SunShot
U.S. Department of Energy

CSP Program Summit 2016

Los Alamos
NATIONAL LABORATORY
EST. 1943

High Temperature Thermal Array for Next Generation Solar Thermal Power Production

Project Dates: December 1, 2012 to August 31, 2016

Project Budget: $2.08M

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energy.gov/sunshot

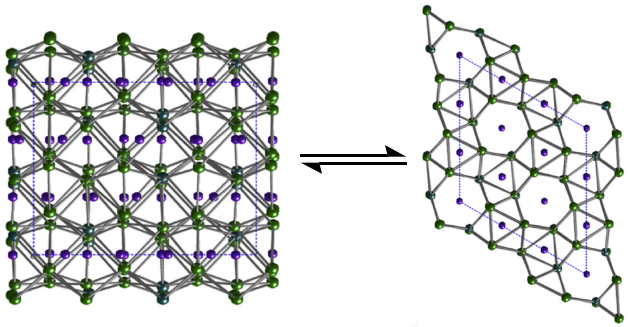
LA-UR-16-22613

LANL CSP Technology

Development of technologies to maximize system exergy and enable the use of high efficiency power cycles.

Thermochemical Storage

Low-cost solid state materials which undergo thermochemically-active thermal storage reaction



Heat Transfer Fluids

CX-500

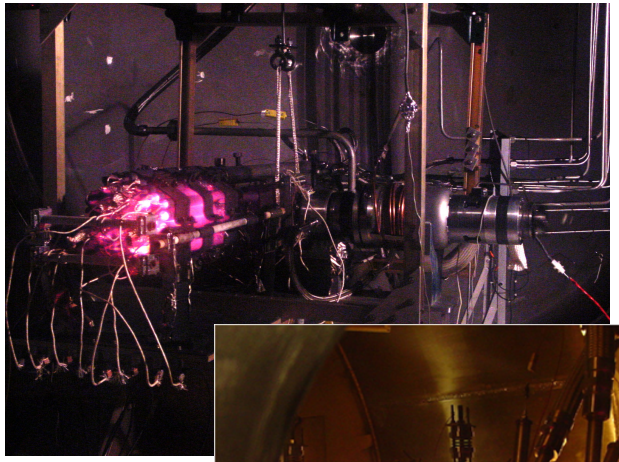
- Clear colorless low-viscosity fluid
- -40°C gel point
- Thermally Stable to + 570°C

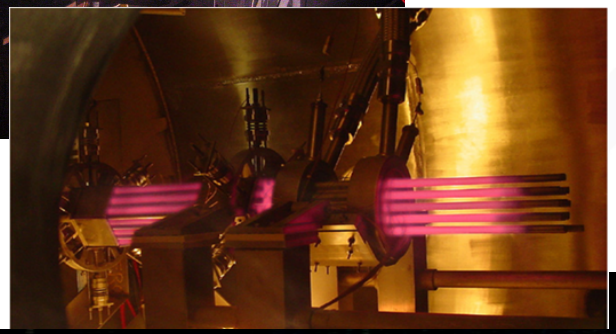
Conductivity, viscosity, specific heat comparable to DowTherm

Thermochemical Storage Technology

Heat Pipe Receiver Technology

LANL Core Competency – High Temperature Heat Pipes



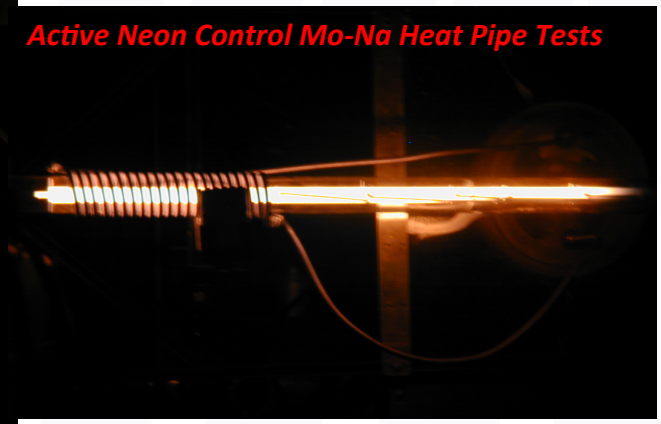


SAFE Heat Pipe Reactor Prototypes

- Heat pipe invented at Building 1, TA-46 in July 1963 by Grover, Cotter, and Erickson
- First technological demonstrations and first practical applications
- High temperature and high heat flux reactor core cooling
- Steady state and transient heat pipe performance.
- High temperature heat pipe degradation
- Heat pipe lifecycle optimization

