature (HTP)-BNNT



Benefits

- One-to-few-walled tubes with high crystallinity
- Very long, high-aspect ratio tubes
- High scale-up potential
- No toxic catalysts (only B and N as reactants)
- Standard industrial cutting/welding lasers
- High service temperature (over 800°C)
- Highly electroactive (due to the B-N polar bond)
- Neutron radiation shielding (due to their B content)

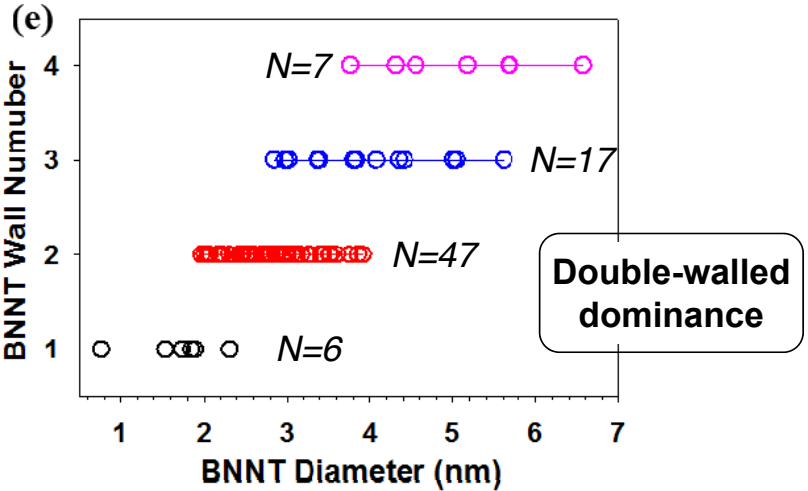
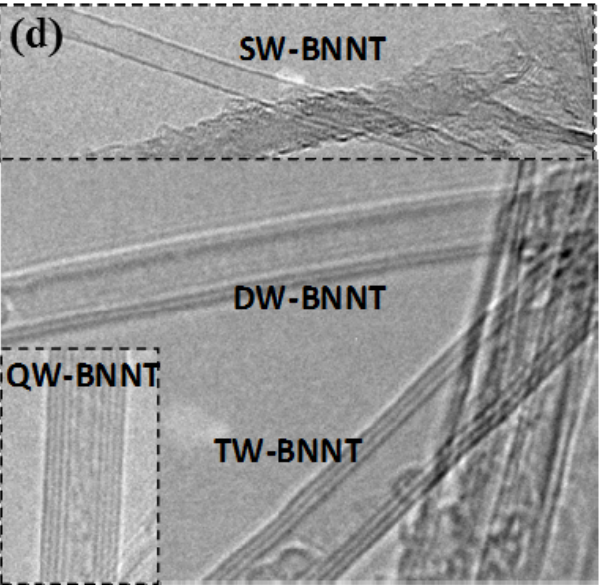


(From: M. W. Smith et al. Nanotechnology, 20, 505604 (2009))

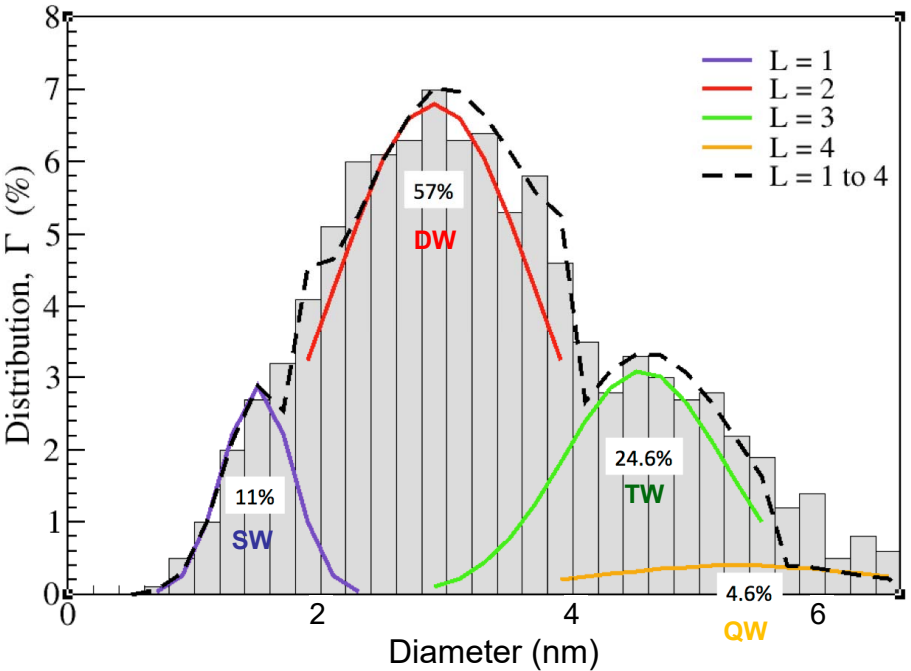


Nanotube Wall Number and Distribution of HTP-BNNTs

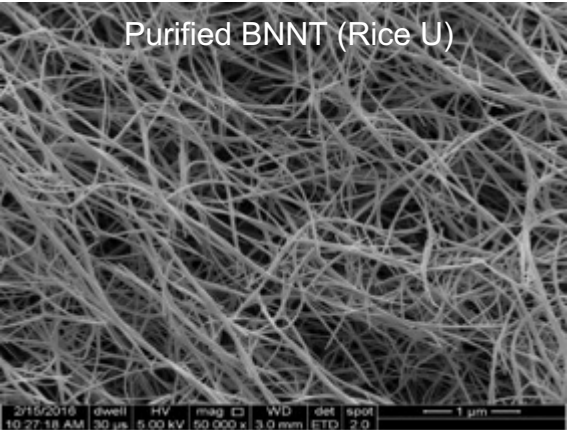
TEM Micrographs



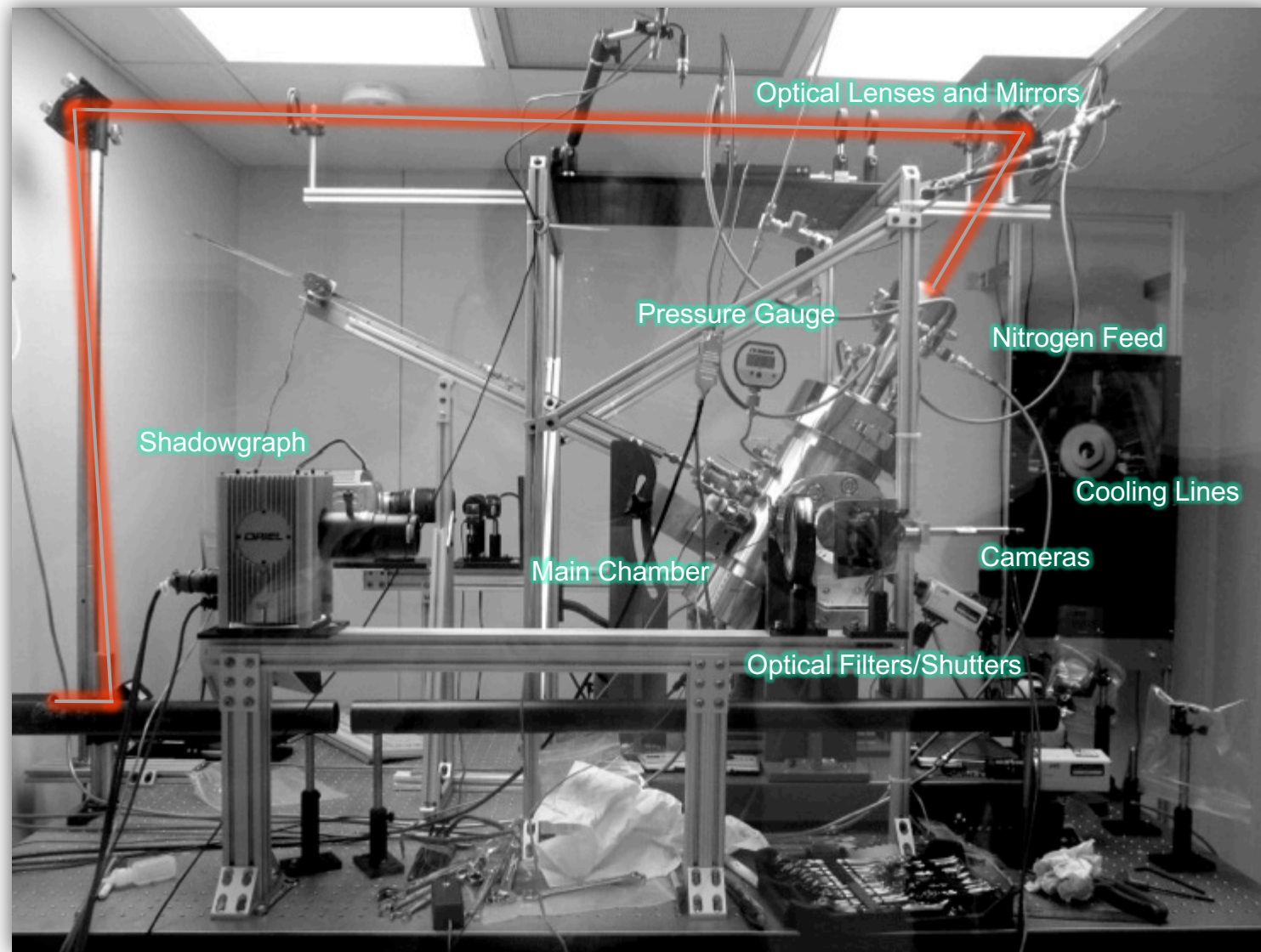
Based on AFM measurements of 1,000 randomly selected individual BNNTs



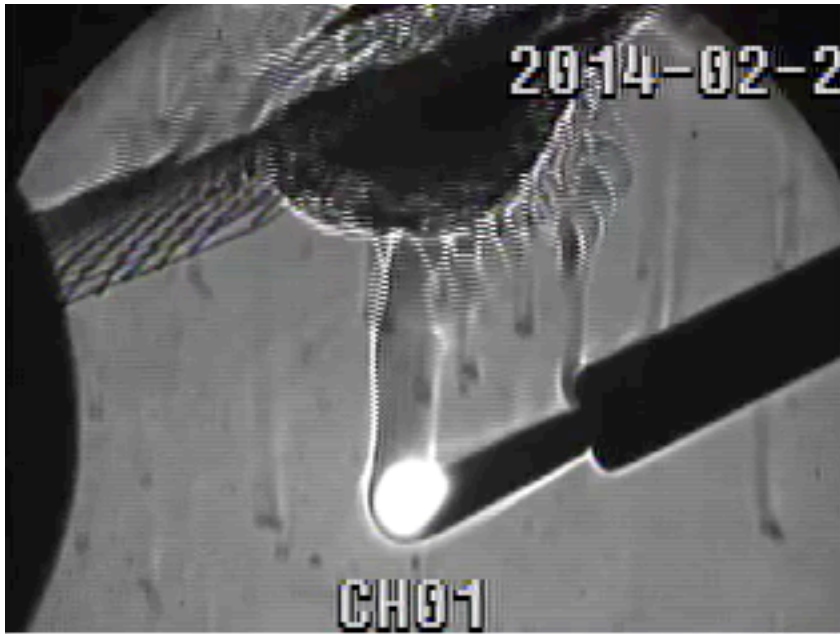
SW: 11%
DW: 57%
TW: 24.6%
QW: 4.6%
Total: 97.2%



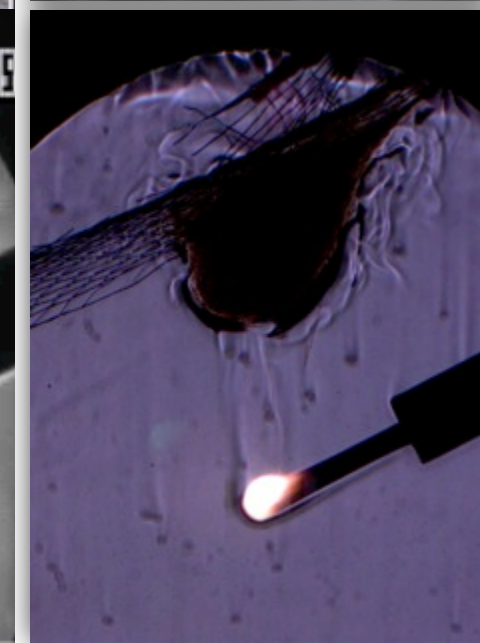
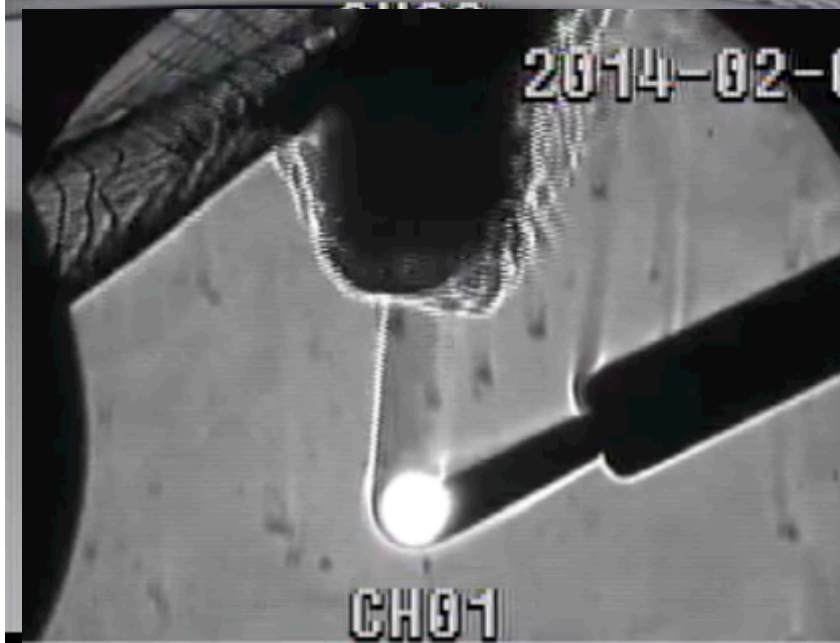
National Institute of Aerospace (NIA) BNNT Science Chamber



NIA Science Rig HTP BNNT Run (Snapshots)

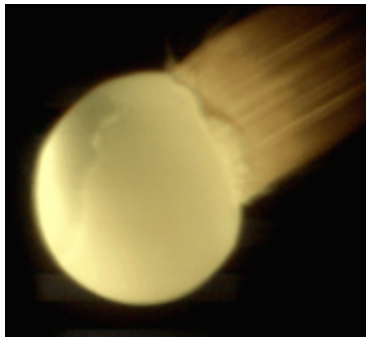


All images credit: NASA/NIA

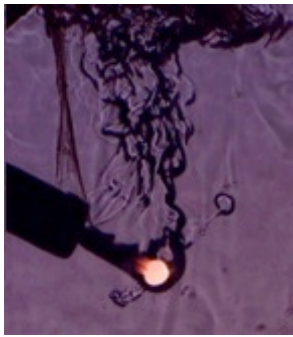


In-situ Optical Diagnostics

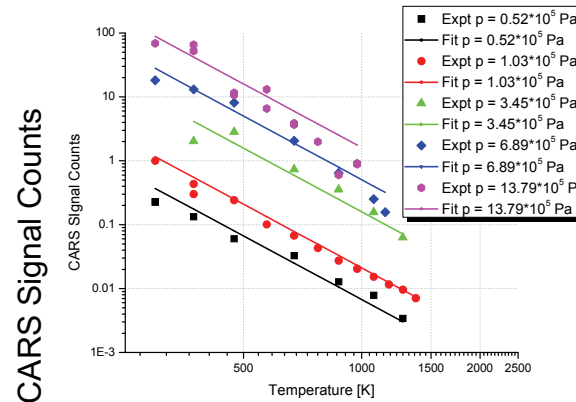
- Understand chemistry and flow physics of nanotube generation
- Improve and validate simulation/modeling
- Optimize material properties, production rate
- Specific Goals:
 - Determine gas and melt-ball temperatures
 - Determine amount of B_2 , B, BN, N and N_2
- In-situ, on-surface measurement:
 - High speed imaging; high speed (1 kHz) optical pyrometer being developed to study melt-ball dynamics
- Off-surface, gas phase measurement:
 - High-speed, high-resolution imaging
 - Shadowgraph and visible emission
 - Species sensitive imaging (BN PLIF)
 - Temperature measurements (CARS)



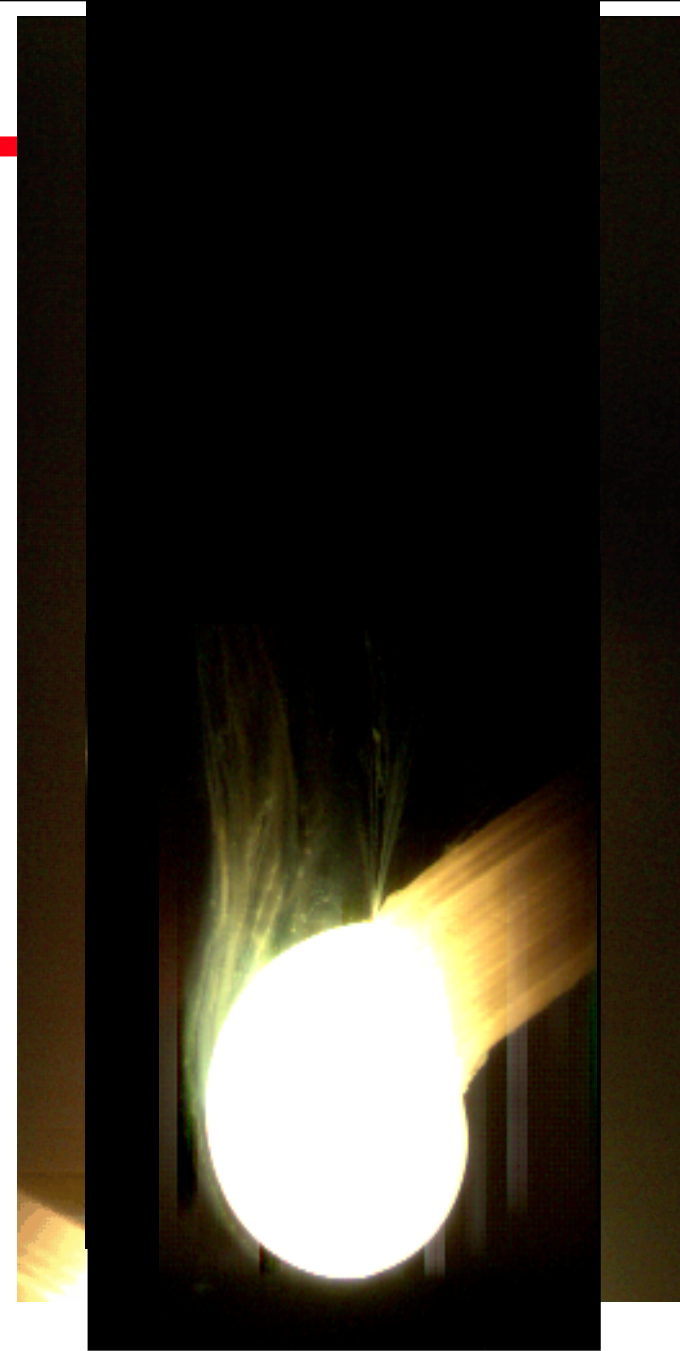
High Speed Camera



Shadowgraph



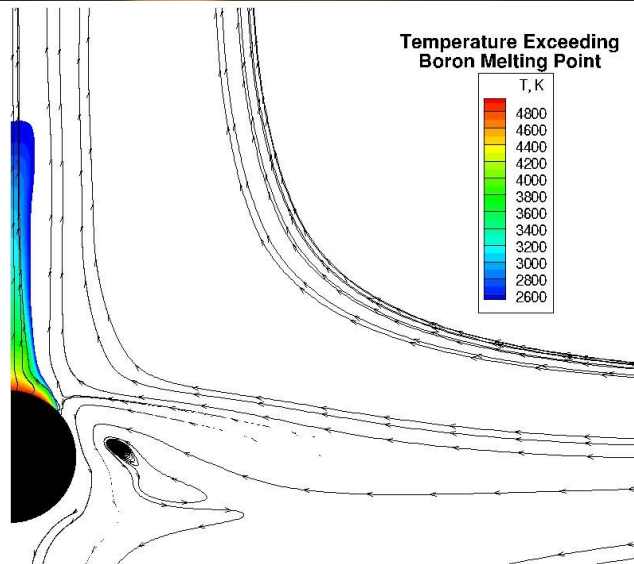
CARS Intensity Measurement



AIAA SciTech2014-1098 (2014)
Proc. SPIE 9060 906006 (2014)

All images credit:
NASA/NIA

Modeling of Laser Ablation and Plume Chemistry in a Boron Nitride Nanotube Production Rig



Contour lines of temperatures and mass fraction of BN in the plume

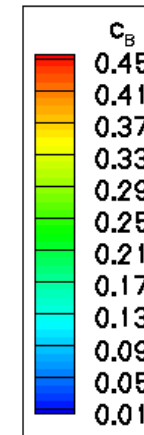
Mass fraction of B, Plume Base

Pressurized Cylinder
Radius = 5 cm
Height = 10 cm

Vertical line on left is cylinder axis.
The second vertical line is offset 1 mm from axis.
The right boundary is a porous wall designed to maintain internal pressure.

