Thermal Vacuum Testing of the Cryostat Heat Removal Subsystem for COSI SMEX

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2026 Spacecraft Thermal Control Workshop
The Aerospace Corporation
210 South Douglas Street, El Segundo, CA 90245, United States
March 31 – April 2, 2026

NASA Goddard SPACE FLIGHT CENTER

Introduction

- Compton Spectrometer and Imager (COSI) is a soft gamma-ray survey telescope (0.2-5 MeV).
- It is designed to probe the origins of Galactic positrons.
- The mission is a collaboration between:
  - the University of California, Berkeley's Space Sciences Laboratory;
  - the University of California, San Diego;
  - the Naval Research Laboratory;
  - NASA's Goddard Space Flight Center;
  - Northrop Grumman;
  - Space Dynamics Laboratory;
  - the Italian Space Agency;
  - and a number of research institutions.
- NASA Goddard designed, fabricated and tested Cryostat Heat Removal Subsystem (CHRS).
- This presentation focuses on the CHRS TVAC testing and lessons learned.

SSL

NORTHROP GRUMMAN

Space Dynamics™ LABORATORY
Utah State University

Goddard Space Flight Center

Agenzia Spaziale Italiana

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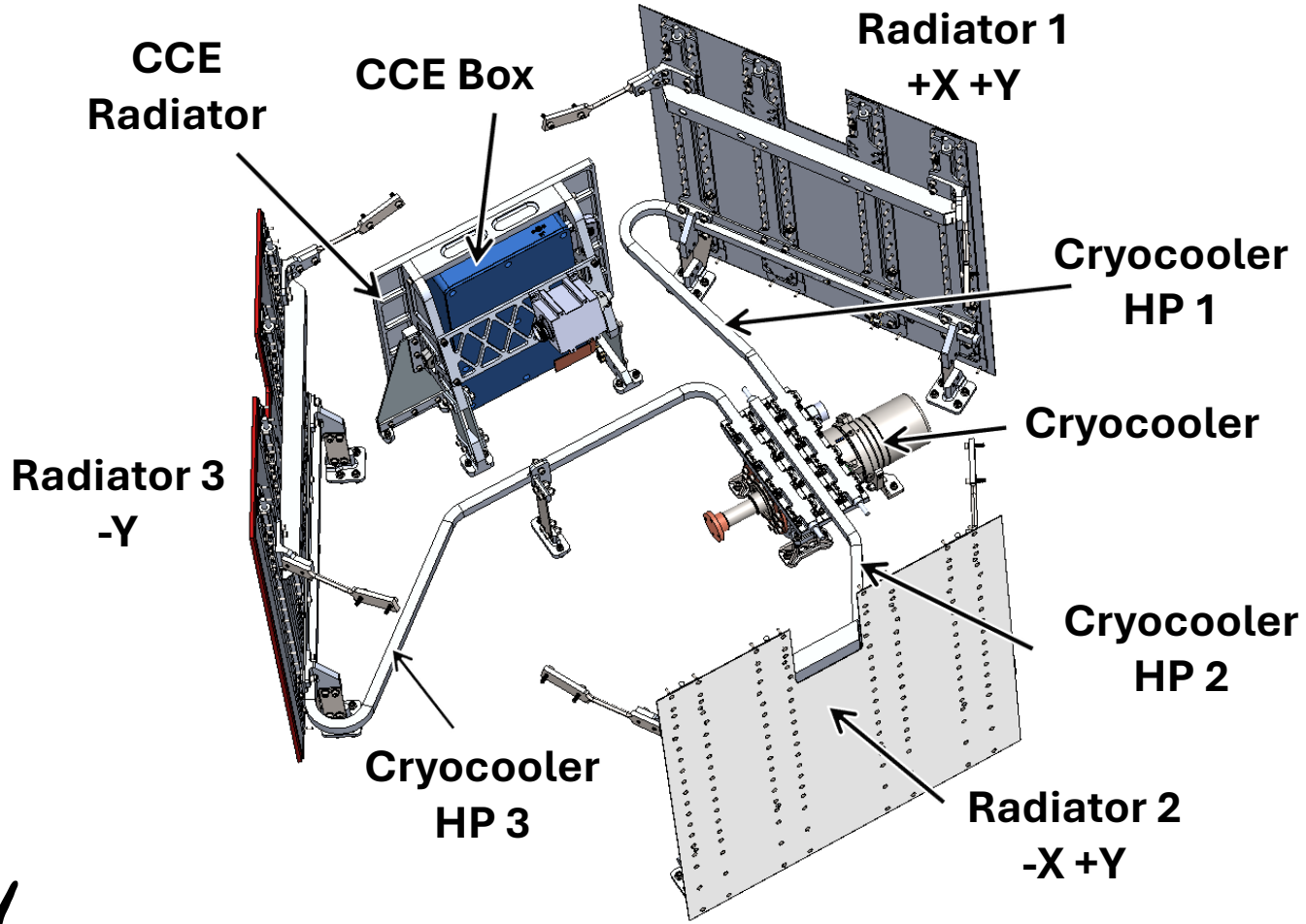
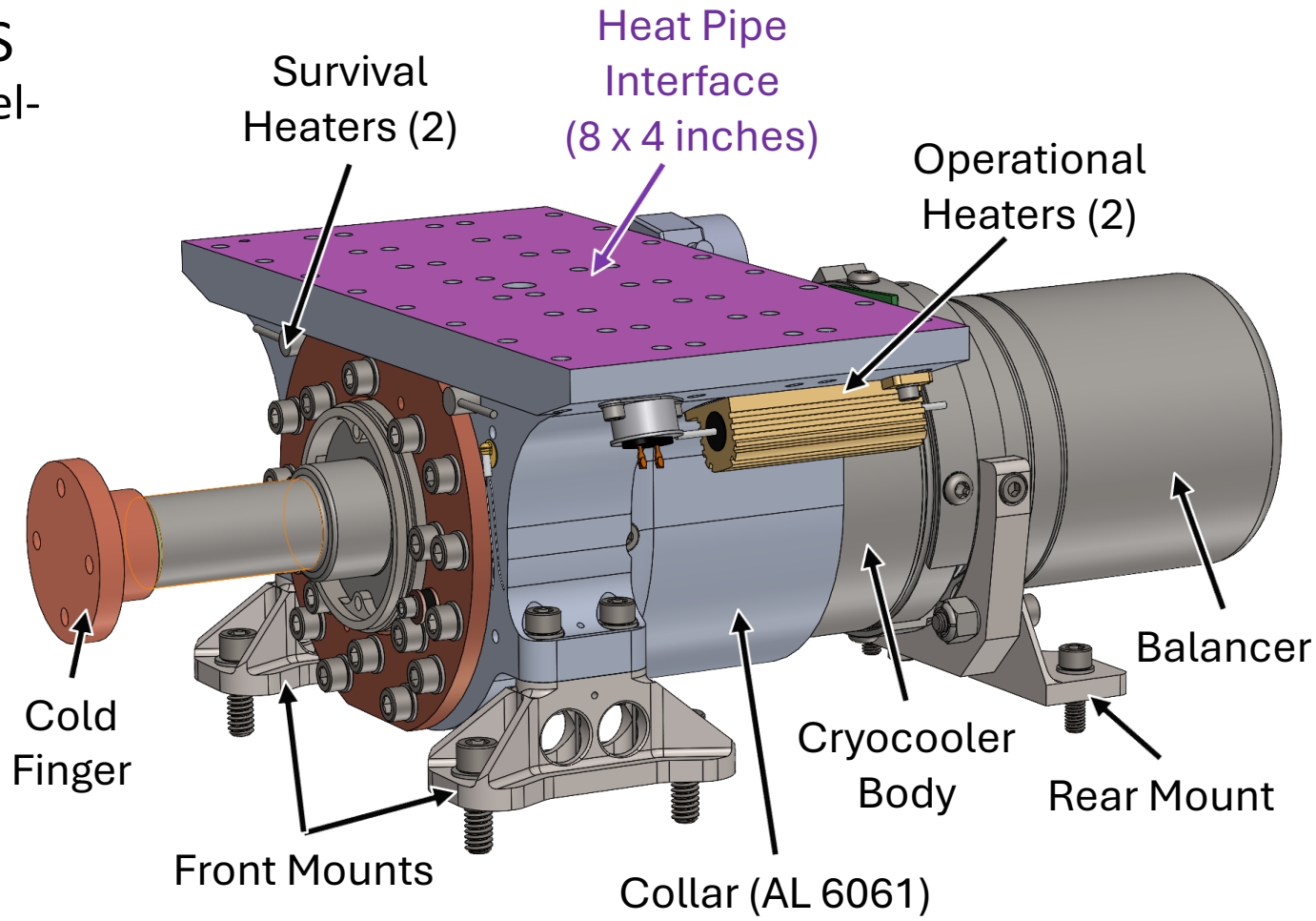
Cryostat Heat Removal Subsystem (CHRS)

