WORKSHOP ON EXTREME ENVIRONMENTS TECHNOLOGIES FOR SPACE EXPLORATION, Pasadena, CA, May 14 – 16, 2003

Thermal Management of Electronics From –200°C to Above 1,000°C

Dr. Jon Zuo, Chief Technical Officer

Advanced Cooling Technologies, Inc.

(717) 295-6058, jon.zuo@1-ACT.com

May 16, 2003

Agenda

- **About ACT:**
  - Company overview.
  - Relationship with Thermacore/Modine.
  - Key technologies and products.
- **Thermal management technologies at temperatures below 500°C.**
- **Thermal management technologies at temperatures above 500°C.**
- **Conclusions and recommendations.**

ACT Company Overview

- **Founded in January 2003.**
- **Headquartered in Lancaster, Pennsylvania.**
- **Current number of employees: 4+ (holders of 40+ U.S. patents).**
- **Accumulated years of professional experience on thermal technology development and system design: 95+.**
- **Business areas:**
  - Technology development: developing innovative thermal technologies (SBIR, STTR, and other government and commercial R&D programs).
  - Engineering services: designing and fabricating thermal devices and systems to meet customers' specific application requirements.

Relationship Between ACT and Thermacore

- **ACT is an independent company. Thermacore does NOT have ownership in ACT.**
- **All ACT founders, officers and employees were associated with Thermacore/Modine in the past.**
- **ACT and Thermacore/Modine signed a Teaming Agreement in March 2003 (see Press Release on next page).**
  - ACT is receiving ALL liquid metal heat pipe projects and future business opportunities from Thermacore/Modine.
  - ACT and Thermacore/Modine will jointly pursue businesses in cryogenic, aerospace and military markets.
  - Thermacore/Modine will receive preferential licensing on technologies developed by ACT.

Joint ACT and Thermacore Press Release

FOR IMMEDIATE RELEASE
Thermacore-Modine's Supporting ACT

LANCASTER, Penn./EWORLDWIRE/April 9, 2003 --- Advanced Cooling Technologies Inc. (ACT) and Thermacore International Inc., a Division of Modine Manufacturing Company, have signed a Teaming Agreement to collaborate on the development of advanced thermal technologies for electronics, energy systems, cryogenics, aerospace, military and other market areas.

The agreement includes a cross licensing of technologies. ACT will receive a license to manufacture and sell liquid metal heat pipe products, and will handle all future business opportunities related to this product line. Thermacore will receive preferential licensing rights to commercialize key new products and technologies developed by ACT.

"As a technology development business," said Dr. Jon Zuo, President and Chief Technical Officer of ACT, "our mission is to develop innovative technologies to solve challenging thermal problems in diverse applications. The partnership with Thermacore-Modine will allow us to expand our strength in technology development without losing the connection to high volume production opportunities."

Tom Neyens, General Manager of Thermacore, stated, "The beneficiaries of this collaboration will be Thermacore customers. The combined efforts of Thermacore and ACT will ensure that they have full access to leading edge thermal solutions for their applications."

About Advanced Cooling Technologies, Inc.
Advanced Cooling Technologies, Inc. is a high technology small business specializing in heat transfer technologies. Founded in January 2003 and headquartered in Lancaster, Pennsylvania, ACT's mission is to develop innovative thermal technologies and provide technology based thermal solutions to customers in electronics, energy systems, aerospace, military and government sectors. ACT's two main business areas are Technology Development and Engineering Services. The Technology Development business undertakes both externally and internally sponsored research and development activities. The Engineering Services business designs and fabricates thermal devices and systems that satisfy customers' specific thermal and mechanical requirements. More information about ACT can be obtained by contacting ACT at: (717) 575-4404 (phone), (717) 581-0662 (fax), http://www.1-act.com/.

About Thermacore International
Thermacore International, a subsidiary of Modine Manufacturing Company, is a global supplier of thermal solutions for the computer, communications, medical, automotive, test equipment and power electronics industries. With manufacturing and design locations in the USA, Mexico, the U.K., and Taiwan, Thermacore provides quality manufacturing to OEMs worldwide with local design support & manufacturing. Modine specializes in thermal management, bringing heating and cooling technology to diversified markets. Modine's products are used in light, medium, and heavy-duty vehicles, HVAC equipment, industrial equipment, refrigeration systems, and fuel cells. Thermacore and Modine have 400 thermal design engineers focused on providing cooling solutions. Visit Thermacore on the web at http://www.thermacore.com/ or e-mail to info@thermacore.com. Phone 717-569-6551 or Fax 717-569-8424.

CONTACT:
Advanced Cooling Technologies, Inc.