Counter gravity heat pipe demonstrations

Materials Compatibility Tests

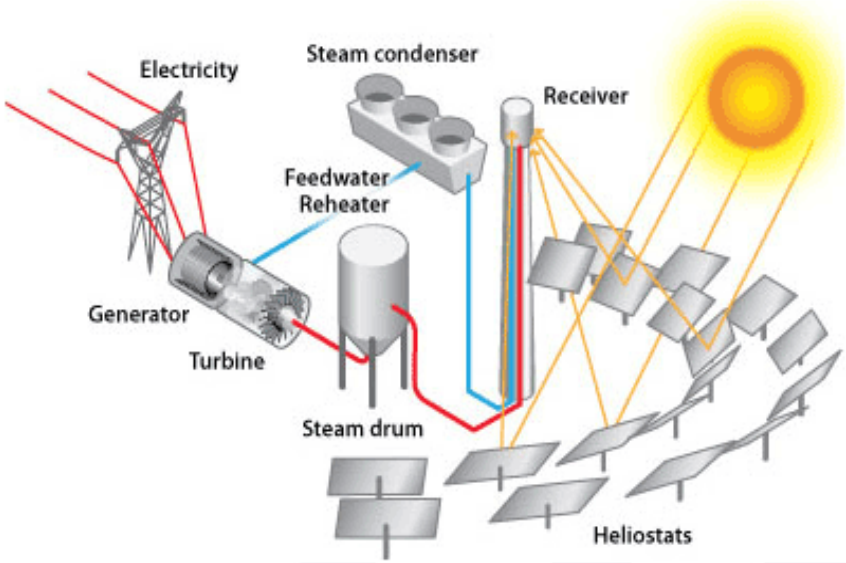


Active Neon Control Mo-Na Heat Pipe Tests

Heat Pipe Receiver Implementation

Power Tower

FY12 - 15
SunShot Lab Proposal Development Process

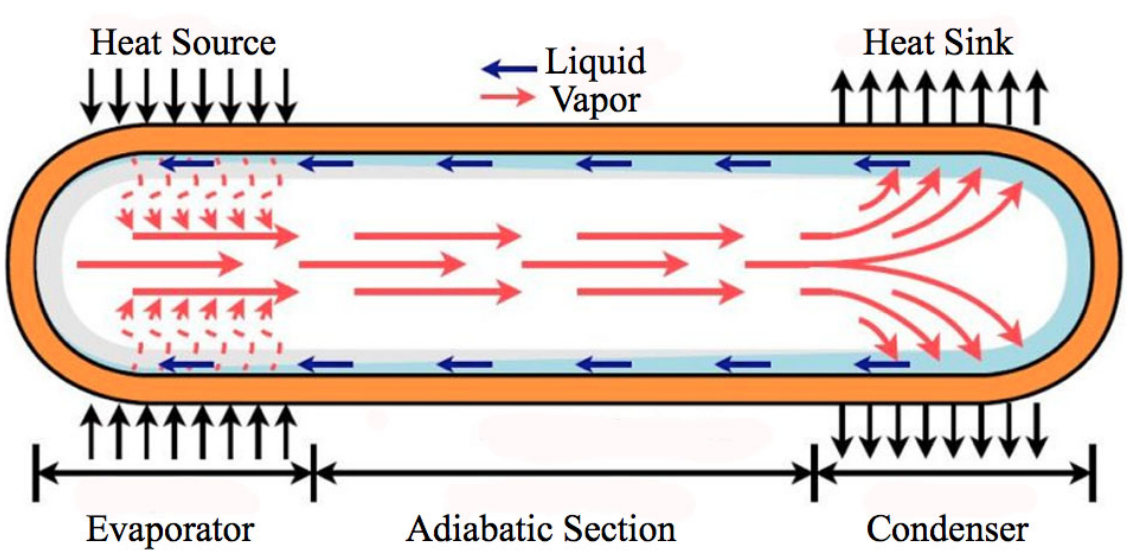


Source: Energy.gov Concentrating Solar Power Tower System Basics

Parabolic Trough

FY 16 – FY18
SuNLaMP - SunShot National Laboratory
Multiyear Partnership

Heat Pipe Operation



- Operates on principle of metal vaporization and vapor transport
- Capillary action draws condensate to evaporator
- Thermal energy captured as latent heat
- Very high concentrations lead to high receiver efficiency
- Heat pipe myths: Heat pipes are “small” and “expensive”.

Value Proposition

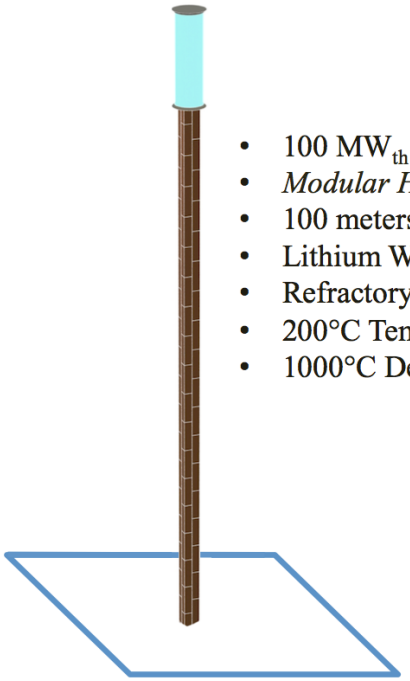
Heat-pipe receiver and thermal transport system leads to significant system efficiency and simplification.

Parasitic Losses		**Heat Transfer Fluid**	**Heat Pipe**
Fluid Pumping		5-10% of Net Power Plant Output	None-passive Operation
Heat Transfer Working Fluid		**Heat Transfer Fluid**	**Heat Pipe**
Chemical Composition	600°C	Unknown composition. Ionic Salts Molten metals, inert gas components	Potassium metal
	750°C		Sodium metal
	900°C		Sodium metal
Working Fluid Quantity		Tons	kilograms
Materials of Construction		**Heat Transfer Fluid**	**Heat Pipe**
Fluid Containment Alloy	600°C	Stainless Steel	Stainless Steel
	750°C	Super Alloy	Stainless Steel
	900°C	Super Alloy	Stainless Steel
Wall Thickness		mm	mm
Corrosion Rates		Microns per year	Microns per decade
Ancillary Systems and Equipment		**Heat Transfer Fluid**	**Heat Pipe**
Fluid Expansion Tanks		Required	Not Required
HTF Fluid Tanks		Required	Not Required
Pumps		Required – Unknown Composition	Not Required
Gaskets			Not Required
Seals			Not Required
Freeze Protection/Heat Tracing			Not Required
Safety		Major fire hazard	Heat pipe rupture self extinguishing

Project Goals

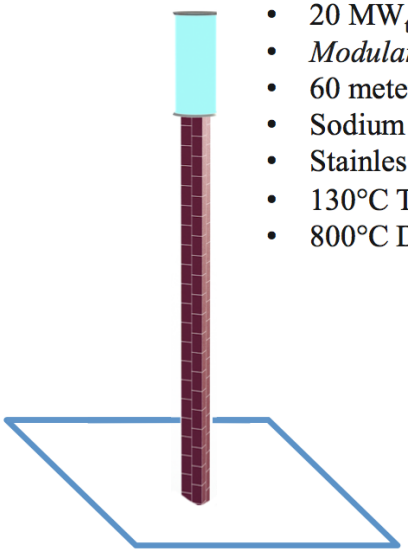
Overcome the key technology gaps to enable the development of an heat pipe power tower system.

High Temperature Tower System



- 100 MW_{th} Capacity
- *Modular Heat Pipe design*
- 100 meters
- Lithium Working Fluid
- Refractory metal envelope
- 200°C Temperature Drop
- 1000°C Delivery Temperature

Moderate Temperature Tower System

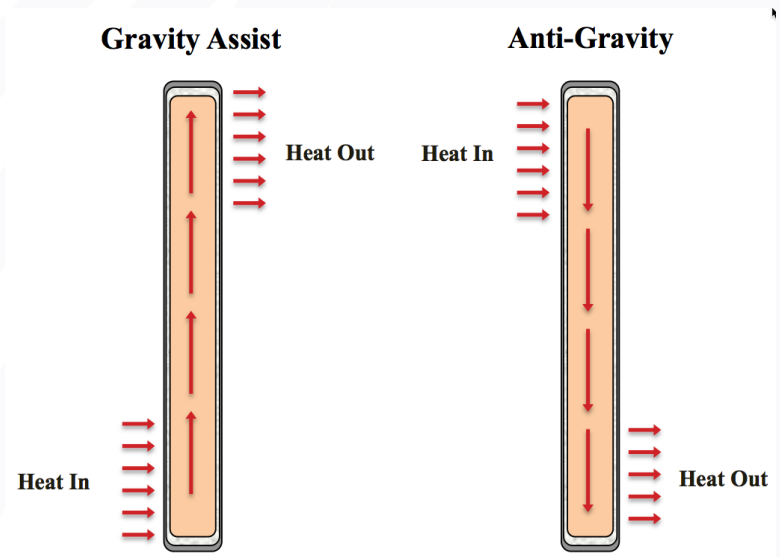


- 20 MW_{th} Capacity
- *Modular Heat Pipe design*
- 60 meters
- Sodium Working Fluid
- Stainless steel envelope
- 130°C Temperature Drop
- 800°C Delivery Temperature