- CHRS provides cooling to an array of 16 high-purity germanium detectors

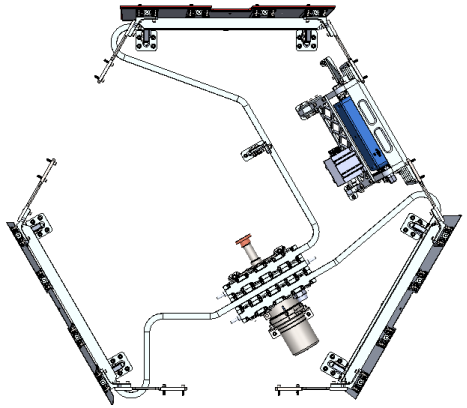
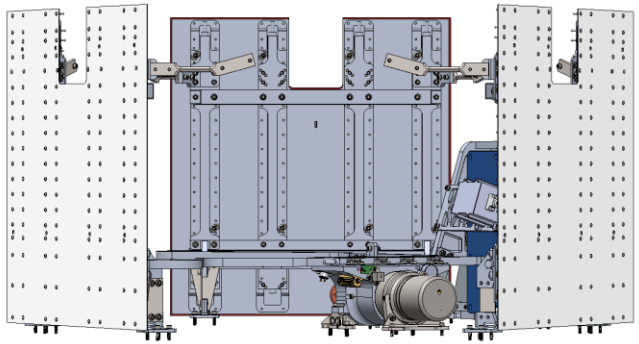
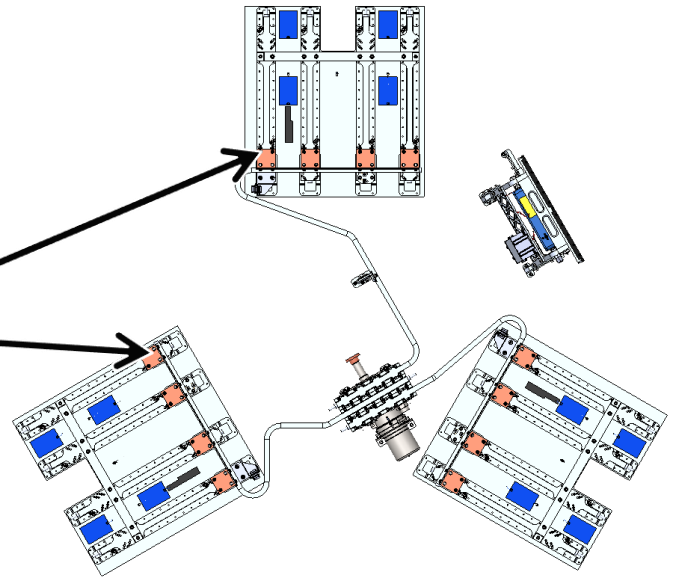
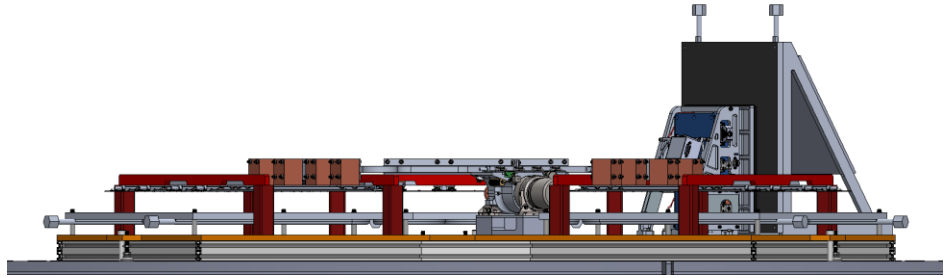


