An Advanced Loop Heat Pipe for Cryogenic Applications

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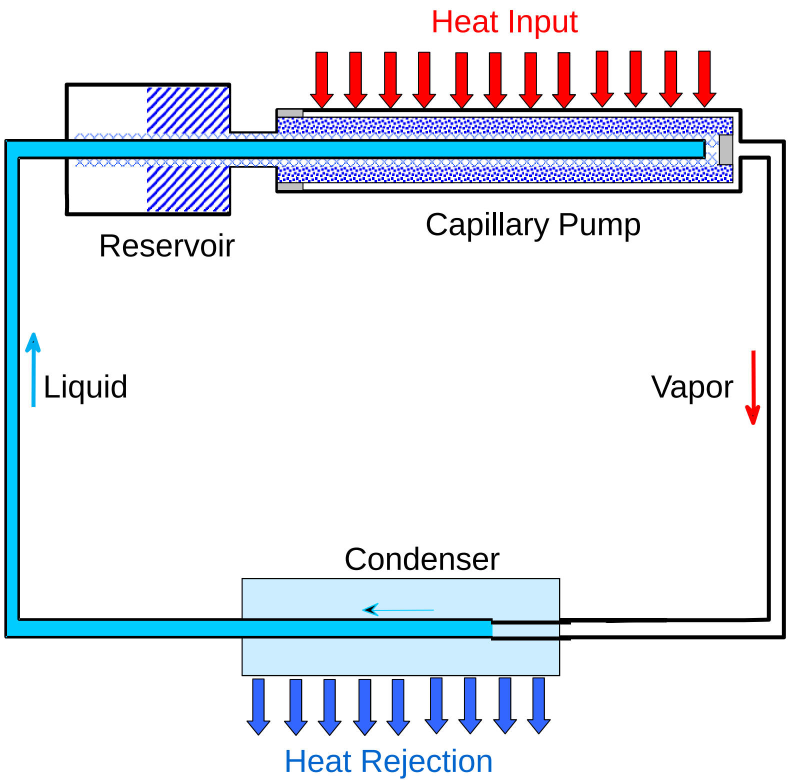
Thermal & Fluids Analysis Workshop (TFAWS)
NASA Ames Research Center, Moffet Field, California, August 1-5, 2016

Outline

- Traditional LHP for Spacecraft Applications
- Technical Challenges in CLHP Development
- Advanced CLHP with a Secondary Evaporator and Hot Reservoir
    - Operational Principles
- An Example: Hydrogen CLHP
- Summary and Conclusions

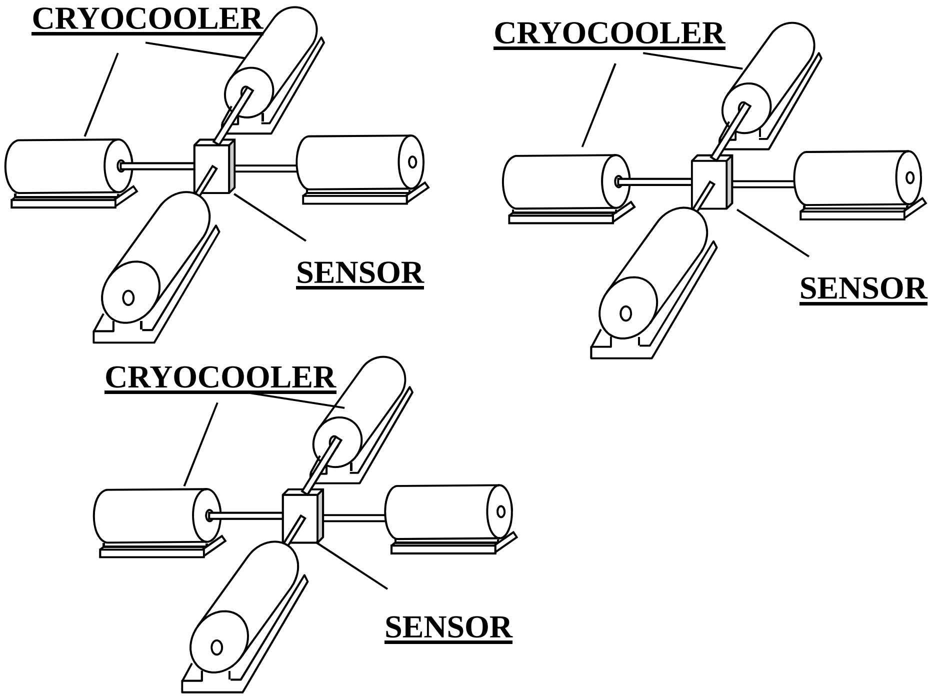
Traditional Loop Heat Pipe

- Application
  - Waste heat is acquired over a small area by the LHP capillary pump and transported to a large area (e.g. space radiator) for rejection.
- No External Pumping Power
  - Waste heat provides the driving force.
- No Moving Parts
- Robust Operation
  - Passive
  - Self-regulating
- High Pumping Capability
- High Thermal Conductance
- Smooth-walled and flexible transport lines provide flexibilities for design, integration and testing.



Disadvantages of Traditional Cryocooling of Sensors

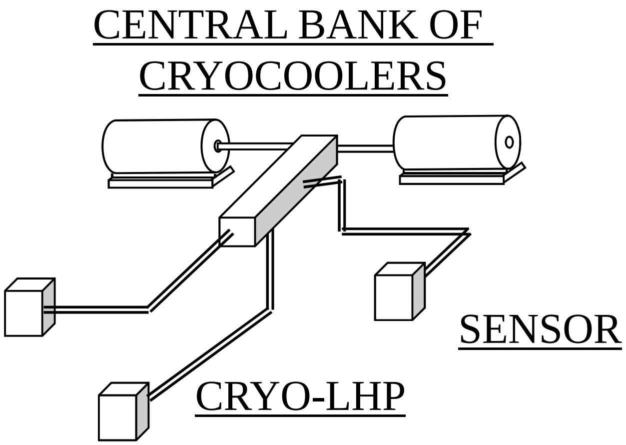
INDIVIDUALLY COOLED SENSORS



**THREE SENSORS,
12 CRYOCOOLERS**

- **Unwanted vibration induced by the mechanical cryocoolers may cause unacceptable jitter to the telescope.**
- **Packaging and integration are difficult in tight spaces especially when two or more cryocoolers are needed for redundancy.**
- **Heat parasitics from one inactive cryocooler may overload the active ones.**

