Heat Pipe/Thermal Technologies at GRC

NESC Thermal Technical Discipline Team Webinar (virtual)
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Biographies

Jim Sanzi

- BS, MS Engineering
- 46 years Heat Pipe experience
- 19 years at NASA Glenn Research Center
- Supporting Thermal Energy Conversion (LET) Branch
- Develop/advance thermal management for space power conversion technologies

Greeta Thaikattil

- BS, MS Mechanical Engineering
- 7 combined years at NASA Glenn Research Center
- 4 years at Thermal Energy Conversion (LET) Branch
- Develop/advance thermal management for space power conversion technologies

Agenda

- Overview of Heat Pipes
- Tests and Technology Development at GRC
  - Heat pipes in Radiators
  - Heat pipes in Reactors
  - Qualification of Heat Pipes
  - Pumped Liquid Metal
  - Miscellaneous Thermal Testing
- Testing facilities

NOTE: There's a variety of thermal technologies that have been developed/used at GRC such as heat pipes, pumped liquid metals, high temperature MLI, materials testing, etc. This presentation mainly focuses on heat pipes, but will also go over other major technology efforts

Introduction

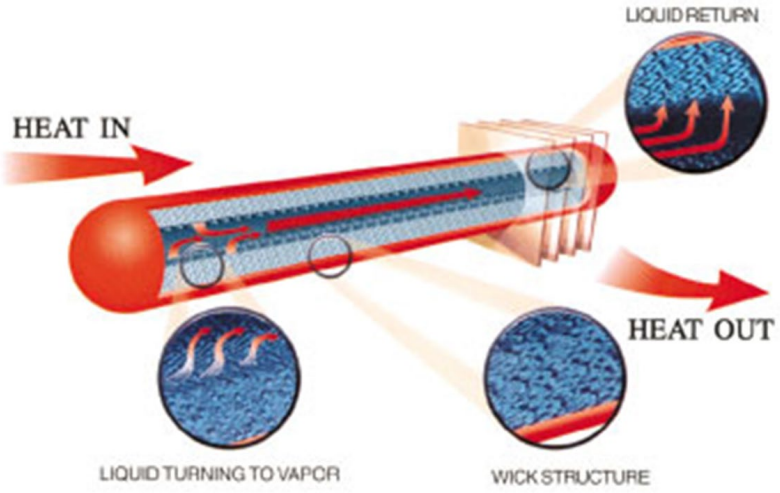


Illustration of a Capillary Two-Phase Heat Transfer Device- a Heat Pipe

What is a Heat Pipe?

- A passive two-phase heat transfer device in a hermetically sealed vacuum tube
- Evaporator region takes ***Heat In*** from Heat Source
- Working fluid inside evaporates and is transported to the other end of the tube
- Here, vapor condenses to release the latent heat to the tube wall/ ***Heat Out***
- Condensed fluid is transported back to the evaporator by the capillary action of an internal wick
- Passive mode of heat transport: no power, no moving parts

Why use a Heat Pipe?

- Great for **isothermal** heat transport
- Can be designed to operate in low/micro-gravity environments
- Can provide redundancy

Applications of Heat Pipes

- Transporting thermal power from a heat source to another component
- Passive heat spreading in radiators
- Applications
  - Fission Surface Power
  - Nuclear Electric Propulsion
  - Aeronautics
  - Cube-satellites
  - Battery management
  - Electronics cooling

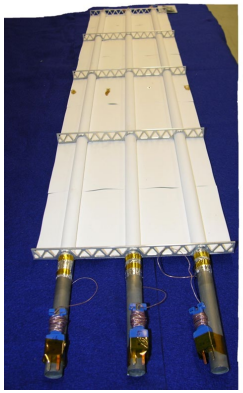
State of the Art Radiators

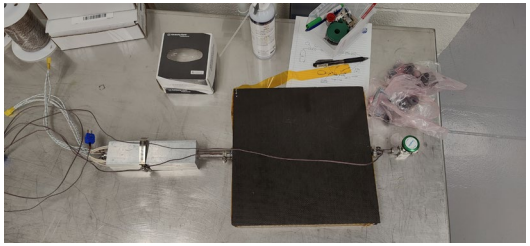
Past/Current

International Space Station Radiators

- Pumped ammonia fluid with aluminum face-sheets
- Designed to operate <10 °C
- Area Density ~9 kg/m2
- TRL 9