Top and bottom boundaries - except for laser spot on bottom left - are fixed temperature, no-slip, equilibrium catalytic.

At time $t=0$ a laser delivers constant energy flux to the 1 mm radius spot on lower left, initiating vaporization of boron target and buoyancy driven plume to rise from hot spot.

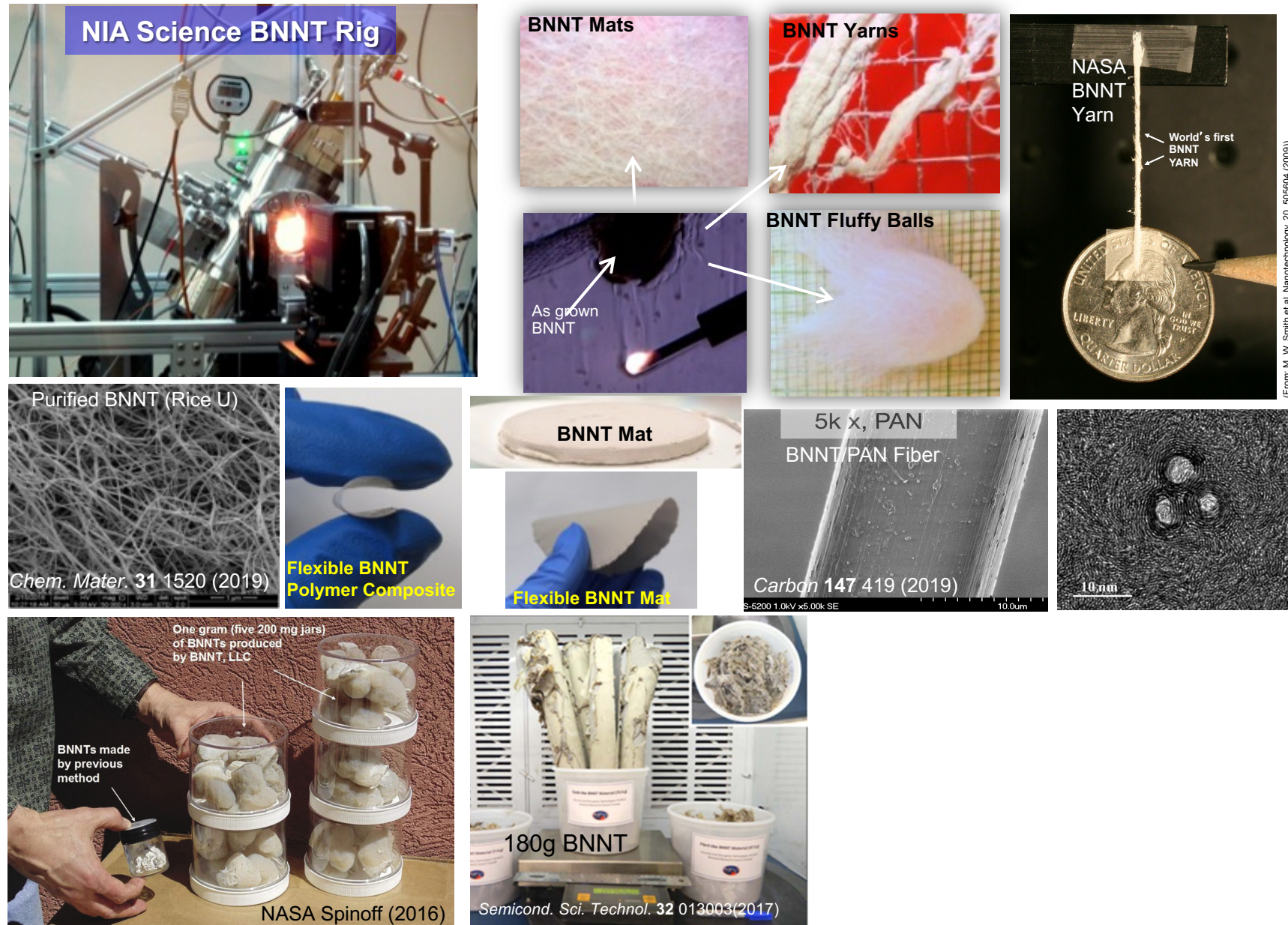


Peter Gnoffo (D305)
Aerothermodynamics Branch
LAURA Code

Proc. SPIE **9060** 906006 (201

J. Thermophysics and Heat Transfer **27** 369 (201

BNNT Scale-Up and Various Forms of BNNT



Dispersion and Purification

Thermodynamic Approach: Effective BNNT Dispersion

Essential for Quality Yarn, Fabric, and Composite Formation



Thermodynamic Approach:
Gibbs Free Energy of Mixing

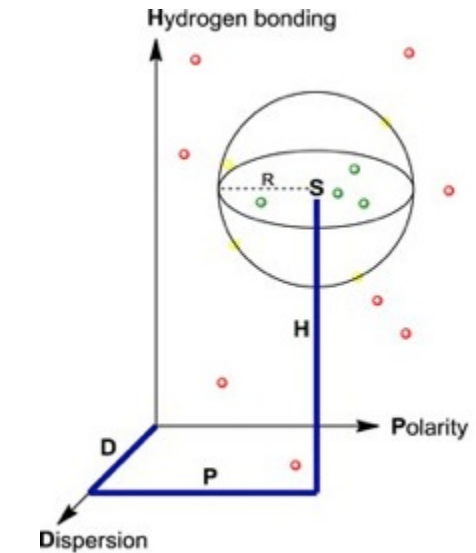
$$\Delta G_{mix} = \Delta H_{mix} - T^* \Delta S_{mix}$$

If ΔG_{mix} is negative,
spontaneous mixing happens
to form a homogeneous
solution

Hansen Solubility Parameters (HSP)
(d_d, d_p, d_h): “like dissolves like”

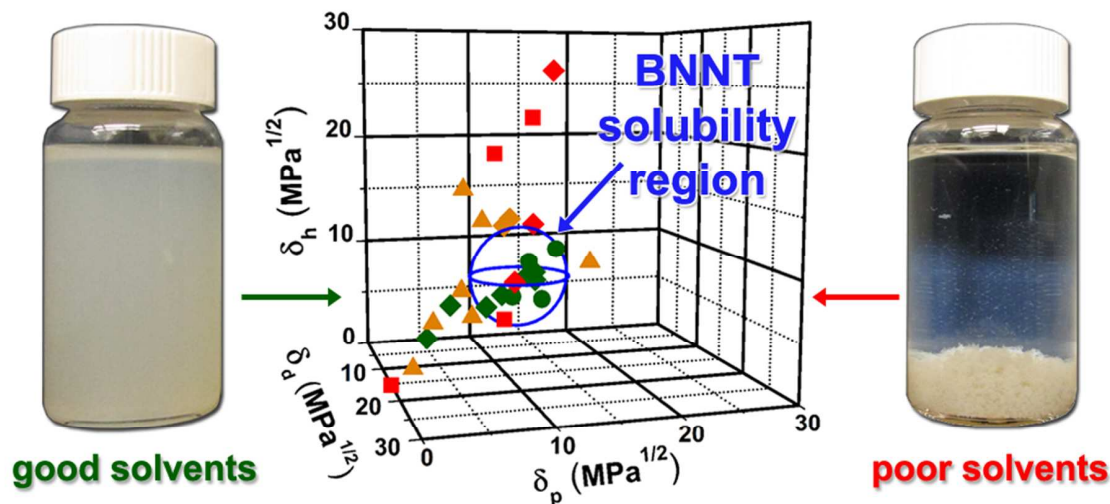
$$\delta_t^2 = \delta_d^2 + \delta_p^2 + \delta_h^2$$

δ_t^2 : Hildebrand parameter
 d_d : dispersion component
 d_p : polar component
 d_h : hydrogen bonding component



Example of 3D Hansen space*

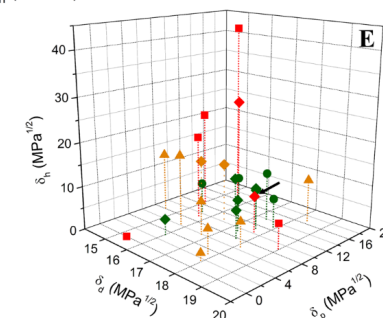
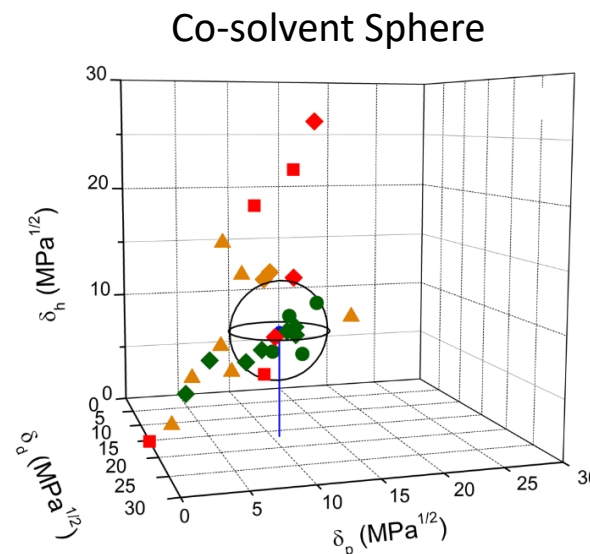
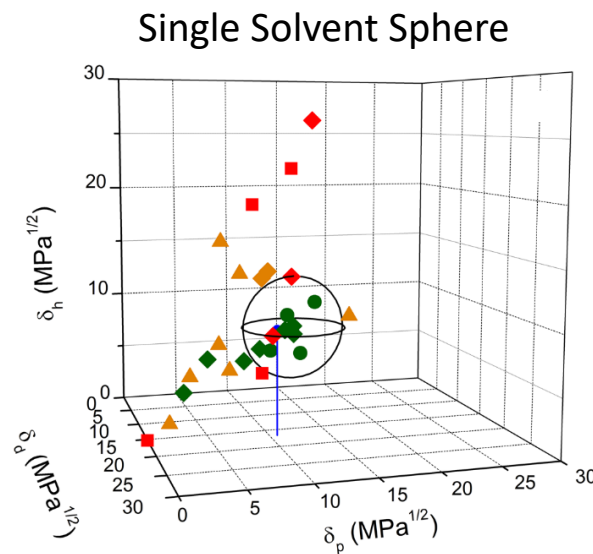
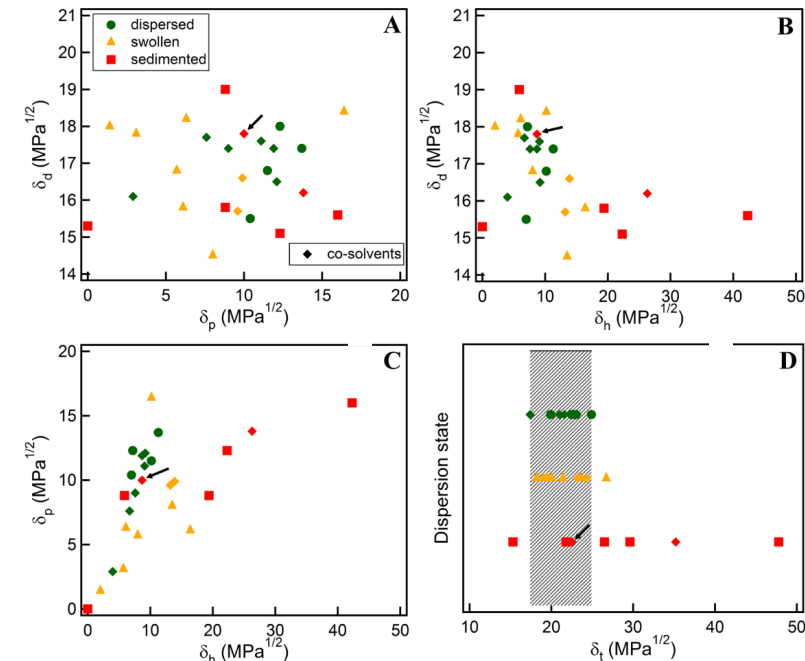
Single and Co-solvents



BNNT Hansen Solubility Parameters
 $\delta_d, \delta_p, \delta_h = 16.8, 10.7, 9.0 \text{ MPa}^{1/2}$
 $\delta_t = 21.8 \text{ MPa}^{1/2}$

Dispersion: Dispersion State of Single and Co-solvents

Co-solvent	δ_d , MPa ^{1/2}	δ_p , MPa ^{1/2}	δ_h , MPa ^{1/2}	δ_t , MPa ^{1/2}	Dispersion state (stirring only)	Dispersion state (stirring + 30 mins sonication)	R_a^c	RED^d
THF-NMP	17.4	9.0	7.6	21.0	swollen	dispersed/swollen ^b	2.51	0.58
DMF-acetone	16.5	12.1	9.2	22.4	swollen ^a	dispersed/swollen ^b	1.54	0.36
DMAc-NMP	17.4	11.9	8.7	22.8	swollen ^a	dispersed/swollen	1.72	0.40
DMSO-THF	17.6	11.1	9.1	23.1	swollen	dispersed/swollen ^b	1.65	0.38
DMF-toluene	17.7	7.6	6.7	21.6	swollen	dispersed	4.26	0.99
IPA-DMF	16.6	9.9	13.9	24.3	sediment	dispersed/swollen ^b	4.98	1.16
ethanol-acetone	15.7	9.6	13.2	23.2	swollen	dispersed/swollen ^b	4.87	1.13
DMF-DCM	17.8	10.0	8.7	22.5	swollen	dispersed/swollen ^b	2.14	0.50
THF-hexane	16.1	2.9	4.0	17.4	sediment	dispersed/swollen	9.37	2.18
DMAc-water	16.2	13.8	26.3	35.2	swollen	sediment	17.62	4.10



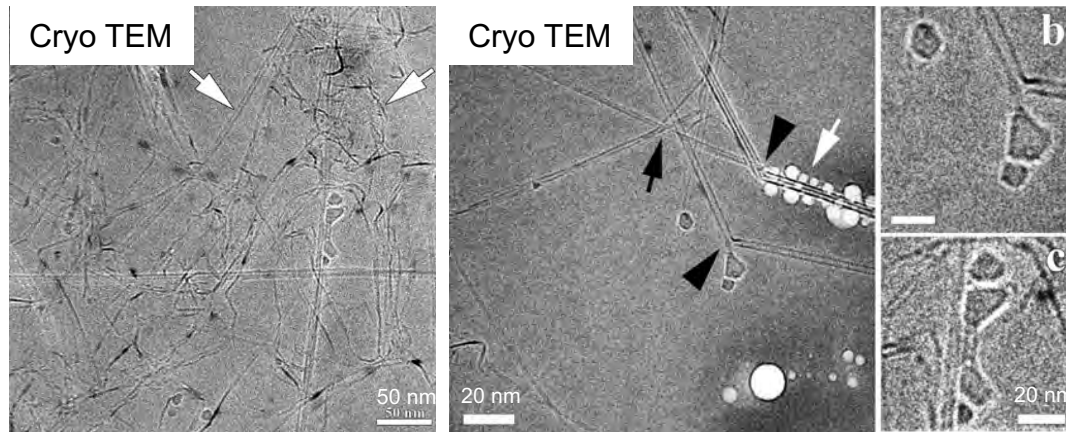
BNNT HSP

δ_d , δ_p , δ_h = 16.8, 10.7, 9.0 MPa^{1/2}

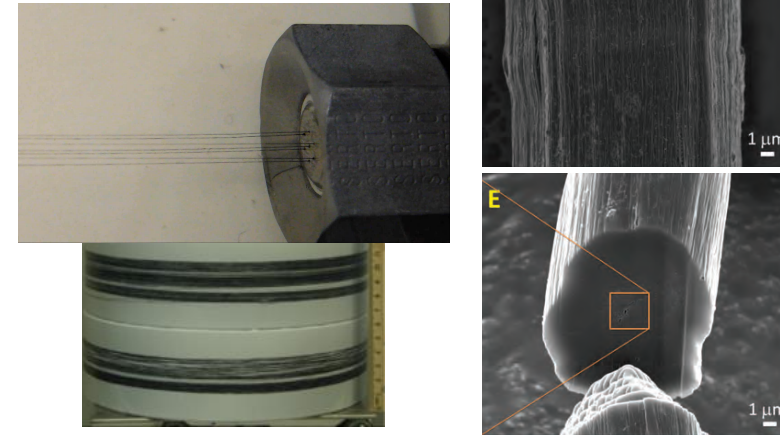
δ_t = 21.8 MPa^{1/2}

Dispersion and Purification

Dispersion in a Superacid (Chlorosulfuric acid)



BNNT in Chlorosulfuric acid (HSO_3Cl)



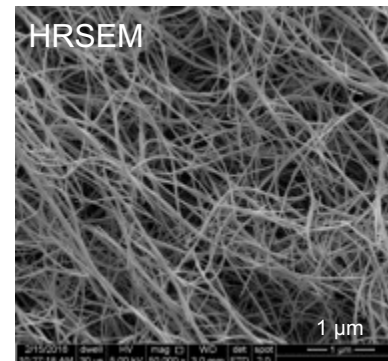
Rice U Nanotube Spinning (*Science* **339** 182 (2013))

