Integration of a Reverse Turbo-Brayton Cryocooler with a Broad Area Cooling Shield and a Heat Pipe Radiator

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Thermal & Fluids Analysis Workshop
TFAWS 2013
July 29-August 2, 2013
Kennedy Space Center
KSC, FL

Agenda

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- Subsystem Design
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  - Broad Area Cooling (BAC) Shield
  - Insulation
  - Distribution Manifold
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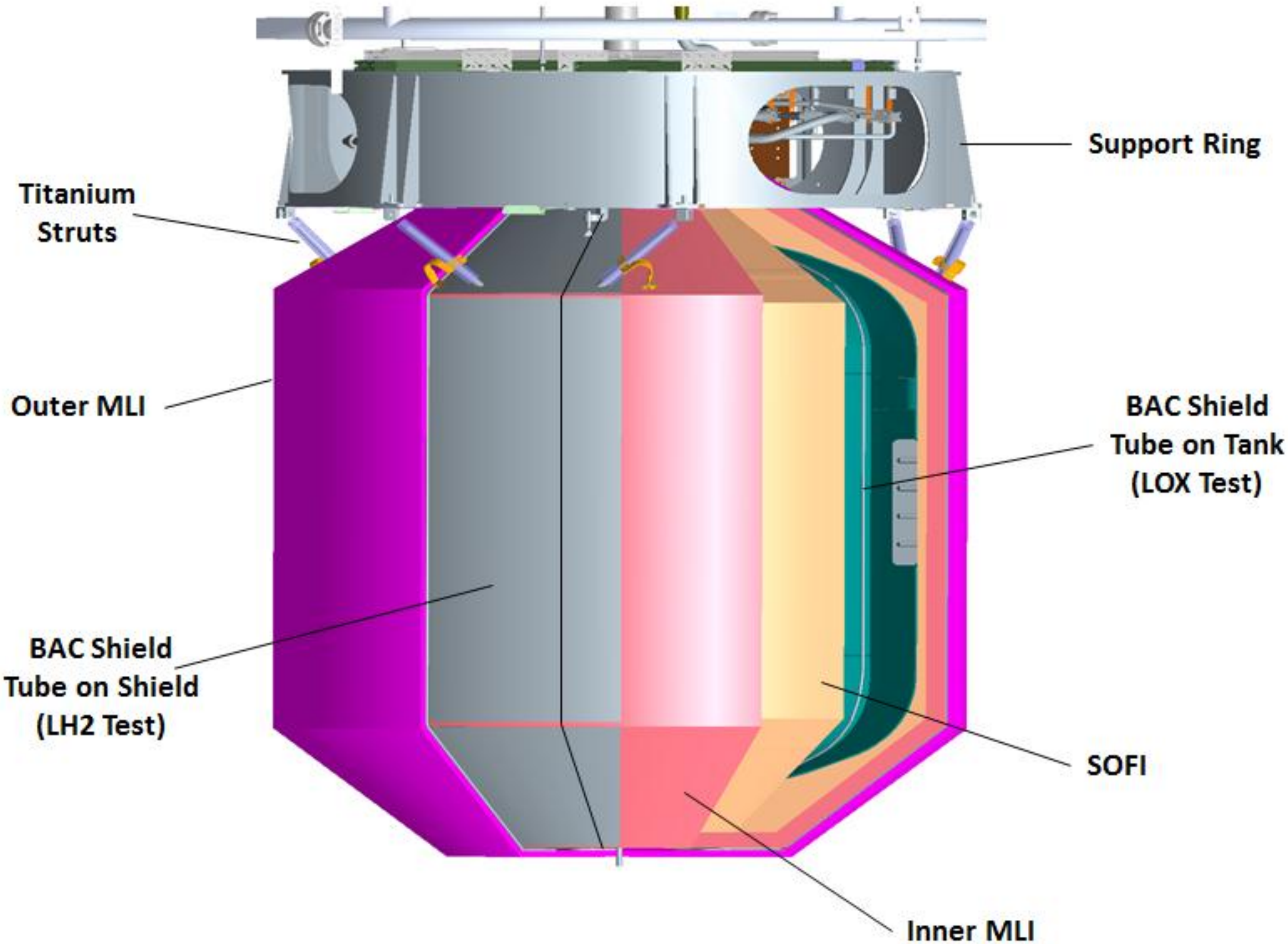
- Cryocooler Operation and Testing
- Conclusion

