

# Lightweight Damage Tolerant High-Temperature Radiators for Space Propulsion

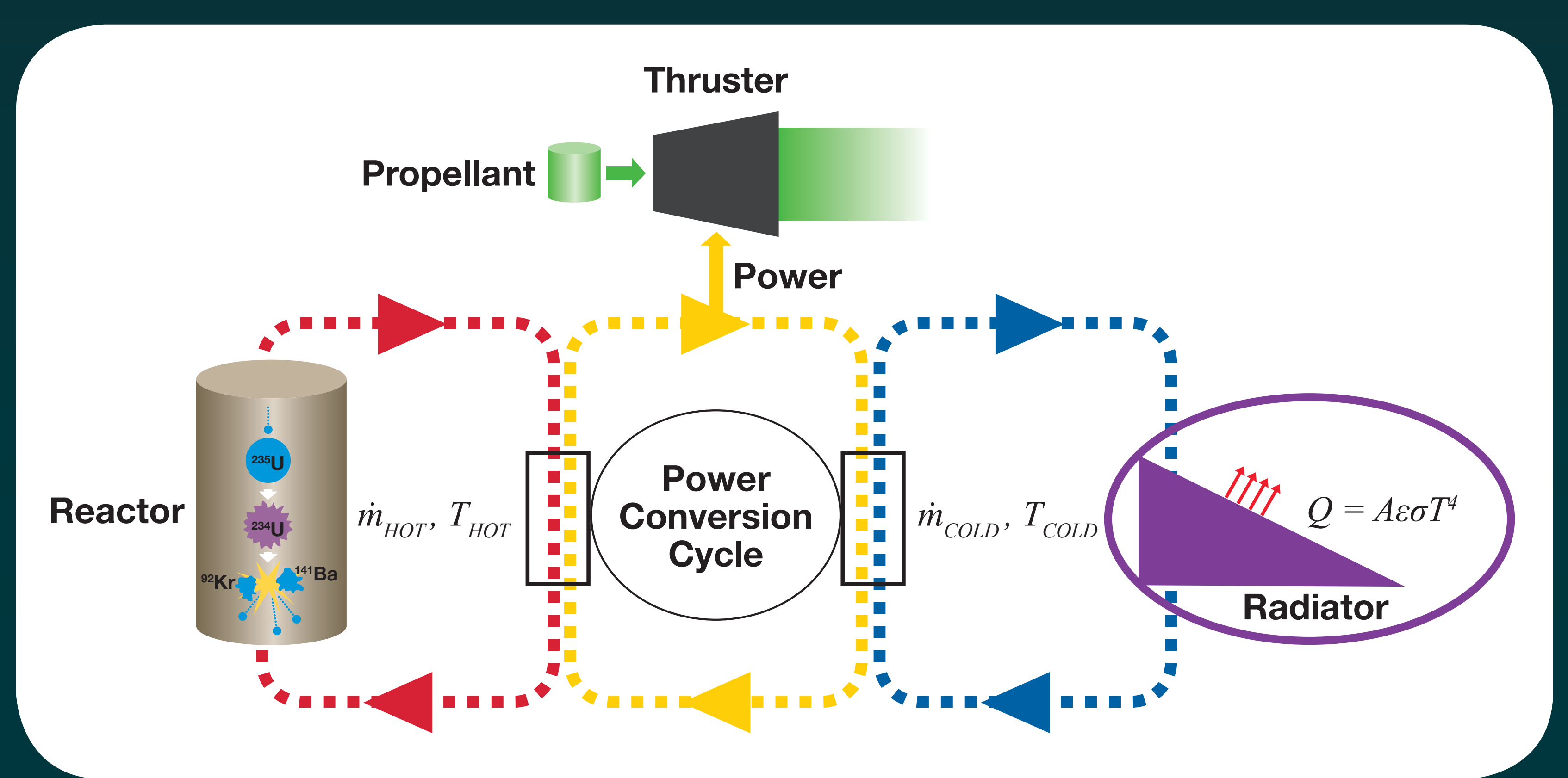
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## Background and Motivation

“Radiator advancement is perhaps the most critical thermal technology development for future spacecraft and space-based systems. Since radiators contribute a substantial portion of the thermal control system mass.”

Thermal Management Systems Roadmap (Technology Area 14), NASA 2012

Game-changing propulsion systems are often enabled by novel designs using advanced materials. Promising new technologies may require high operating temperatures and will benefit from the use of advanced lightweight materials in a heat rejection system. Radiator performance dictates power output for nuclear electric propulsion (NEP) systems. Carbon nanotubes (CNT) and carbon fiber materials have the potential to offer significant improvements in operating temperature, thermal conductivity, and mass properties.



## Radiator Requirements

What is needed in radiators for space power and propulsion?