Cryocooler

- Cryocooler: SunPower CryoTel CT-S
  - Spaceflight version of commercial CryoTel-CT cooler
  - TRL-9: over 80 successful SunPower cryocooler launches into space.
  - Design heritage reaching back to RHESSI and AMS coolers
  - 11W lift @ 77K
  - Heat rejection power:
    - Cryocooler = 60 to 165 W
    - CCE = 22 to 55 W



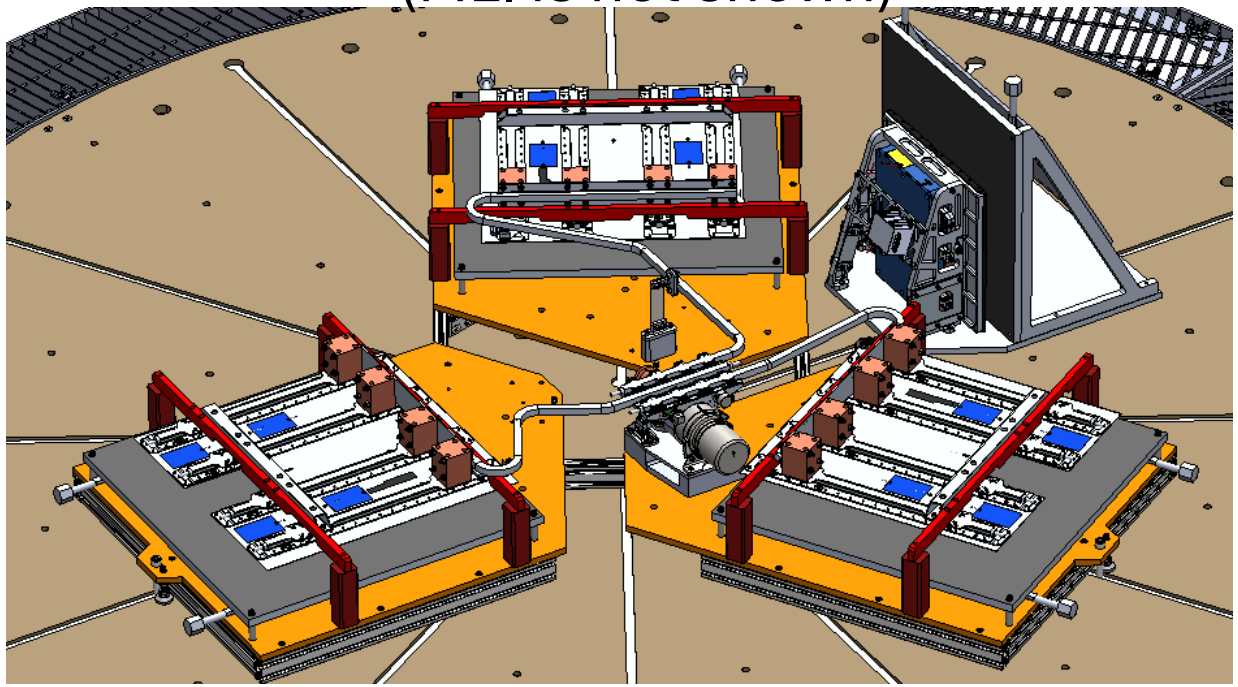
FLIGHT vs. FLAT Configurations

	TOP VIEW	SIDE VIEW
FLIGHT		
FLAT (TVAC) All HPs are horizontal **<u>12 copper adapters</u>** added to transfer heat from cryocooler HPs to radiator HPs		