Purification: Wet Thermal Oxidation

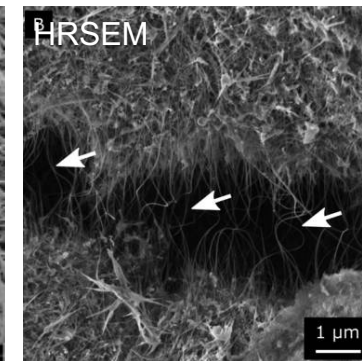


As grown BNNT

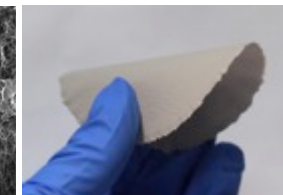
Purified BNNT



Purified BNNT



BNNT Film (superacid)

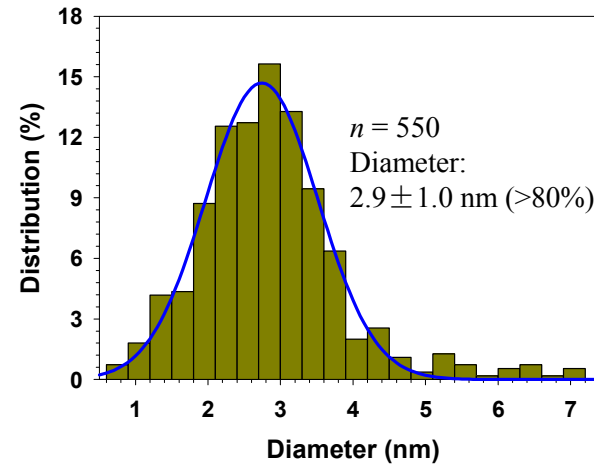
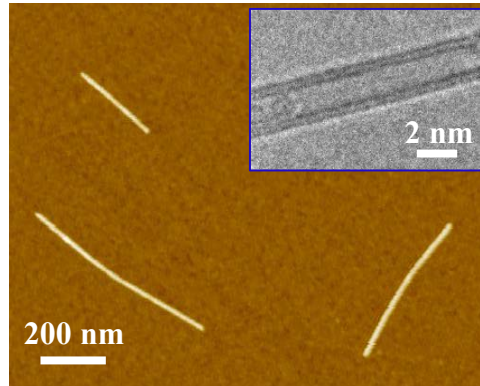


Flexible
BNNT Mat

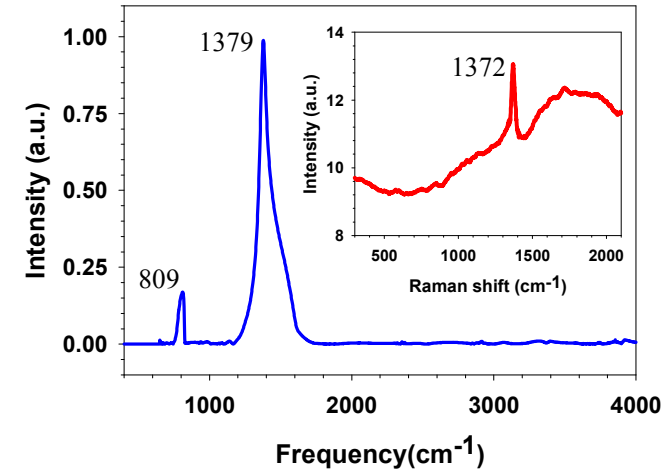
Mechanical and Thermal Properties

In-situ Single BNNT Test inside of an SEM

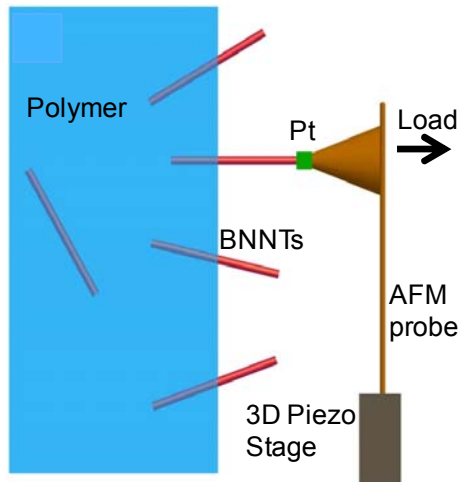
AFM



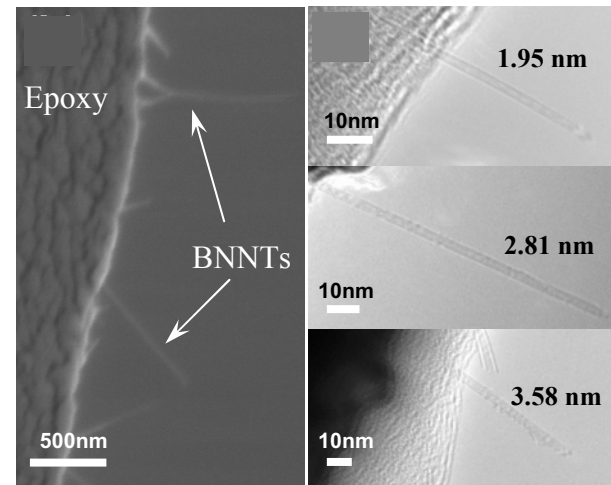
FTIR and Raman



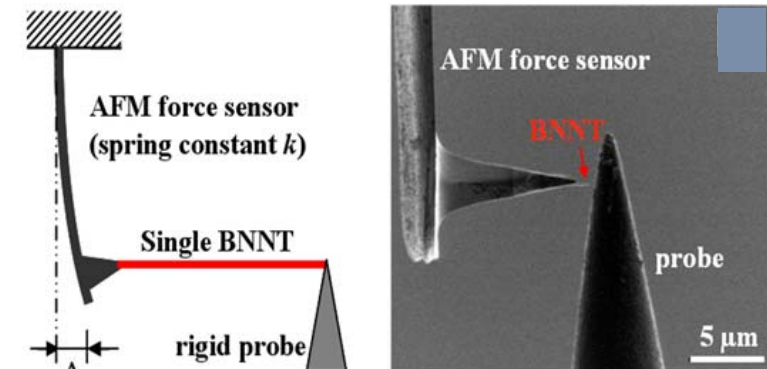
Pull-Out Test



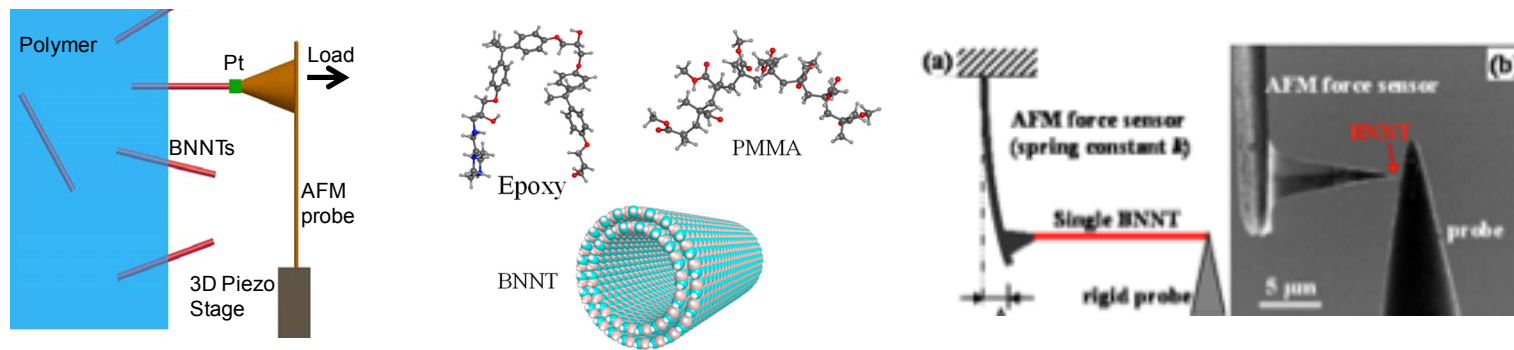
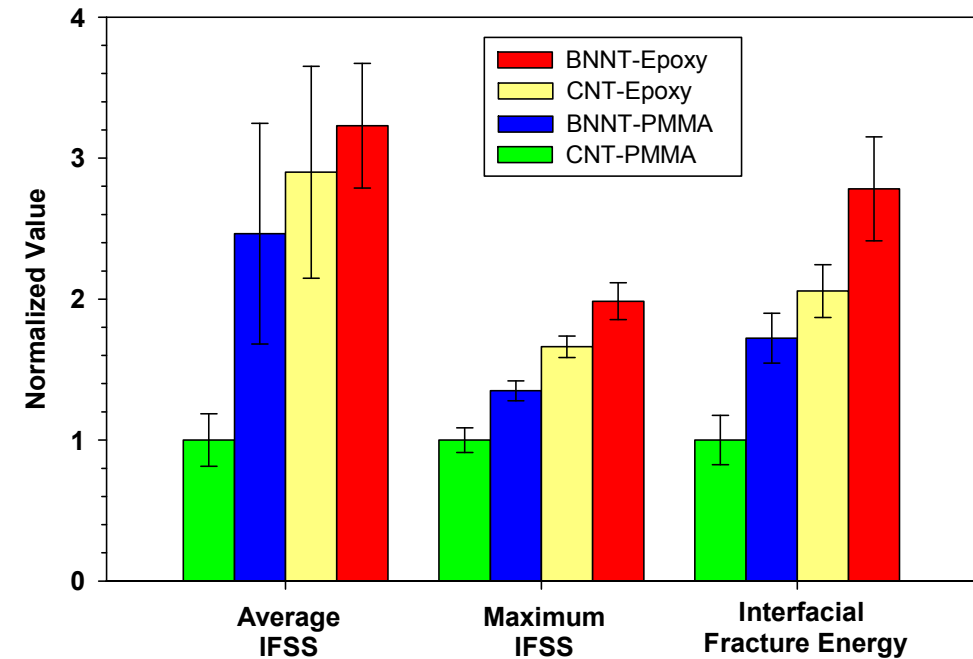
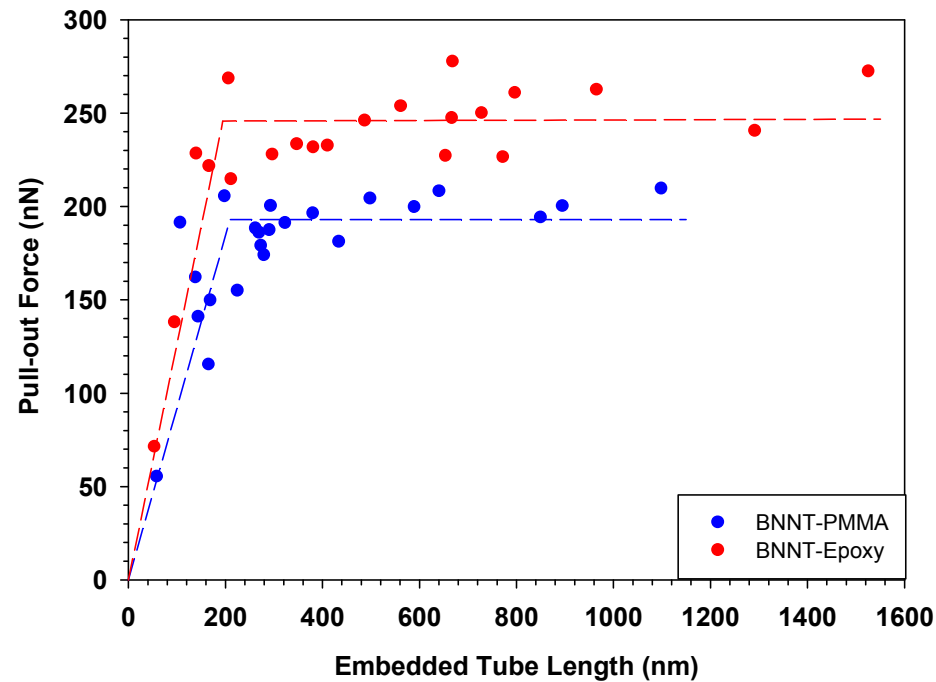
SEM



Tensile Test



Interfacial Strength: *In-situ* Single Nanotube Pull-Out Test

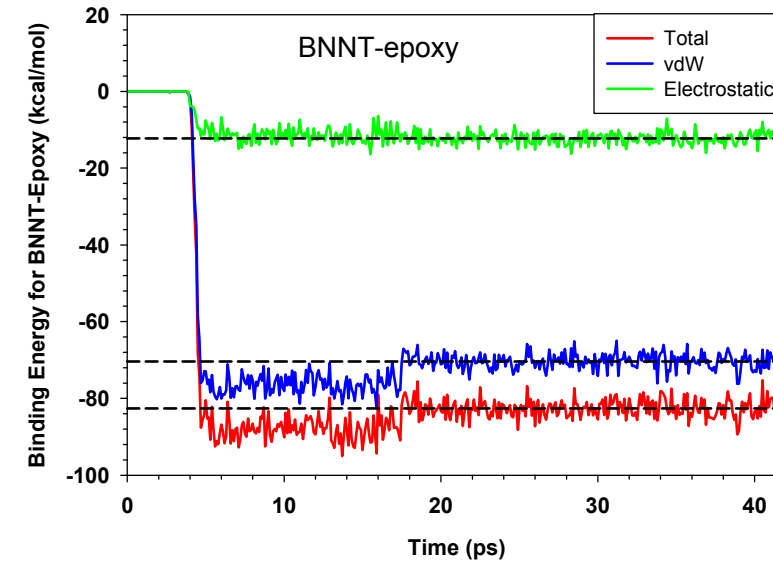
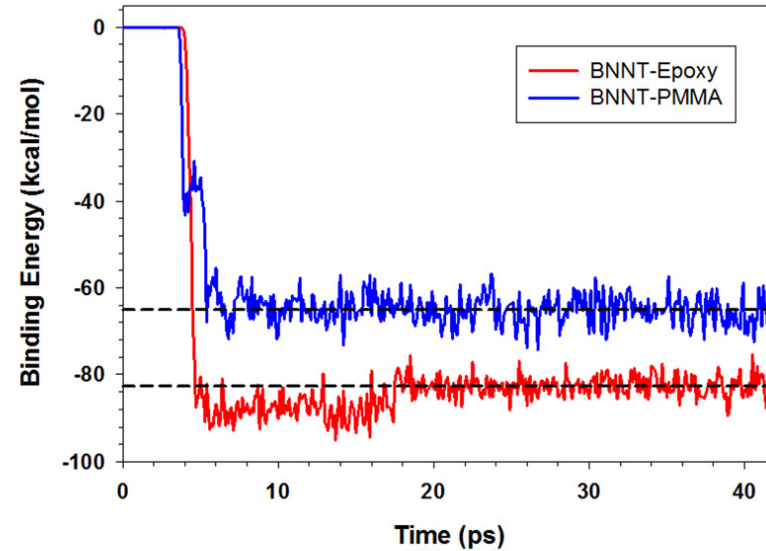


BNNT Tensile Test Results

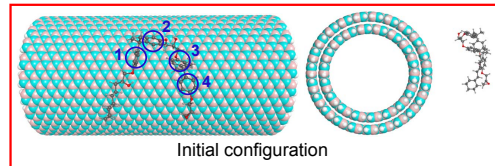
Diameter	Elastic modulus (GPa)	Breaking Strength (GPa)
D = 2.5 nm	760-960	14-38

Interfacial Strength: *In-situ* Single Nanotube Pull-Out Test

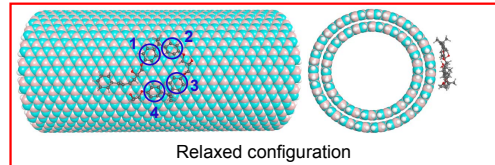
Credit: Prof Ke (SUNY Binghamton)



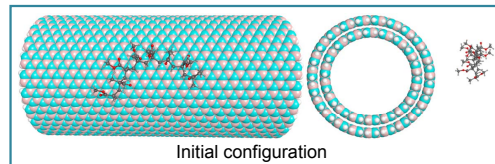
BNNT/Epoxy



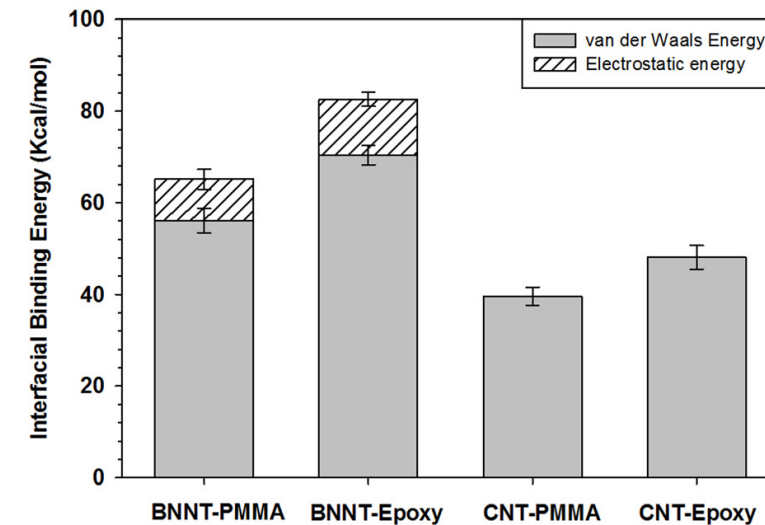
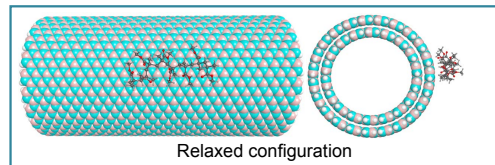
BNNT/Epoxy



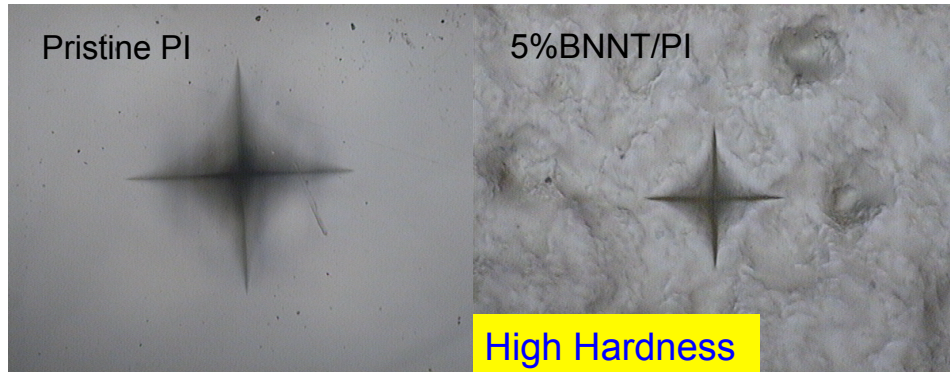
BNNT/PMMA



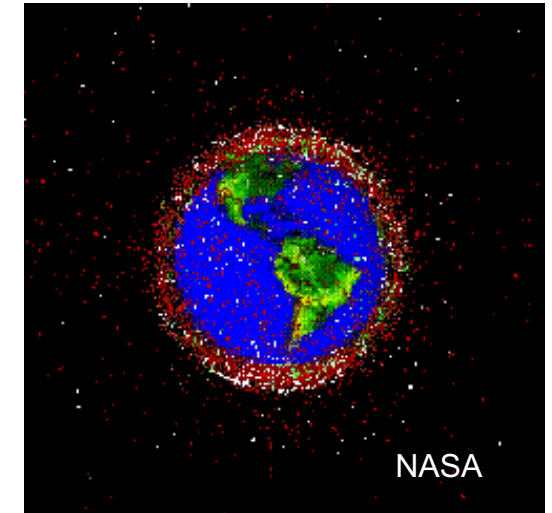
BNNT/PMMA



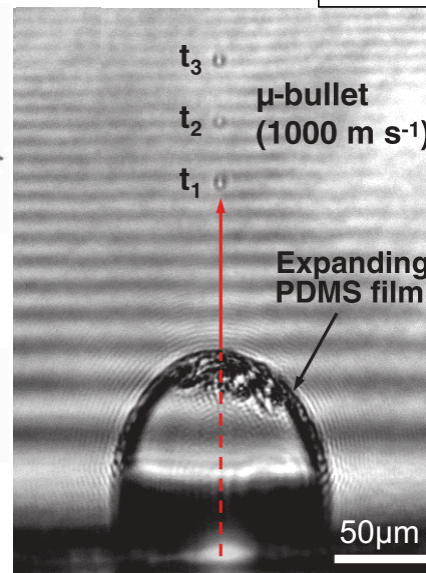
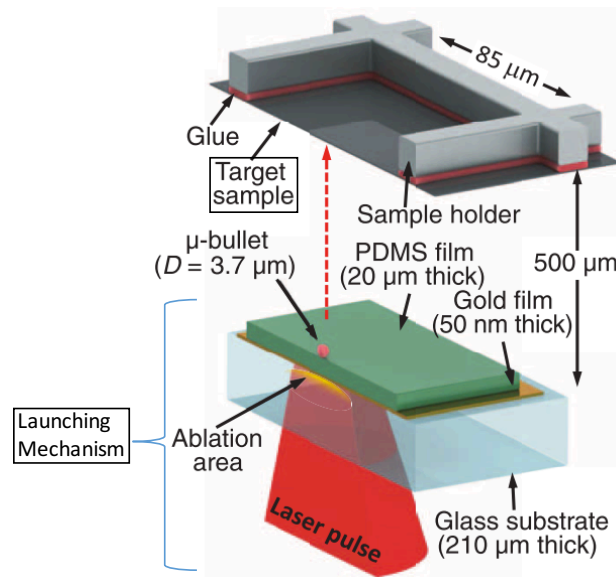
High Velocity Laser Induced Micro-Bullet Impact Test: BNNT Nonwoven Mat (Micro-Ballistics)