Introduction

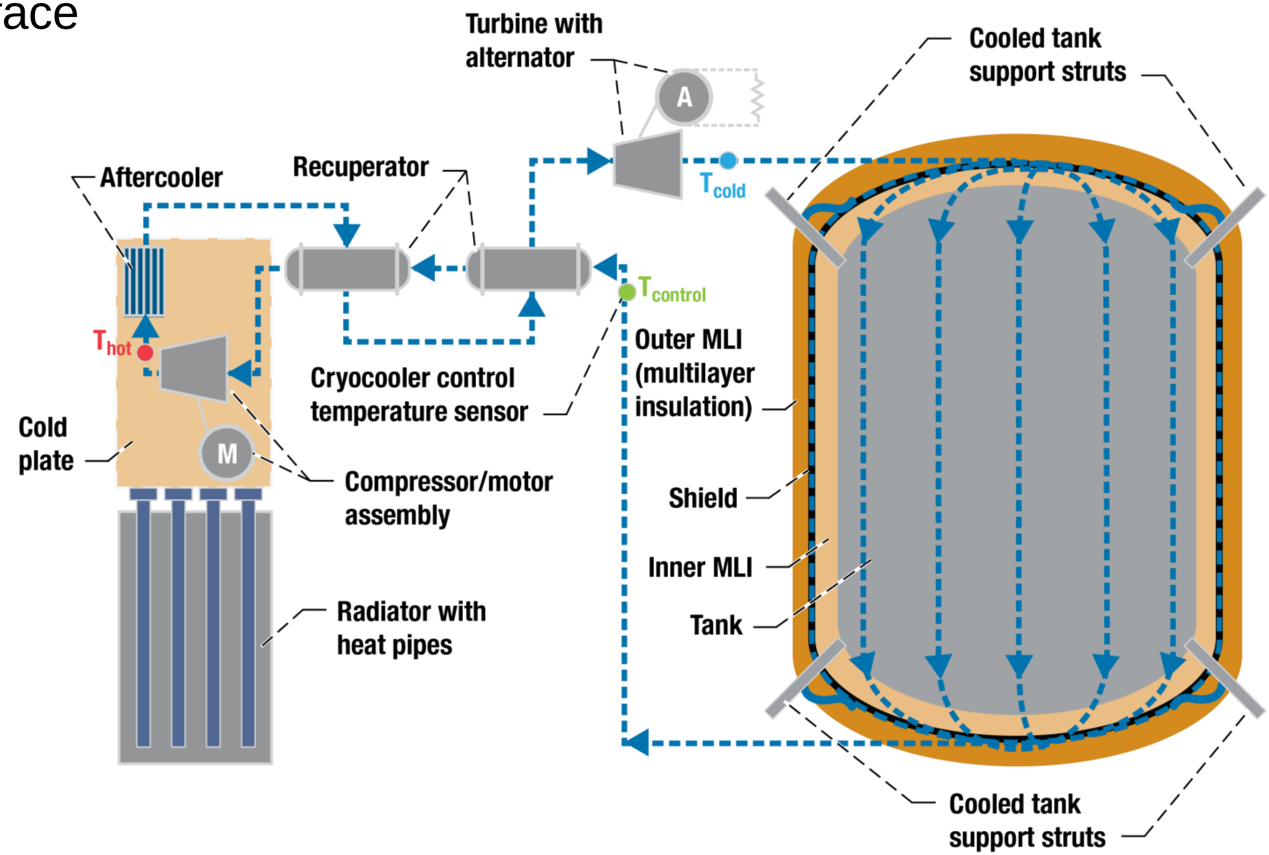
- NASA Glenn Research Center (GRC) Cryogenic Boil-Off Reduction Testing (2012-2013)
  - Ground test to reduce liquid hydrogen (LH2) boil-off from spacecraft propellant tanks
    - Reduce MLI Radiation Heat Leak by 66% and
    - Reduce Penetration Conduction Heat Leak by 60%
  - Broad Area Cooling (BAC) via a cooled shield within the multilayer insulation (MLI) layers
  - Strut cooling via thermal straps linked to the BAC shield tubing
  - Active cooling via integrated Reverse Turbo-Brayton Cycle (RTBC) Cryocooler