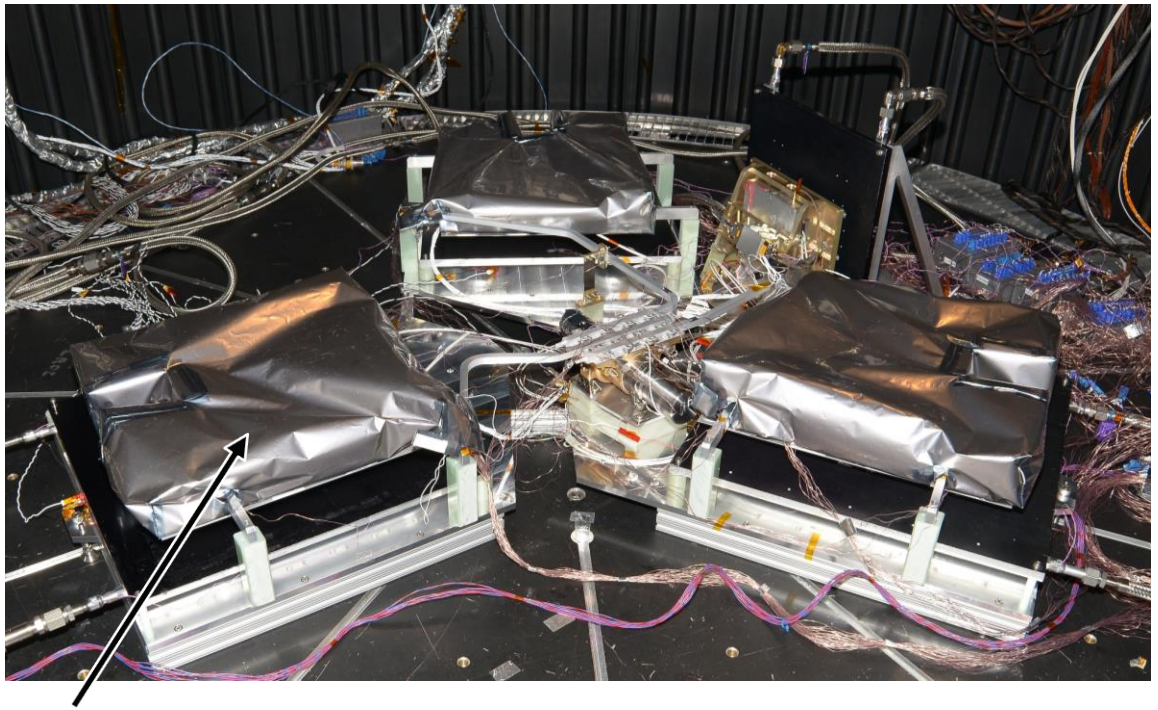
TVAC Setup

CAD Model

(MLI is not shown)