- Low mass
- Efficient Radiation
- Small Areal Density
- Damage tolerance
- Areal densities of 2–4 kg/m<sup>2</sup>

What is currently available

- Conventional — metal or composite
  - High mass
- Low operating temperature
- Does not meet the areal density requirement
- Performs as required in the environment

## Radiator Material Comparison

Fin Material	High Temperature Tolerance (Want HIGH)	Axial Thermal Conductivity (Want HIGH)	Density (Want LOW)
Aluminum	Low	Moderate	Low
Molybdenum	High	Moderate	High
Carbon-Carbon Composite	High	Moderate	Low
Carbon-Polymer Composite	Low	Moderate	Moderate
Bare Carbon Fiber	High	High	Low

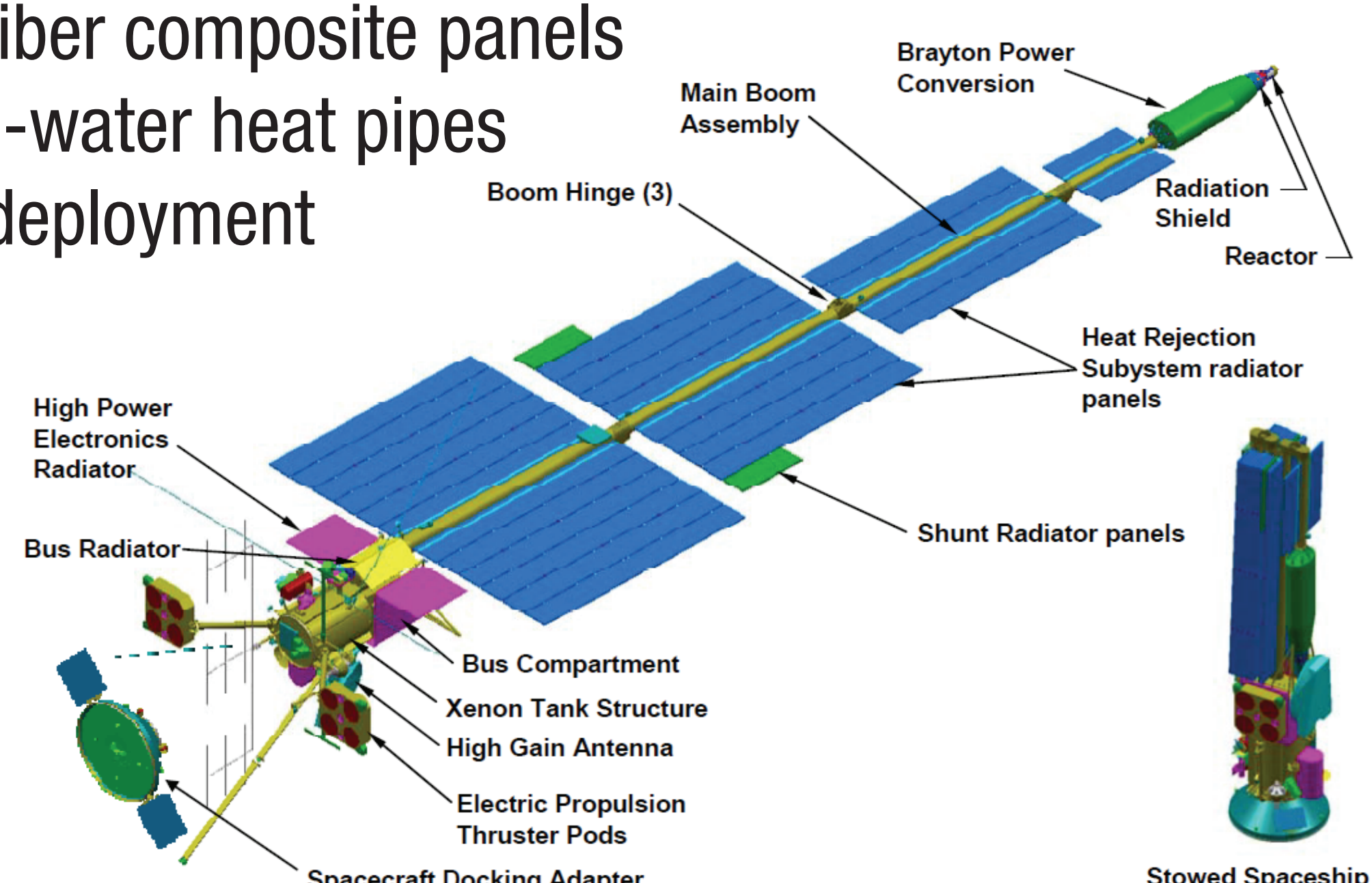
Ref. 1



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## JIMO Radiators

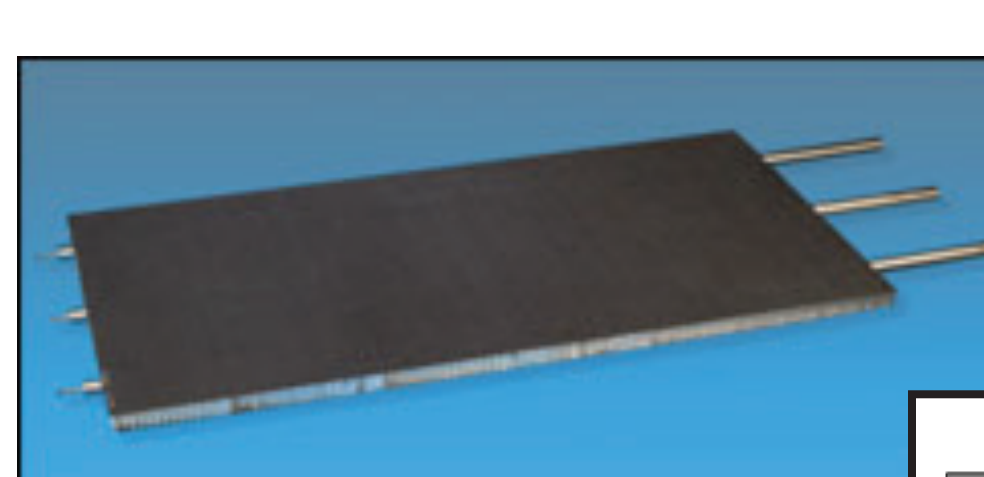
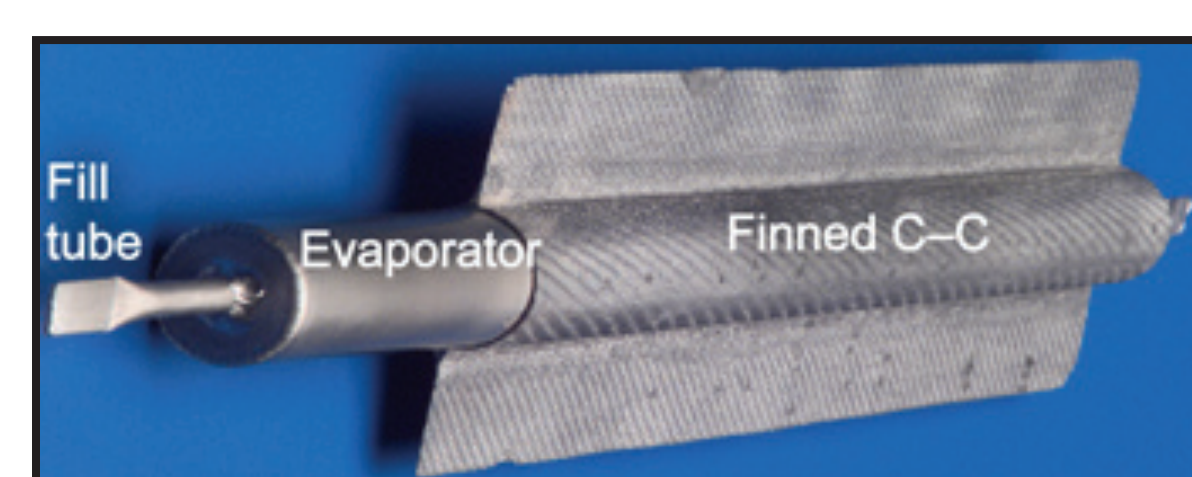
- Operating temperature: 100°C
- Main fluid loop: NaK
- Carbon fiber composite panels
- Titanium-water heat pipes
- Scissor deployment