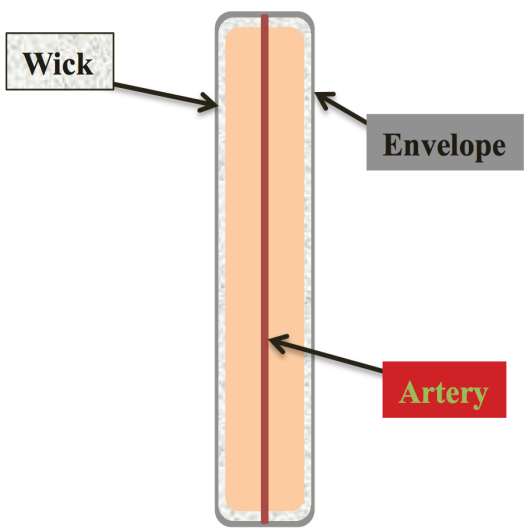
Power Tower- Operational Challenges

1. *Anti-Gravity* - heat accepted at the top
2. *High Thermal Transport Capacity* - Artery for high thermal transmission
3. *Self-Priming* – Cold start capability

1. Anti-Gravity Operation



2. Heat Pipe with Artery



3. Self Priming

- Wick and wall dewet
- Artery can not self-prime

LANL Self-Priming High Capacity Heat Pipe

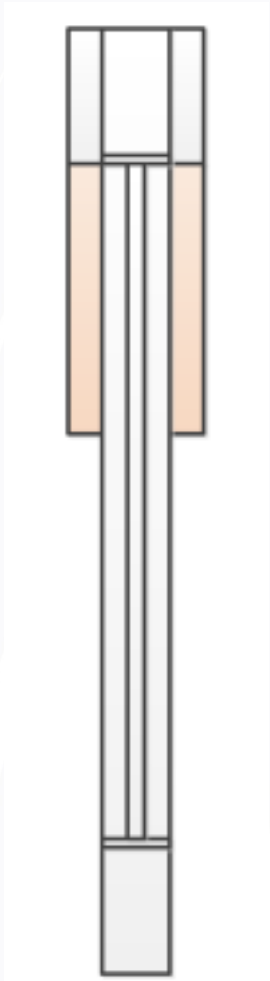
New heat pipe design

1. High Temperature
2. Systems Compatibility
3. Anti-Gravity
4. High Thermal Transport Capacity
5. Self Priming

New design enables heat pipes to be interconnected providing thermal transport pathway

6. Large Extended Heat Pipe System

New design enables heat pipe tower applications



Technical Challenges and Project Milestones

Phase 1

- Countergravity Physics
- Demonstration of countergravity-high capacity pipe

Phase 2

- Countergravity cold-start demonstrations
- High temperature heat pipe fabrication methods

Phase 3

- Demonstration of thermal connectivity
- Fabrication of 1/8-scale heat pipe module

Key Results and Milestones

Scaling Relationships

System Design Criteria
- Tower height
- Tower radius
- Heat pipe length
- Evaporator length
- Condenser length

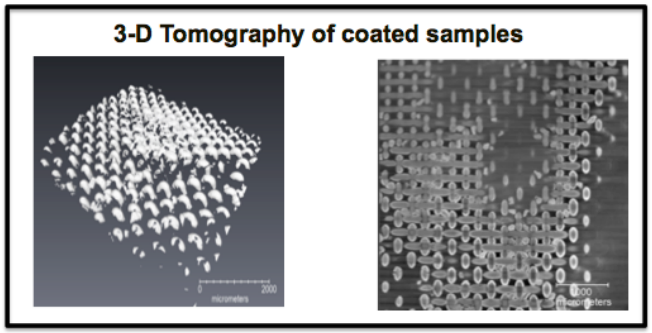
Wick and Wall Properties
- Wick permeability
- Effective pore radius
- Porosity
- Wick thickness
- Wall thickness
- Transport layer thickness

Momentum Equation
- Gravity head
- Liquid friction pressure drop
- Vapor friction pressure drop
- Total pressure drop
- Saturation pressure
- Maximum capillary pressure rise

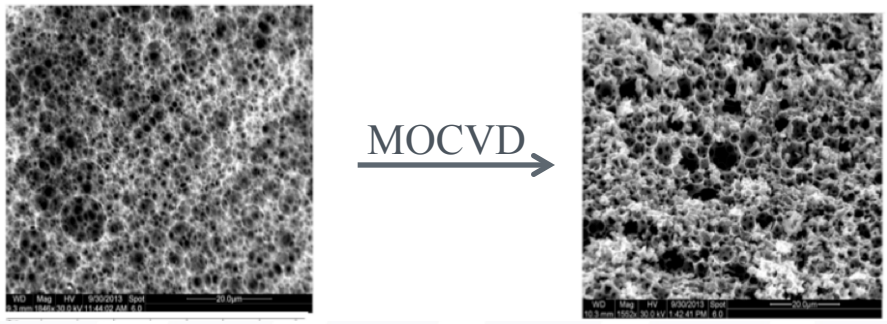
Schematic system designs for 1, 10, and 100 MW towers developed with ~100°C temperature drop.

Wick Development

Metal Templated Wick Fabrication



Foam Templated Wick Fabrication

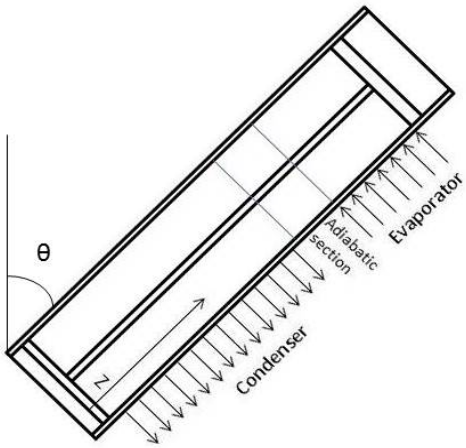


Key Results and Milestones

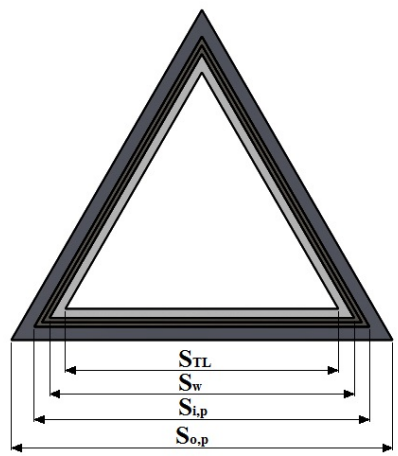
Detailed physics model for variable countergravity heat pipe system

The physics-based heat pipe models were extended to include sodium and lithium thermophysical properties and the heat pipes models were constructed.