Jon Zuo
PHONE: 717.575.4404
FAX: 717.581.0662
EMAIL: jon.zuo@1-ACT.com
URL: http://www.1-act.com/, http://www.thermacore.com/

KEYWORDS: computer, thermal, communications, medical, automotive, equipment, power, electronics, Mexico, UK, United Kingdom, Taiwan, Thermacore, Modine, ACT, Advanced Cooling Technologies, technology, heating, cooling, vehicle, fuel cell, refrigeration, industrial, HVAC, engineer, energy, cryogenics, aerospace, military, liquid metal heat pipe

ACT Key Technologies and Products

- **Heat pipes:**
  - Cu/H_2O, Cu/methanol, Al/SST/NH_3, cesium, potassium, and lithium.
  - Grooved, mesh screen, sintered powder metal wicks.
- **Loop heat pipes:**
  - Cryogenic loop heat pipes (N_2, O_2, H_2).
  - Liquid metal loop heat pipes (cesium).
- **Pumped single and two-phase loops:**
  - High performance two-phase flow cold plates.
  - Miniature pulsating flow loops.
- **Energy conversion:**
  - High temperature conversion: AMTEC, Thermionics.
  - Lower temperature conversion: Pulsating flow thermal-to-electric conversion.

Agenda

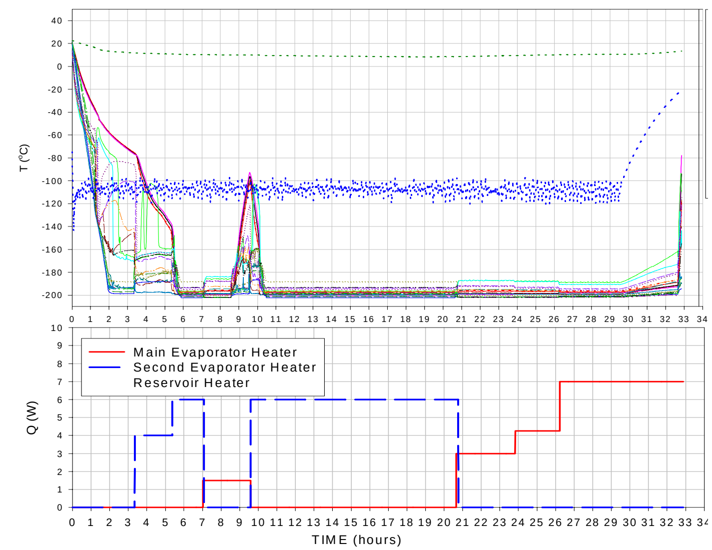
- **About ACT.**
- **Thermal management technologies at temperatures below 500°C:**
  - Cryogenic loop heat pipes.
  - Miniature loop heat pipes.
  - Aerospace loop heat pipes.
  - Lightweight materials for two-phase heat rejection systems.
- **Thermal management technologies at temperatures above 500°C.**
- **Conclusions and recommendations.**