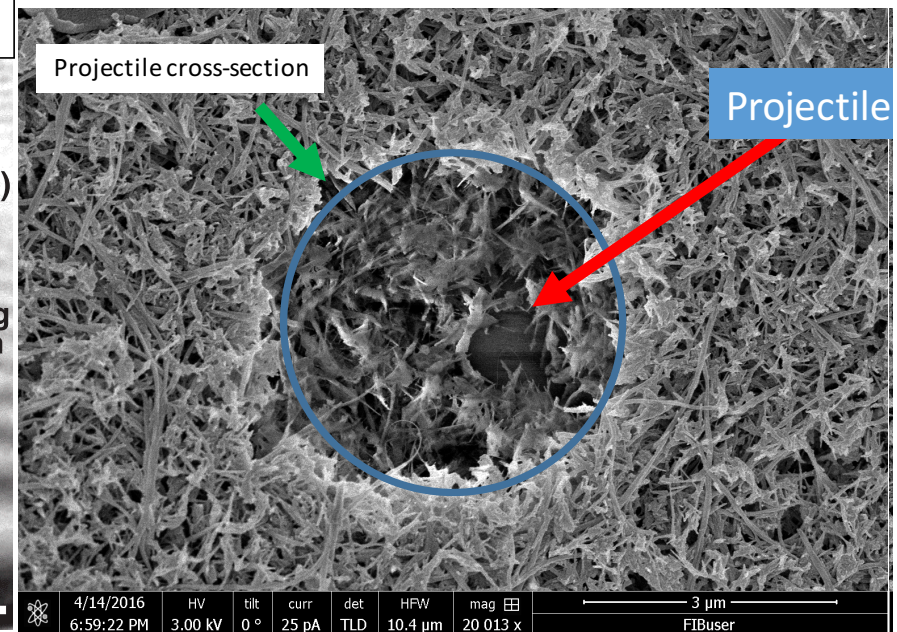
Simulated Micrometeorite Impact Test



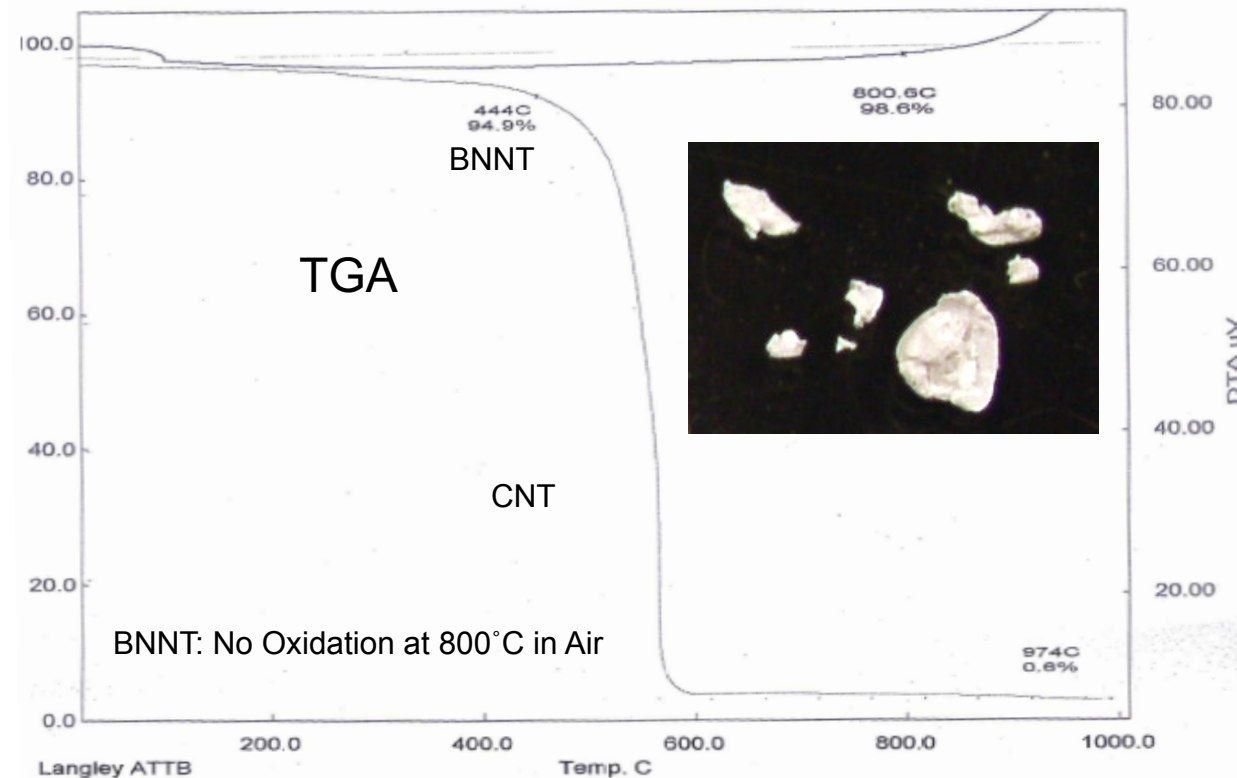
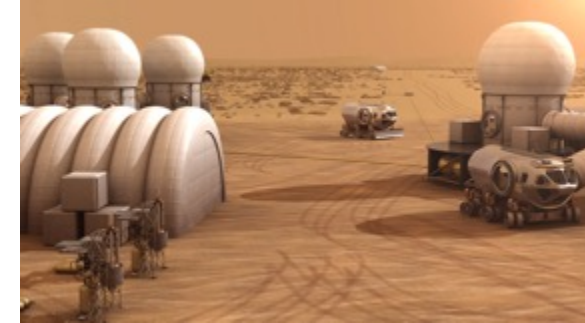
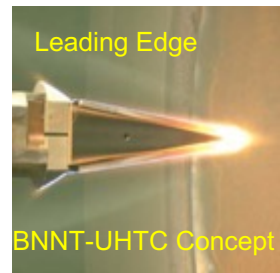
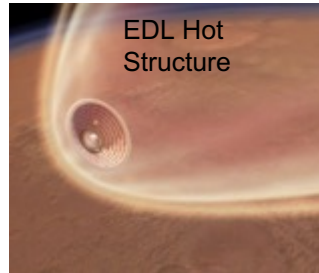
Ballistic Velocities: 100-1500 m/s
Laser Induced Projectile Impact Test (LIPIT)



Imaging Technique



Thermal Properties of BNNT



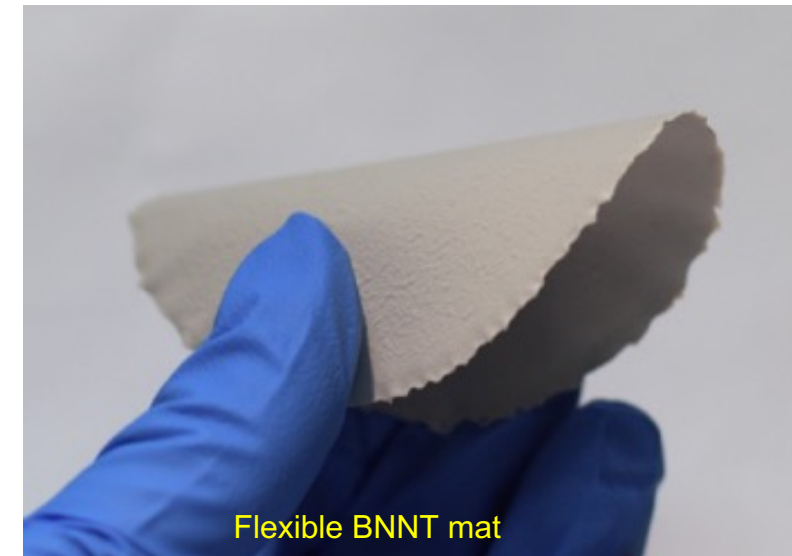
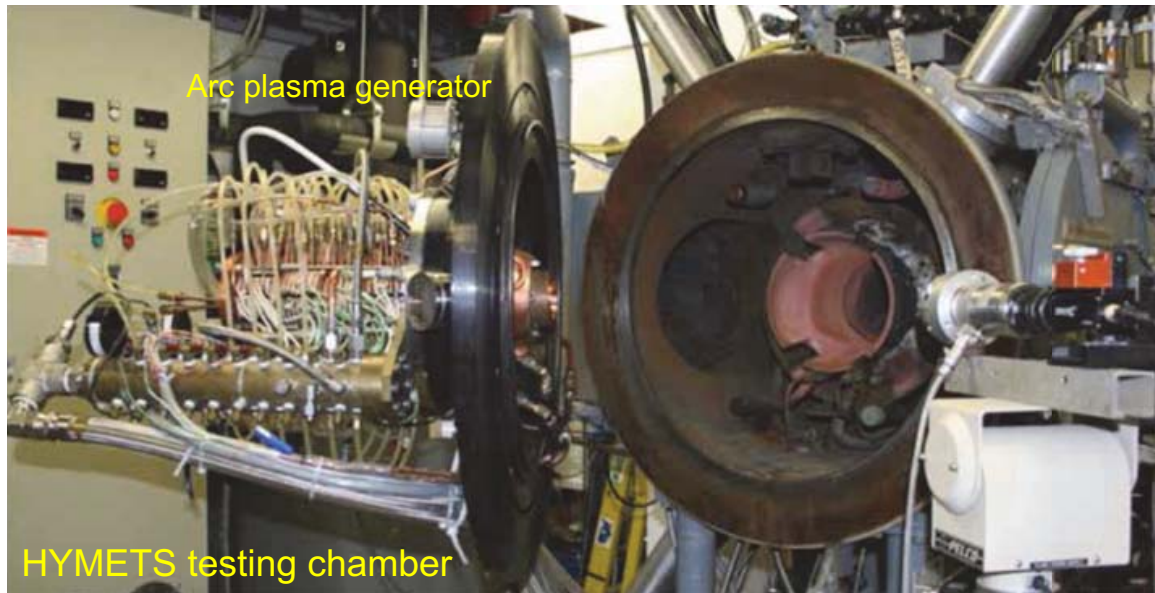
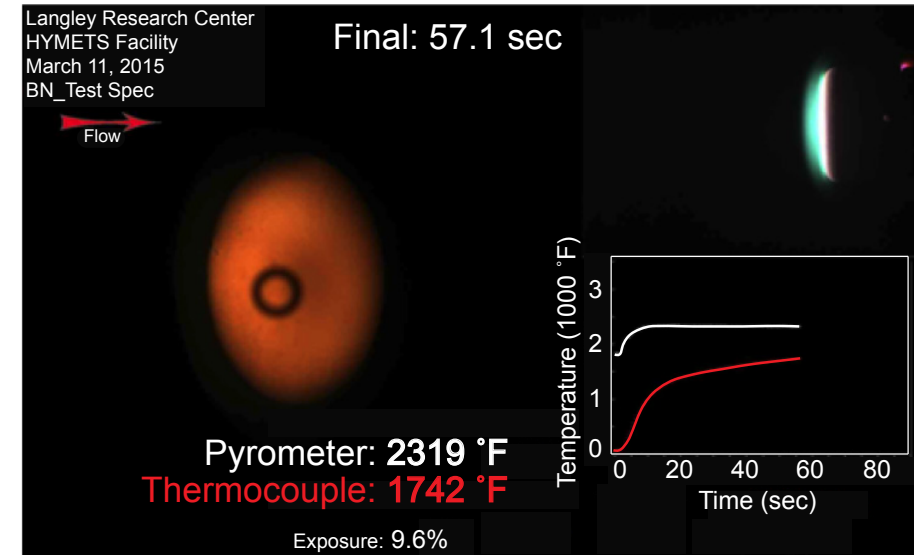
Hypersonic Materials Experiment Test System (HyMETS)

LaRC HYMETS Test Conditions

- Specimen Surface Temperature (°C): 1260
- Specimen Stagnation Pressure (atm): 0.013-0.079
- Free Stream Mach Number: 5.0
- Free Stream Enthalpy (kJ/kg): 5350-26749

HYMETS TEST for BNNT Mats

- Heat flux: Set at 50 W/cm^2 (2nd Gen Mars EDL)
- Duration: 1 min - 5 min
- Atmosphere: Air (with 5% Ar)
- Cooled under Vacuum



Hypersonic Materials Experiment Test System (HYMETS)

Sample: BNNT Mat (as grown, nonwoven)

- Fabricated by a vacuum filtration process
- Diameter: 25 mm, Thickness: 2 mm, Density: $\sim 0.3 \text{ g/cm}^3$



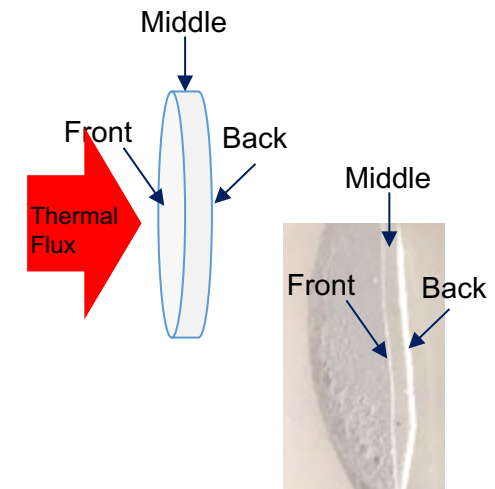
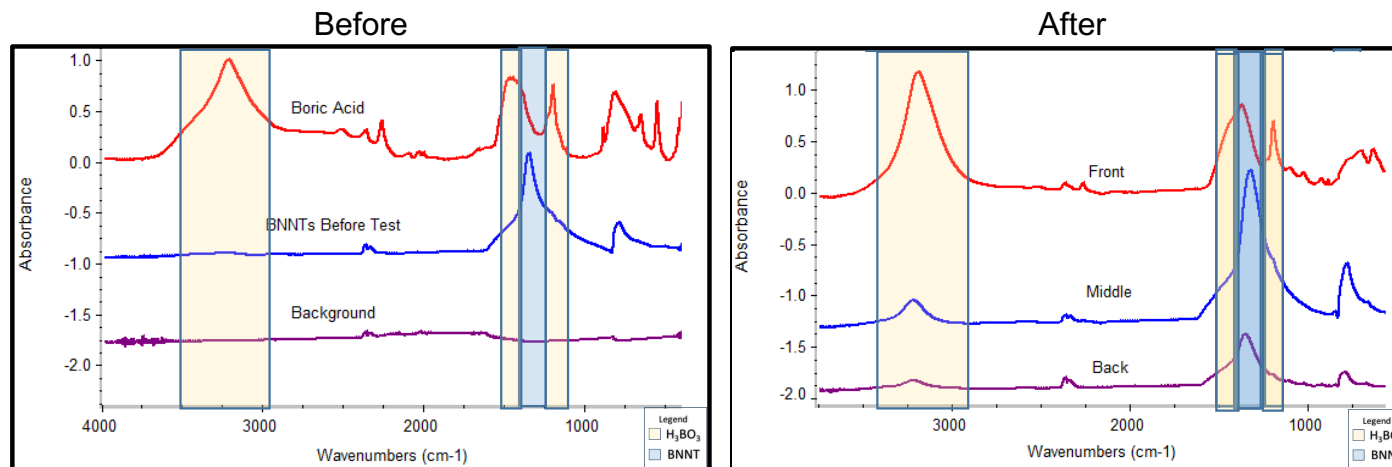
HYMETS Test Conditions

- Test duration: 1 min
- Surface temperature: 2400 °F (1315 °C)

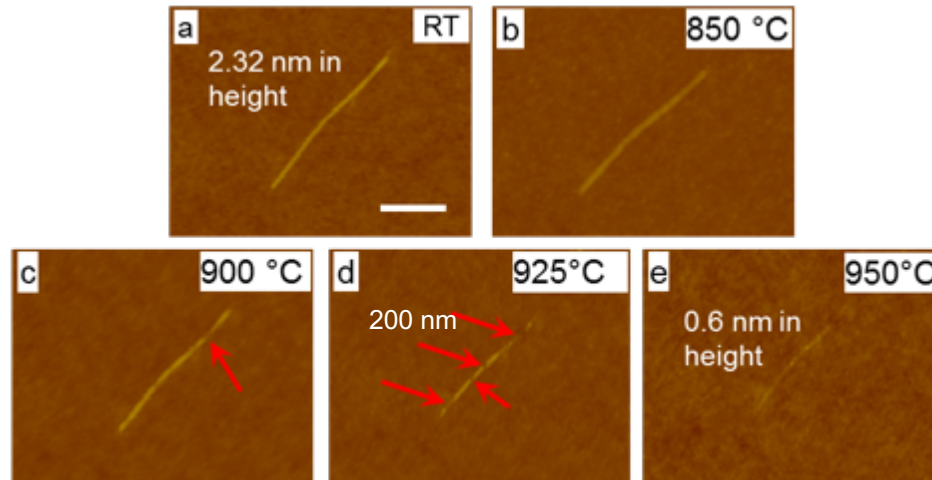


Video Clip: BNNT mat under a hypersonic test

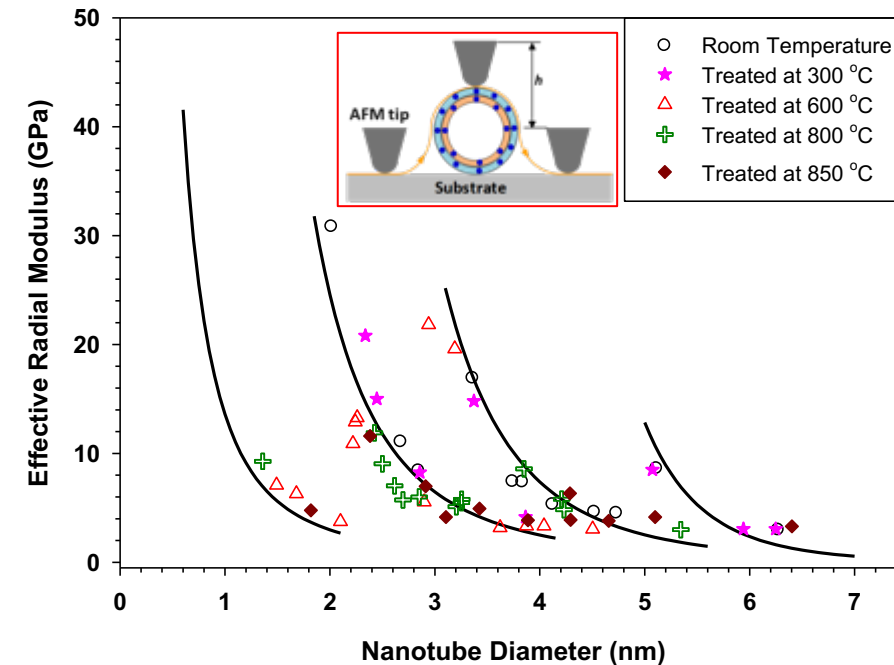
FT-IR Analysis of BNNT mat



Superior Structural and Mechanical Properties of BNNTs in High Temperature Environments