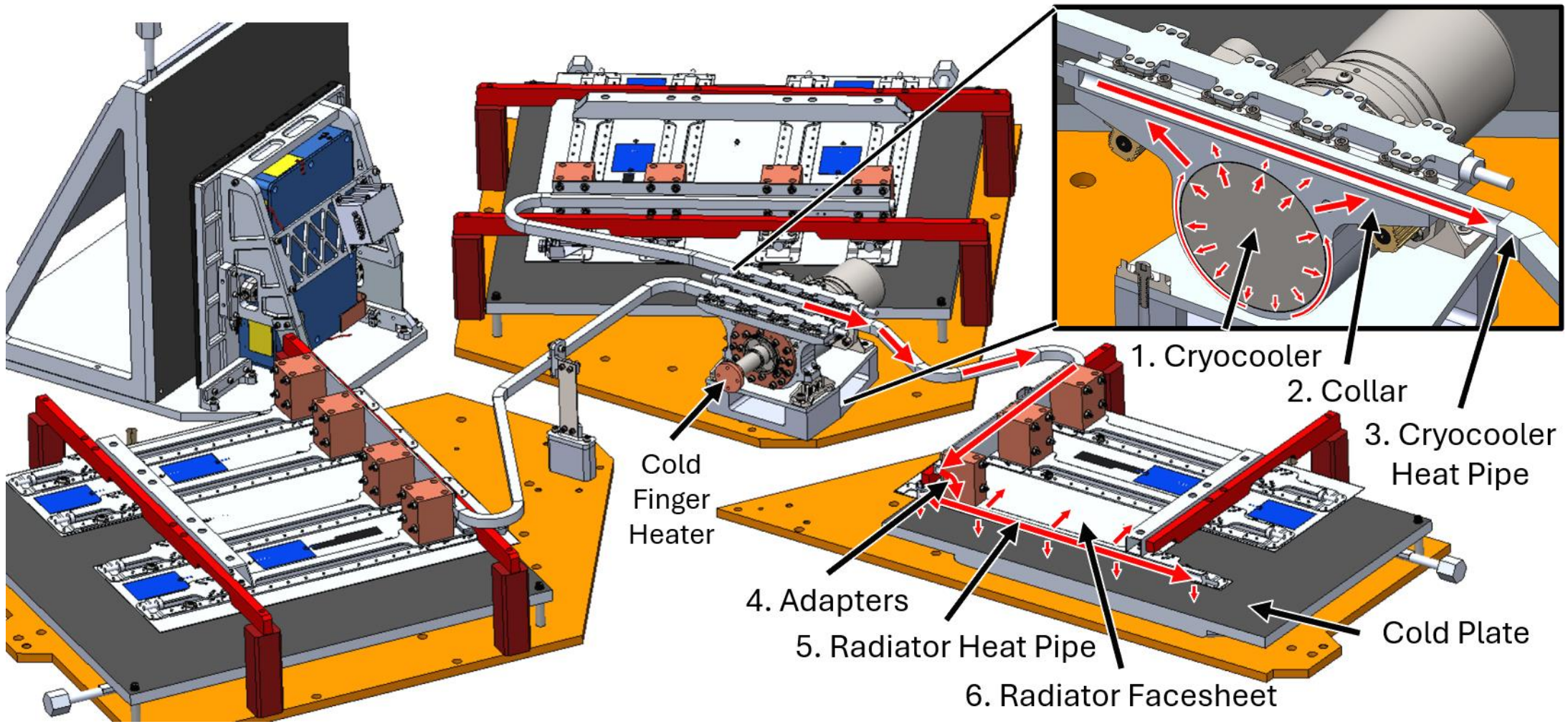


CHRS in the Chamber

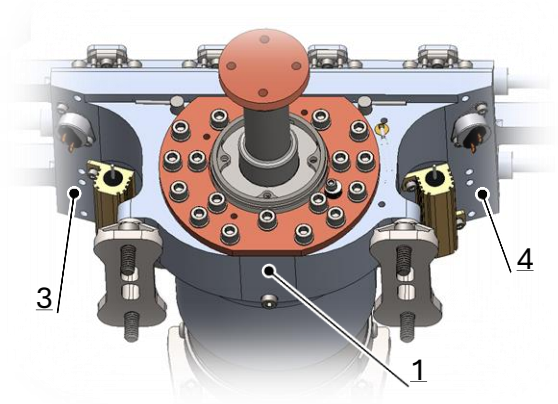


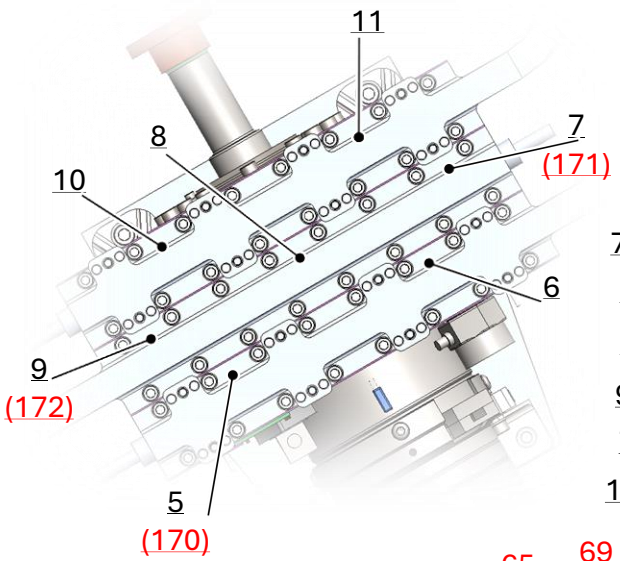
- The radiator back sides were covered with MLI.
- Cold plate temperatures were controlled individually.
- Almost 200 thermocouples in addition to the flight temperatures sensors.