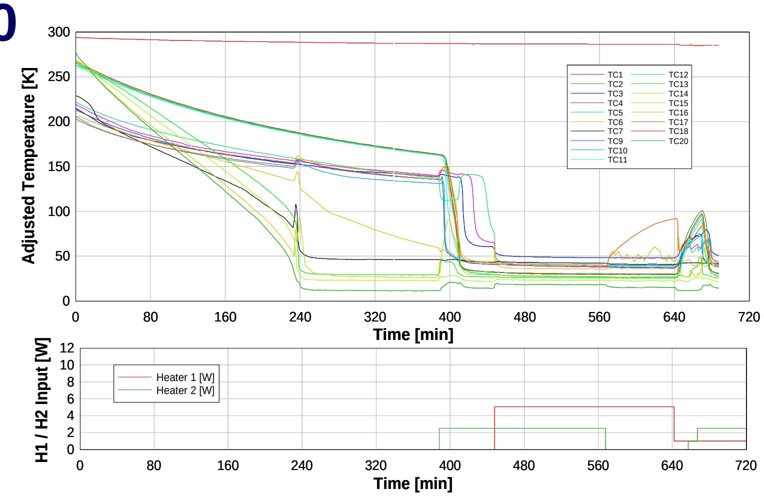
Previously Demonstrated Loop Heat Pipes

Application	Transport Length	Working Fluid Temp. Range	Casing Material	Wick Material	Max Heat Load	Max Evap. Heat Flux	ΔT
Avionics	0.6 m	Ammonia -40 to 80 ^{O}C	SST, Al	Nickel, SST POREX	200 W	5 W/cm^2	15 K
High Heat Flux Electronics	0.6 m	Ammonia -40 to 80 ^{O}C	SST	Nickel Titanium	500 W	100 W/cm^2	35 K
Solar Energy	2 m	Menthol 55 to 140 ^{O}C	SST	Stainless Steel	1 kW	15 W/cm^2	20 K
Anti Icing	1 m	Ammonia -40 to 80 ^{O}C	SST	Nickel	1.5 kW	15 W/cm^2	15 K
IR Sensor	1 m	Oxygen 55 to 150 K	SST	Stainless Steel	10 W	2 W/cm^2	5 K
Electronics	1 m	Water 90 to 250 ^{O}C	Copper	Copper	175 W	20 W/cm^2	25 K
Space Radiator	2 m	Ammonia -40 to 80 ^{O}C	SST	Nickel	500 W	12 W/cm^2	10 K
IR Sensor	2.5 m	Hydrogen 15 to 30 K	SST	Stainless Steel	5 W	1 W/cm^2	5 K
Aerospace Electronics	2.5 M	Nitrogen 70 to 120 K	SST	Stainless Steel	20 W	3 W/cm^2	7 K

Thermacore Cryogenic LHP Program Summary

- An Oxygen LHP with 2 transport lines was demonstrated reliable startup and operation in temperature range from 70 to 130K.
- A Hydrogen LHP with 3 transport lines was demonstrated reliable startup and operation in temperature range from 20 to 30K.
- A Nitrogen LHP with 3 transport lines was demonstrated reliable startup and operation.



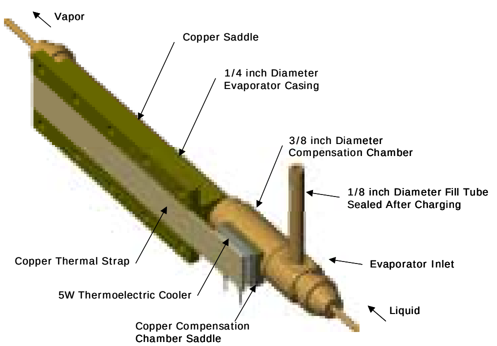


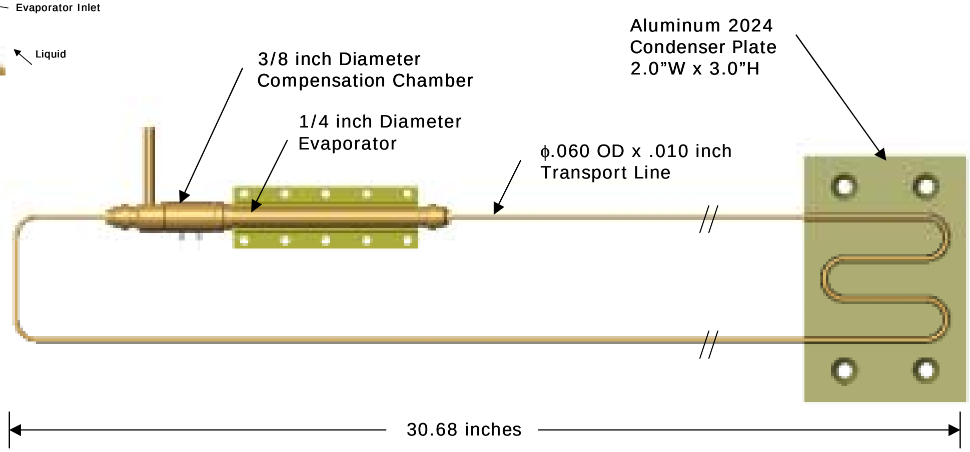
Key Issues Associated With Cryogenic LHPs

- **Reliable startup from critical state (room temperature).**
  - Startup heater/evaporator approach.
  - Two line vs. three line approach (flexibility, manufacturability, reliability).
- **Reliable operation at low power condition.**
  - Heat leakage.
- **Startup and operation against gravity.**
  - For ground testing.
  - Secondary wick design.
- **Thermacore cryogenic LHP program contact information:**
  - Dmitry Khrustalev, (717) 569-6551 ext.346, d.k.khrustalev@thermacore.com.

Thermacore Miniature LHP Program Summary

- Miniature LHPs with 1μm SST wicks and TEC were demonstrated during a NASA GSFC Program.
- Polyethylene wicks with 1.5μm pore radius are under development.





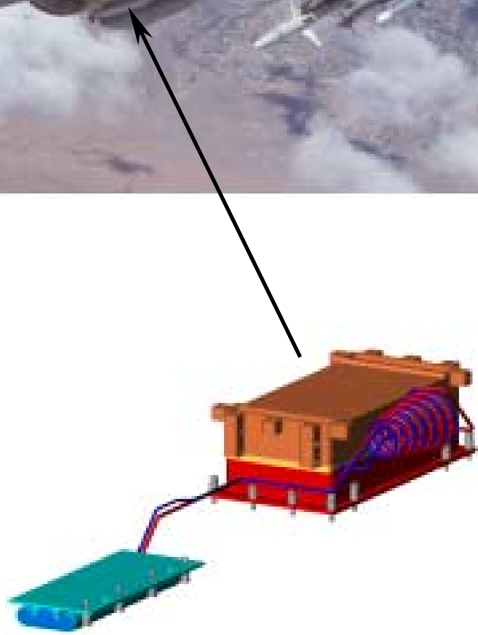
Key Issues Associated With Miniature LHPs