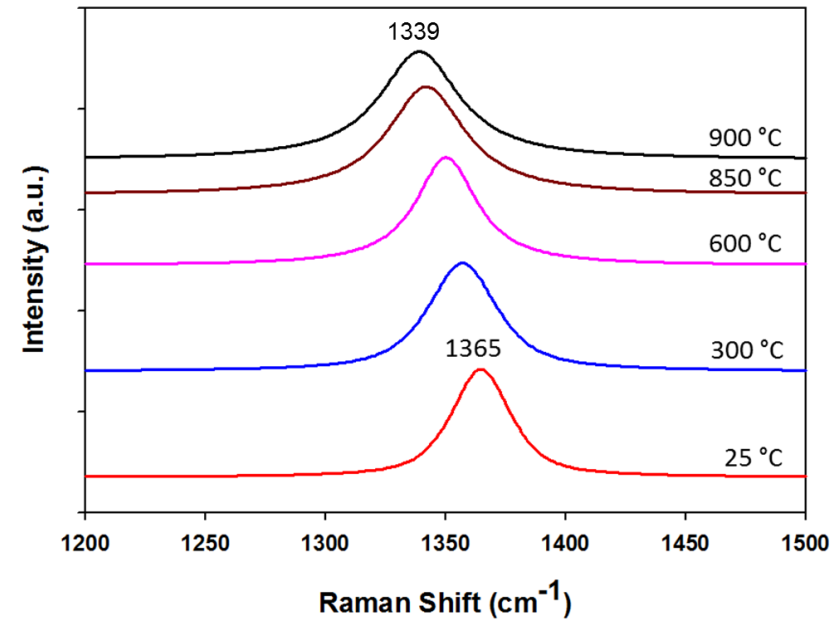
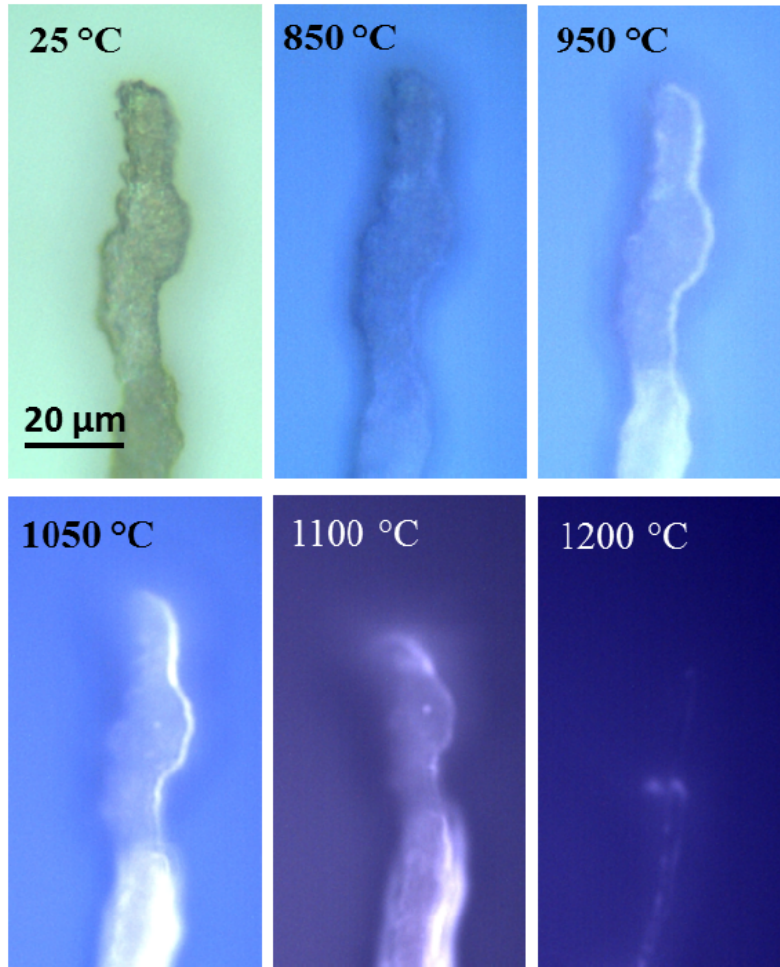


AFM studies show that **individual** BNNTs can survive at up to 850 °C in air and captures the sign of their structural degradation at 900 °C and above. (the red arrows mark the positions of the oxidation-induced tube broken sites).



AFM-based nanomechanical compression tests (illustrated in inset drawing) show that the mechanical properties of **individual** BNNTs remain intact after thermally baked at up to 850 °C in air.

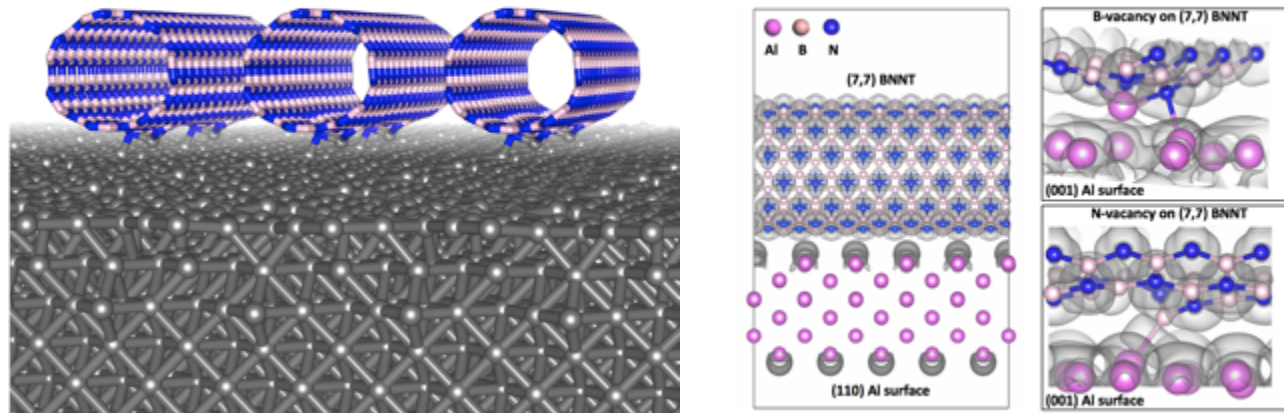
In Air



Noticeable structural damage to BNNT occurs at ~1050 °C in Air

BNNT Metal Matrix Composite (MMC)

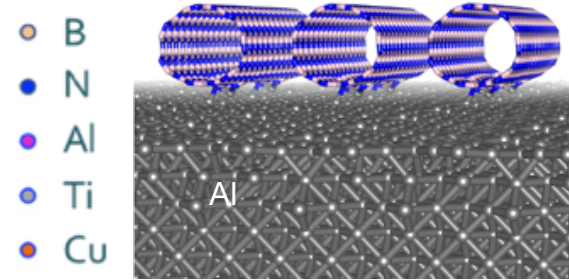
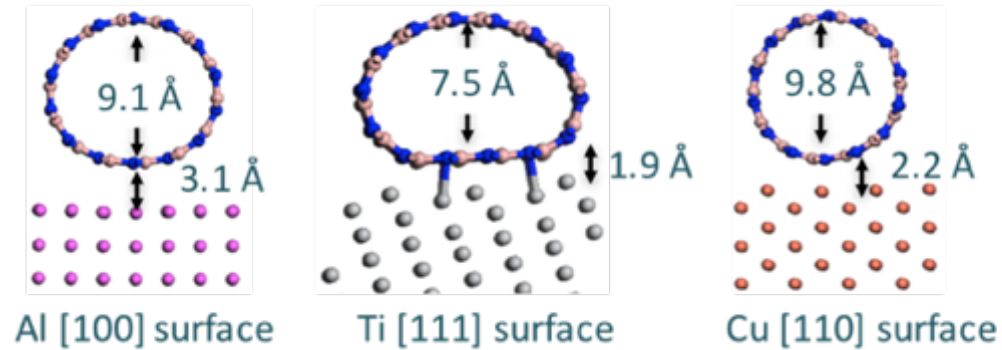
BNNT Ceramic Matrix Composite (CMC)



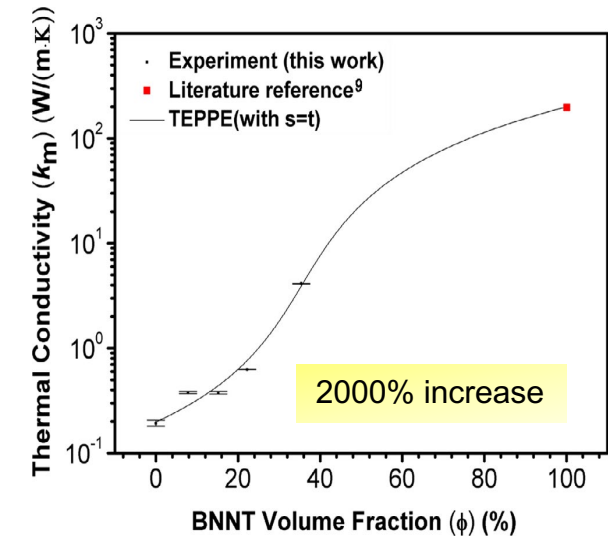
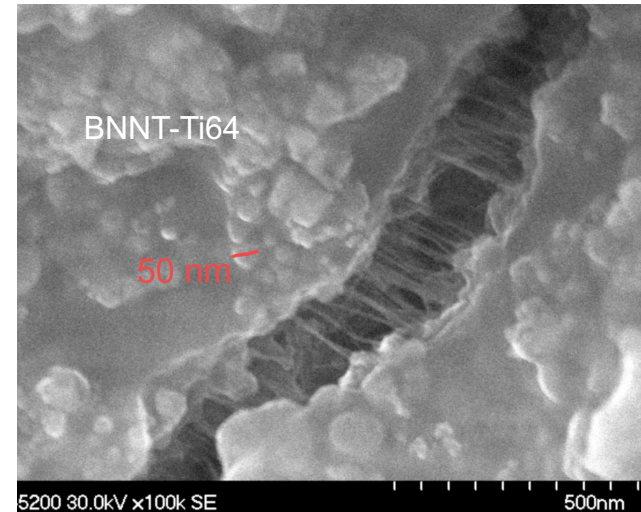
BNNT Metal Matrix Composite (BNNT-MMC)

Pristine BNNT (7, 7)

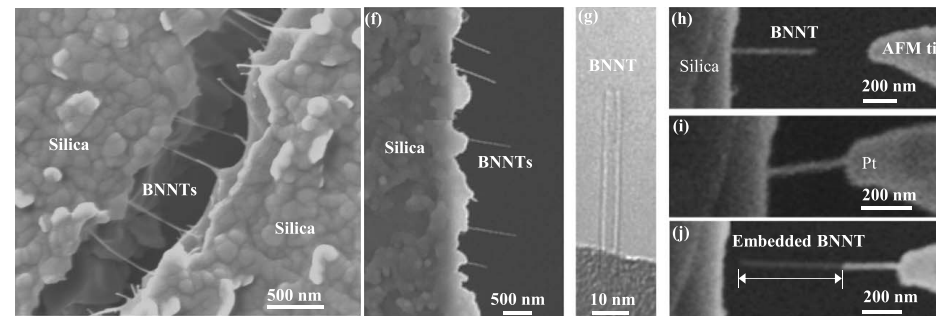
U Queensland: Prof Bernhardt & Dr. Rhomann (AFOSR/AOARD)



Binding Energies**	Al[100] Surface	Ti[111] Surface	Cu[110] Surface
Pristine	-0.41	-1.77	-0.95
N-vacancy	-0.69	-2.00	-1.23
B-vacancy	-1.26	-3.30	n/a
C sub N	-0.64	-2.17	-1.26
C sub B	-0.51	-1.41	-1.00

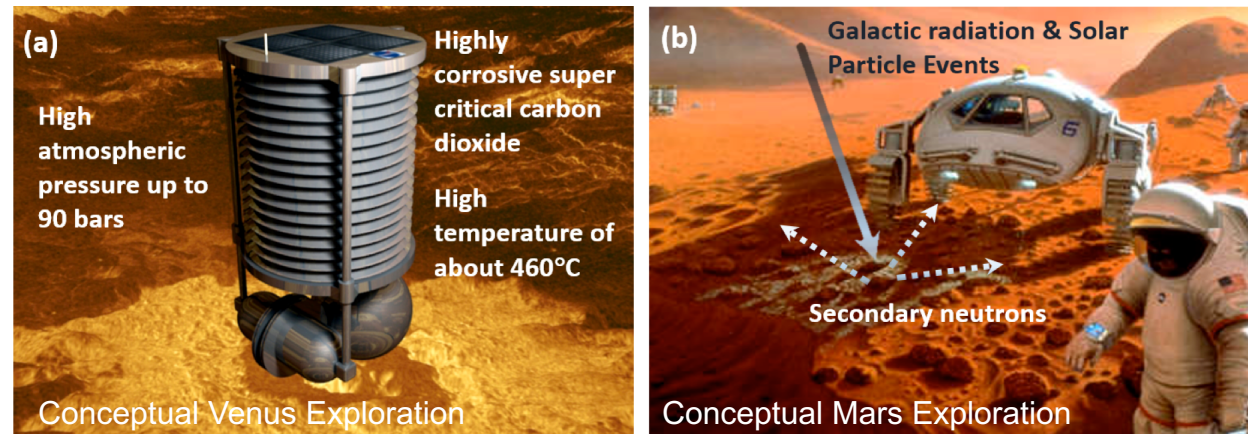


J. Am. Cer. Soc. **109** 7584 (2019)



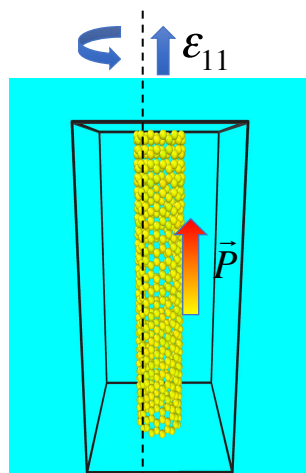
Multifunctional BNNT Polymer Composites

- Electroactive Properties
- Radiation Shielding Properties



Results: Piezoelectricity under Deformation

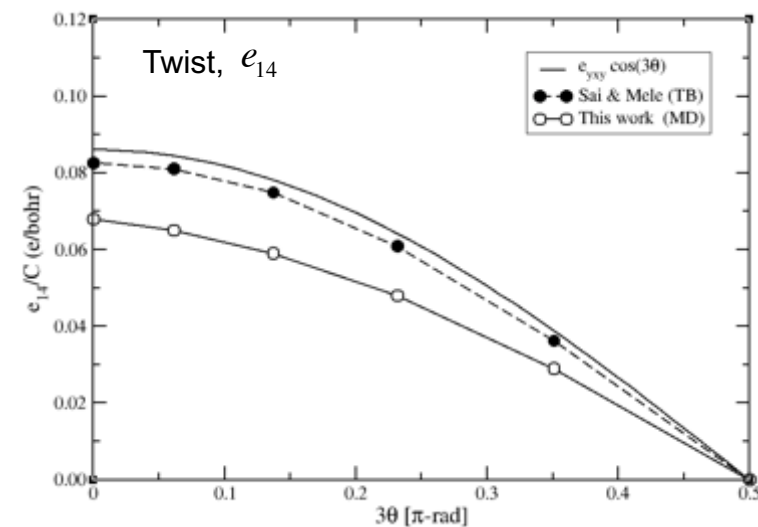
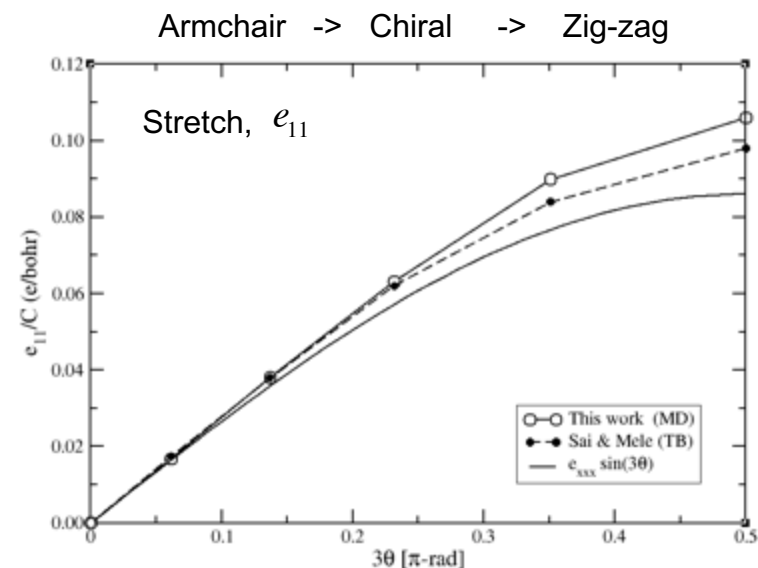
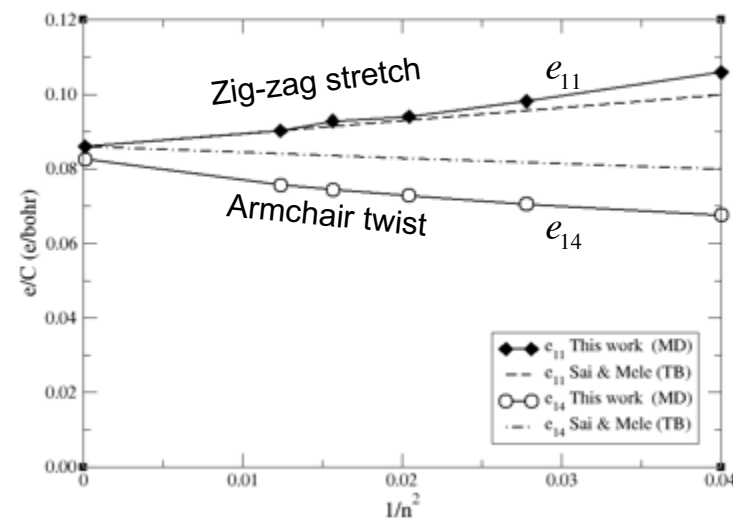
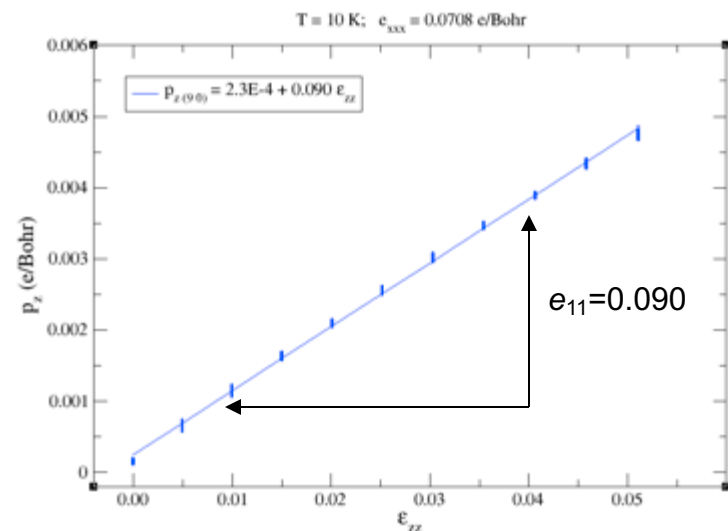
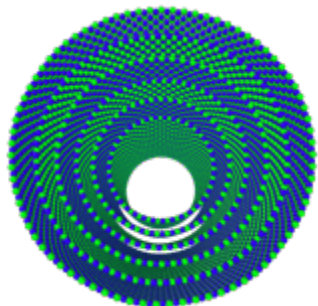
The Molecular Dynamics (MD) model is successful in representing the piezoelectric properties of BNNTs



$$p_z(\text{stretch}) = e_{11}\epsilon_s$$

$$p_z(\text{twist}) = e_{14}\epsilon_t$$

MWBNNT



Polymer Matrix:

- Polyimides [CP2, (b-CN)AMPB/ODPA (bCNAO), (b-CN)APB/PMDA (bCNAP)]
- Polyurethane
- PMMA
- Nylon 6,10

Inclusions:

- h-BN (hexagonal boron nitride powders)
- BNNT (purchased CVD, large, large diameter tubes)
- BNNT (high pressure, high temp, CO₂ laser as grown)

Alignment (stretched)

No alignment (unstretched) and stretched (up to 100%)

Polyimide (CP2)

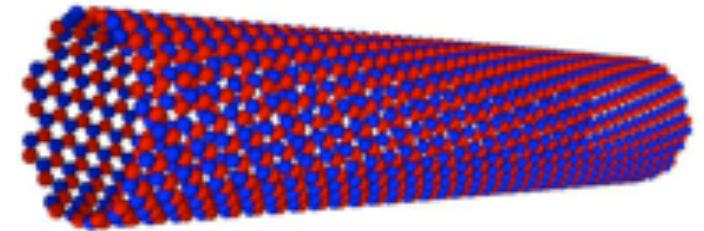
Polyimide (bCNAO)

Polyimide (bCNAM) (unstretched and stretched 100%)

5wt%hBN/polyimide (stretched 110%)

5wt%BNNT(CVD)/polyimide

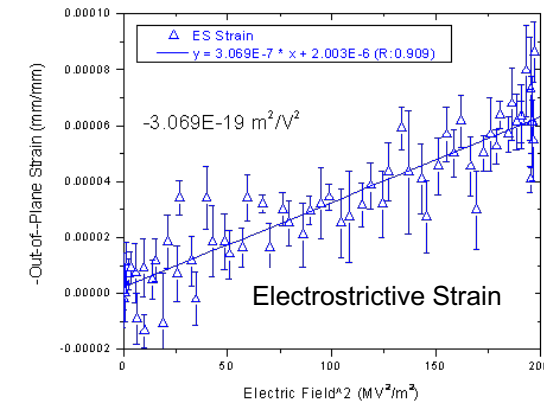
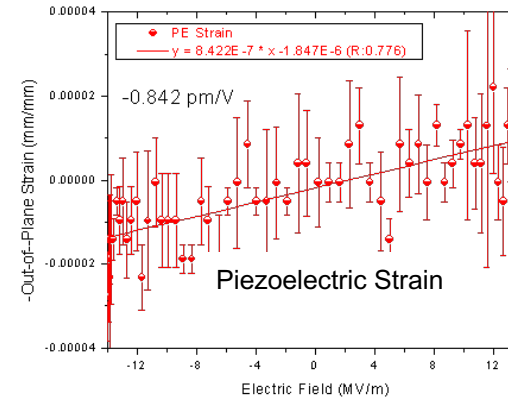
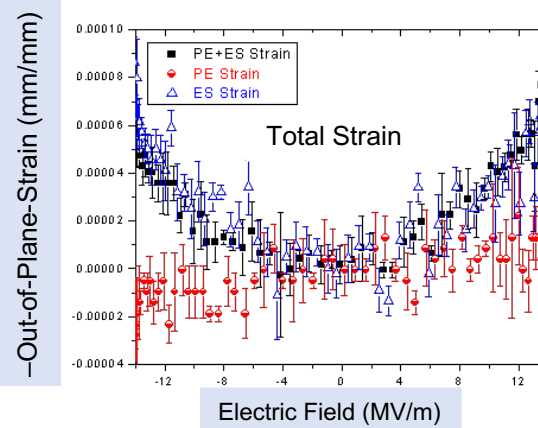
2wt%BNNT(laser)/polyimide (unstretched and stretched 100%)



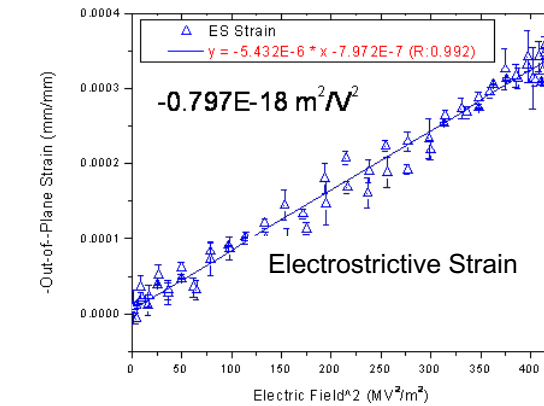
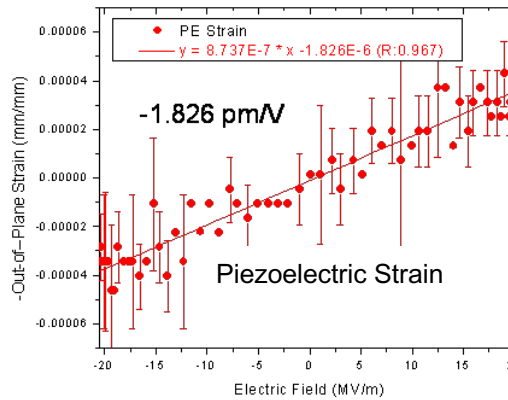
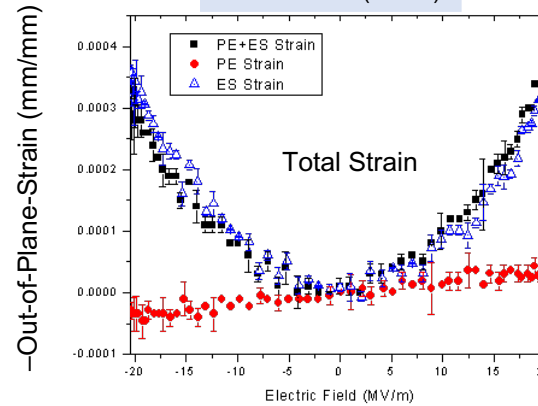
Actuation of Unstretched/Stretched 2% BNNT/Polyimide

Origin of Actuation → BNNT

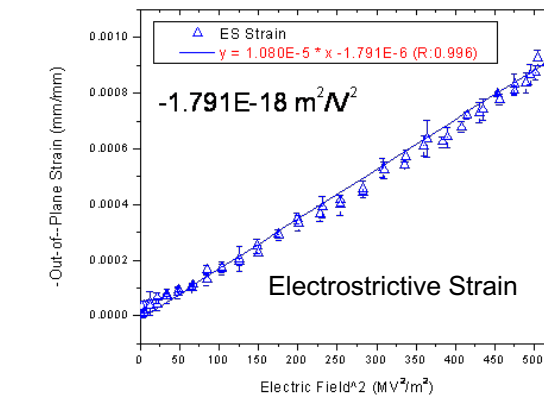
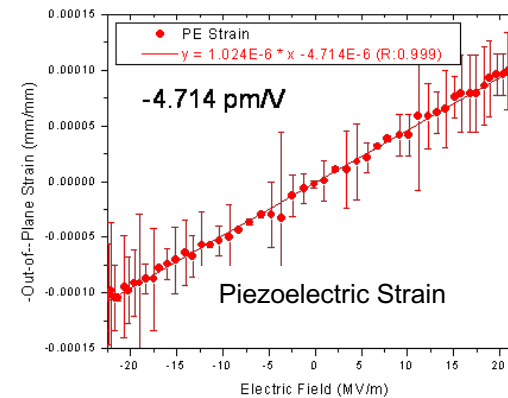
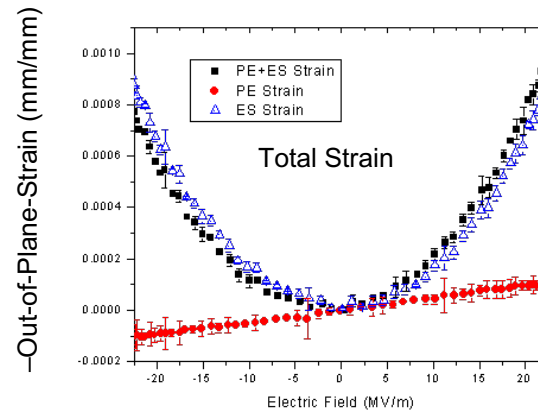
Unstretched



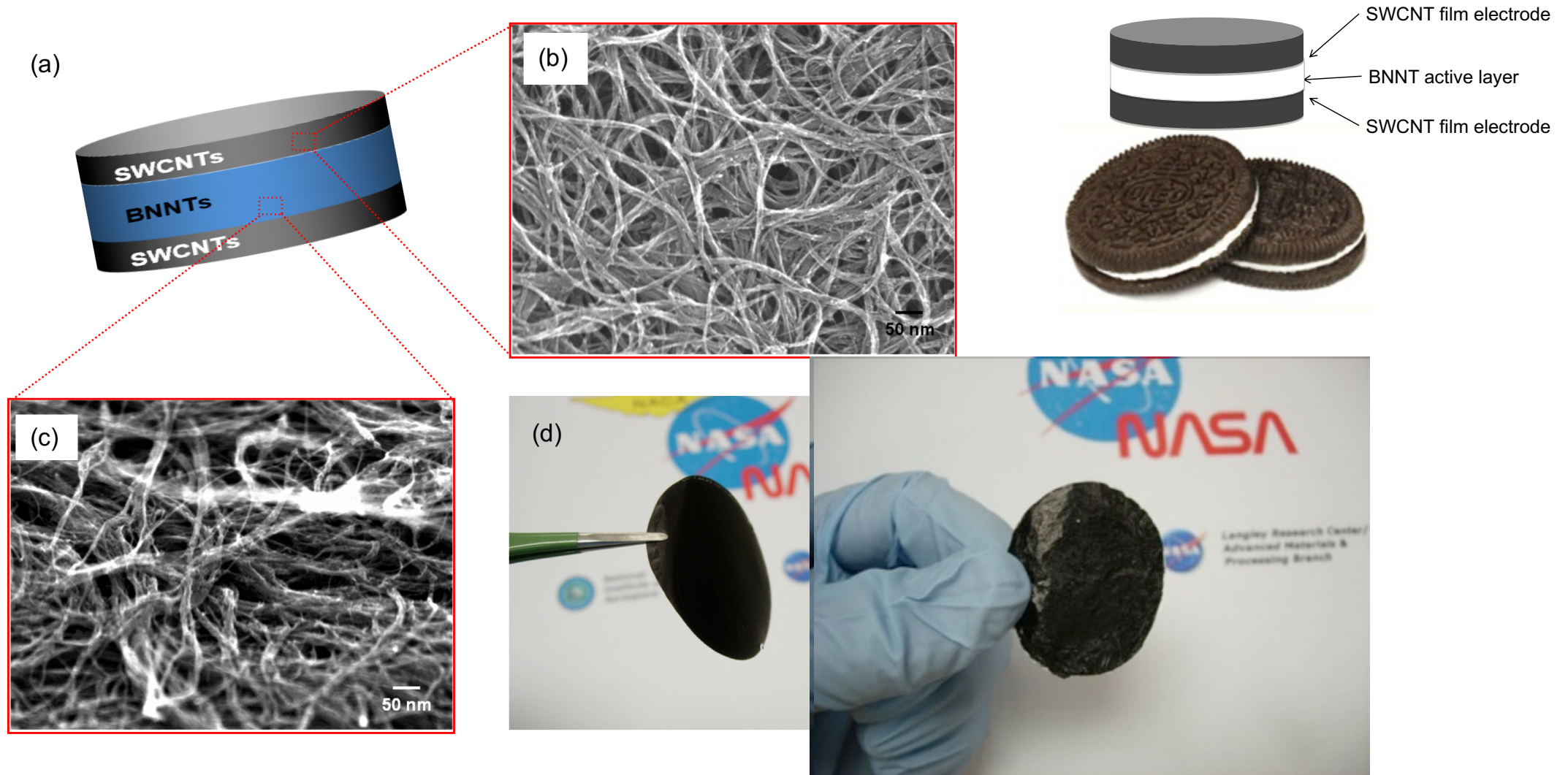
100% Stretched
@225°C, Quenching



100% Stretched
@225°C, Annealing

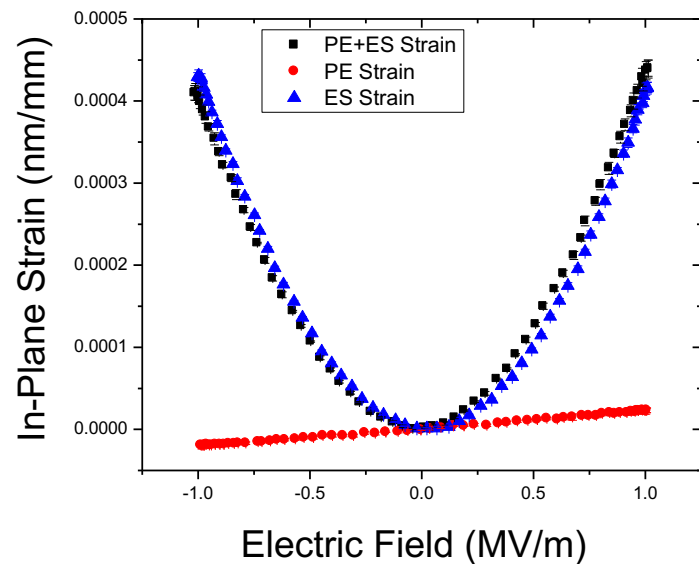


Langley All-Nanotubes Actuator/Sensor (LaRC-ANAS) Film



Goal: Flexible, transparent, large actuation, high sensitivity, mechanically durable

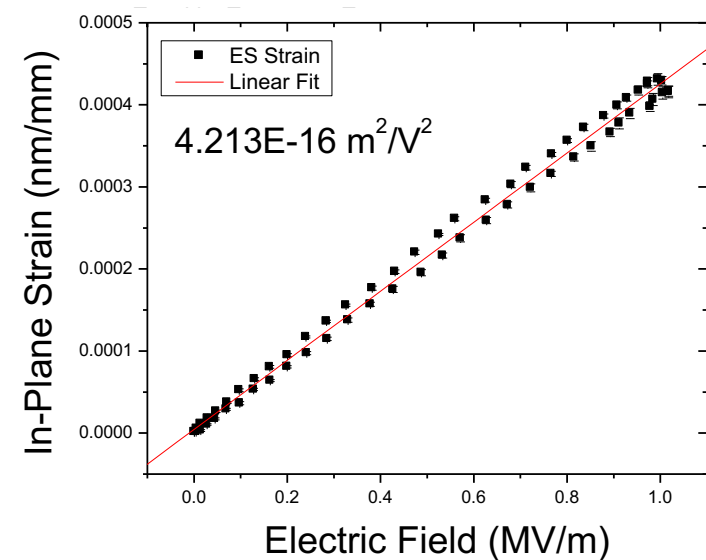
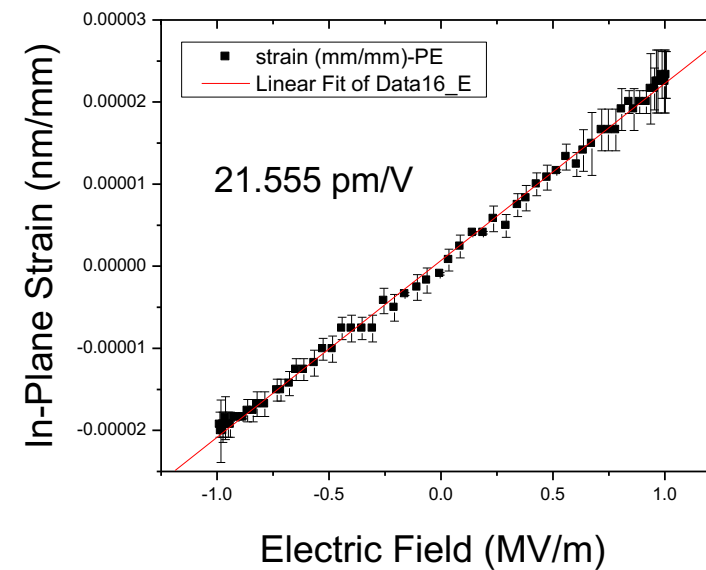
All-Nanotubes Actuator/Sensor Film: In-Plane Strain



Field induced strain (e_{33})

$$e_{33} = d_{33} \cdot \mathbf{E} + M_{33} \cdot \mathbf{E}^2 + \dots$$

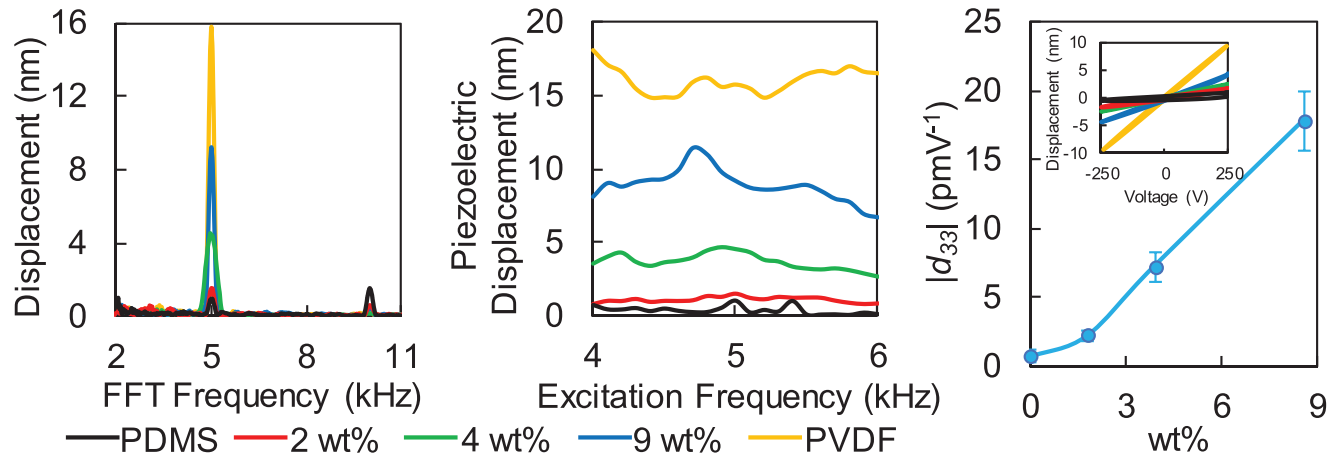
d_{33} : piezoelectric coefficient
 M_{33} : electrostrictive coefficient
 E : applied electric field