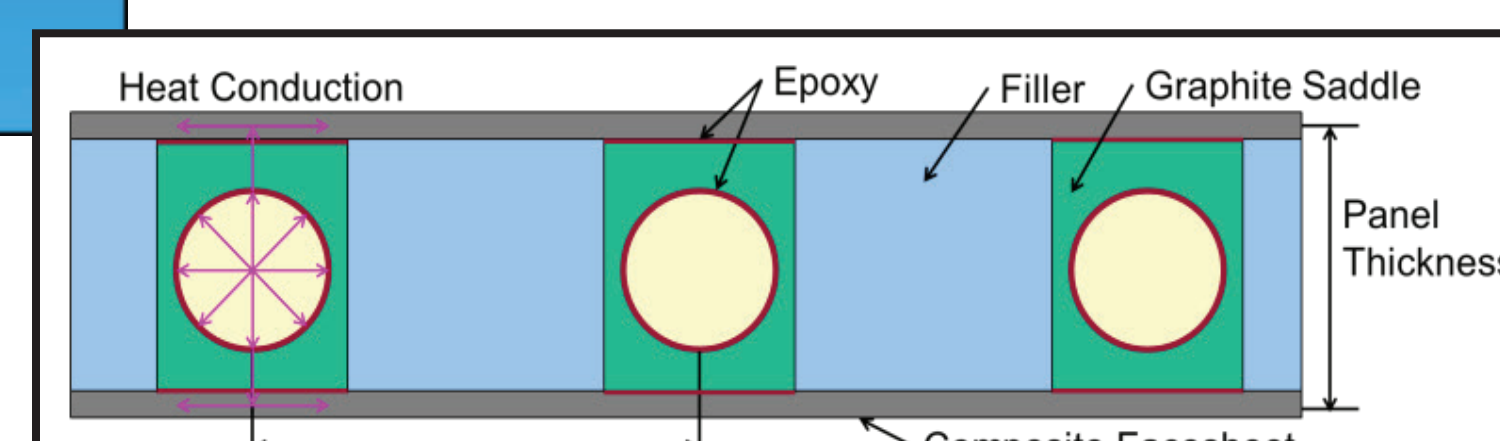
Ref. 1, 2, 3

## Typical Conventional Fin Construction

Wrapped Fin

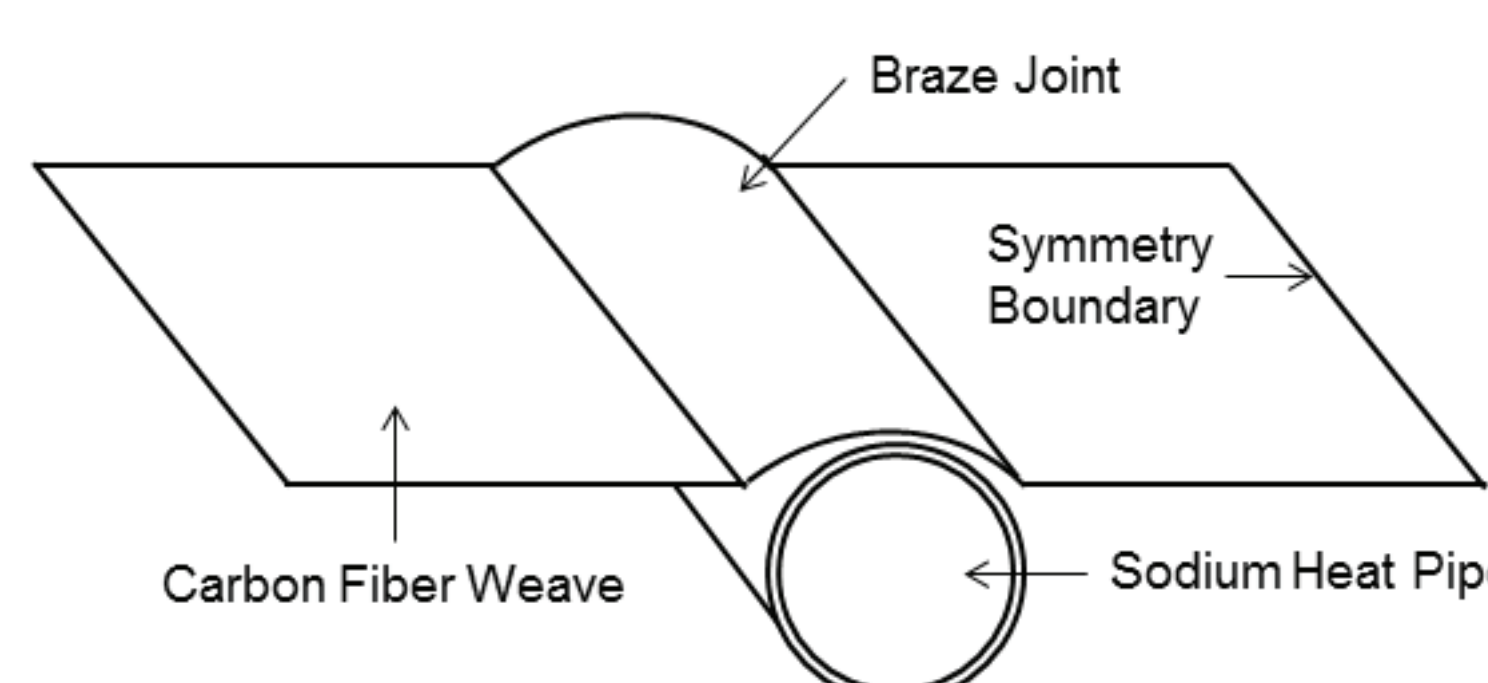


Structural Panel



## Possible Designs

- Separate structural from thermal
- Use woven high thermal conductivity carbon fibers with no matrix material
- Attach fibers directly to metal heat pipe through high temperature brazing
  - Ceramics to metal