New



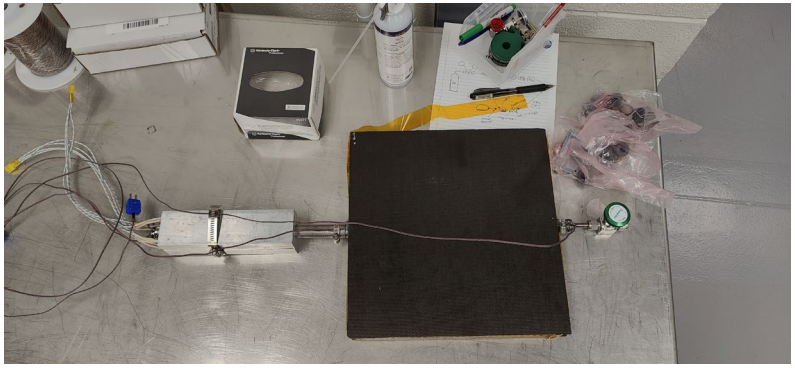


Heat Pipe based Radiators

- Face-sheets (Aluminum, Carbon-Carbon, etc.) bonded to heat pipes
- Heat Pipes are fluidically and hermetically independent- offering redundancy
- Can be designed to operate from 125-300 C
- Lightweight design: areal density ~3 kg/m2
- TRL 5

Heat Pipes in Radiators

Creare, Phase II SBIR
Aluminum Brazed Fin to Titanium-Water Heat Pipe

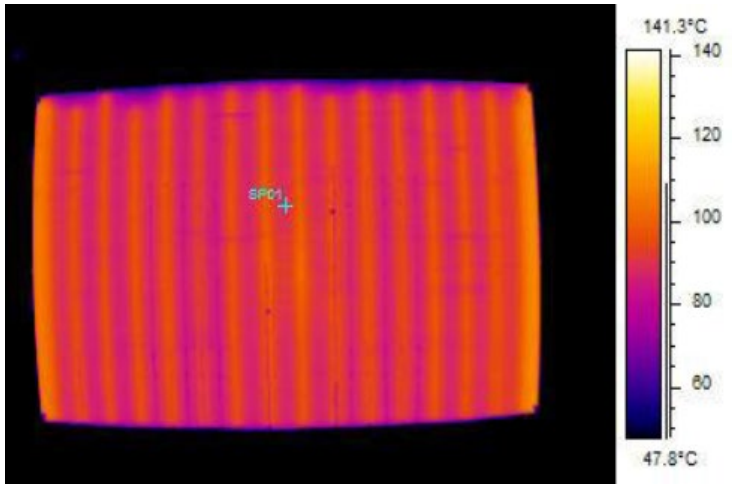


Advanced Cooling Technologies, Phase I SBIR
Titanium-Water heat pipe with Carbon Facesheet, AIAA 2007-4822

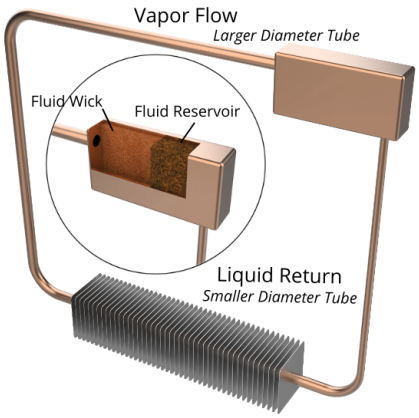
Heat Pipes in Radiators

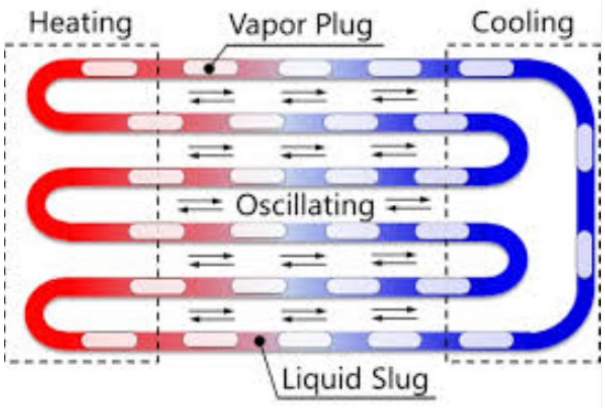
Full Scale Radiator Demonstration (RDU) for Fission Surface Power NETS 2011