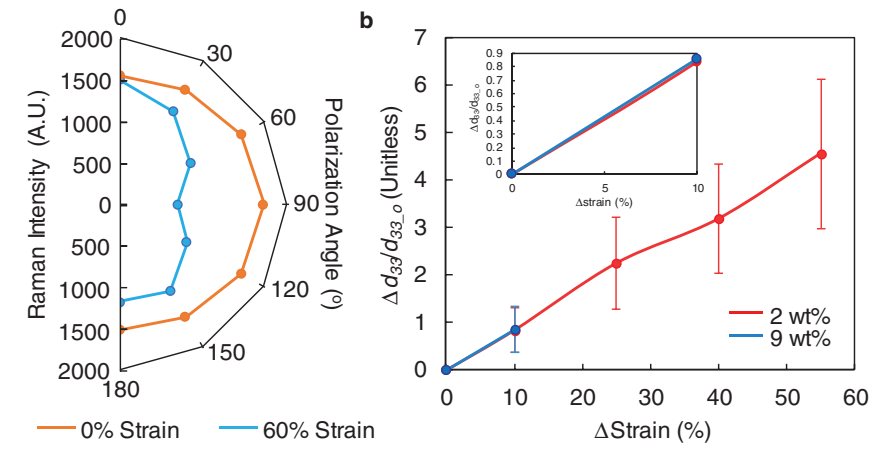
Multifunctional Properties of BNNT/PDMS (Poly(dimethylsiloxane))



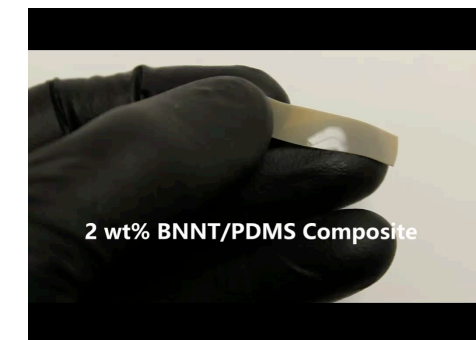
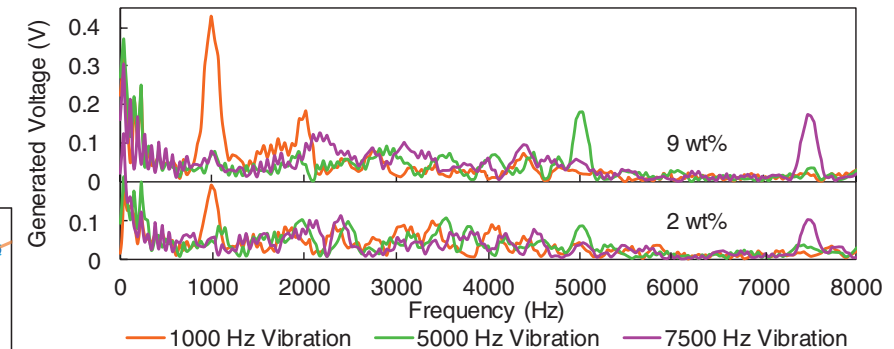
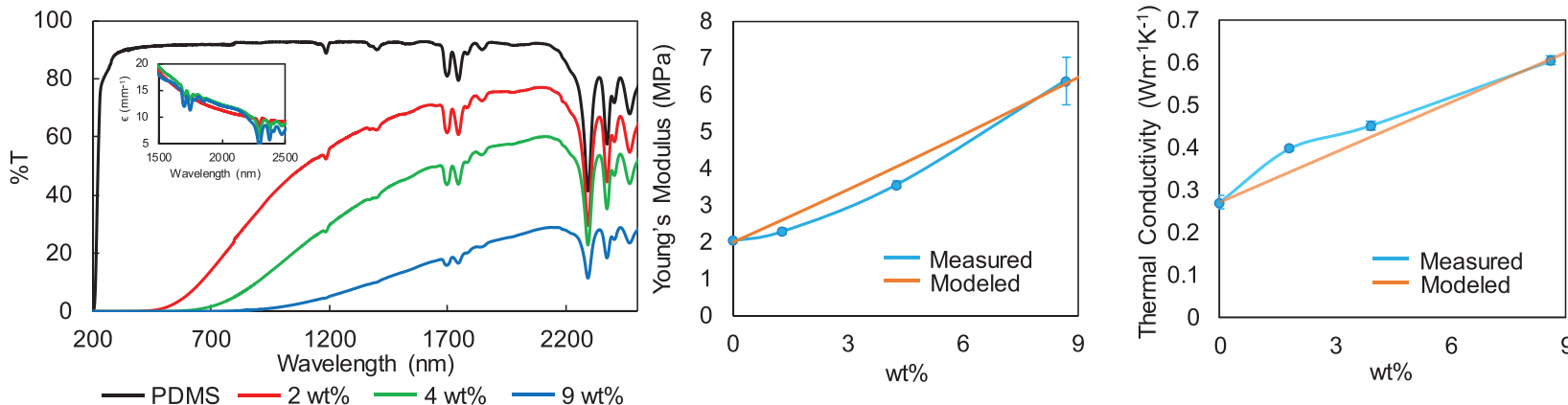
Piezoelectric Properties of BNNT/PDMS



Alignment Effect & Vibration Sensing of BNNT/PDMS



Optical, Mechanical, and Thermal Properties of BNNT/PDMS

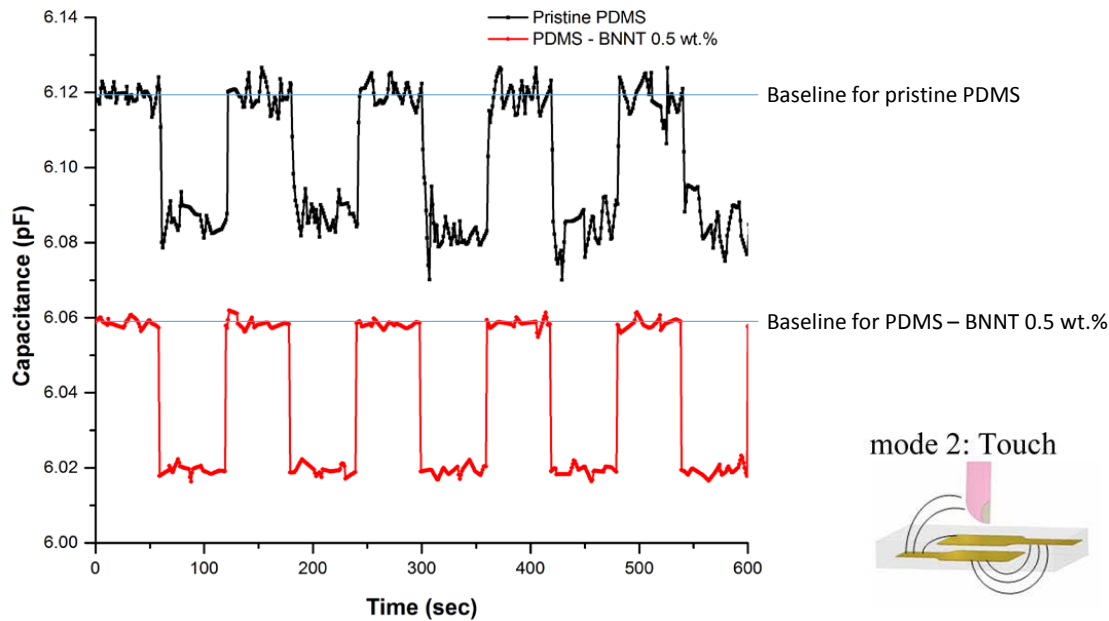
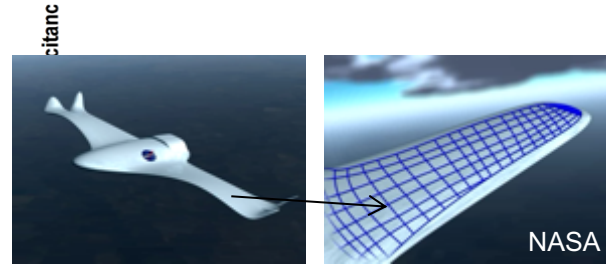
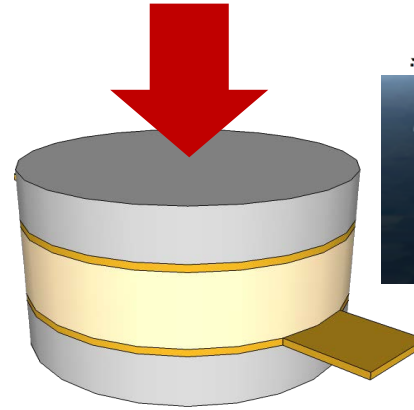


2D Printed Electronics as Sensory Applications: BNNT Composites Capacitive Sensors

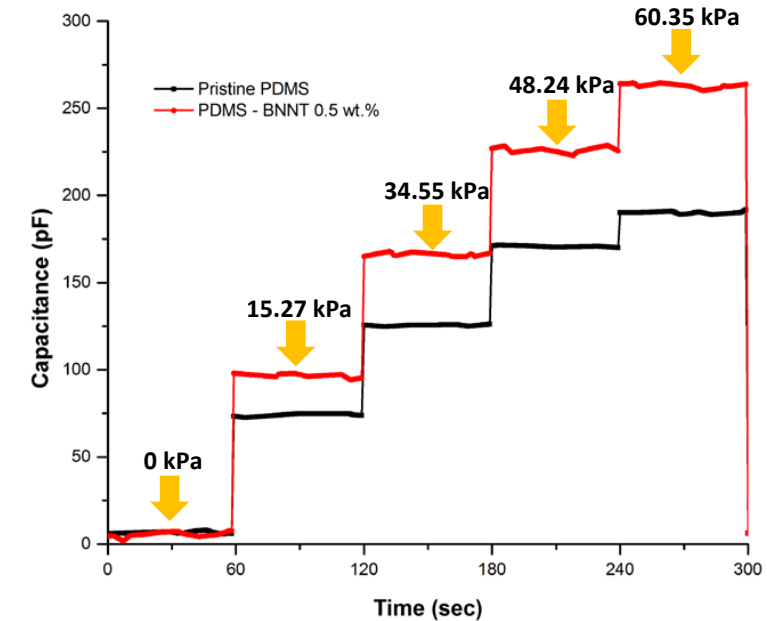
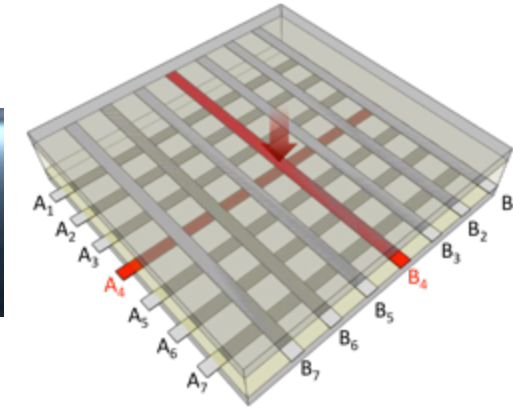


Touch Sensitive Sensor

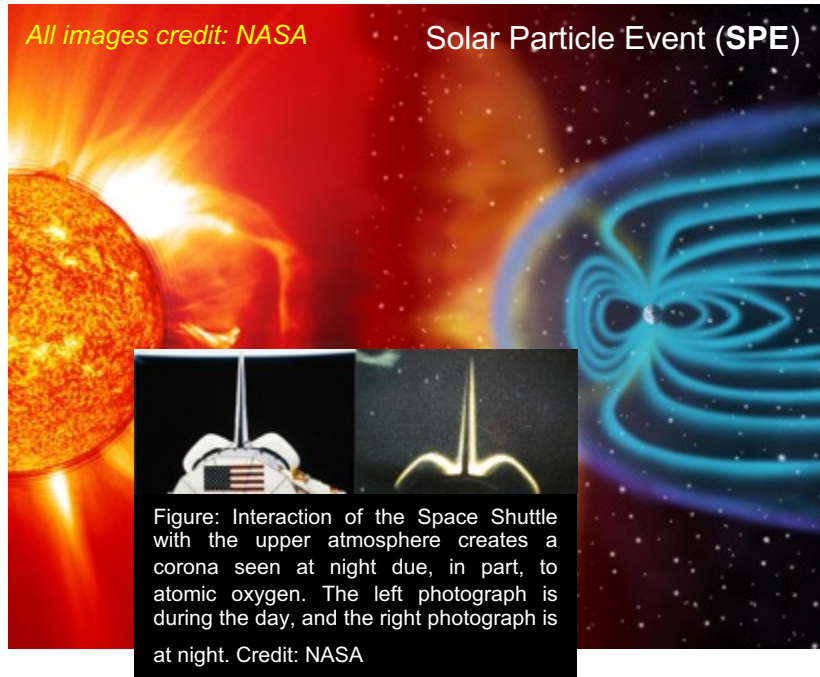
By touch



Pressure Sensitive Sensor



Radiation Shielding Properties



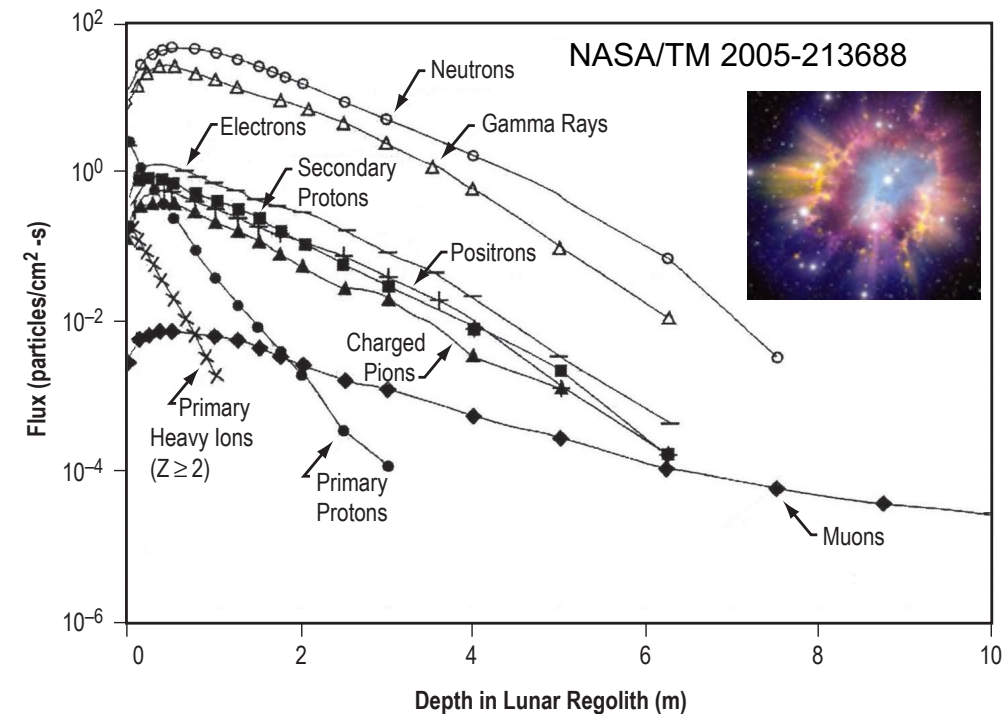
Science **340** 1080 (2013)

Measurements of Energetic Particle Radiation in Transit to Mars on the Mars Science Laboratory

C. Zeitlin,^{1*} D. M. Hassler,¹ F. A. Cucinotta,² B. Ehresmann,¹ R. F. Wimmer-Schweingruber,³ D. E. Brinza,⁴ S. Kang,⁴ G. Weigle,⁵ S. Böttcher,³ E. Böhm,³ S. Burmeister,³ J. Guo,² J. Köhler,³ C. Martin,³ A. Posner,⁶ S. Rafkin,¹ G. Reitz⁷

The Mars Science Laboratory spacecraft, containing the Curiosity rover, was launched to Mars on 26 November 2011, and for most of the 253-day, 560-million-kilometer cruise to Mars, the Radiation Assessment Detector made detailed measurements of the energetic particle radiation environment inside the spacecraft. These data provide insights into the radiation hazards that would be associated with a human mission to Mars. We report measurements of the radiation dose, dose equivalent, and linear energy transfer spectra. The dose equivalent for even the shortest round-trip with current propulsion systems and comparable shielding is found to be 0.66 ± 0.12 sievert.