Cooling with Cryogenic LHP Applications



THREE SENSORS
2 TO 6 CRYOCOOLERS

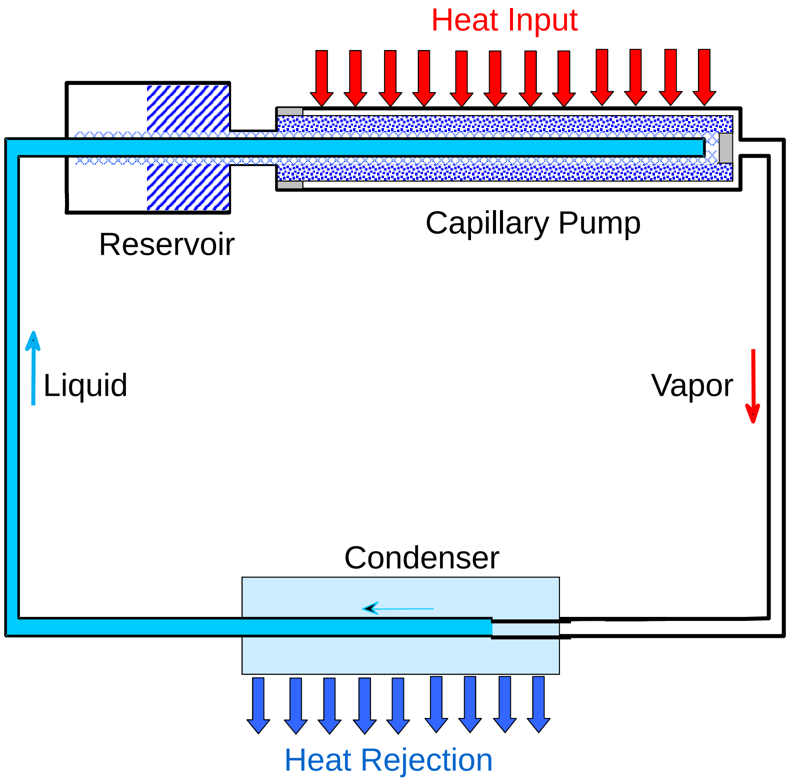
- **Jitter-free observations of the telescope at a target may prove invaluable for most space missions.**

- **The redundant cryocoolers can be thermally isolated from the active one on the spacecraft.**

- **A flexible heat transport device is therefore needed to provide a cryogenic link between the IR sensors and cryocoolers.**

Technical Challenges in CLHP Development

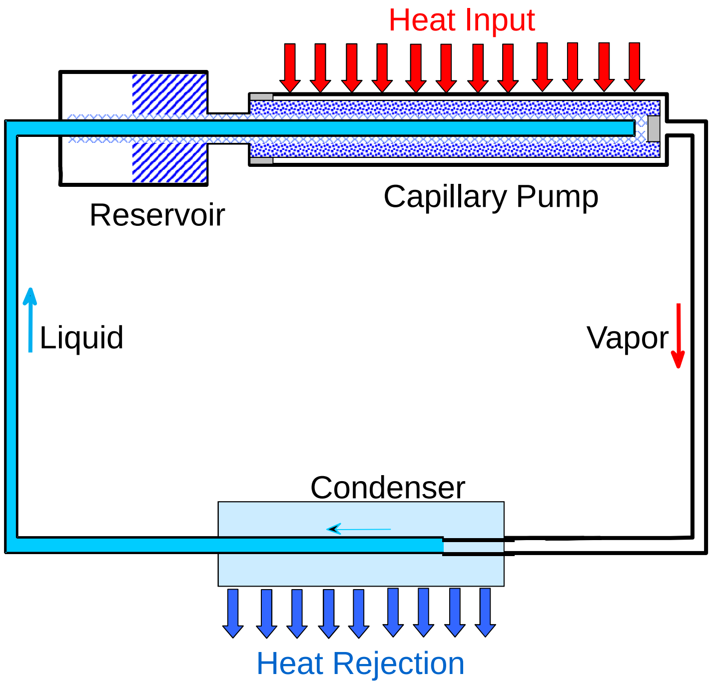
- start-up from an initially supercritical state
- parasitic heat gains along the liquid return line
- containment of the system pressure at ambient temperature
- coefficient of thermal expansion mismatch between the wick and the evaporator shell



Start-up from an Initially Supercritical State

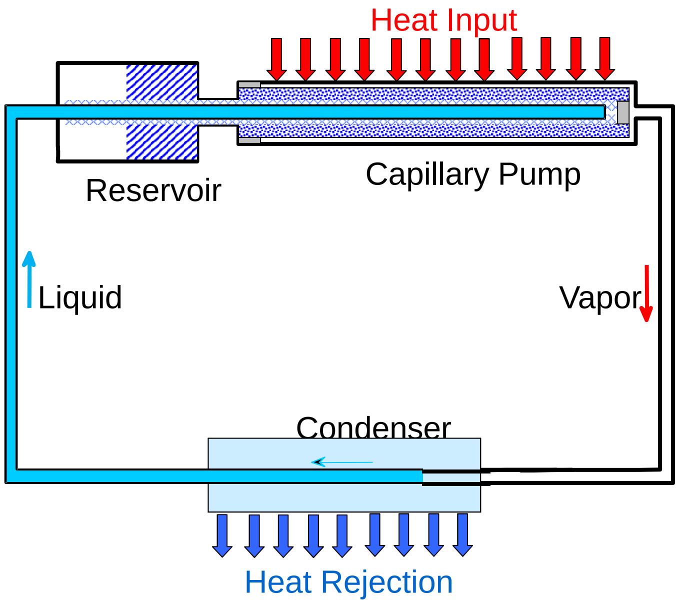
- **No liquid will be formed if the pressure in an LHP is greater than the critical pressure of the working fluid even if the temperatures of a component is below the critical temperature.**

- **When the LHP pressure is below the critical pressure of its working fluid, liquid will be formed at places where the temperature is lower than the critical temperature.**



Pressure Containment

- **A minimum amount of the working fluid is required in order for the CLHP to operate properly over the desired cryogenic temperature range.**
- **At ambient temperature, the gas pressure will be very large, resulting in pressure containment issues.**
- **Prior to start-up, only a small volume of the supercritical fluid (in the condenser) can be cooled.**
- **The pressure of the system may still be above the critical pressure, and no liquid can be formed even if the condenser is below the critical temperature.**