Heat Pipe model with a header and artery model using 30 nodes along heat acceptance and rejection region.



Variable descriptors for Operational cross-section



Heat Pipe Limits

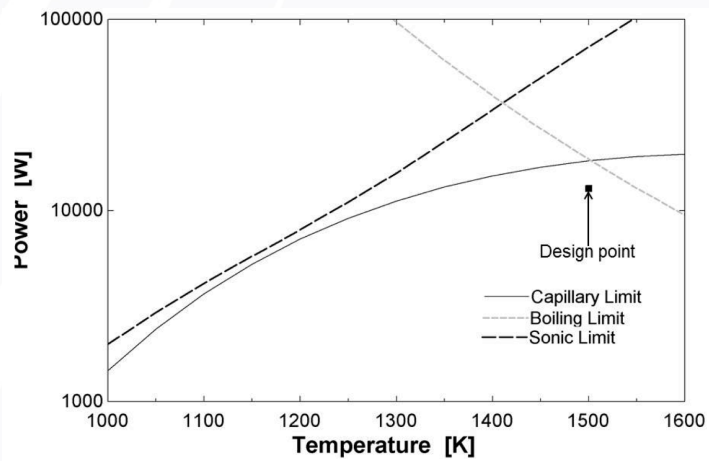
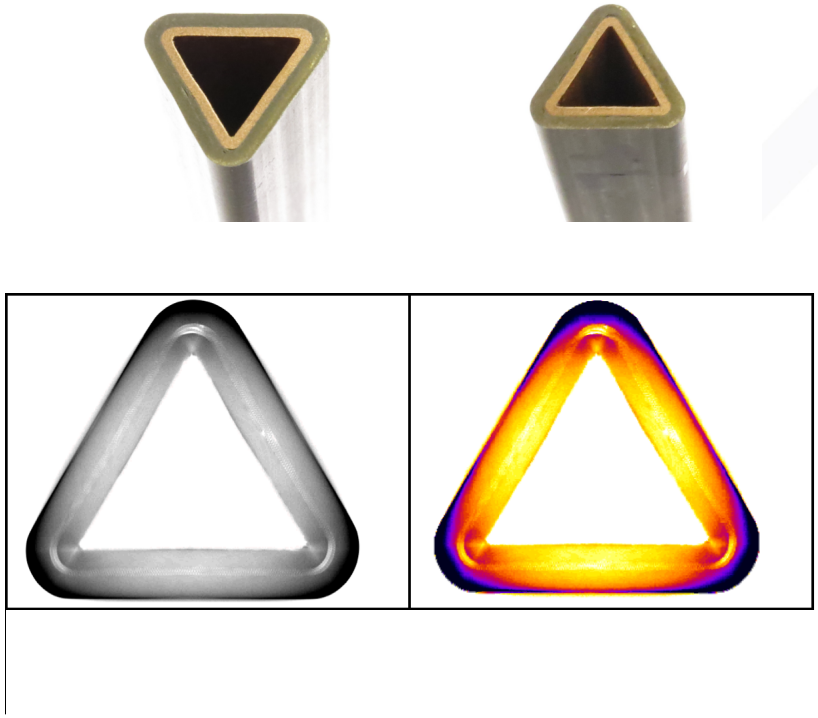


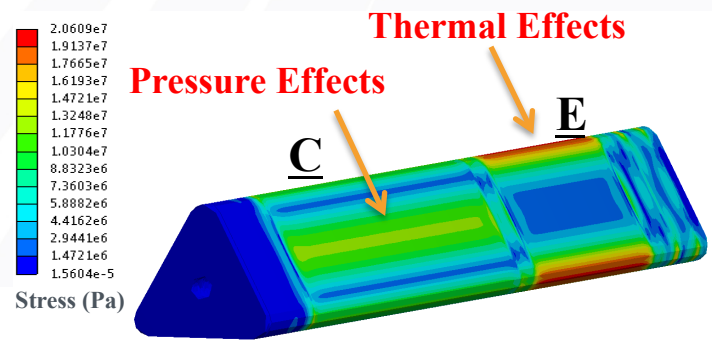
Figure 19. Heat Pipe Limits over a Temperature Range

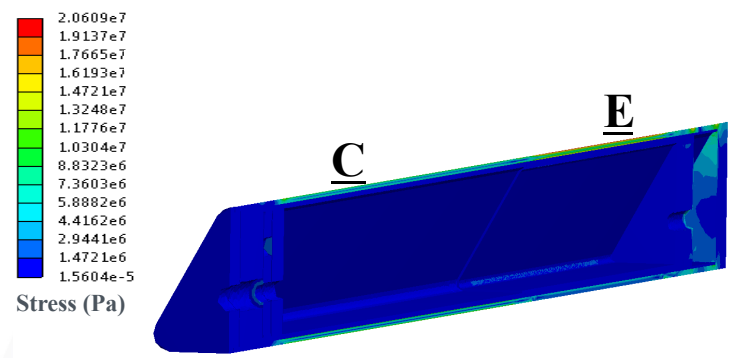
Key Results and Milestones

Fabrication techniques for module development.