Galactic Cosmic Ray (GCR) and produced Secondaries in lunar regolith



Spacecraft data nails down radiation risk for humans going to Mars

Nature News, May 30, 2013, Ron Cowan

Interviewed Sheila Thibeault at NASA Langley about the study published in *Science*

Mars Science Laboratory (MSL) during its cruise to Mars between 6 December 2011 and 14 July 2012 (253 days)

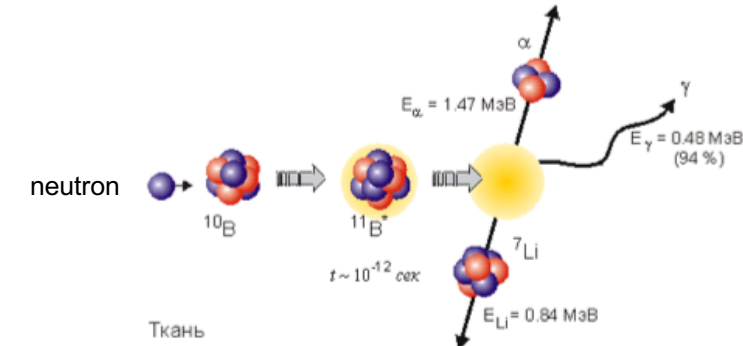
Mars Round Trip Dose Equivalent is around 0.66 Sievert

MRS Bulletin **40** 836 (2015)

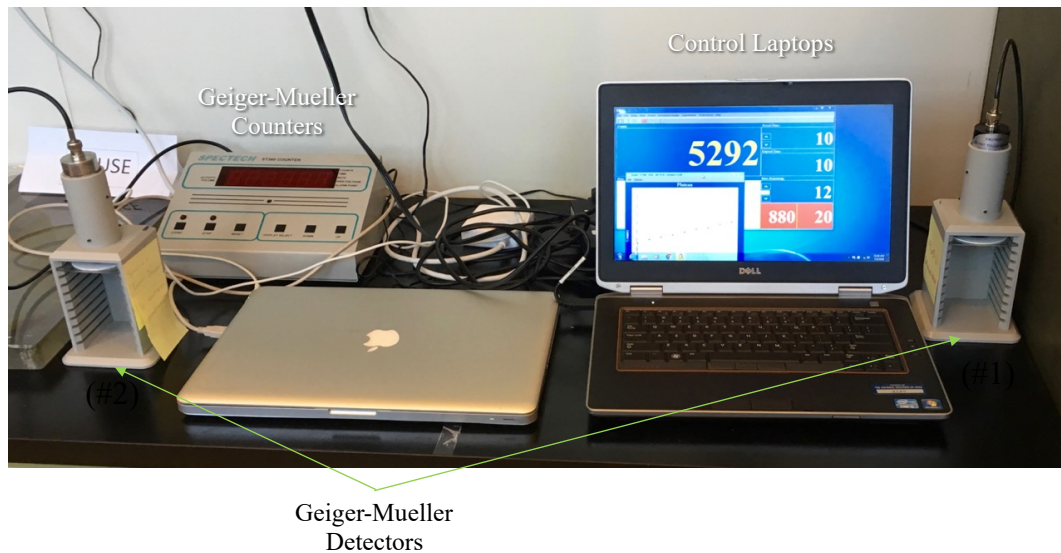
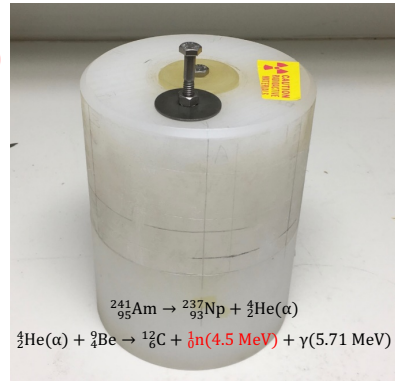
Radiation Tests: LaRC Radiation Exposure Test Facility

Neutron Source

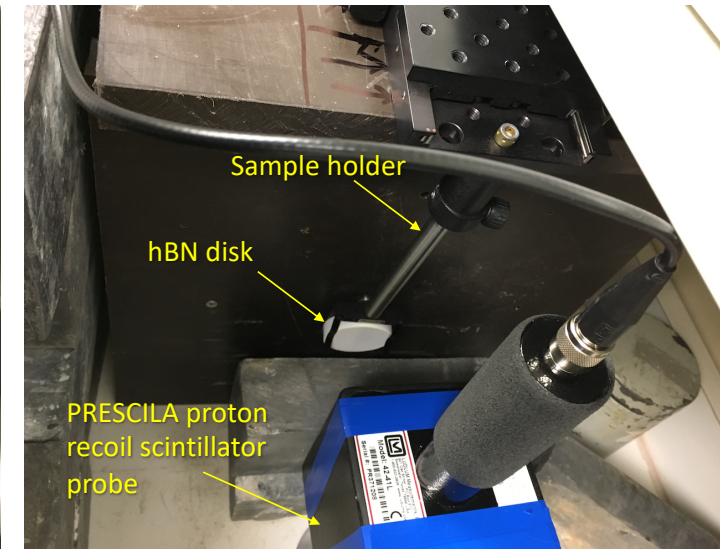
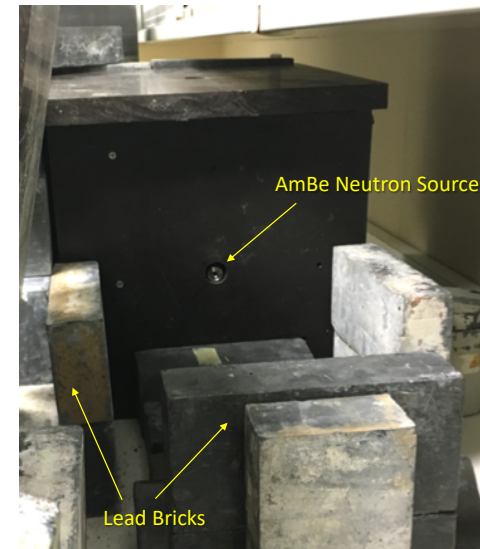
- Radioactive Source: Am/Be (1 Curie) source produces fast neutron (4.5 MeV) and thermal neutrons (<0.5 eV) by borated PE cylinder (44 mm thick)
- Sample: 2"x 2"
- Detection Foil: 1.25" Indium Foil (0.5mm, 19 barns), $^{115}\text{In}(n, \gamma)^{116}\text{In}$



Low Dose Rate (45 mrem/hr, dose equivalent rate)



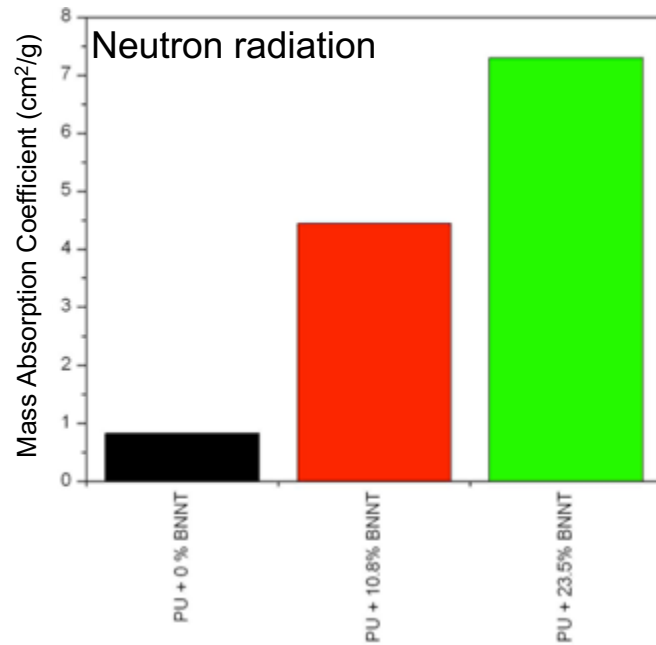
High Dose Rate (800 mrem/hr, dose equivalent rate)



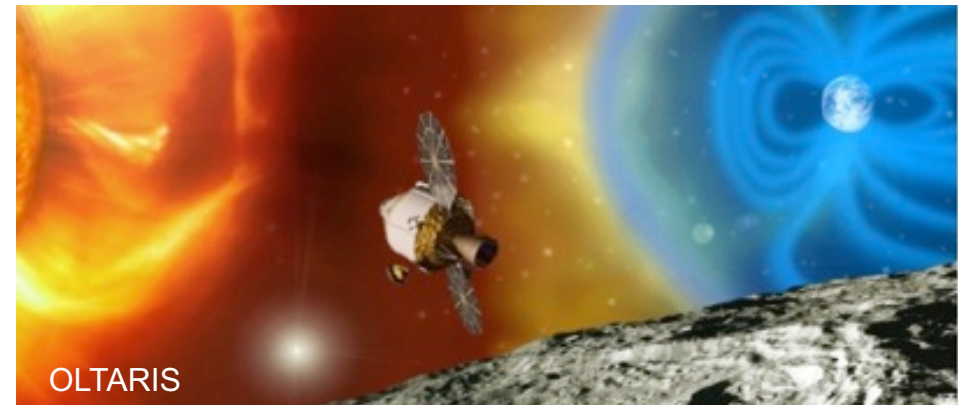
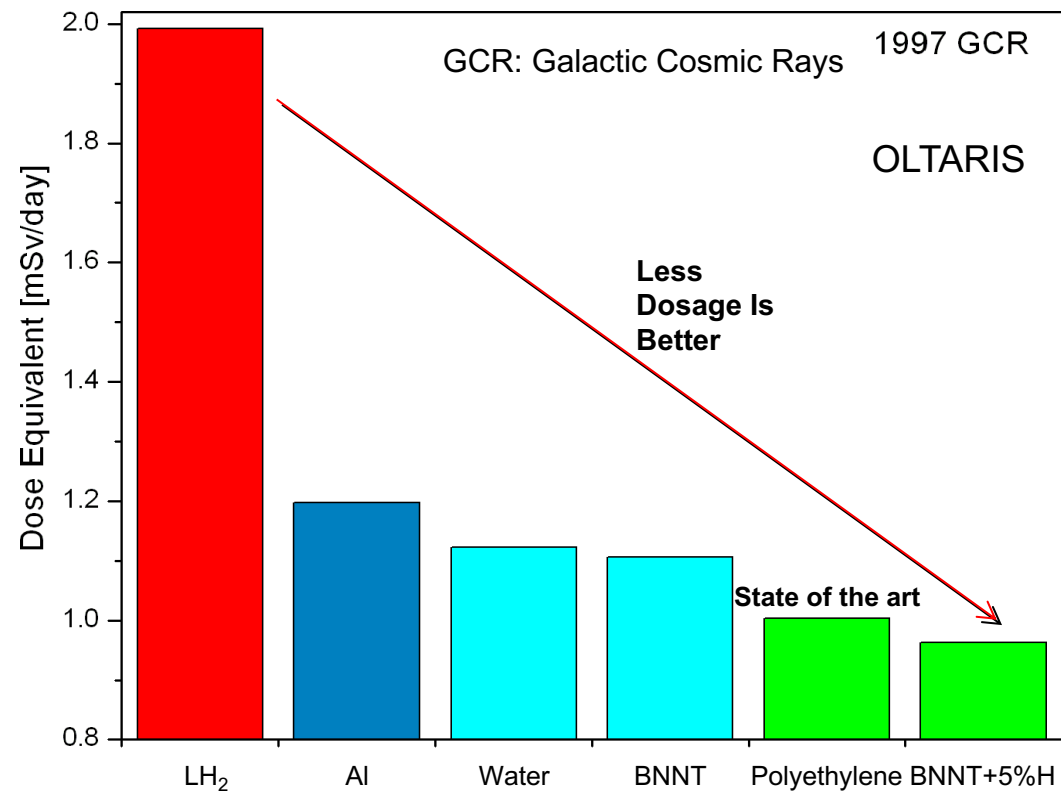
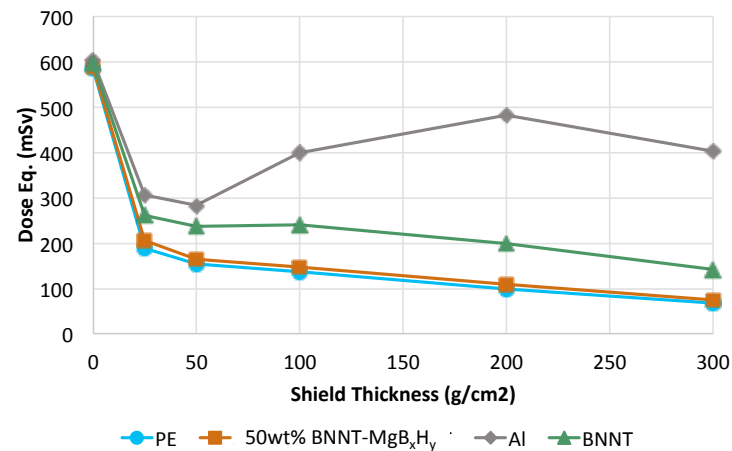
Dose Equivalent Rate Measurement

- Neutron survey meter: Ludlum Portable Survey, Model 2363
- Probe: PRESCILA proton recoil scintillator probe (Model 42-41L)
- Detection range: 0.1 mrem/hr to 1 rem/hr

Radiation Shielding Effectiveness of BNNT Composites

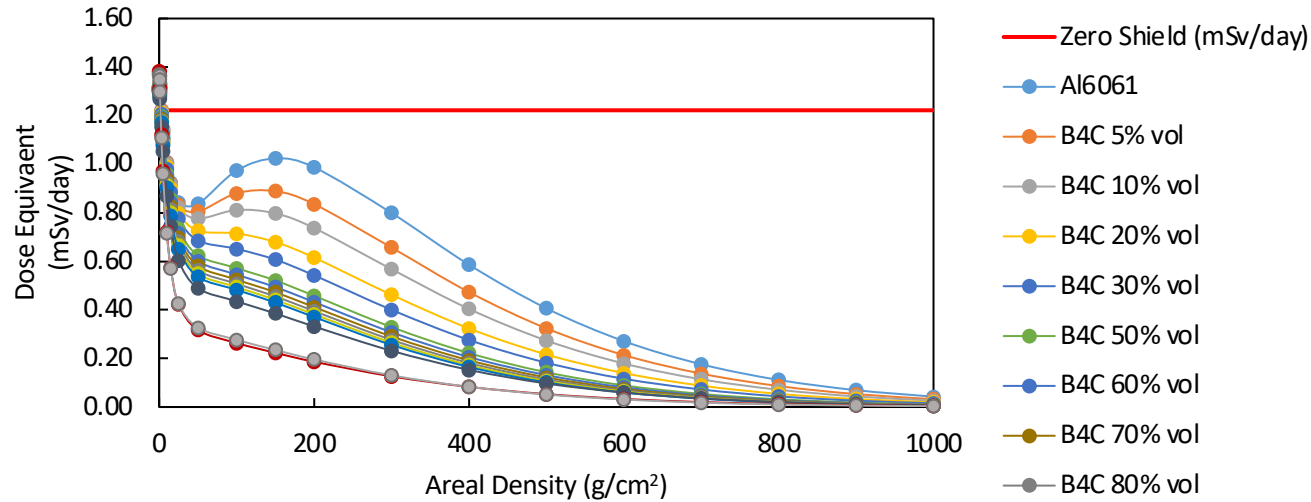


BON-14 GCR Model in **Free Space** with 1977 Solar Min. incident on Vehicles with varying thicknesses



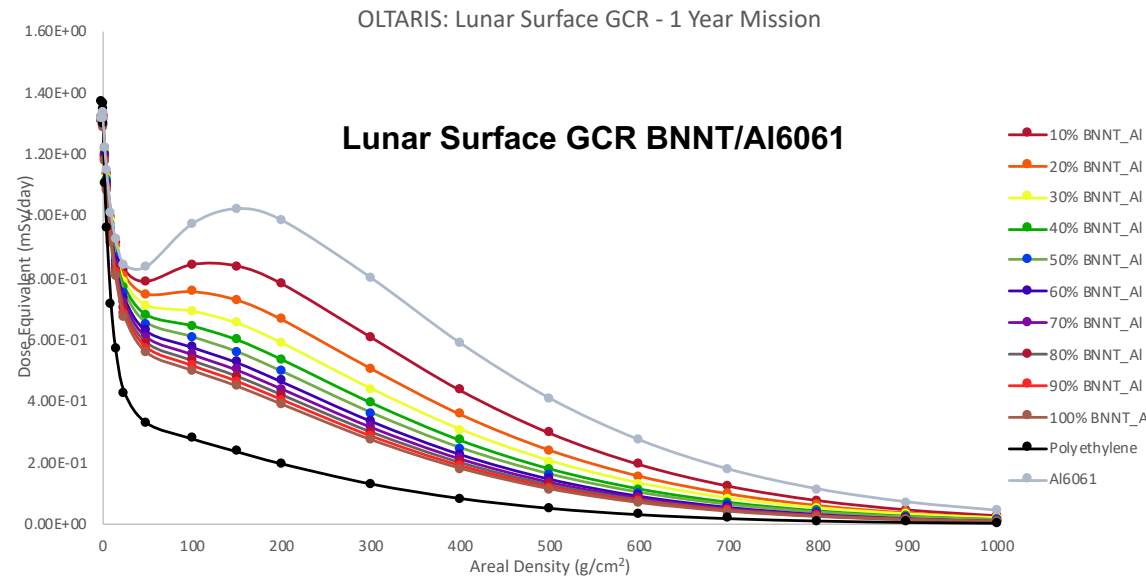
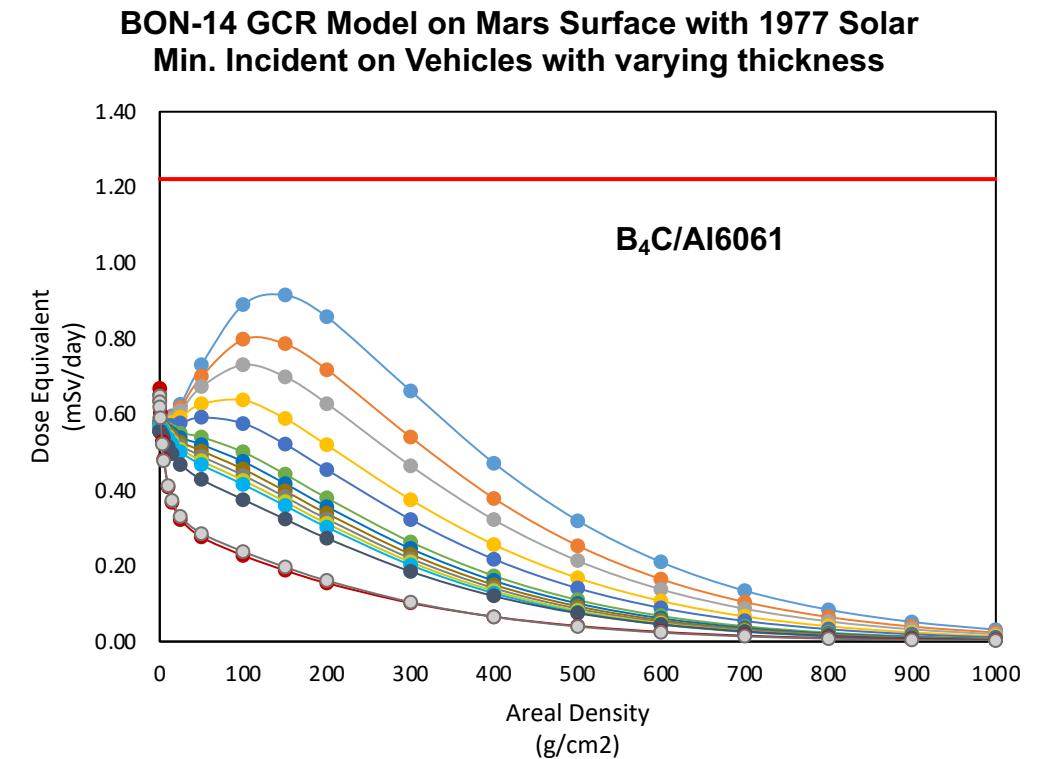
OLTARIS: GCR Lunar and Mars Surface Environment

BON-14 GCR Model on Lunar Surface with 1977 Solar Min. Incident on Vehicles with varying thickness: B₄C/Al6061



BON-14 GCR Model on Mars Surface with 1977 Solar Min. Incident on Vehicles with varying thickness

Parameters
Environment Selection: GCR, Mars Surface
Mission Definition: Select historical Solar Min/Max
Historical Min/Max: August 1972 (King)
Mission Duration Days: 365
Mars Surface Parameters: MarsGRAM Atmosphere
Elevation: 0.0 km



Summary



- High Temperature-Pressure BNNT synthesis method was introduced.
- BNNT dispersion was successfully achieved by thermodynamic approach using Hansen solubility parameters for single and co-solvent systems.
- Interfacial shear strength and fracture energy of BNNT with polymer, metal, and ceramic matrices were superior to those of CNT.
- BNNT exhibited excellent thermal stability under a simulated planetary entry environment along with flame resistance and retardation properties
- BNNT and BNNT polymer composites exhibited excellent piezoelectricity as well as electrostrictive behavior even without poling.
- BNNT exhibited excellent neutron radiation shielding effectiveness and hydrogen containing BNNT showed superb shielding effectiveness against GCR and SPE.

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NASA Education Programs

NASA Internship, Fellowship, and Scholarship (NIFS)

<https://intern.nasa.gov/>

NASA Space Grant

<https://www.nasa.gov/stem/spacegrant/about/index.html>

NASA Pathways Program

<https://www.nasa.gov/careers/pathways-program>

NASA Space Technology Graduate Research Opportunities (NSTGRO)

<https://www.nasa.gov/directorates/spacetech/strg/nstgro>

NASA Fellowship

<https://www.nasa.gov/stem/fellowships-scholarships/index.html>

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1998-00	NRC Research Associate at NASA Langley Research Center
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