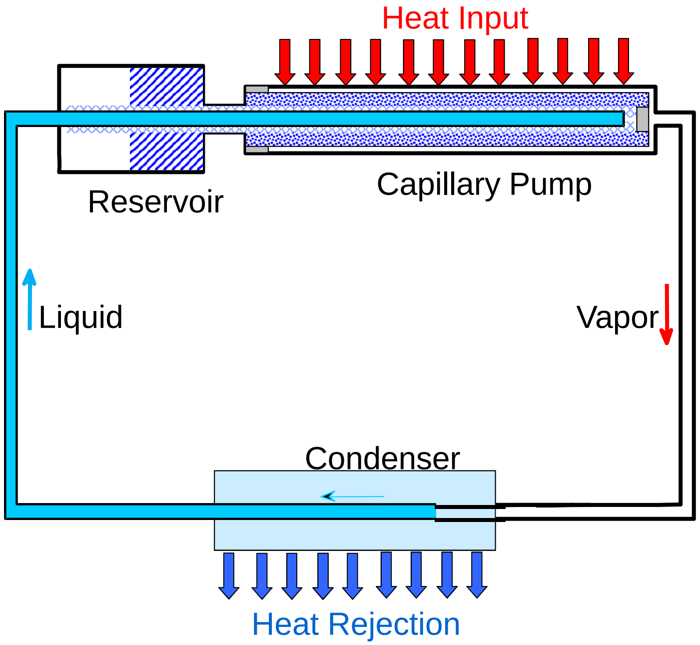
Parasitic Heat Gains Along the Liquid Line

- There is an inherent heat leak from the evaporator to the reservoir, and the reservoir can also gain heat from ambient.

- All heat gains must be compensated for by the cold liquid returning from the condenser.

- High parasitic heat gains along the liquid line will raise the returning liquid temperature, ultimately leading to a higher reservoir temperature.

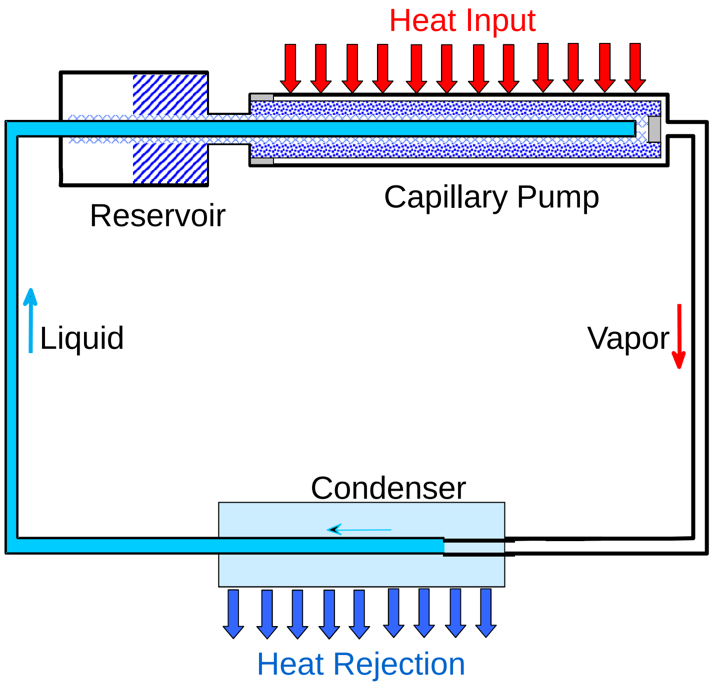
- The CLHP cannot operate when the reservoir temperature is above the critical temperature.



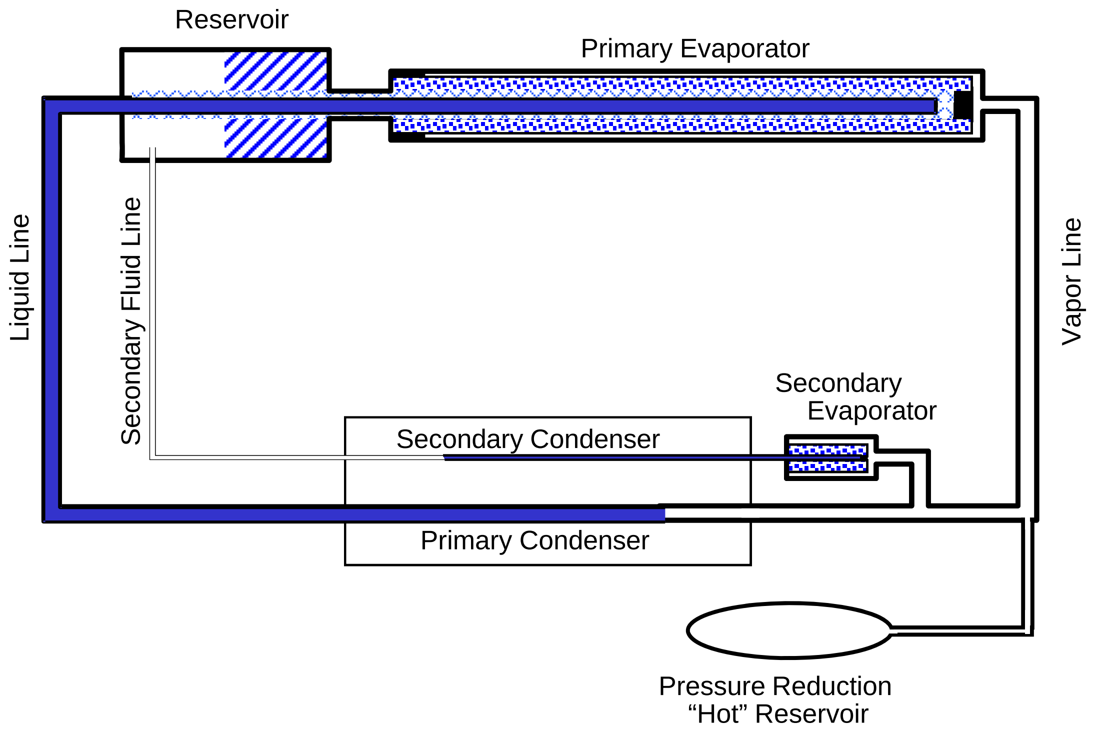
Mismatch of Coefficients of Thermal Expansion

- **A tight seal is required in order to prevent the vapor at the outer surface of the primary wick from penetrating into the liquid core of the evaporator.**

- **A mismatch in the CTEs between the primary wick and the evaporator shell over the range from the ambient temperature to cryogenic temperature could affect the required tightness of the seal between the two components.**