Ref. 4



Carbon fiber radiator design

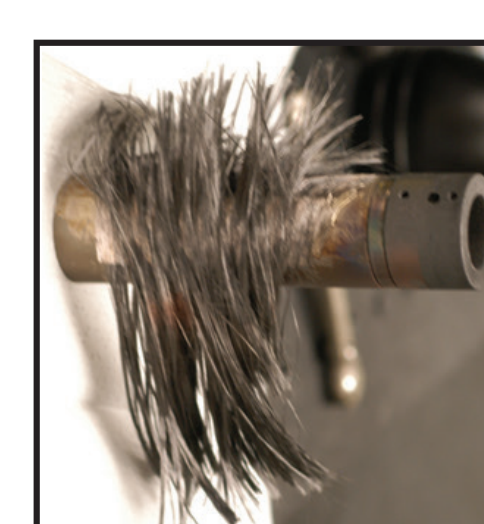
Ref. 5

## Characteristics of Pitch Carbon Fiber K13D2U

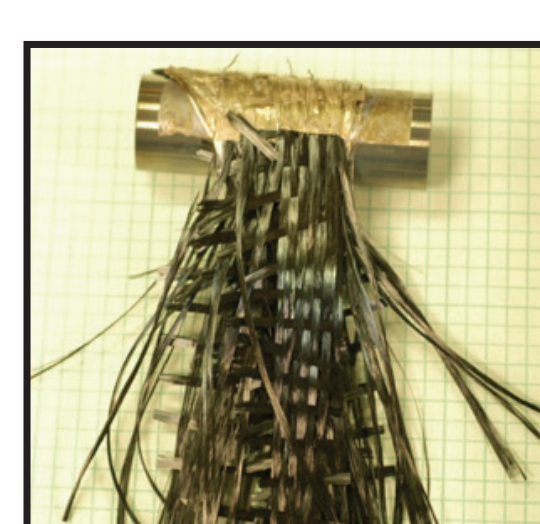
- Low density (2.2 gm/cm<sup>3</sup>)
- High axial thermal conductivity (800 W/mK)
- Broad operating temperature range (0–>2000°C)
- High emissivity (0.8)
- Readily available
- No readily available woven textile material

## Manufacturability of Fins

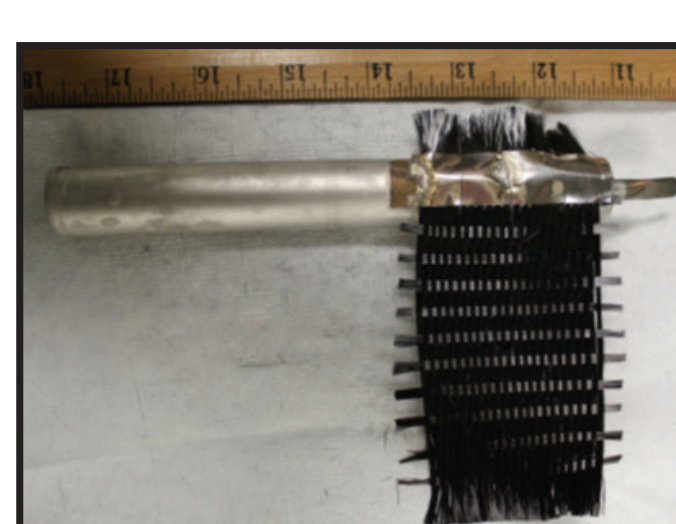
- No commercial mats made with this material
- Hand woven in the laboratory
- Collaborated with a textile manufacturer\* to develop a method to weave fibers on a mass scale



First articles were with unwoven fibers across tube



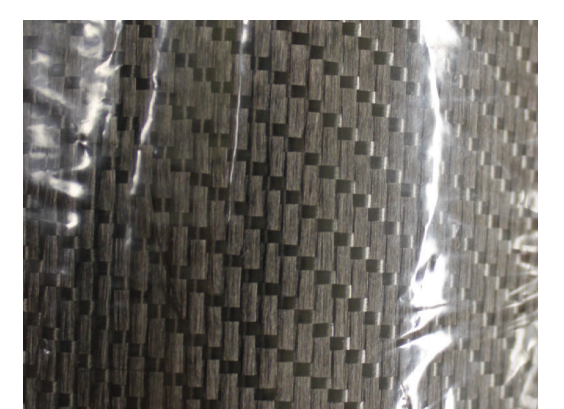
Developed a method to hand weave fibers in the laboratory