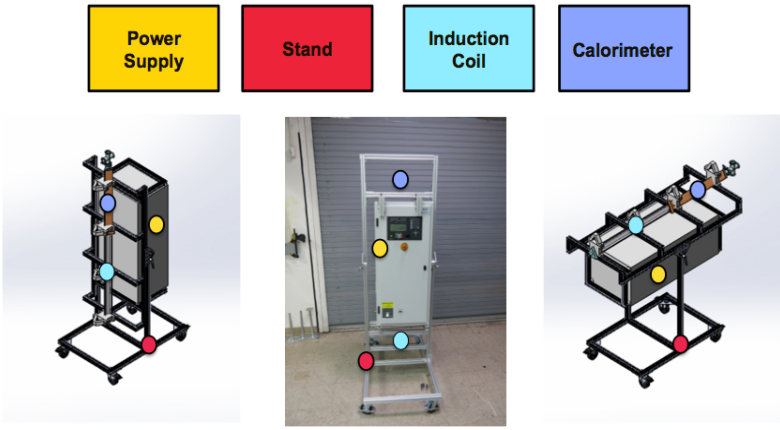
Finite Element Analysis (FEA) performed in ANSYS to model thermal and structural responses



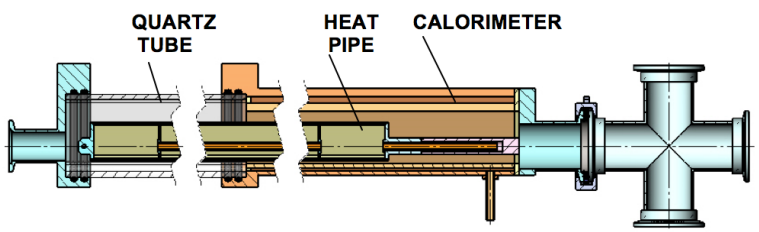


Key Results and Milestones

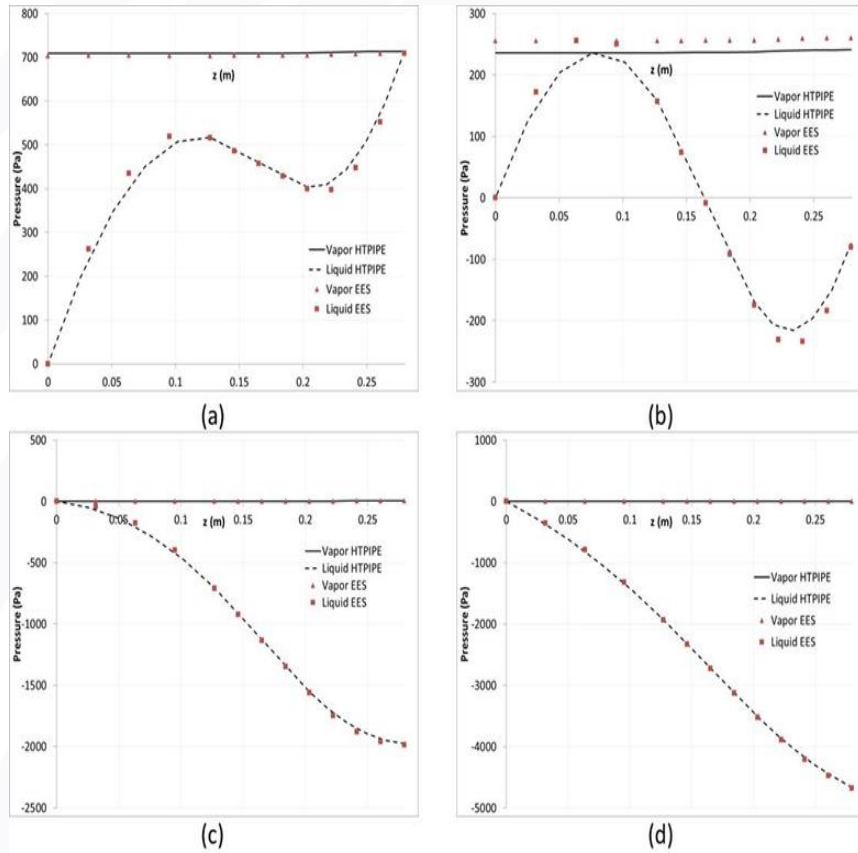
Test Bed Design and Testing



New Induction Coil and Calorimeter Design