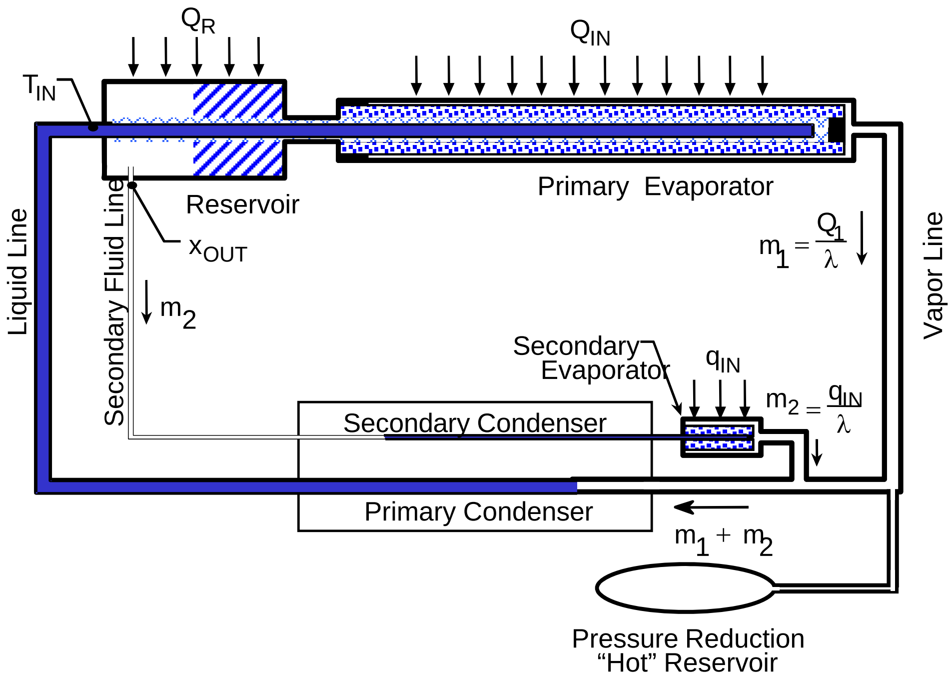
Concept of Advanced LHP



- **Add a secondary evaporator and a hot reservoir to the loop.**
- **The hot reservoir reduces the system pressure and helps startup success.**
- **The secondary evaporator ensures startup success and helps maintain the loop operating temperature.**

Operation of Advanced LHP

- Cool the primary and secondary condensers and secondary evaporator by cryocooler. Liquid will form in those locations.
- Apply power to the secondary evaporator to circulate fluid to cool the reservoir and primary evaporator. Liquid will form in those locations.
- Apply power to the primary evaporator to start the loop.
- The operation of the secondary pump also provides active cooling for the reservoir.

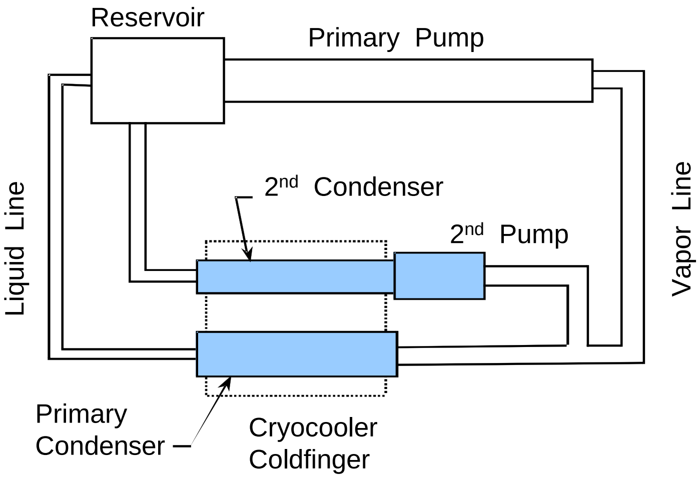


Overcoming Technical Challenges of CLHP

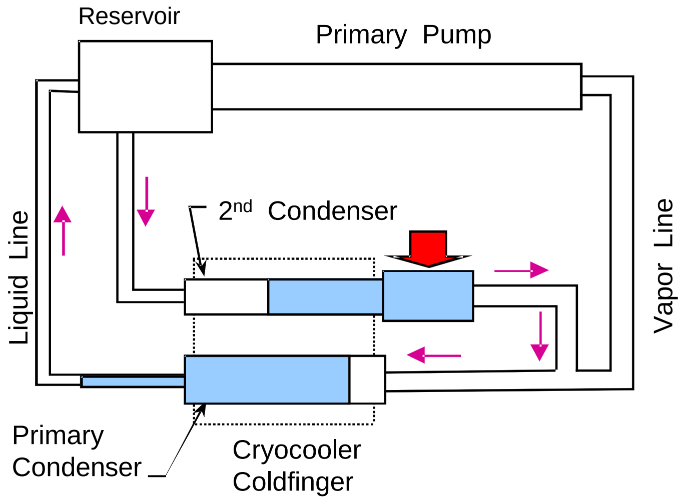
- A mismatch of coefficient of thermal expansion between the capillary pump and the primary wick
  - Solved by using the same material for capillary pump and primary wick
- Containment of the system pressure at ambient temperature
  - Solved by using a hot reservoir attached to the CLHP to reduce the system pressure
- Start-up from an initially supercritical state
  - Solved by using a hot reservoir attached to the CLHP to reduce the system pressure
- Parasitic heat gain at cryogenic temperatures
  - Solved by applying power to the secondary evaporator to cool the reservoir.