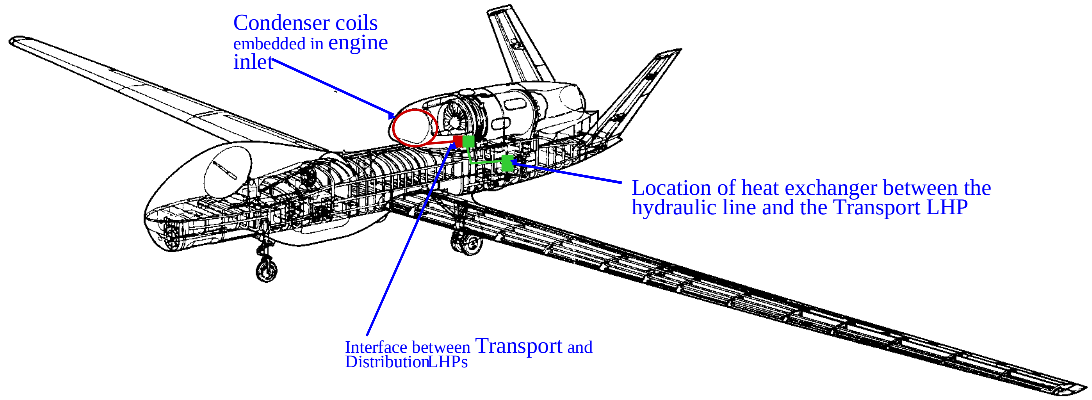
- **Heat leakage, heat leakage and heat leakage.**
  - Heat leak across evaporator wick increases as wick diameter shrinks.
- **Low conductivity wicks.**
  - Materials.
  - Manufacturing processes.
- **Low cost manufacturing requires:**
  - Innovative structures (knife edge seal…)
  - Innovative materials (porous polyethylene…new working fluids…)
- **Thermacore miniature LHP program contact information:**
  - Dmitry Khrustalev, (717) 569-6551 ext.346, d.k.khrustalev@thermacore.com.

Thermacore Flight Heritage

- **1992 – Sintered Powdered - Artery Free N_2 Heat Pipe - GSFC**
- **1993 – GE Technical Services/MSFC**
  - Copper/Ethanol Heat Pipe for Connecting Stirling Engine Cryo-Cooler to Refrigerator/Freezer – In Cabin STS Flight
- **1994 – GE Technical Services/MSFC**
  - Stainless Steel/Acetone Heat Pipe for Connecting Stirling Engine Cryo-Cooler to Refrigerator/Freezer – In Cabin STS Flight
- **1997 – DTX LHP Flight Experiment – STS 87**
  - Program Management
  - Majority of Funding
  - Manufactured Wick Structure
- **1998 to 2000 – Copper/Water Heat Pipes**
  - NASA GSFC
  - Naval Research Laboratory

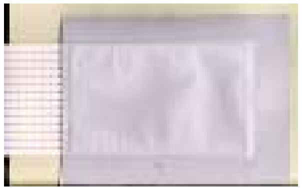
More Recent Aerospace LHP Examples

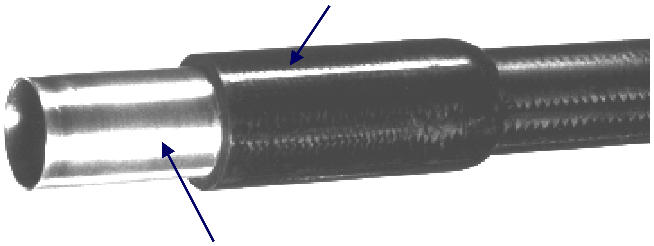




Thermacore Lightweight Materials Programs

- **Laminate heat pipes – 4+ years of operation demonstrated.**
- **Carbon/epoxy/metal composite materials – pressure and thermal cycling tested.**
- **Mg/NH_3 heat pipes – chemical compatibility and thermal performance demonstrated.**