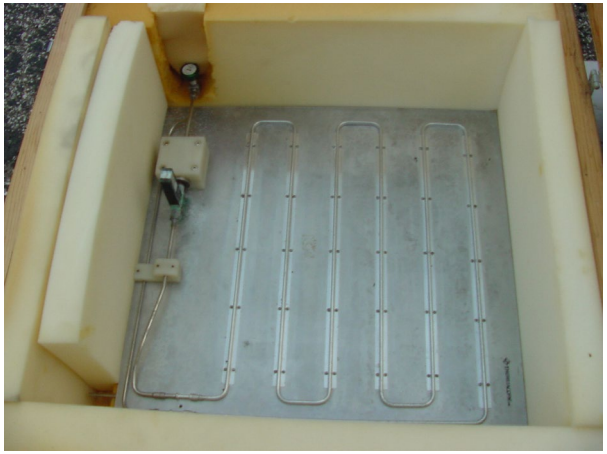
- RDU was thermal vacuum tested
- Frozen start with cold wall- IR camera image
- Radiator panel, made of Carbon-Carbon, was built by Materials Innovations, Inc
- The heat pipes were provided by Thermacore Inc.
- Specs
  - 2.5 M x 3M panel
  - Dissipated 6KWth
  - Operated at 400 K
  - Areal density of 3 kg/m2 double sided
- Test advanced this radiator design to **TRL 5**



Heat Pipes in Radiators







Aluminum NH3 Loop Heat Pipe
HT2009-88509 LHP

Aluminum-Alkane OHP
Phase II SBIR by ThermaVant

Heat Pipes in Reactors

Kilopower Reactor Using Stirling TechnologY (2018)

- Collaboration between NASA & LANL
- 1 kWe Integrated test between a reactor and Stirling engines
- Sodium heat pipes used to cool the core and transport thermal power to engines
  - 800 C
  - Great load balancing & redundancy
- First integrated fission power system for space application in 50 years
- First heat pipe cooled reactor

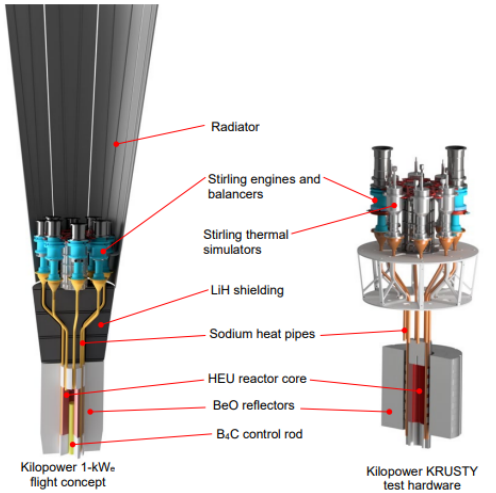


Figure 1.—Kilopower 1-kW_e nuclear power system flight concept comparison with Kilopower Reactor Using Stirling TechnologY (KRUSTY) nuclear test hardware. HEU, highly enriched uranium.

20180007389.pdf (nasa.gov)

Heat Pipes in Reactors

Consolidated Heat Pipe 2023-2024

- Follow on development from KRUSTY
- Sodium Heat Pipes directly coupled to Stirling engine for efficient thermal power delivery
- Tested in ambient-air in June 2023
- Vacuum testes in 2024
- Proved an isothermal interface to the Stirling engines
- 58x reduction in temperature differential at interface compared to previous design

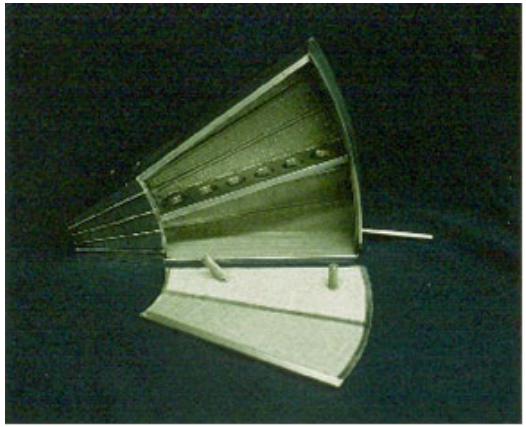
LET Thaikattil, G. Paper_TFAWS 2023.final.pdf (nasa.gov)