Reduced Boil-Off Test Hardware

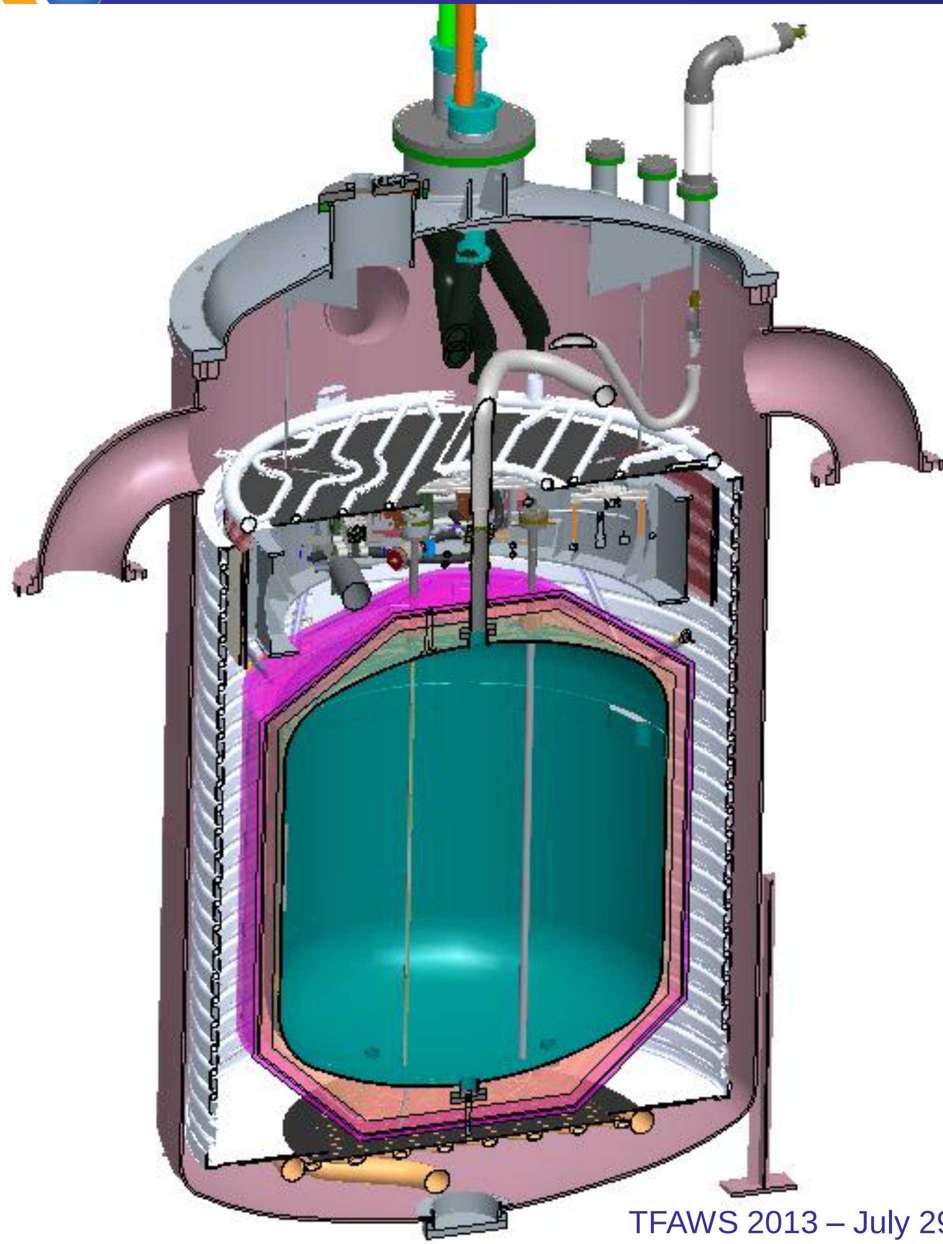


Integrated System Overview

- Unique, innovative integrated thermal control system
  - Process flow from cryocooler cools large BAC shield surface area (8 m^2)
  - Single closed loop for both cryocooler and BAC shield
  - Cryocooler compressor and aftercooler mounted directly to the radiator surface



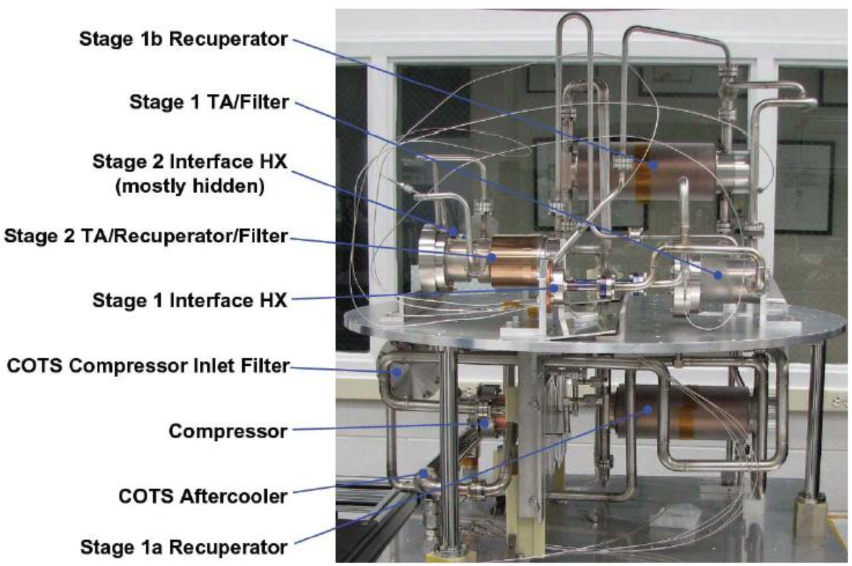
Integrated System at Test Facility

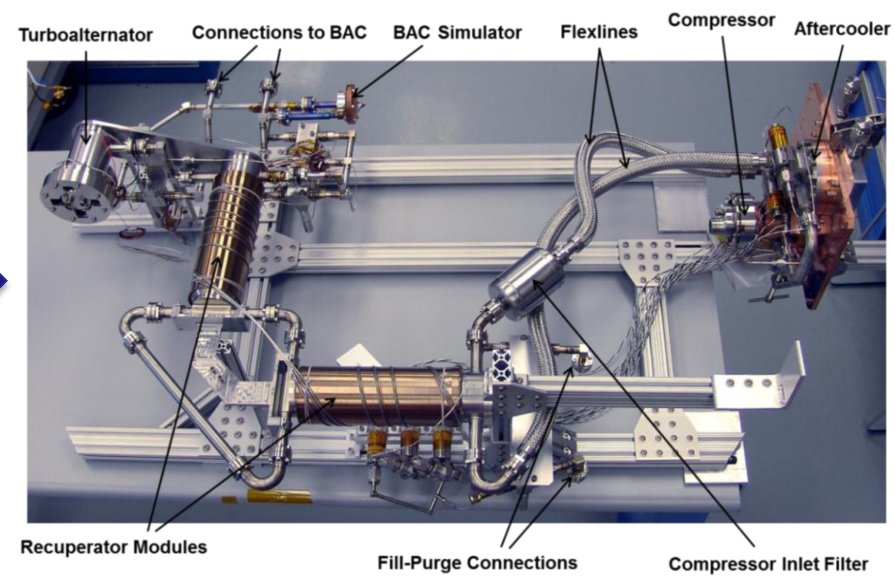


- NASA GRC's Small Multipurpose Research Facility (SMiRF)
  - Vacuum levels as low as 8.5e-6 torr
  - Temperatures controlled as low as 110K via cold wall

Reverse Turbo-Brayton Cycle Cryocooler

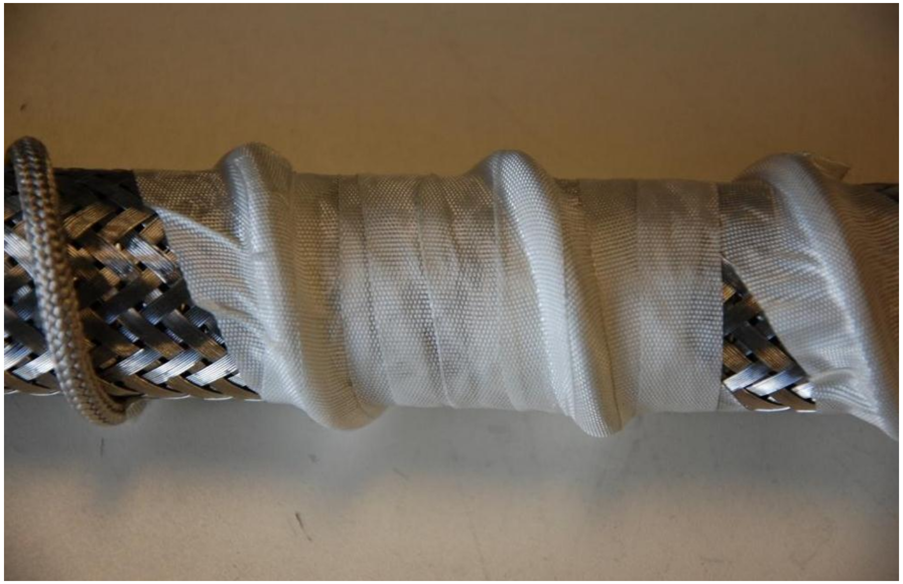
- RTBC Cryocooler from Creare, Inc. modified from existing hardware for a previous project
  - Eliminated a second-stage turboalternator
  - Replaced commercial compressor inlet filter and aftercooler with flight-like versions
  - Modified compressor flow passages for lower flow rates
  - Repackaging of cryocooler assembly
  - Reconfiguration of tubing, valves, and fitting to fit BAC interface