Heat Flow Diagram

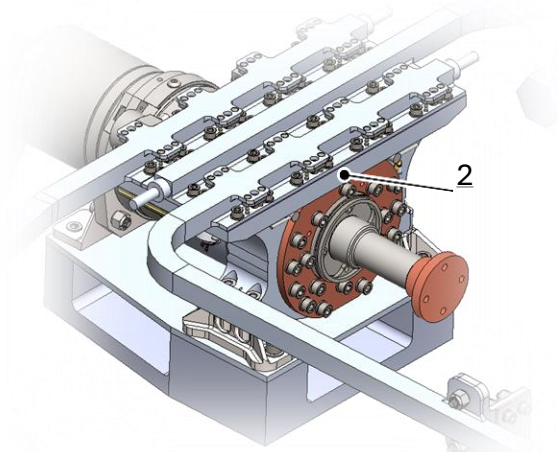


CHRS Thermocouple Locations





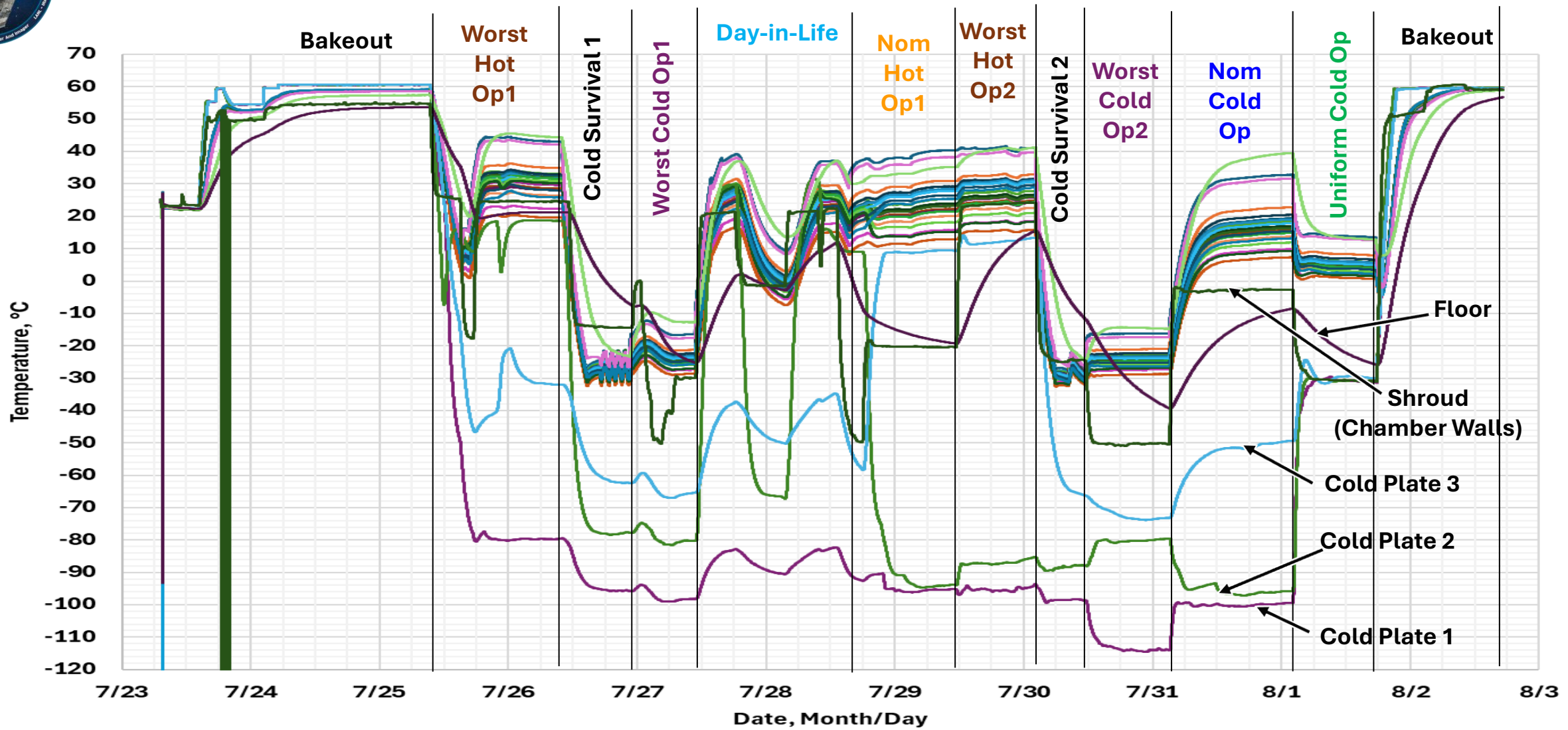
Radiator 2 (-X +Y)
TCs 42 – 71



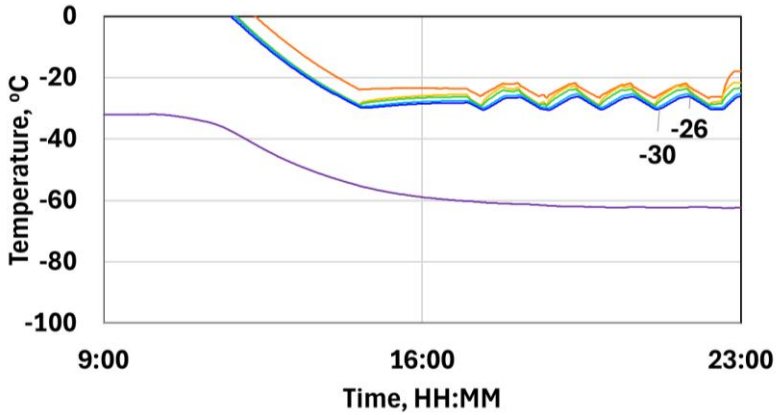
Radiator 3 (-Y)
TCs 72 – 101

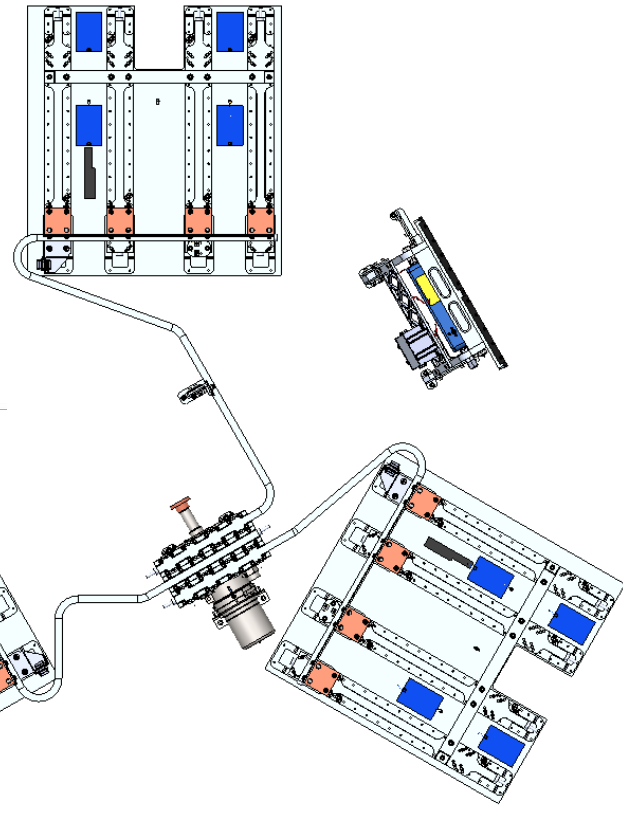