Start-up of CLHP

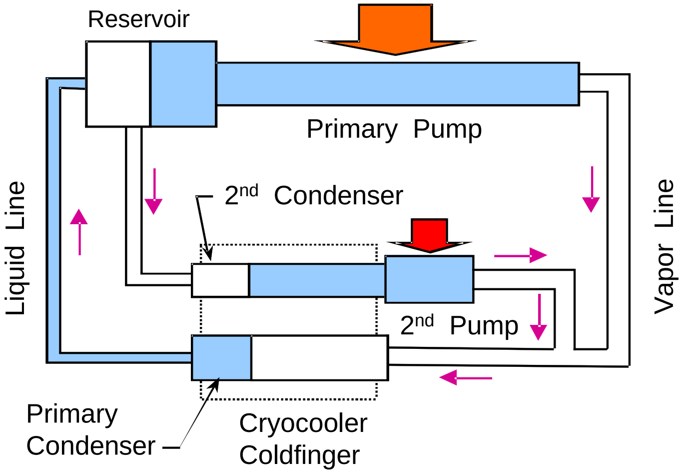
Cryocooler Cooldown



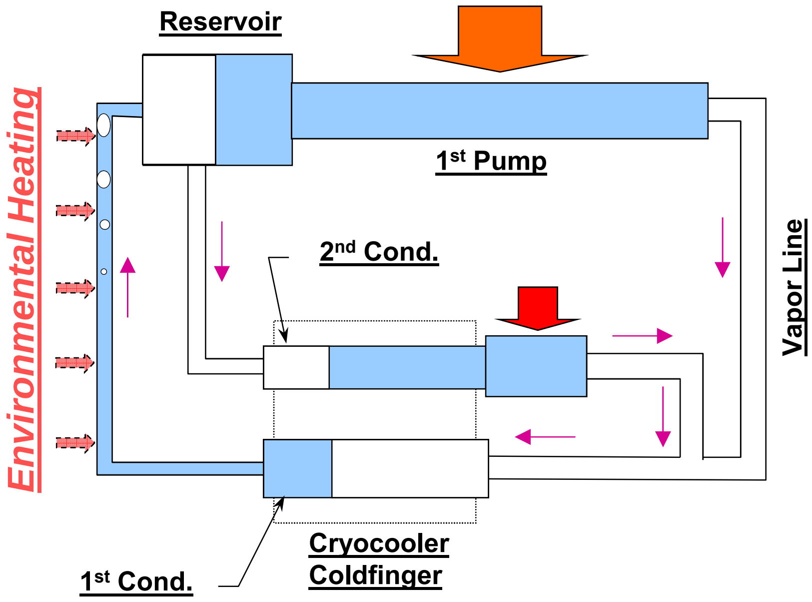
Cooling & Pumping of 2nd Pump



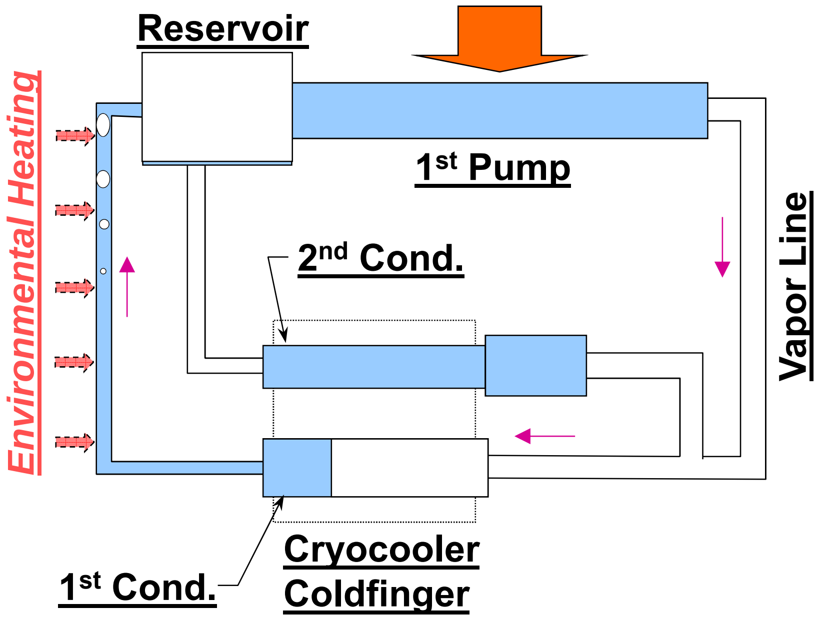
Startup



Management of Prarsitics



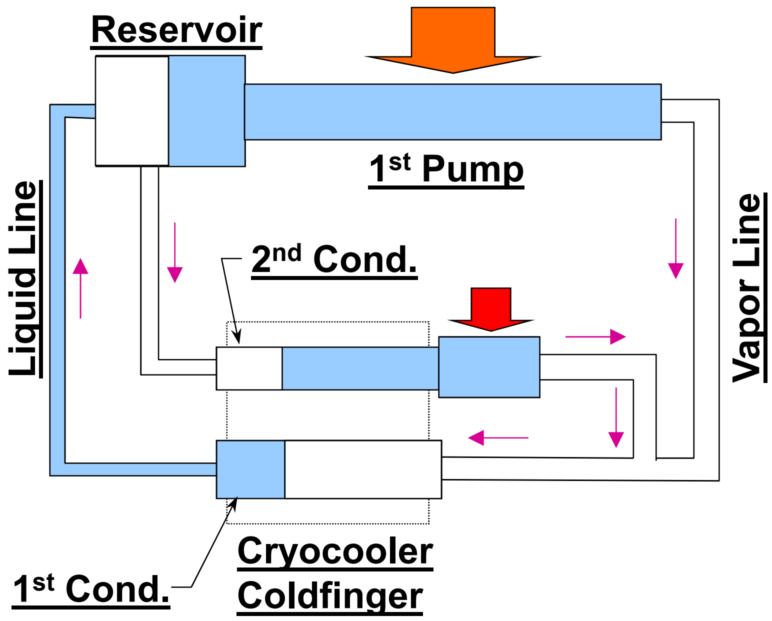
2nd Pump to Manage Parasitics



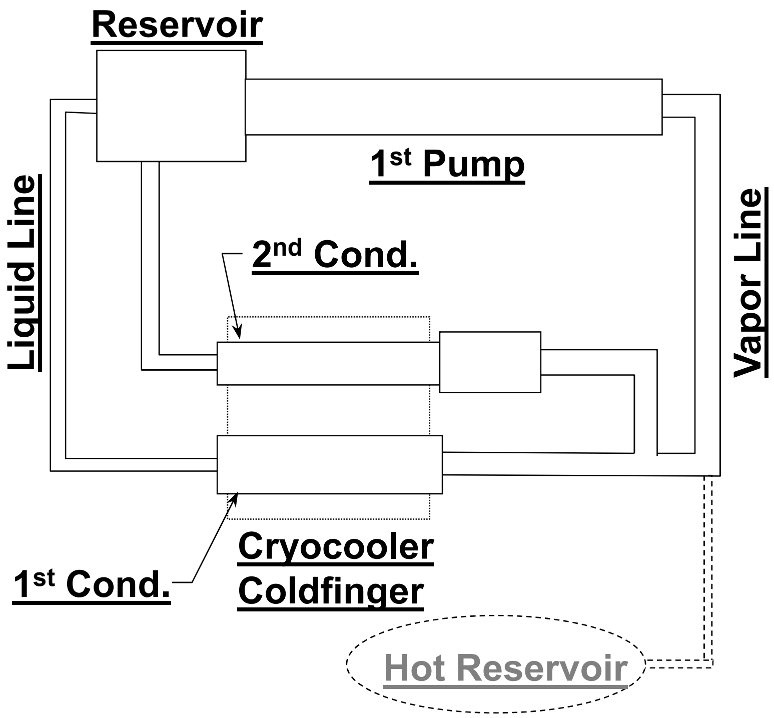
No Parasitics Management → Failure

Environmental Heating (Parasitics) ⇒ Boiling in Liquid Line
⇒ Vapor Build-up in Reservoir (if not properly managed)
⇒ System Failure