RTBC Performance In Cold Environments

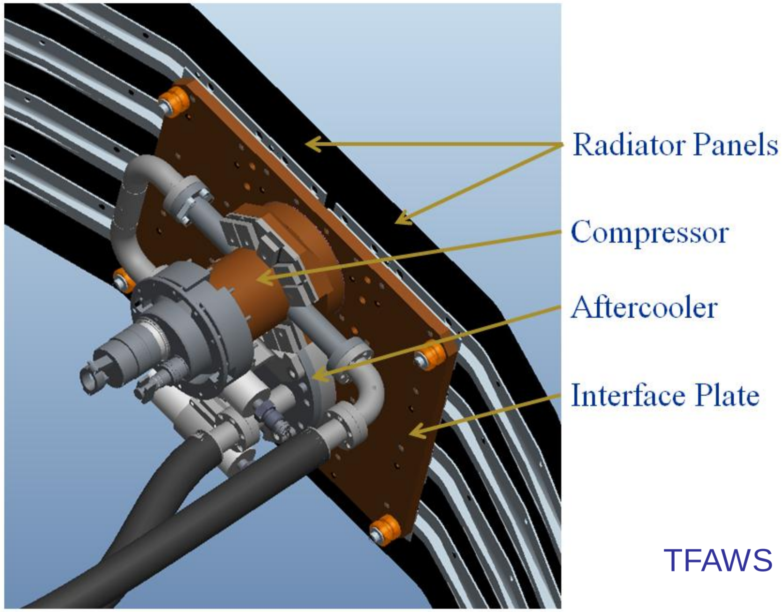
- Cryocooler requires heating along Flexlines between Compressor, Recuperators, and Inlet Heaters when testing in cold environments

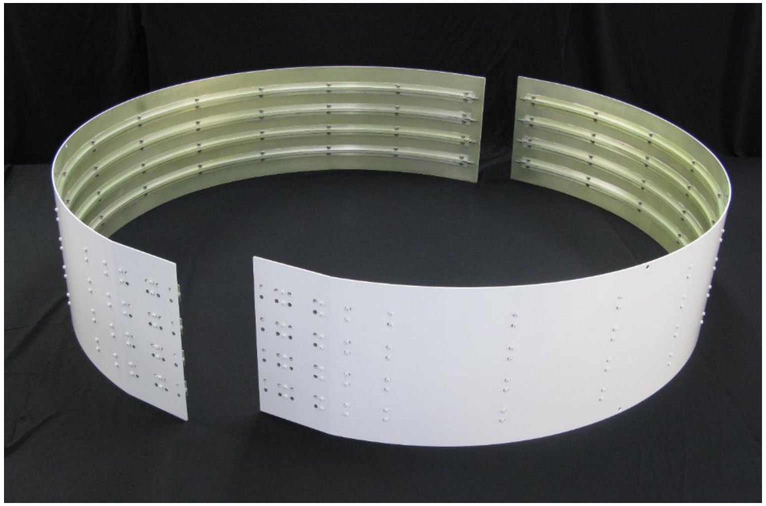


- With heaters, cryocooler start-up was successfully at temperatures as low as 200K