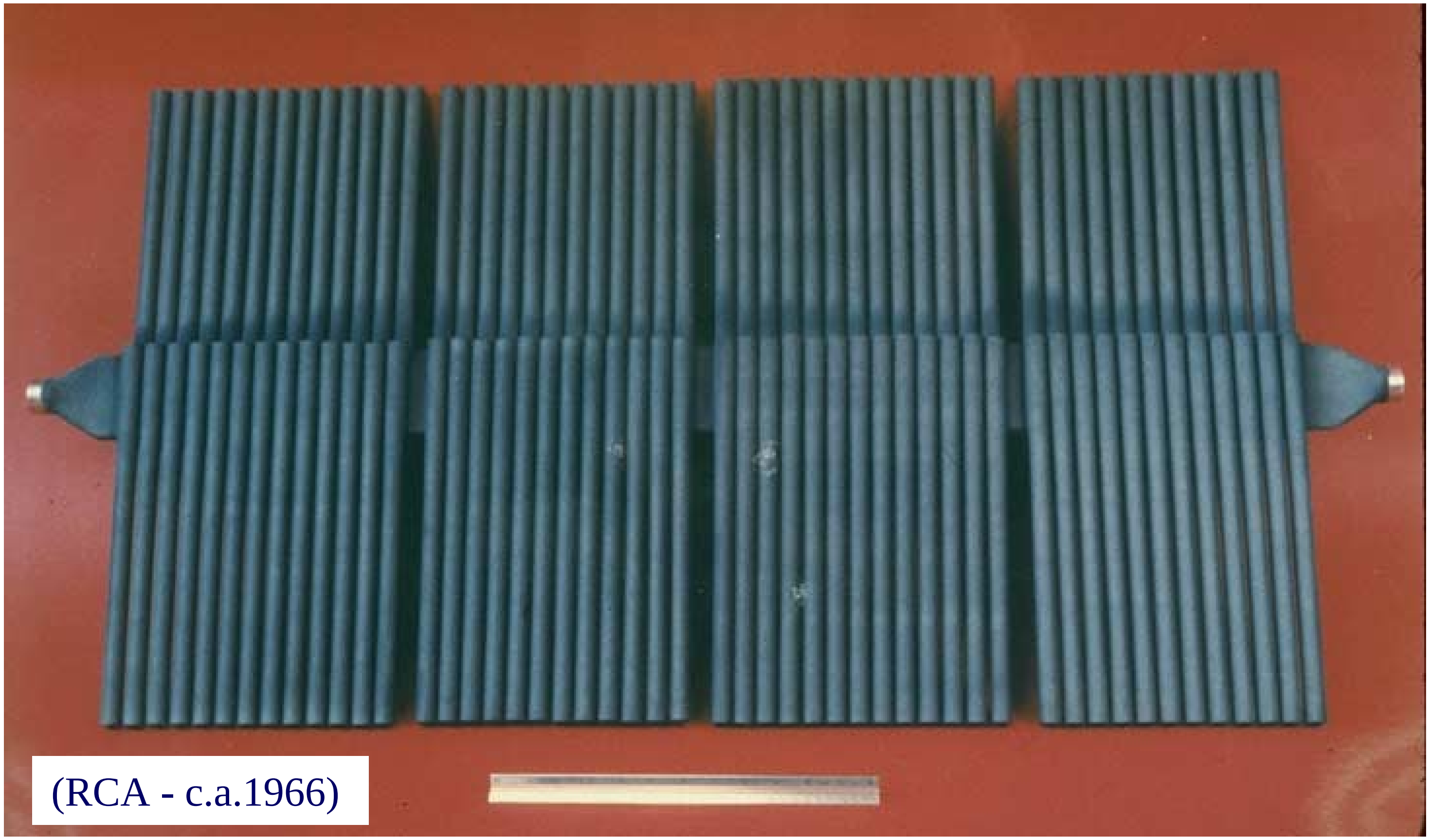




Agenda

- **About ACT.**
- **Thermal management technologies at temperatures below 500°C.**
- **Thermal management technologies at temperatures above 500°C:**
  - Liquid metal heat pipes – examples.
  - Liquid metal loop heat pipes – examples.
- **Conclusions and recommendations.**