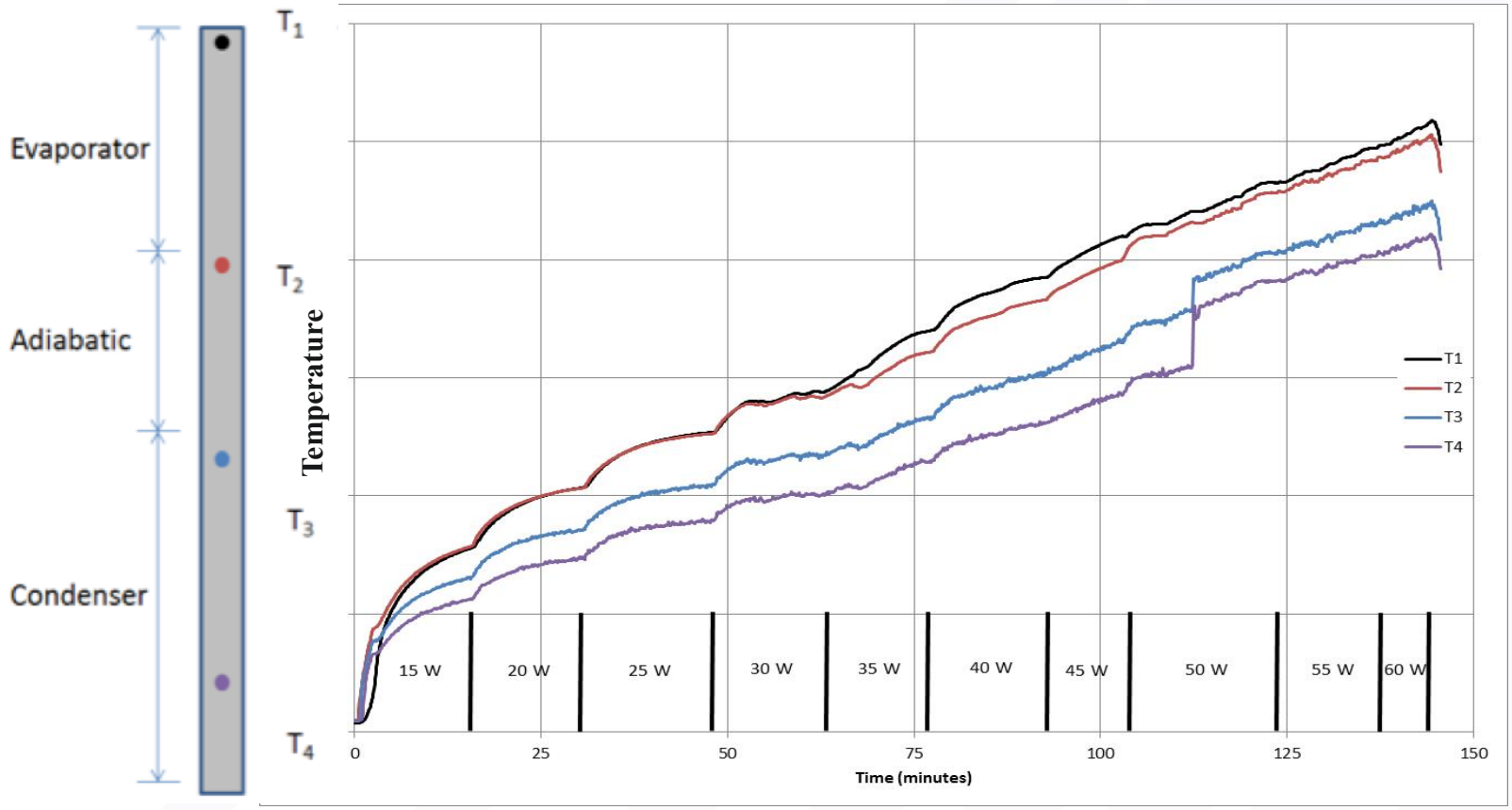


Experimental Validation of Counter-Gravity Physics



Key Results and Milestones

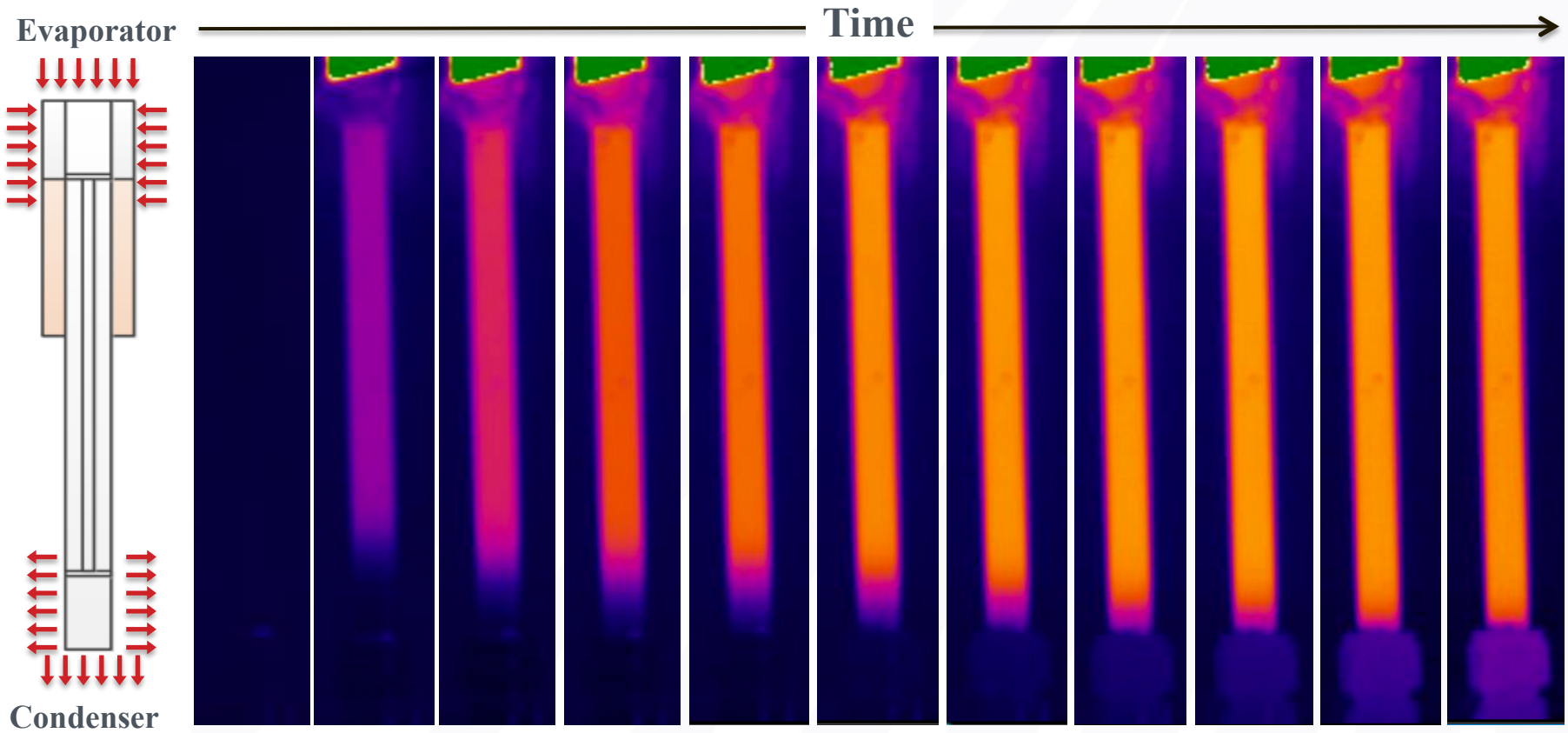
Self-Priming Countergravity Artery Heat Pipe



- **Smooth uniform start**
- **20-50 times increase in axial heat flux**
- **Heat pipe limits were not reached**