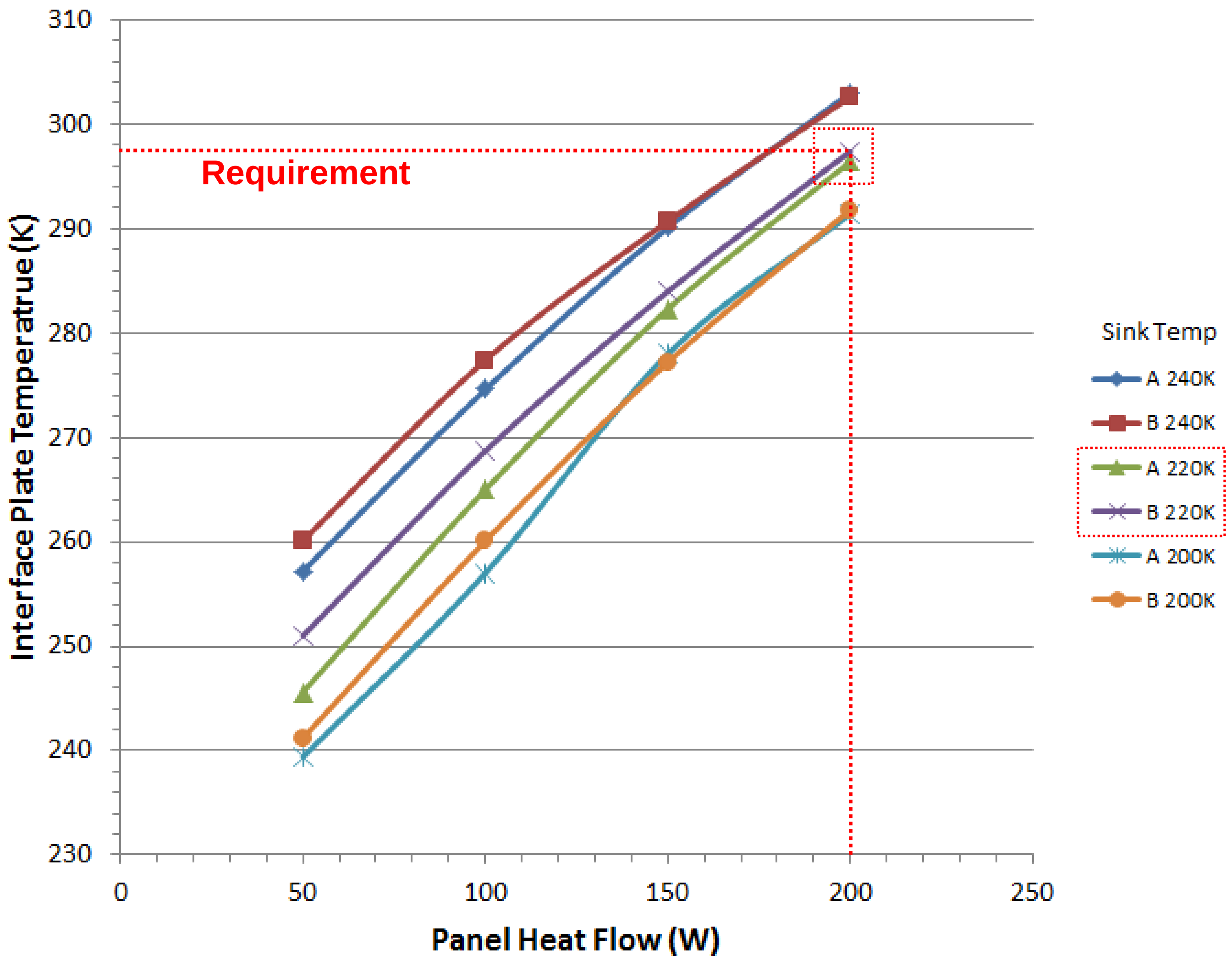
Constant-Conductance Heat-Pipe Radiator

- CCHP Radiator from Active Cooling Technologies, Inc.
  - Two thick aluminum panels; each rejects at least 200 W at 300 K to a sink temperature of 220 K
    - Four ammonia-aluminum constant conductance heat pipes per panel
    - Full assembly has a 1.5 m diameter, height of 0.36m, 0.125 in thick
    - Painted surface with Aeroglaze A276, measured emissivity of 0.935
  - Radiators bolted directly to the heat rejection plate of the cryocooler, aka the radiator interface plate
    - Nusil CV-2943 used as a thermally conductive gap filler between radiator and interface plate