Further developed the hand weaving method



Hand woven in the lab



Textile from Manufacturer

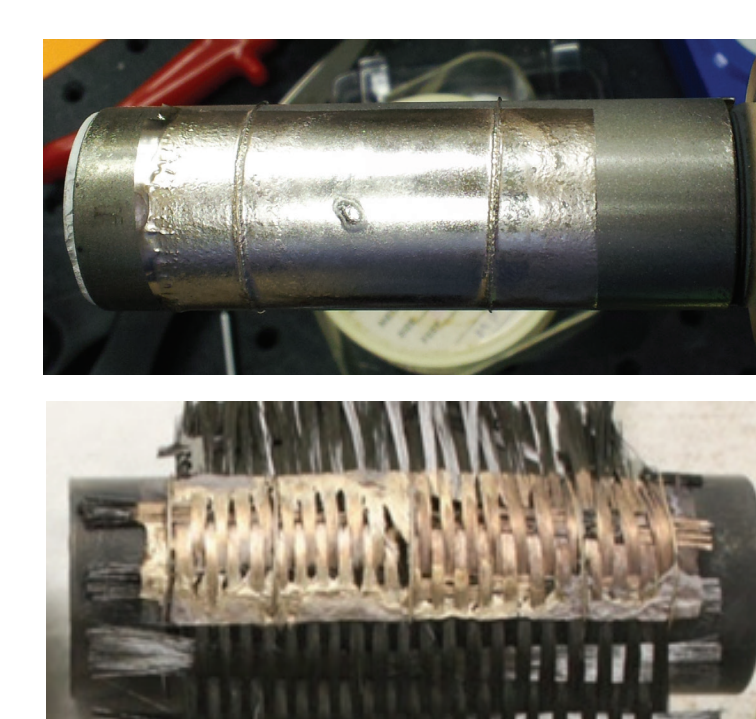
\* Textile Engineering and Manufacturing

## Attachment

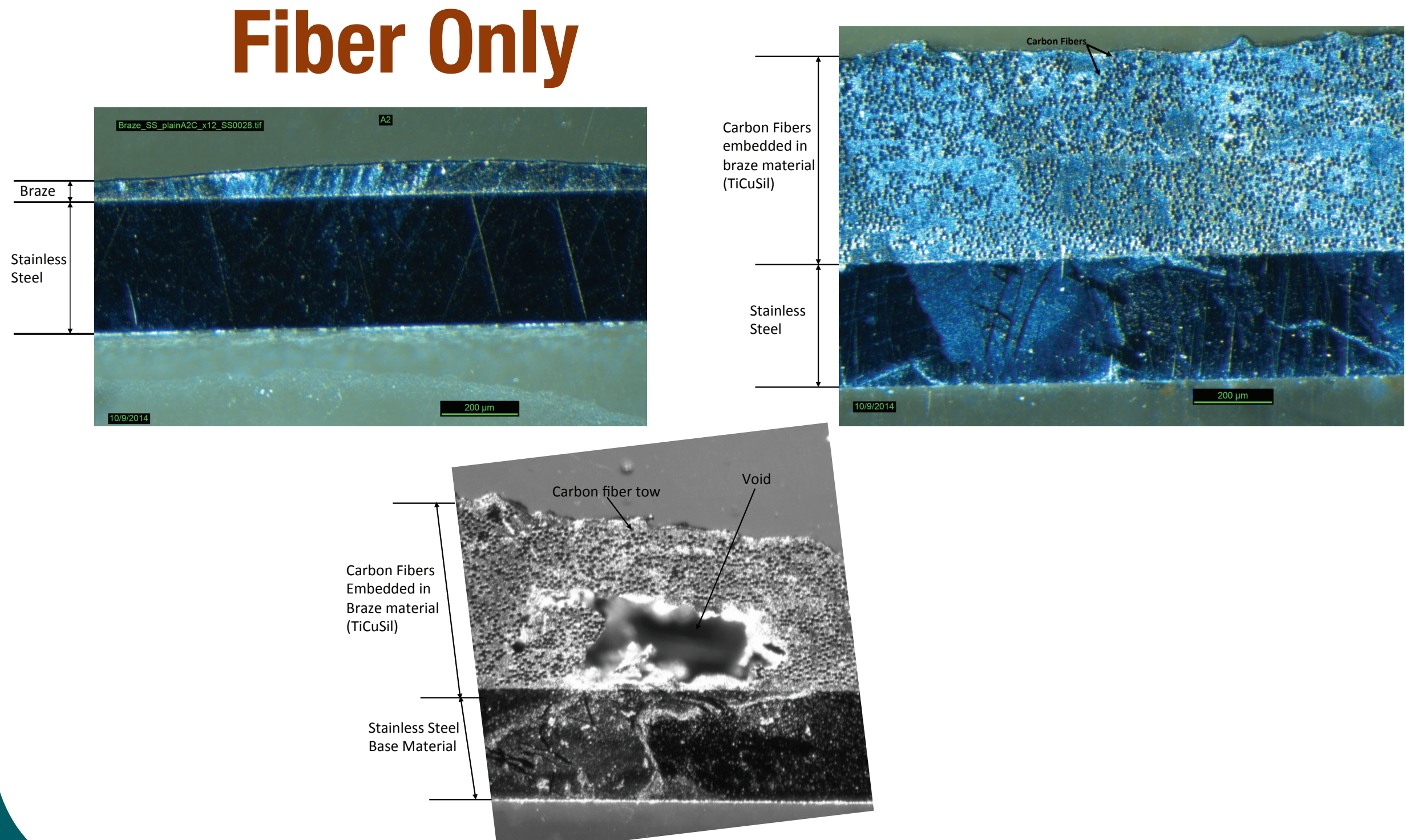
- Two important considerations for attachment
  - Thermal contact
  - Strength of attachment