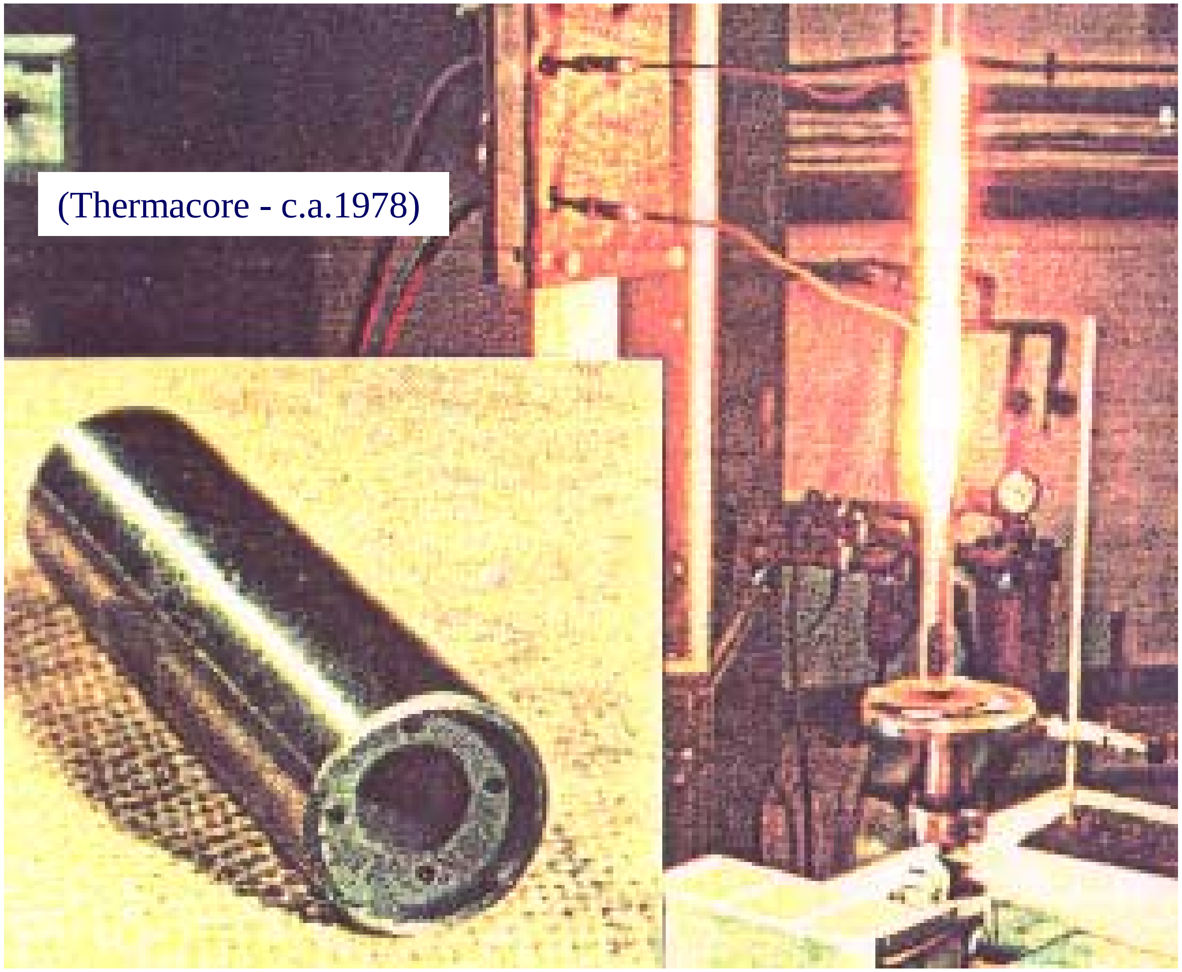
50kW – 1000K Radiator Panel Prototype



(RCA - c.a.1966)

50 - 1 kW – Sodium/Stainless Steel Heat Pipes Mounted on a Section of Liquid Lithium Pumped Coolant Loop

Core Heat Removal Prototype Heat Pipe



Molybdenum/Lithium Heat Pipe – 6 kW @ 1800 K

Prototype Spacecraft Heat Pipe Radiator Elements

(Thermacore - c.a.1980)