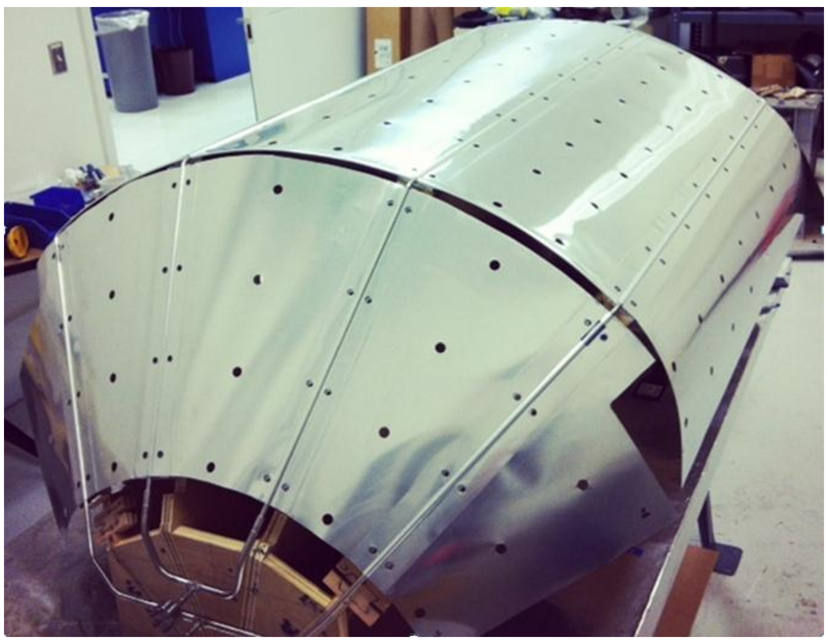


CCHP Radiator Panel Performance

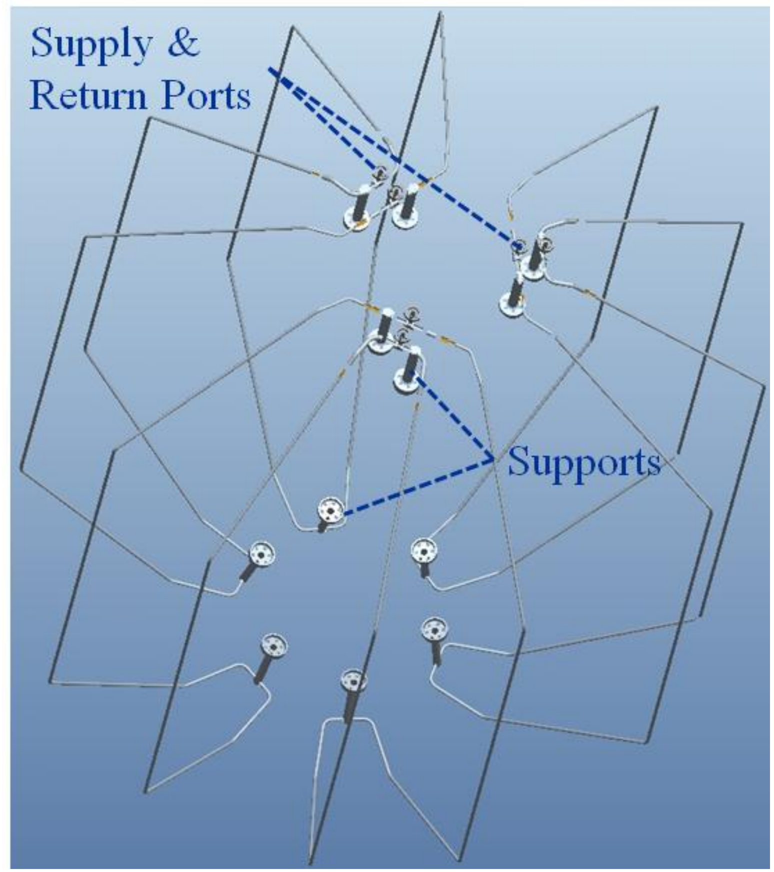


Broad Area Cooling Shield

- NASA-developed aluminum shields with stainless steel tubing
  - Three 120° sections, each with two cooling loops

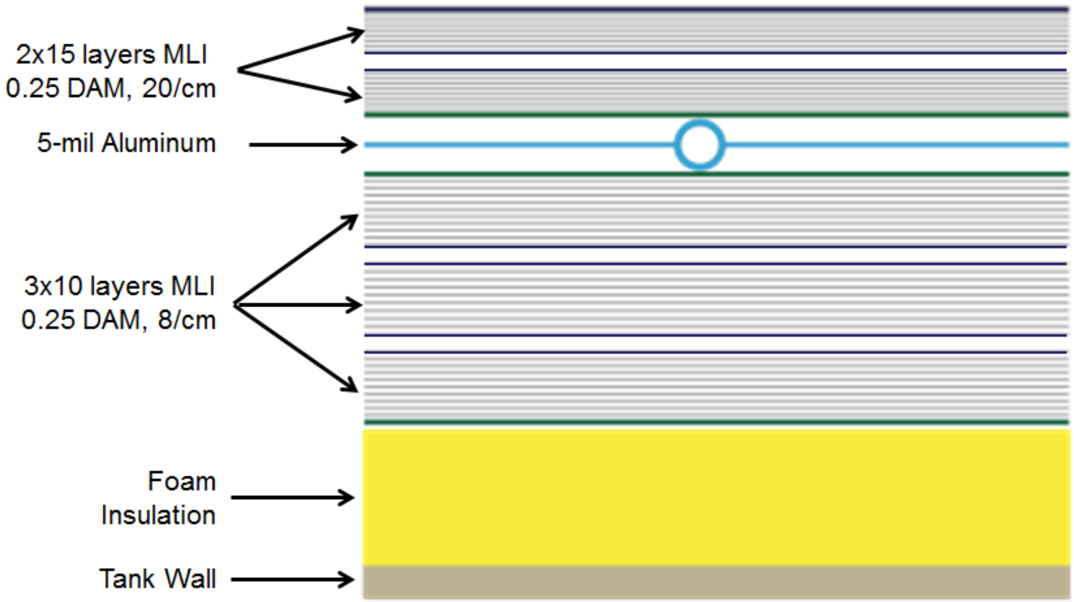


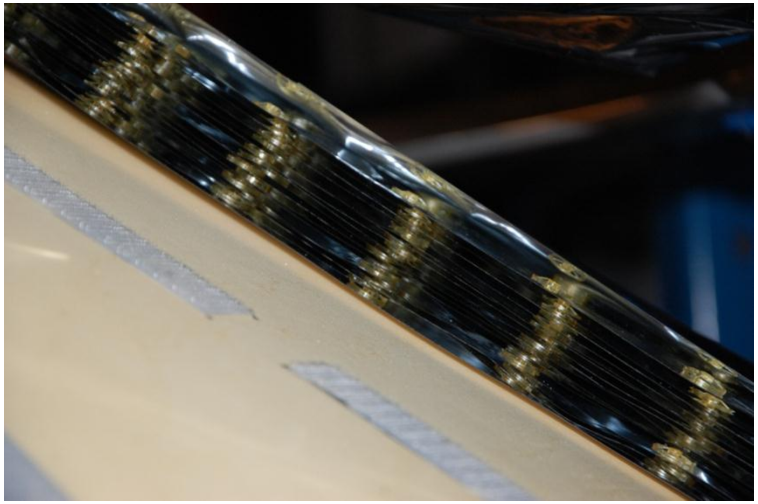
BAC Shield 120° Section



Multilayer Insulation (MLI)

- The BAC shield is located within the MLI layers
  - 30 layers of conventional high-density MLI outside shield
  - 30 layers of low-density MLI inside shield
  - Two types of low-density MLI were tested:
    - Conventional MLI, requires additional supports for BAC shield fabricated from low-conductivity Ultem 1000
    - Self-Supporting MLI, eliminates need for Ultem supports