Pressure Reduction Reservoir



Normal Operation (P_{SYSTEM} < 20psia)

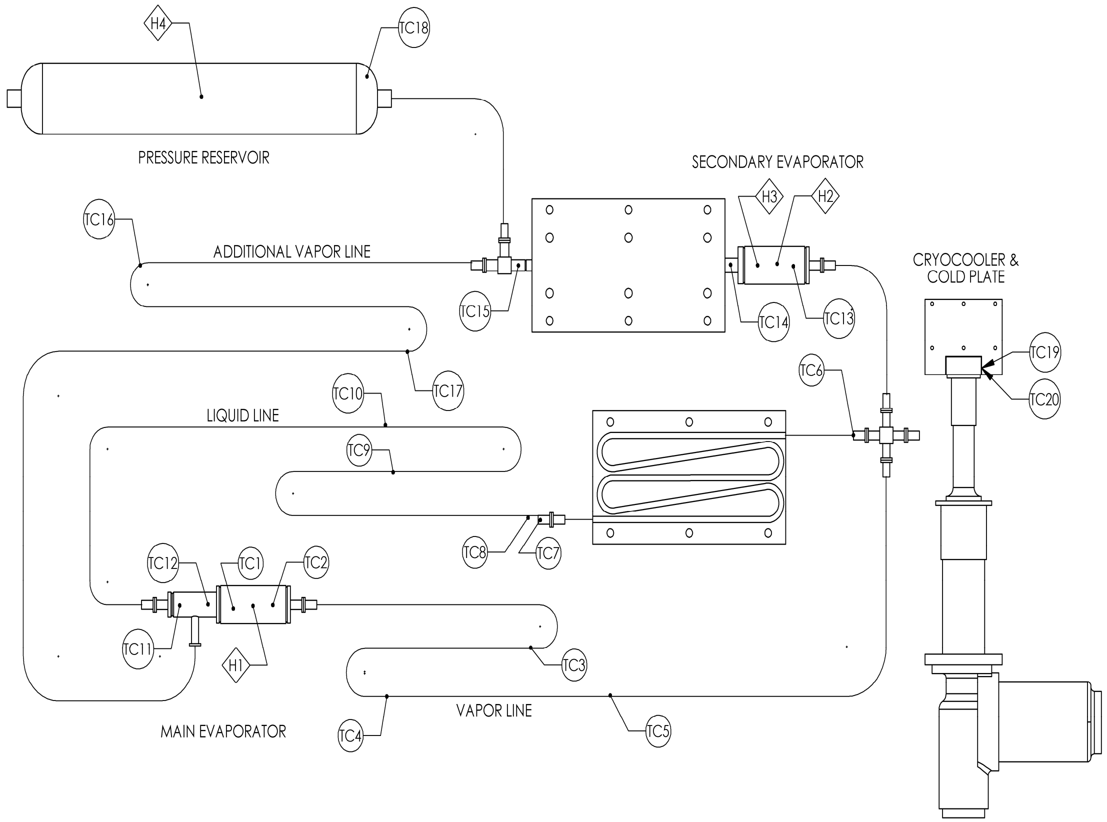


Dormancy in Hot Environment

System Pressure > 3,000psia w/o Hot Reservoir

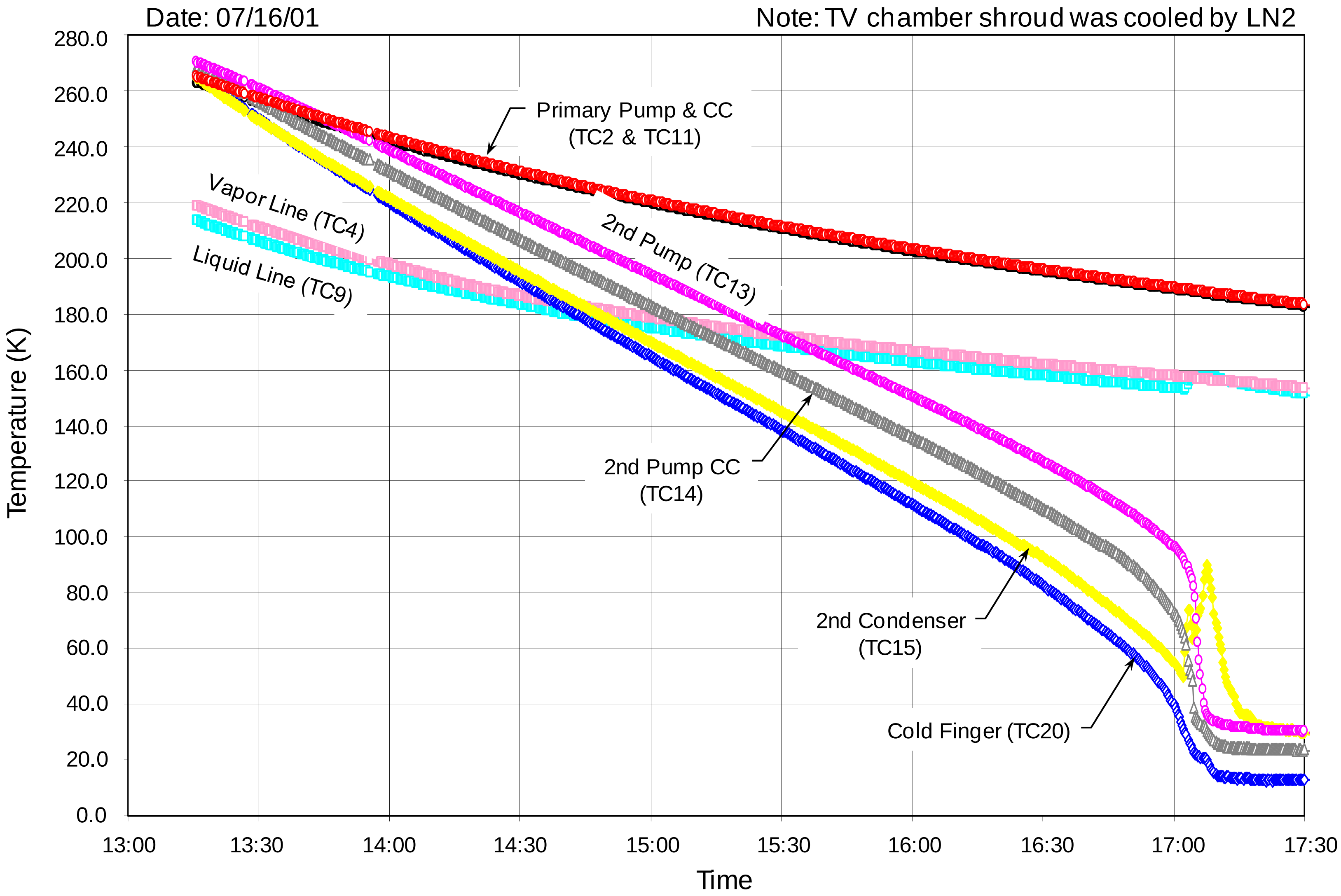
System Pressure < 100psia with Hot Reservoir