Key Results and Milestones

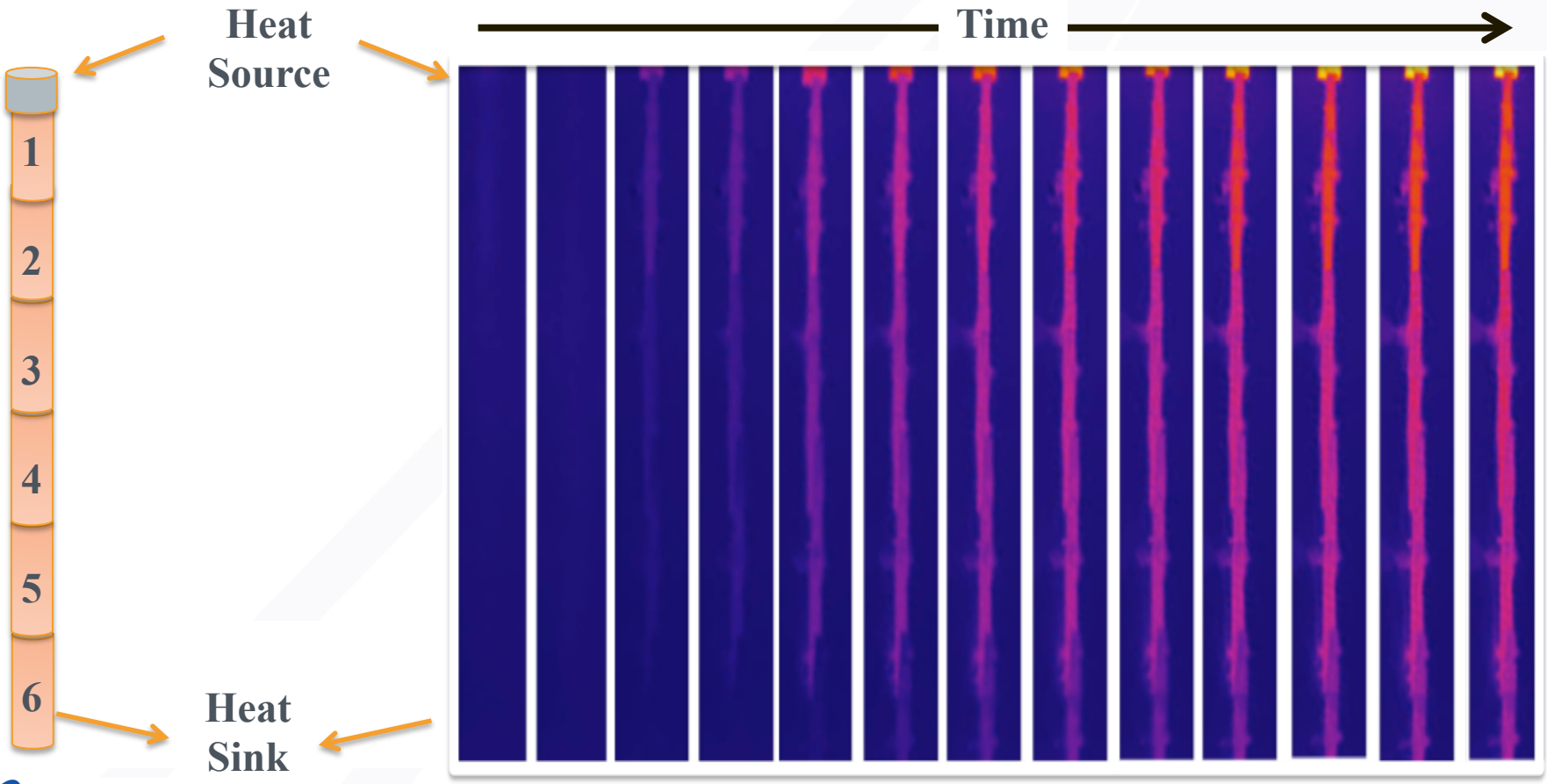
Infrared imaging of heat pipe during start shows the heat pipe has a homogeneous temperature representative of a smooth start.



Physics-based model and experimental tests agree within 15%

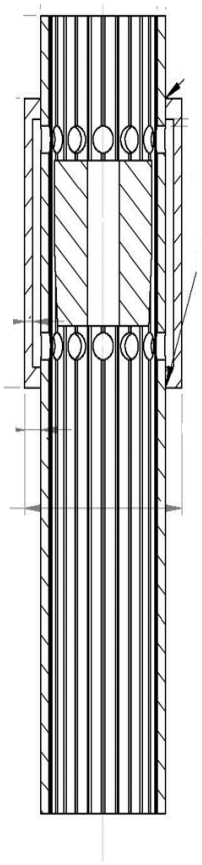
Key Results and Milestones

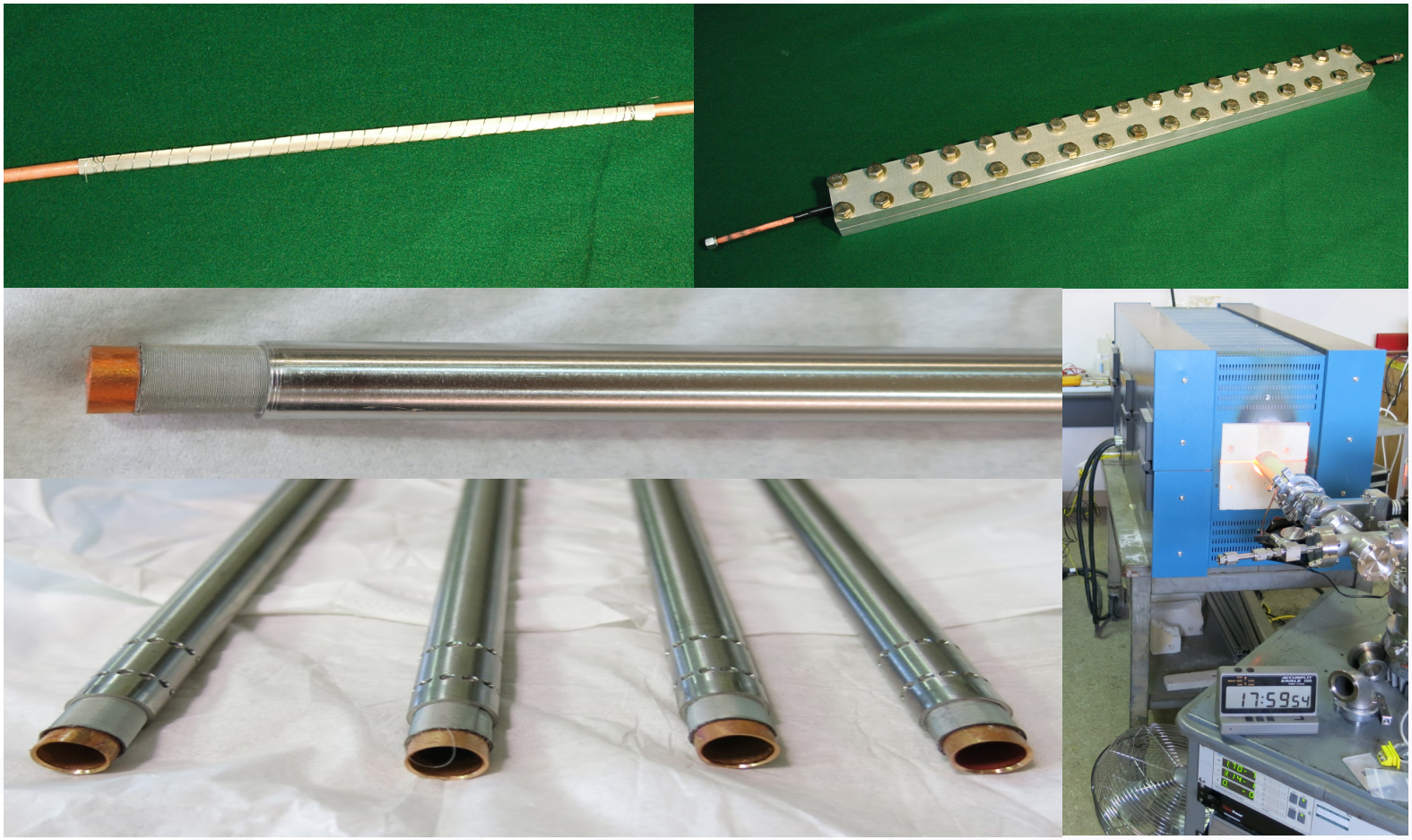
Thermal array with six coupled heat pipes.