- With carbon fibers
  - More dense weave, brazing quality drops with internal heating
    - Radiative losses
  - Isothermal furnace-external heating of all components

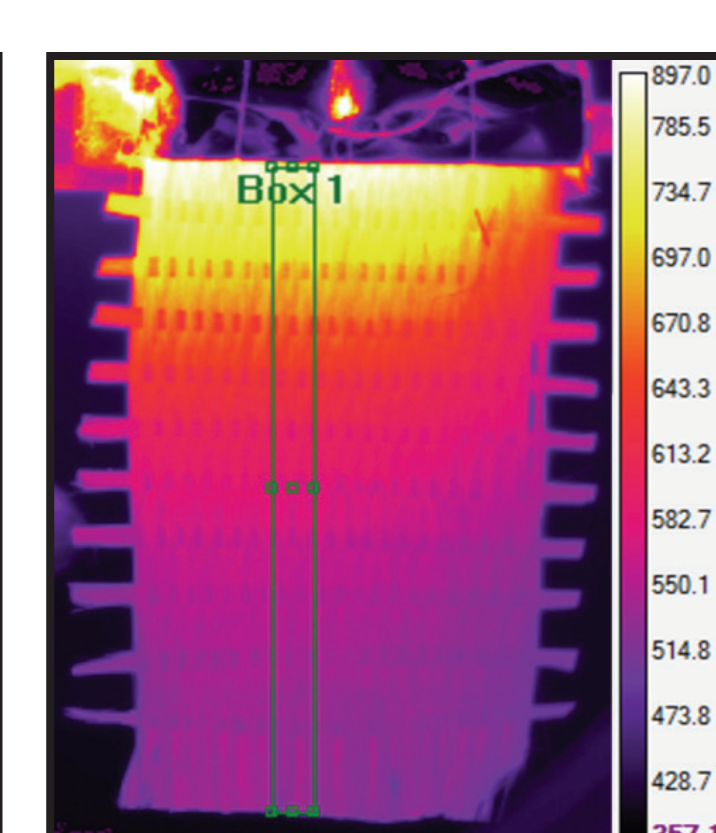
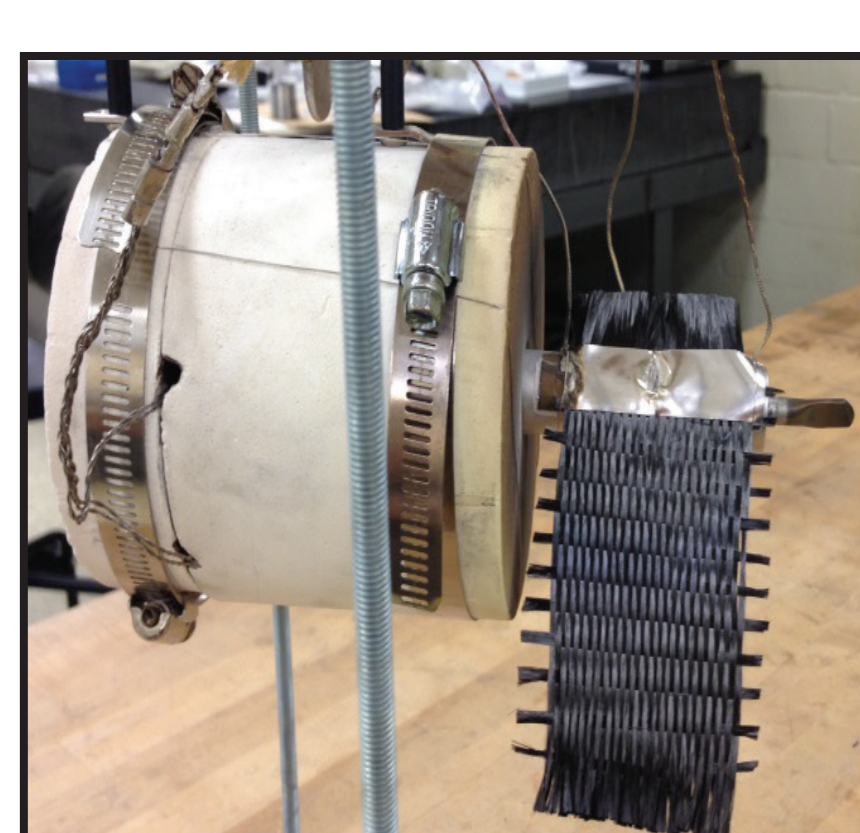