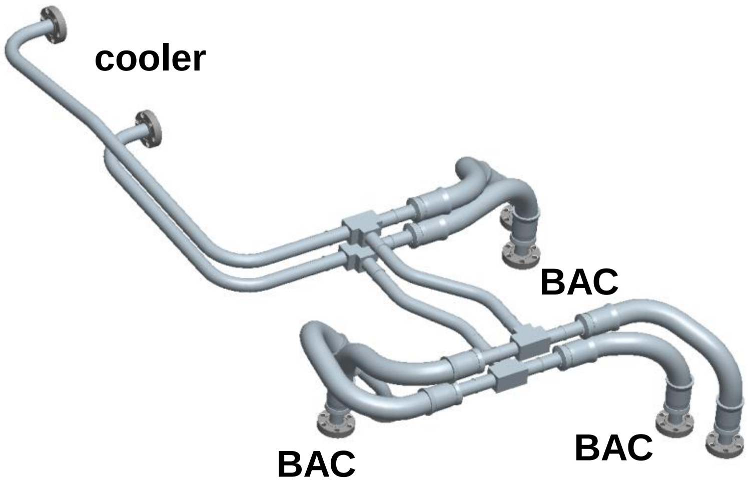


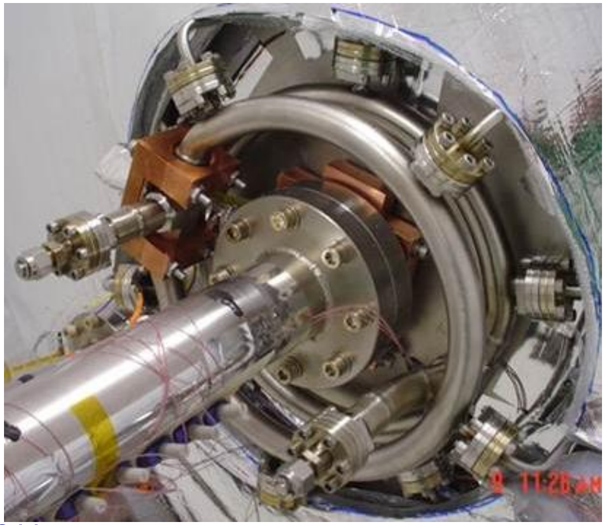


Self-Supporting MLI (SSMLI)

Distribution Manifold

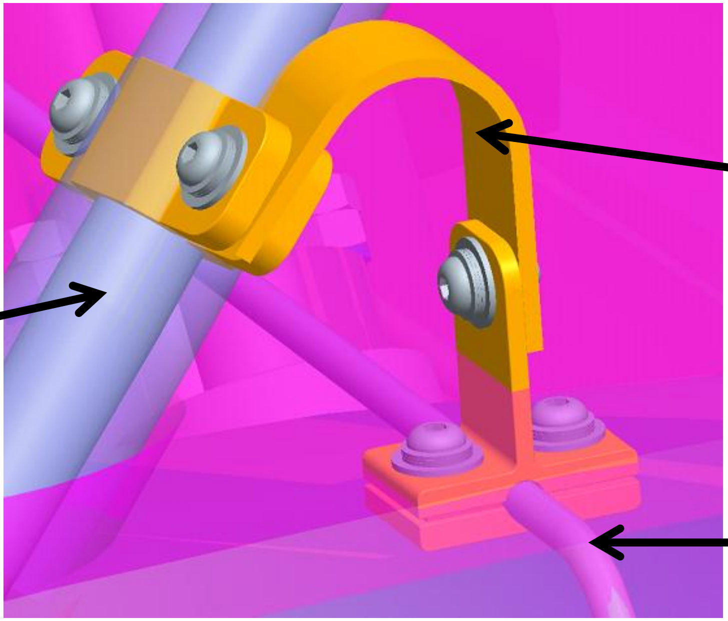
- Flexhoses
  - Relatively short manufacturing lead time
  - Difficult to meet precision cleanliness requirements
  - Non-compact design with suboptimal flow distribution
  - Increases cold gas fraction of system
- Toroidal Header
  - Relatively long manufacturing lead time
  - Meet precision cleanliness requirements
  - Compact design with uniform flow distribution
  - Increases cold gas fraction of system





Heat Traps

- Copper straps and clamps were used to trap a portion of the heat entering the tank through the penetrations
  - Twelve tank struts
  - Fill/Drain piping
  - Vent line piping
    - Removed after first round of testing
    - Cooling from venting provides more heat removal than the heat trap