Radiator 1 (+X +Y)
TCs 12 – 41

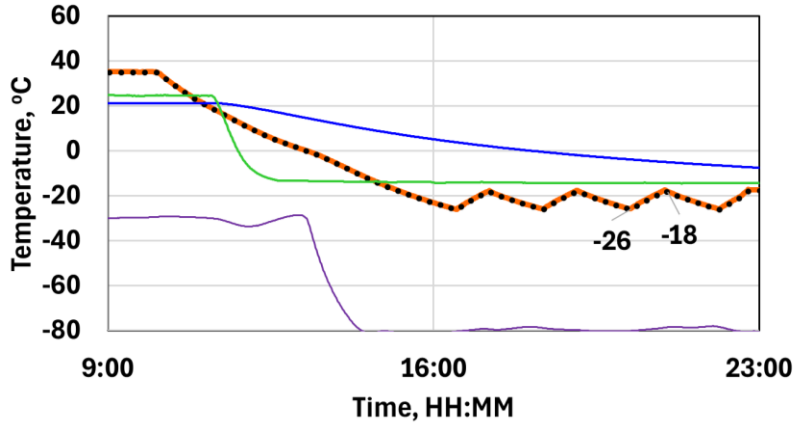
CHRS Test Profile

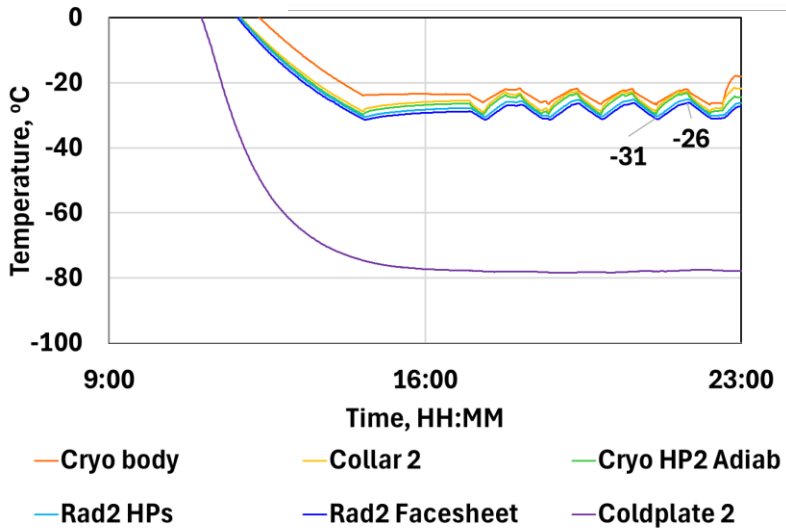


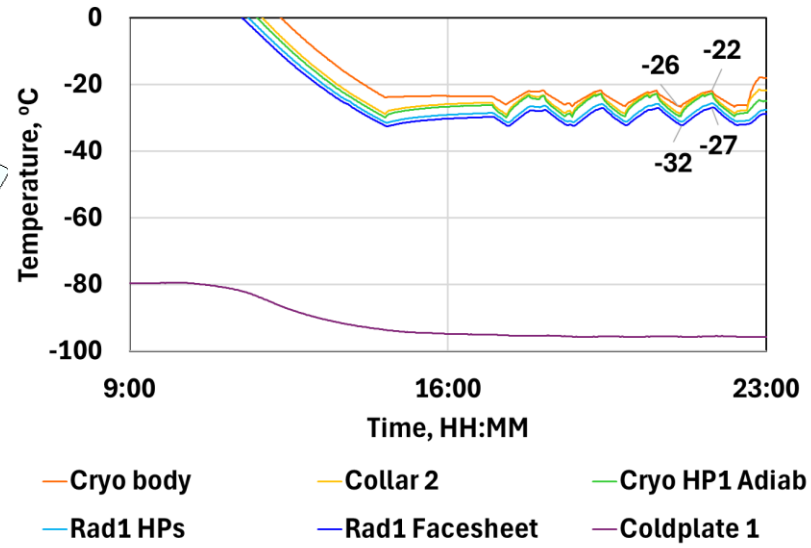
Cold Survival



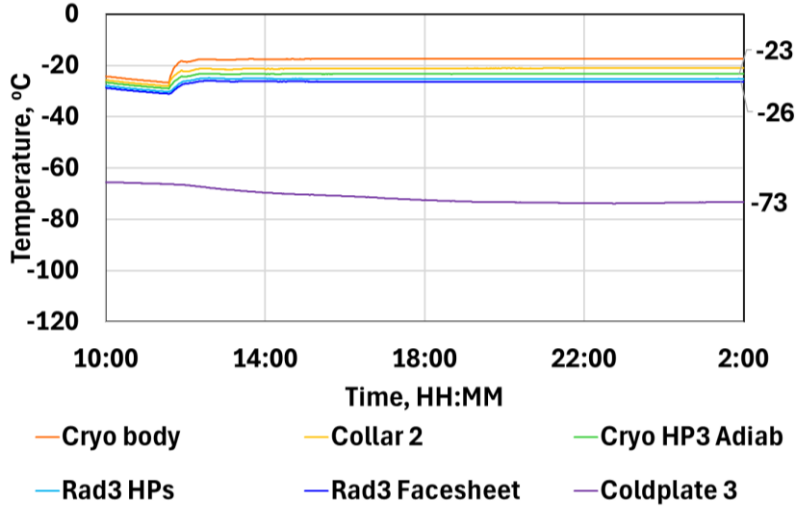


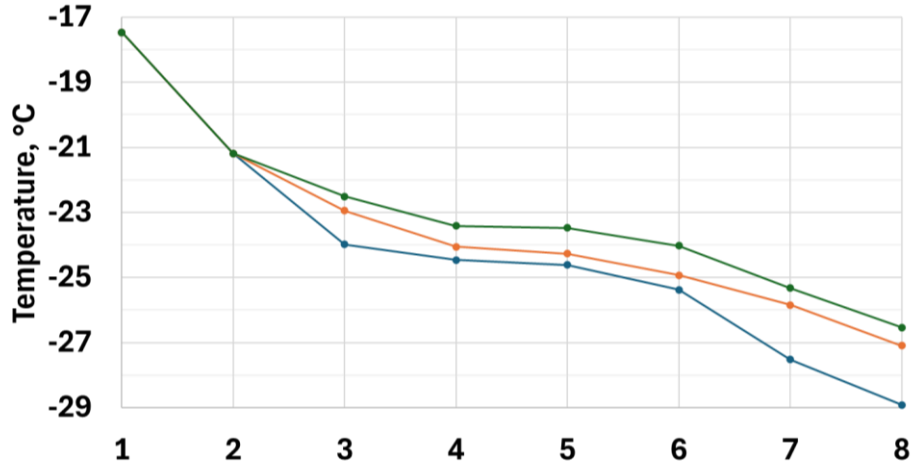