## Attachment – Braze Material Only and Braze with Carbon Fiber Only

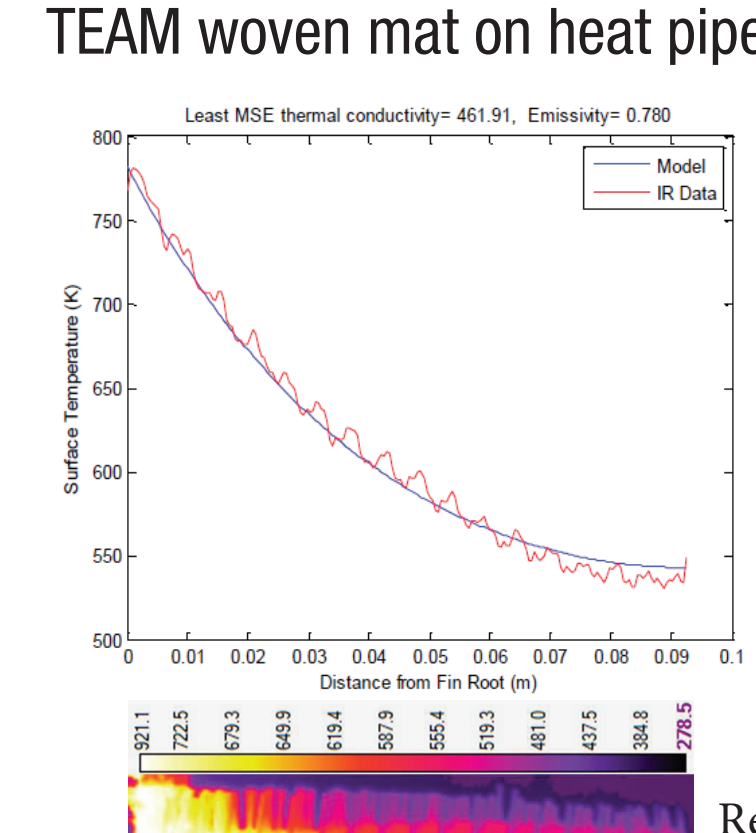


## Test Setup for Heat Pipe Sample

- Left image is current setup for testing heat pipe samples.
- Right IR image is a heat pipe with fin sample under test.
- Analysis of the surface temperature indicates:
  - Power rejected per meter of heat pipe ~980 W/m
  - A specific power of 38.1 kW/kg for that fin.



TEAM woven mat on heat pipe



Ref. 6

## Future Work

- Continue improving brazing technique
- Build a demonstration unit
- Continue to reduce experimental uncertainties
- Continue to look for potential opportunities for further advancement and implementation

## References

- 1 R.W. Hyers, et al., Lightweight High-Temperature Radiator for Space Propulsion, Advanced Space Propulsion Workshop, 2012, Huntsville, AL
- 2 Mason, Lee S., A Power Conversion Concept for the Jupiter Icy Moons Orbiter, Journal of Propulsion and Power, vol. 20, No. 5, 2004
- 3 Project Prometheus Final Report, Jet Propulsion Laboratory, NASA Report No. 982-R120461, 2005
- 4 Tomboulia, B. N. and R. W. Hyers, High-Temperature Carbon Fiber Radiator for Nuclear Electric Power and Propulsion: Project Overview and Update, Nuclear and Emerging Technologies for Space 2014, Infinity Science Center, MS, February 24–26, 2014
- 5 D.G. Walker, E.A. Vineyard, R. Linkous, Modeling and Analysis of a Heat Exchanger with Carbon-Fiber Fin Structures, <<http://www.heatpumpcentre.org/en/projects/completedprojects/annex%2033/publications/Documents/Vineyard%20carbon%20fiber%20hx.pdf>>, accessed June 4, 2014.
- 6 Tomboulia, B.N., Lightweight, High Temperature Radiator for In-Space Nuclear-Electric Power and Propulsion, PhD Dissertation, U. Mass, 2014