Advanced Hydrogen CLHP

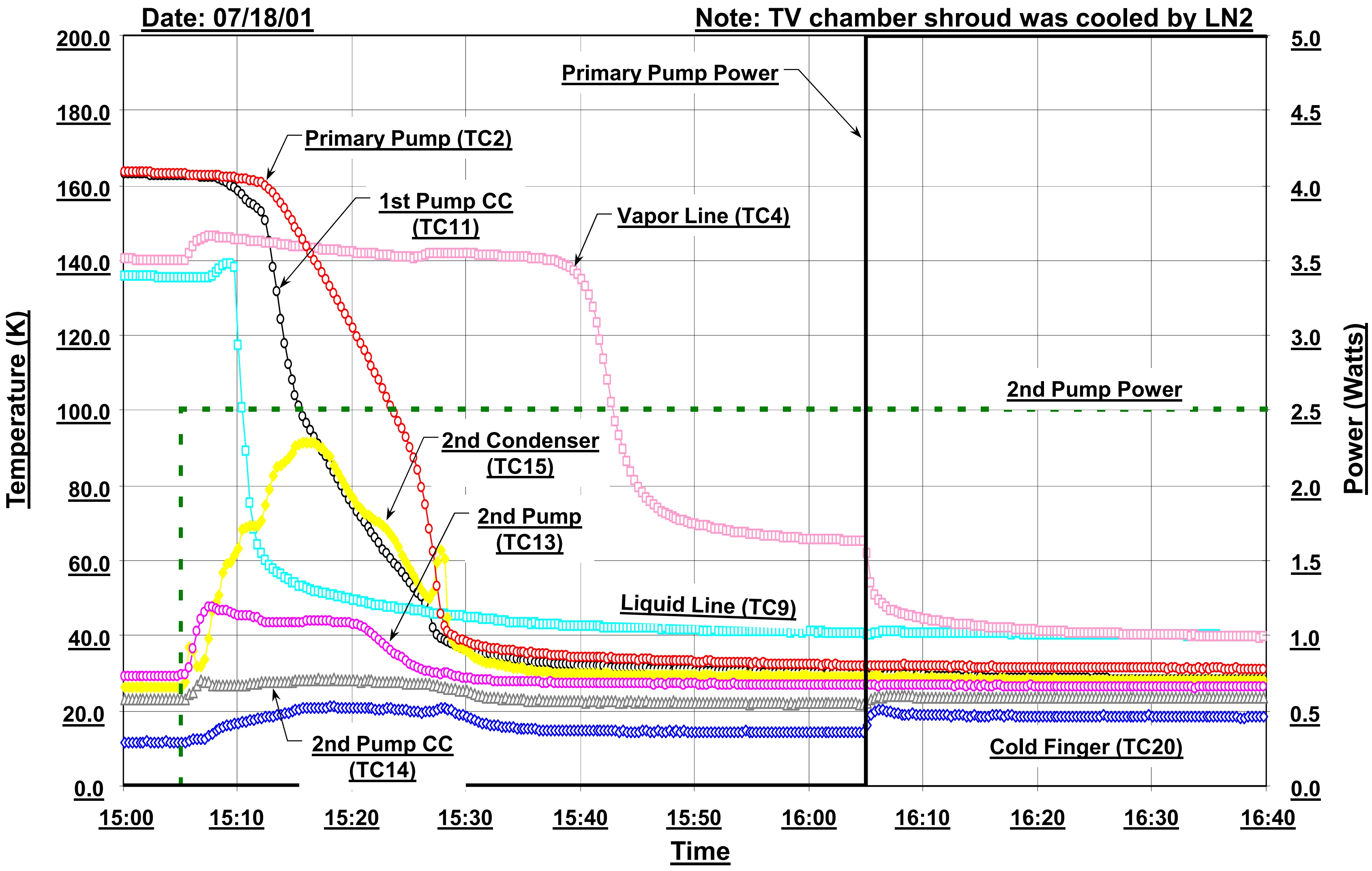


- **Demonstrated successful startup and stable operation over temperature range of 20K to 30K.**