AIAA SciTech 2025

Qualifying Heat Pipes

Life Testing

CP 2 Titanium-Water Life Test with 50,000 Hrs. Ref.
NASA/CR-2007-214820



Inconel 718 sodium heat pipe –Thermacore, tested for 10 years, no degradation
16th International Heat Pipe Conference (16 IHPC)
Lyon,France May 20-24, 2012

Low- Gravity Testing

Ninth International Conference
Two-Phase Systems for Ground and Space Applications 2014

Thermosyphon Flooding in Reduced Gravity
NASA/TM2013-217905

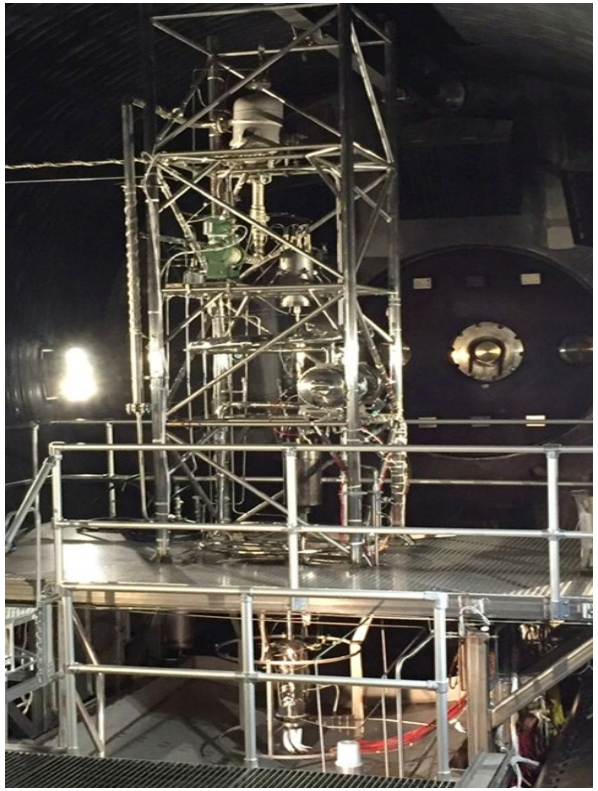
Radiation Testing

Titanium-Water Thermosyphon Gamma Radiation Exposure
NASA/TM—2012-217732 AIAA-2012-4078

Pumped Liquid Metal in Heat Transport

40 kW Technology Demonstration Unit (TDU)

- Pumped liquid metal - alternative to heat pipes in heat transport
  - An active mode of heat transfer
  - Pumped NaK loop (870K),
  - An Annular Linear Induction Pump (ALIP) was used to pump NaK from a simulated reactor to Stirling engines
  - 4x 12 kWe Stirling engines; A 12 kW Stirling engine-pair was tested
- (TDU) was tested in VF 6
- Structure was representative of a 40 kW Fission Surface Power unit



TDU with Stirling Engine Technology
NASA/TM -2016-219382

Misc. Thermal Testing

- High temperature Multi-Layer Insulation (MLI)
- Thermal Interface Materials
- Custom heat pipe evaporator interfaces
- Studies of NaK in space environments
- Bonding of heat pipes to various heat source elements

Titanium water thermosyphons with enhanced surface area

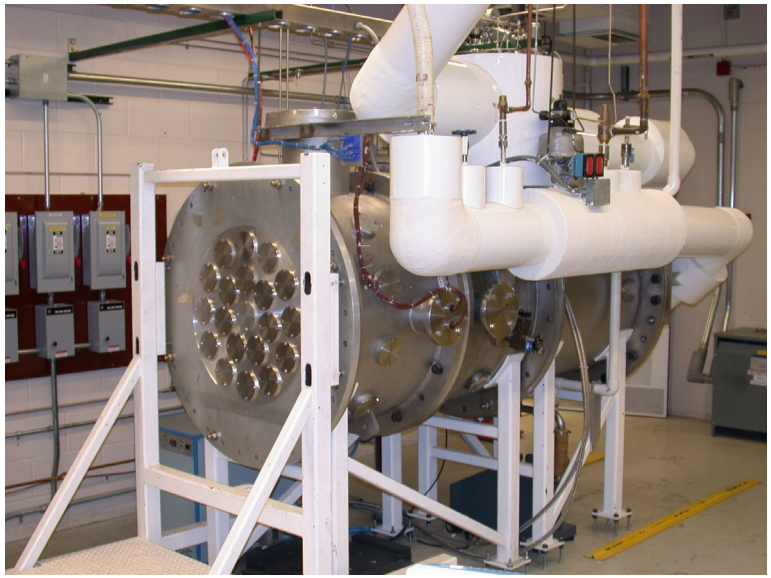
Instrumented 600 W heater with 5 layers of SS foil with quartz fabric