Integrated System Being Installed in Chamber

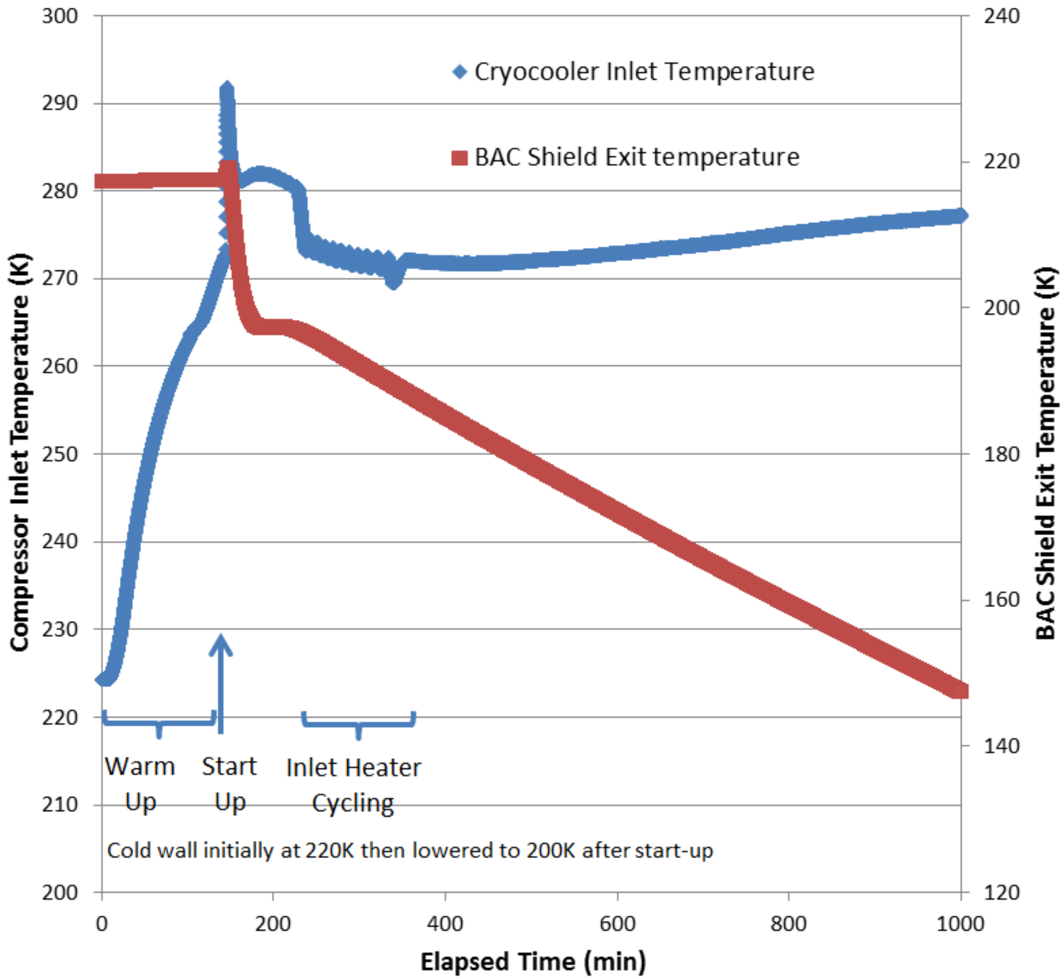
Cryocooler Operation and Testing

- Testing of the cryocooler both prior to and following integration with the associated subsystems showed relatively consistent performance

Test Description	Net Cooling	Rejection Temp.	BAC Temp.
Pre-integration	11	300	80
Pre-integration	15	300	90
Integrated System	13.5	281	80
Integrated System	16.4	277	90

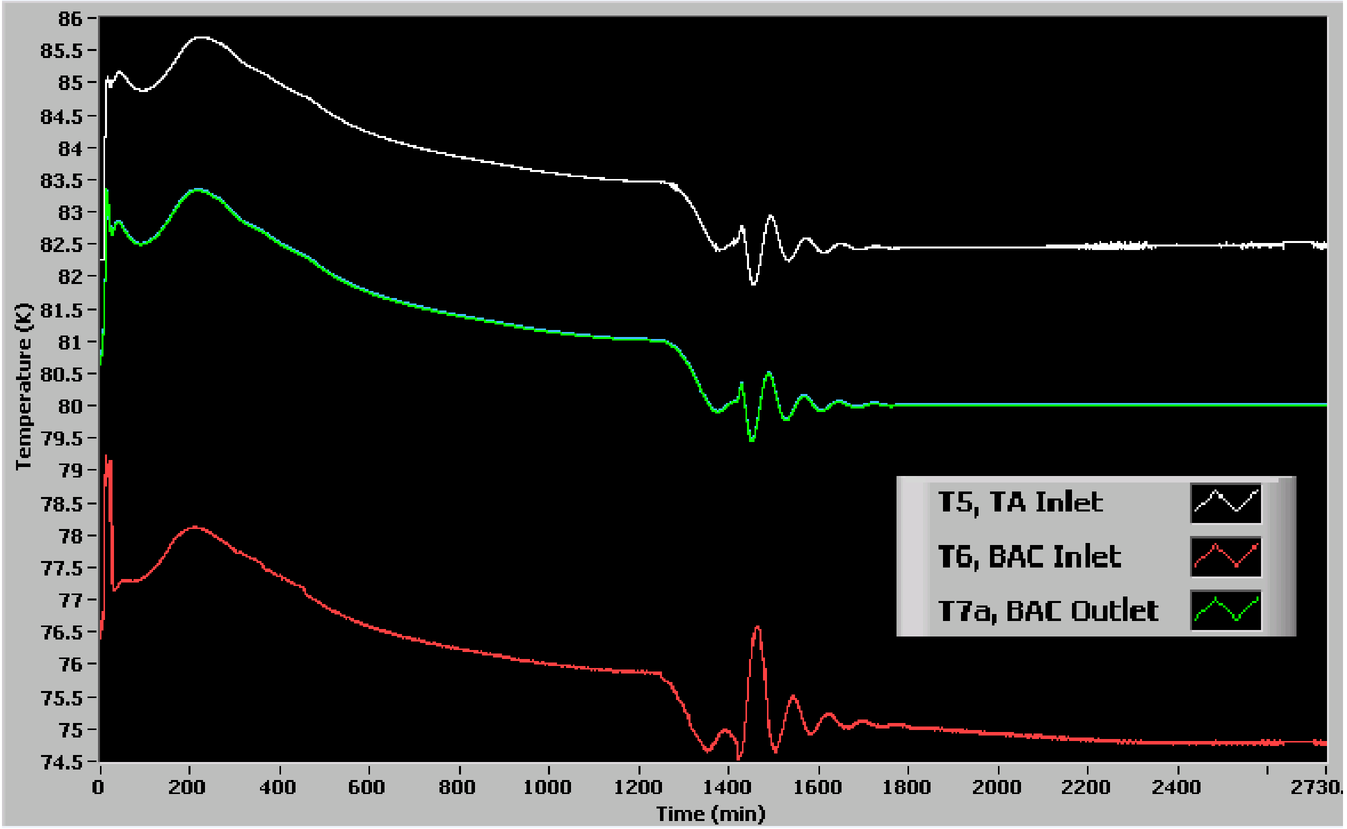
Cryocooler Operation: System Start-up

- The start-up of the system at cold temperatures (< 220K) was demonstrated successfully



Cryocooler Operation: System Start-up

- Compressor speed constrained for 1200 minutes due to operational requirements
- Delays ability to reach 80 K until constraint is lifted and compressor speed it raised.



Conclusion

- Integrated system testing reflects a unique approach to boil-off reduction similar to proprosed future flight configurations
  - Large surface area application of broad area cooling shield technology
  - Direct mounting of an RTBC cryocooler to a heat-pipe radiator
  - Direct integration of a cryocooler/circulator loop with broad area cooling tubing loops
- Radiator and cryocooler performance both met or exceeded performance expectations for the system
- Further data reduction to be published by the principal investigator

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