Fabrication of 1/8-scale heat pipe module

Fabrication wick structure and 1st hydroforming stage.





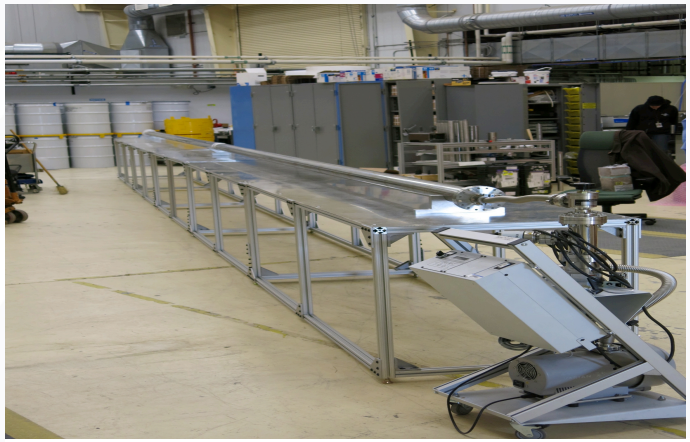
Work will complete in August 2016.

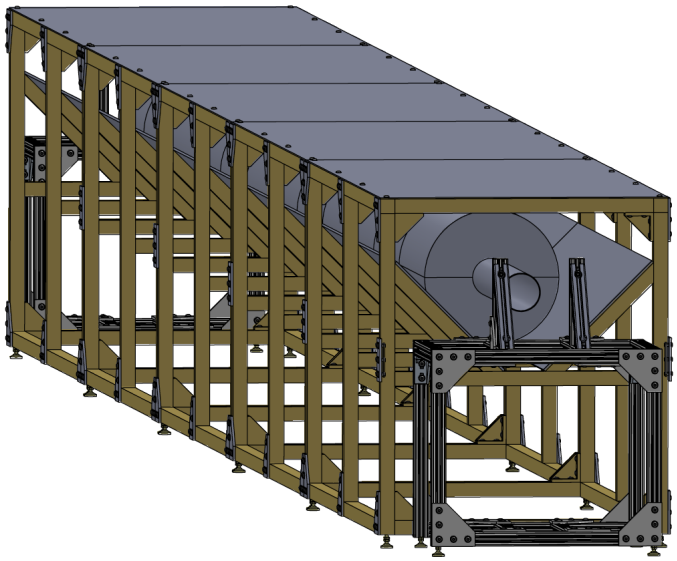
Next Steps

CRADA and Project Partners

- Full-scale module development
- Full scale coupled array testing
- Sub-scale field tests
- Systems Integrtaion
- Manufacturing method development

40ft Oven for Heat Pipe Fab.





Questions
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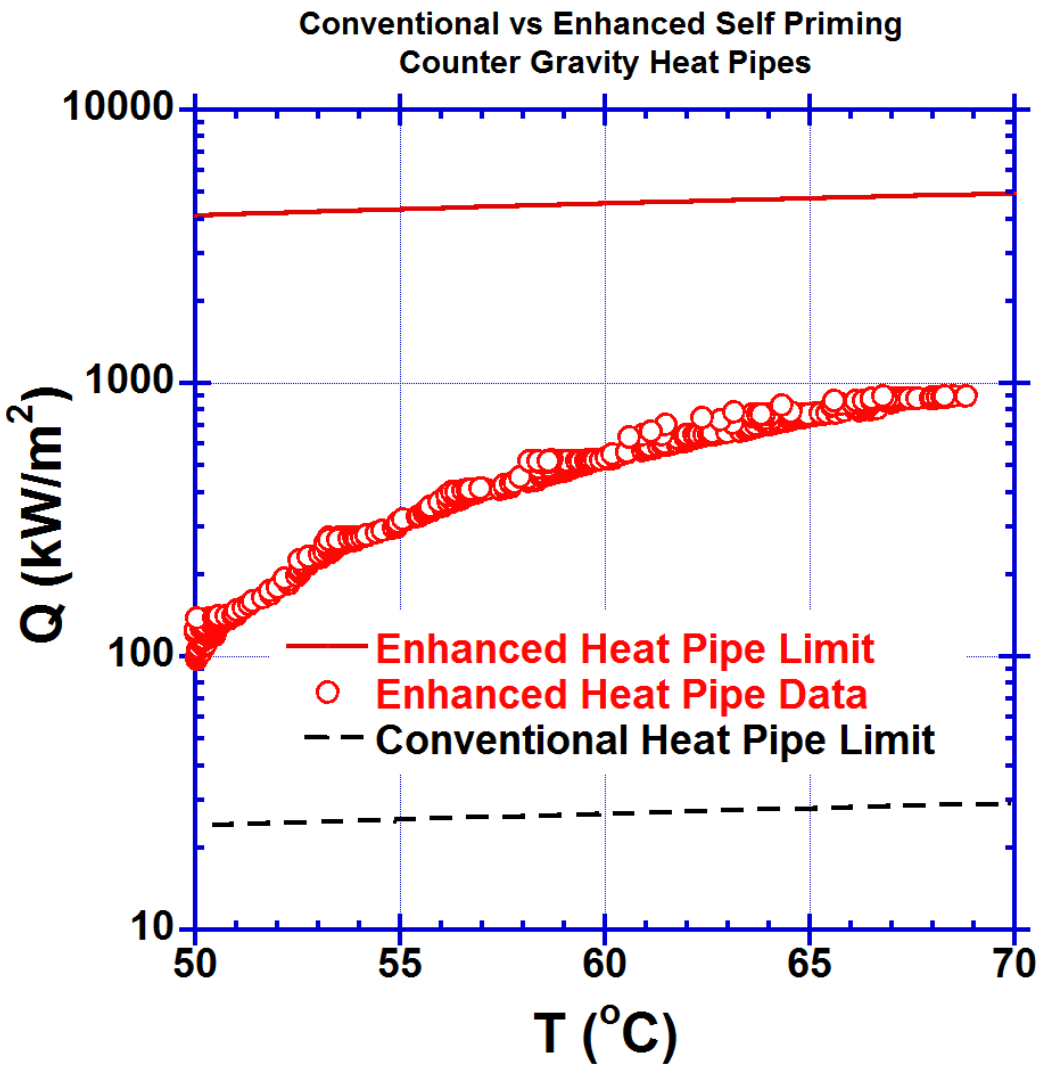
Scaling Heat Pipe Limits