5.5 Meter Long
Sodium/Super Alloy
Radiator Heat Pipe

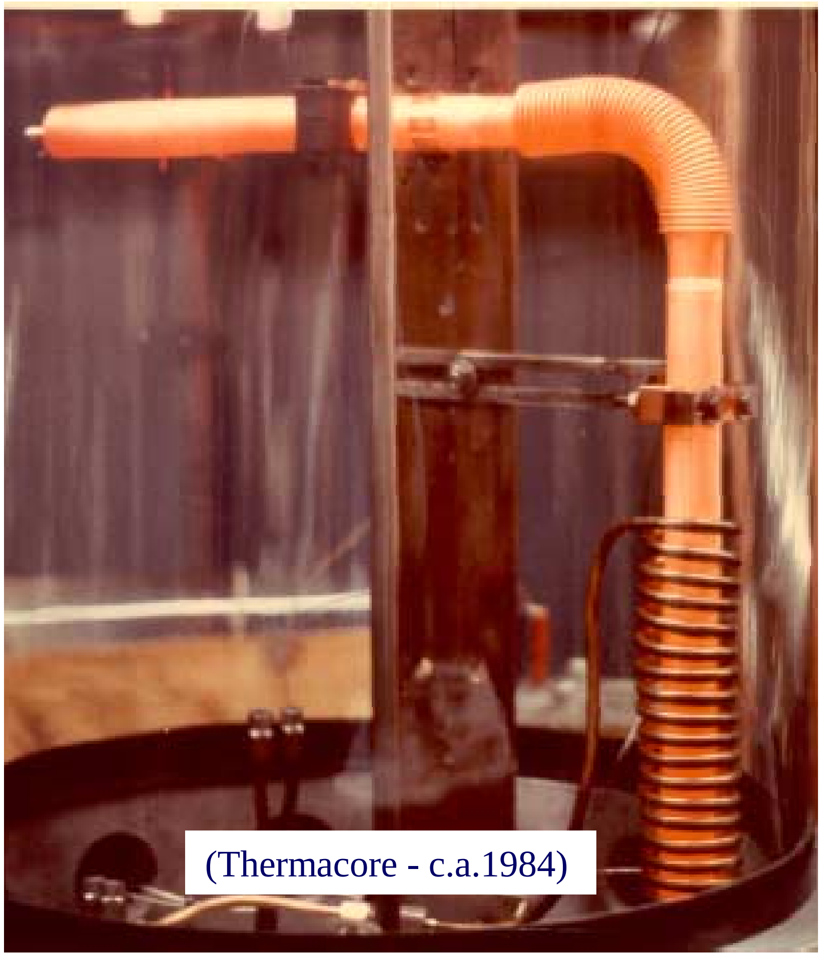
5,000 Watts
@ 1000 K

(Thermacore/LANL c.a.1982)

5 Meter Long
Potassium/Titanium
Radiator Heat Pipe

3,000 Watts
@ 800 K

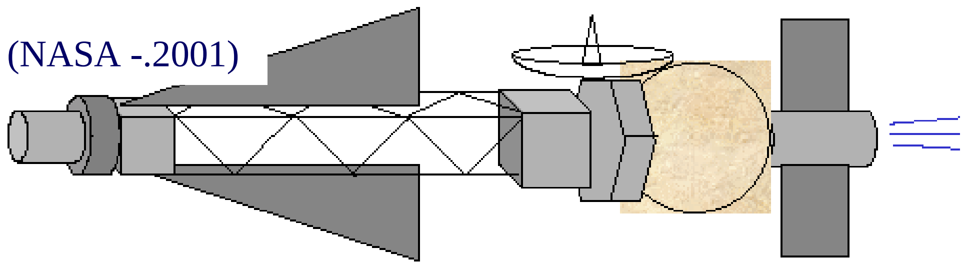
Flexible Sodium/SST Radiator Section

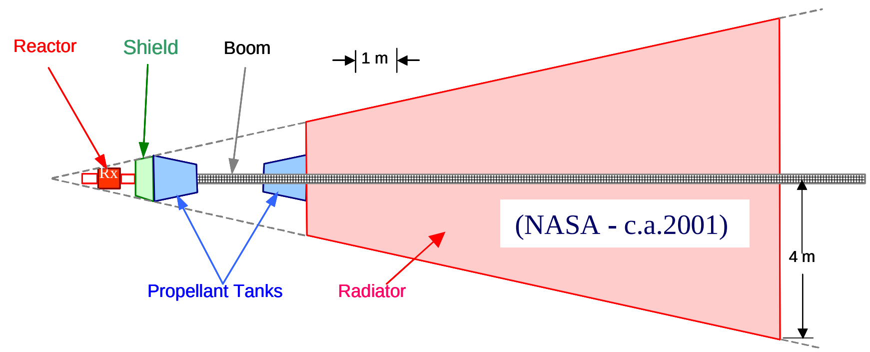

(Thermacore - c.a.1984)

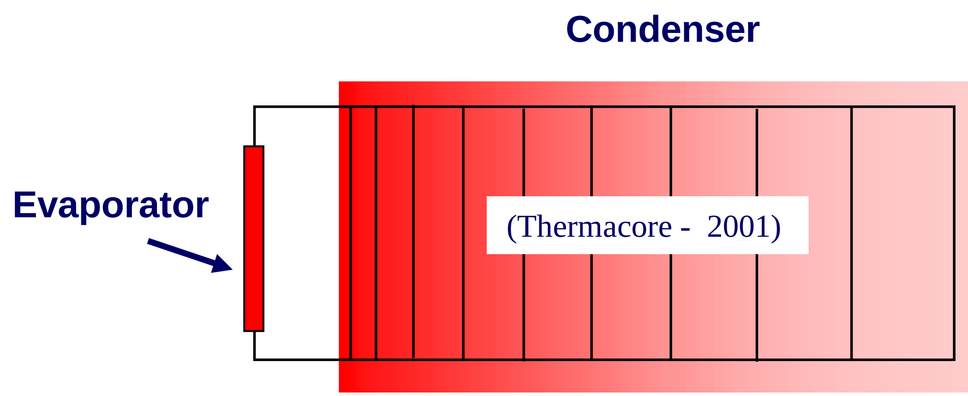

(Thermacore - c.a.1984)

2 kW at 1000 K

Safe Affordable Fission Engine (S.A.F.E.)