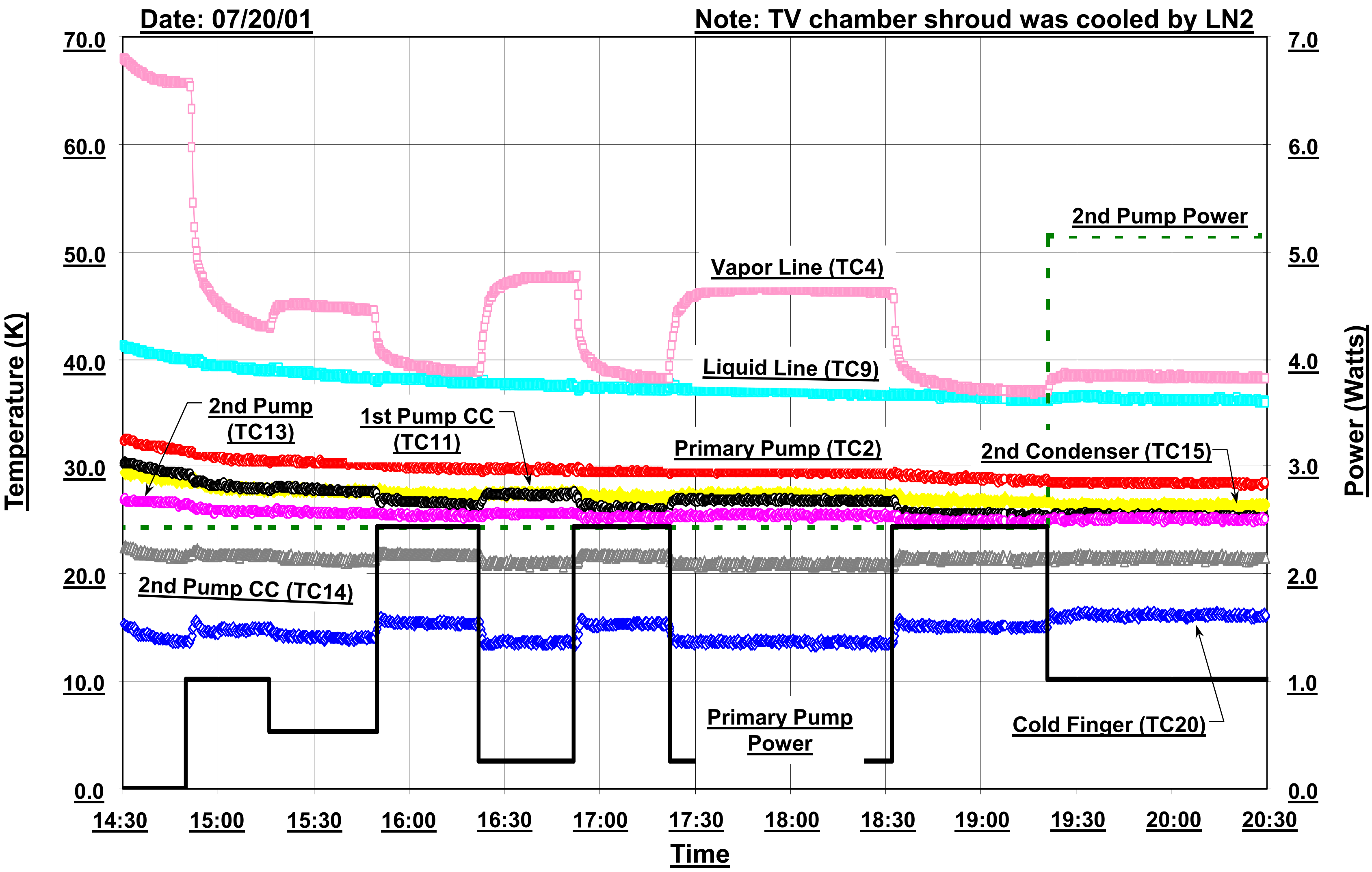
Cooldown of Hydrogen Advanced LHP



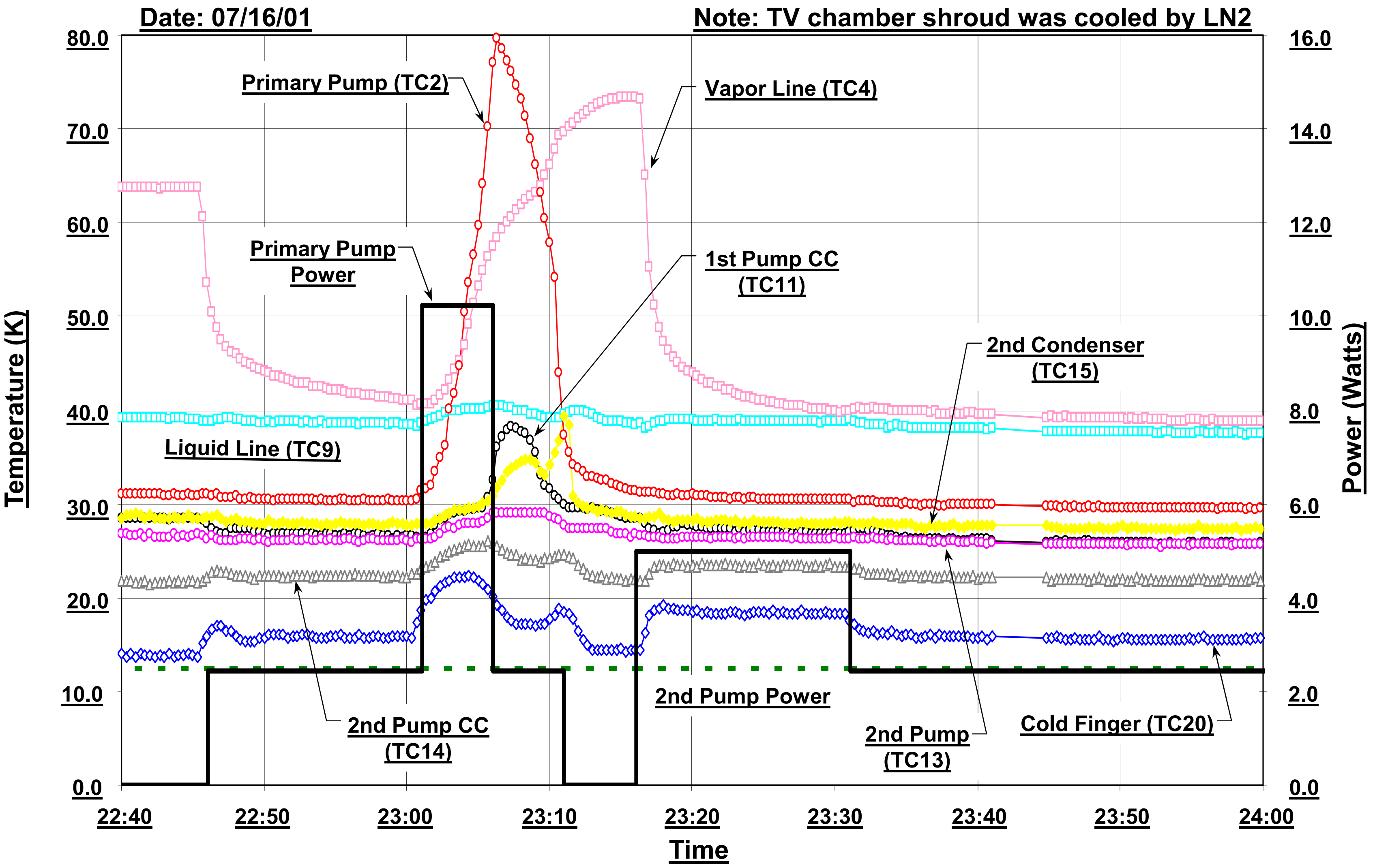
Startup of Hydrogen Advanced LHP



Power Cycle Test of Hydrogen Advanced LHP



Deprime and Recovery of Hydrogen Advanced LHP



Summary of Advanced Hydrogen LHP Operation

- **N2-ALHP_1 worked well in all phases of operation. It was capable of starting and functioning reliably even in a very hot (298K) surrounding shroud.**
- **The N2-ALHP_1 cryo-transport capacity was 20 watts over a distance of 2.5 meters in 298K shroud.**
- **Its resilience and robustness −with respect to start-ups, rapid power changes, recovery from failures, and parasitics handling − were however most impressive.**

Questions?