Tightly Clamped	Loosely Clamped
Grafoil HT1205	
Grafoil HT705	
Aavid Thermalloy	Aavid Thermalloy
Silver Leaf	
Copper Leaf	
T-Mate	
No Interface	No Interface

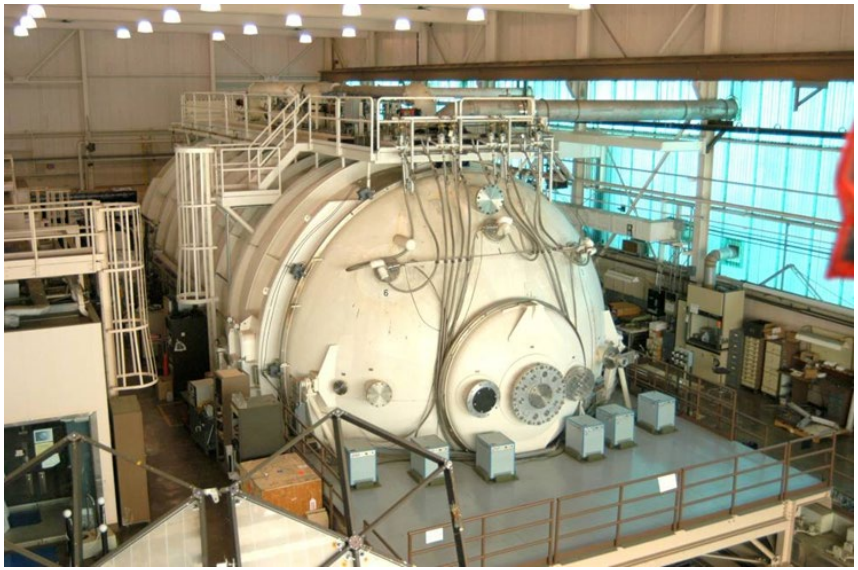
IECEC063009c-2009

Thermal Vacuum Testing Facilities

Liquid Nitrogen Cold Wall
Vacuum Facility 17

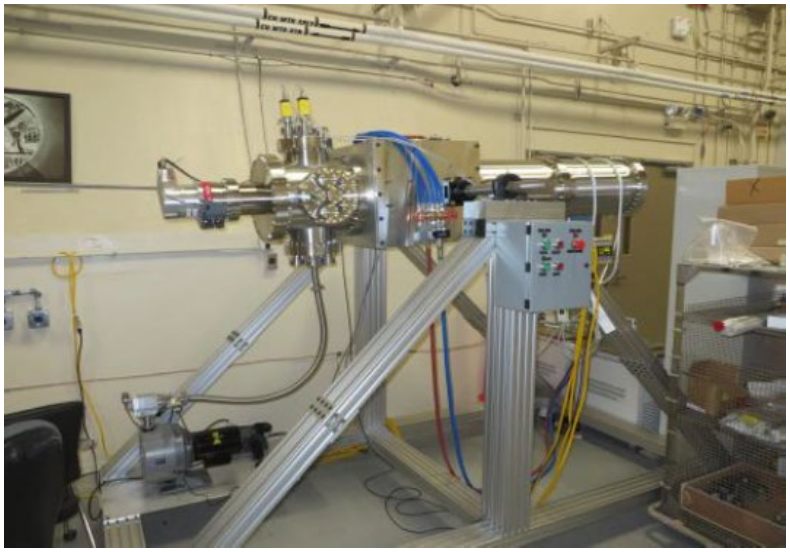


Vacuum Facility 6
25’ Dia. X 68’ Long
Liquid Nitrogen Cold Wall



Thermal Vacuum Testing Facilities

Rotatable Vacuum Chamber



Vacuum Bell Jar

Questions