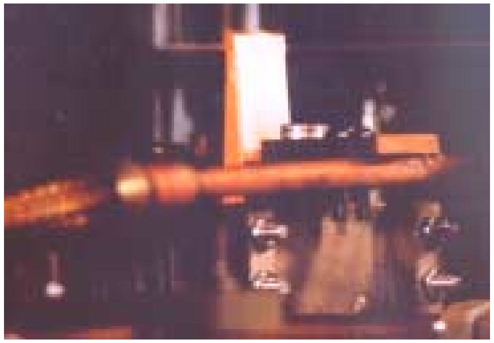






Freeze Tolerant LHP Radiator

Leading Edge Heat Pipes

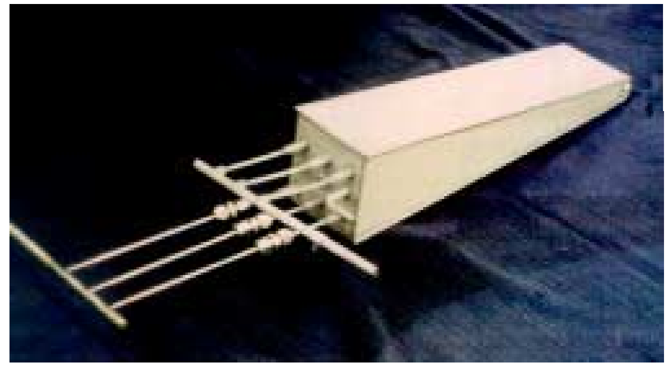


Cowl Leading Edge

Lithium - Tungsten Heat Pipe Operating at 1500 K and 126 kW/cm^2

Wing Leading Edge

Sodium – Super Alloy Heat Pipe Operating at 1000 K and 100 kW/cm^2

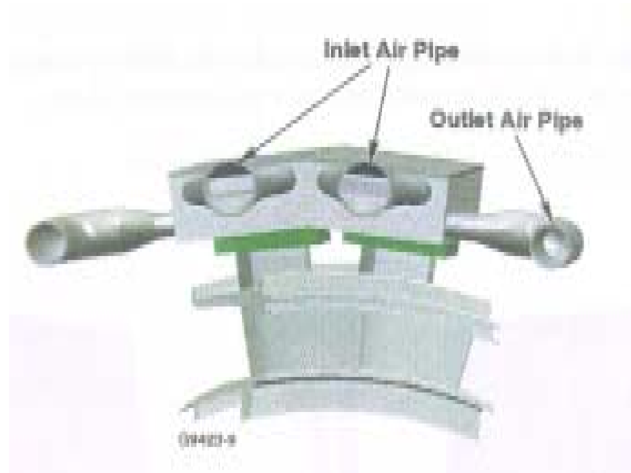


Wing Leading Edge

Lithium – Niobium Alloy Heat Pipe Operating at 1500 K and 10kW

Other High Temperature Heat Pipes

Isothermal furnace liner (600 to 900°C)



Heat pipe turbine vanes (800 to 1,000°C)

Liquid Metal Loop Heat Pipes

- **Materials:**
  - Cesium working fluid.
  - Titanium envelope
  - Titanium aluminide wick.
- **Demonstrated performance:**
  - 600W heat transport at 850K.
  - Self-priming during start-up.
- **Liquid metal LHP advantages:**
  - More tolerant to non-condensible gases (e.g. H2 permeation).
  - Ground testing in any orientation.
  - Reduced mass by eliminating wicks in adiabatic and condenser sections.
  - Serpentine condenser allows more uniform heat rejection from fins (improved fin efficiency).

Liquid Metal LHP Challenges

- **Wick development**
  - SST wicks in conventional liquid metal metal heat pipes can not be used – sintering and operating temperatures are too close.
  - Titanium aluminide had wetting problems.
  - Need to develop ~ 1 micron refractory metal wicks (tungsten…).
- **Start-up**
  - Alkali metals solid at room temperature.
  - S 113°C, Na 98 °C, K 64°C, Cs 28°C.
  - Unlike Heat Pipe, LHP can not start-up with frozen liquid line.
- **Possible solutions:**
  - Trace heater or heat pipe.
  - Auxiliary small heat pipe for start-up.
  - Binary mixtures or other fluids.

Agenda

- About ACT.
- Thermal management technologies at temperatures below 500°C.
- Thermal management technologies at temperatures above 500°C.
- Conclusions and recommendations.

Conclusions and Recommendations

- **Reliable startup and operation of cryogenic LHPs have been demonstrated for:**
  - Ethane, Nitrogen, Oxygen and Hydrogen LHPs in laboratory.
  - Flight demonstration is the logical next step.
- **TEC enhanced miniature LHP operation and control have been demonstrated in laboratory and are being designed for military aircraft applications.**
- **Liquid metal heat pipes are relatively mature technologies.**
- **Liquid metal loop heat pipes need substantial development to address:**
  - Startup from frozen state.
  - Wick materials technology.