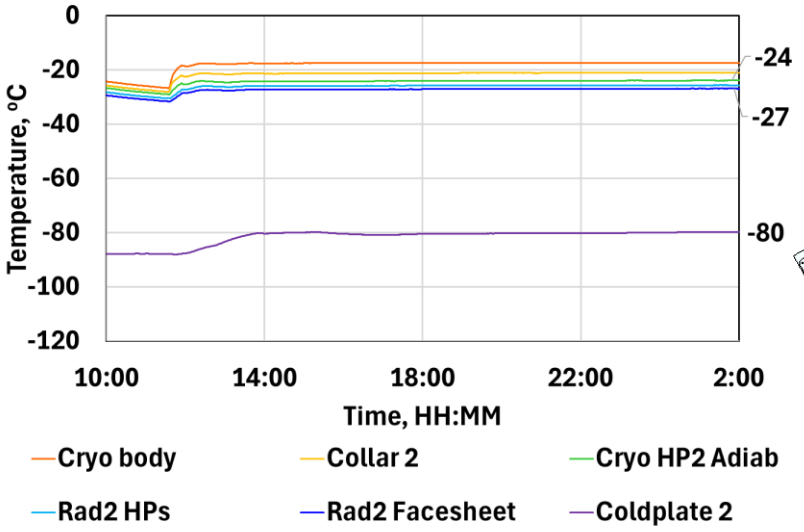


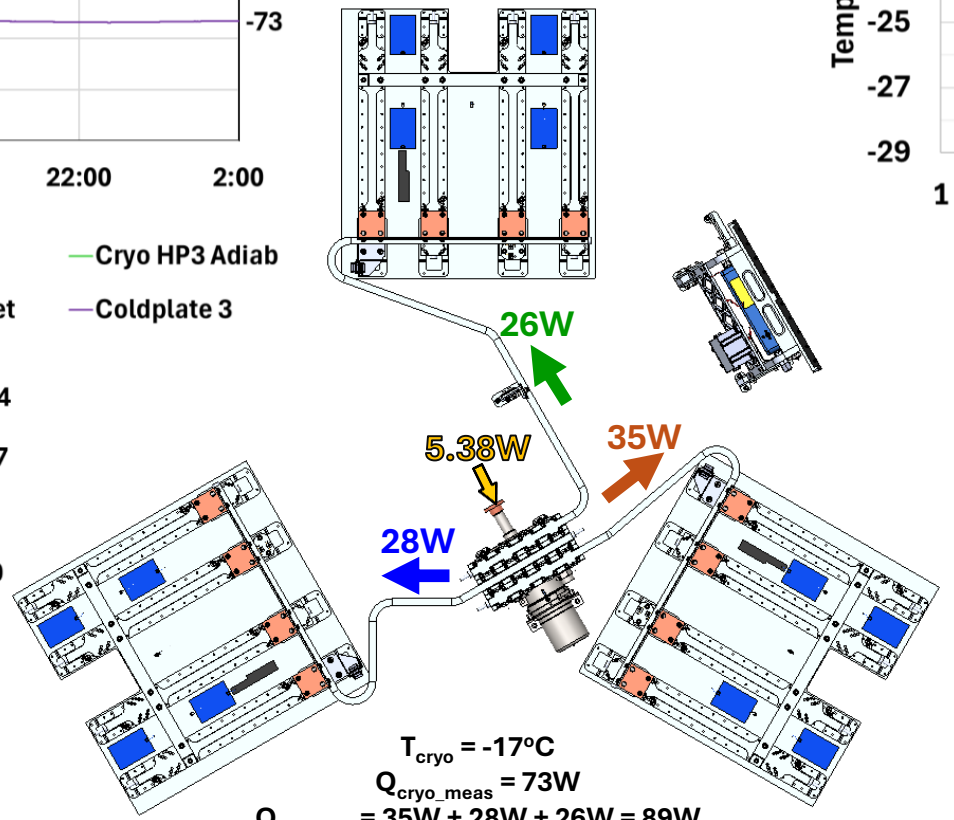
Worst Cold Op 2





CHRS Component, 1 - Cryocooler, 2 - Collar, 3 - Cry HP Evap, 4 - Cryo HP Adiab, 5 - Cryo HP Cond, 6 - Adapters, 7 - Rad HPs, 8 - Rad Facesheet



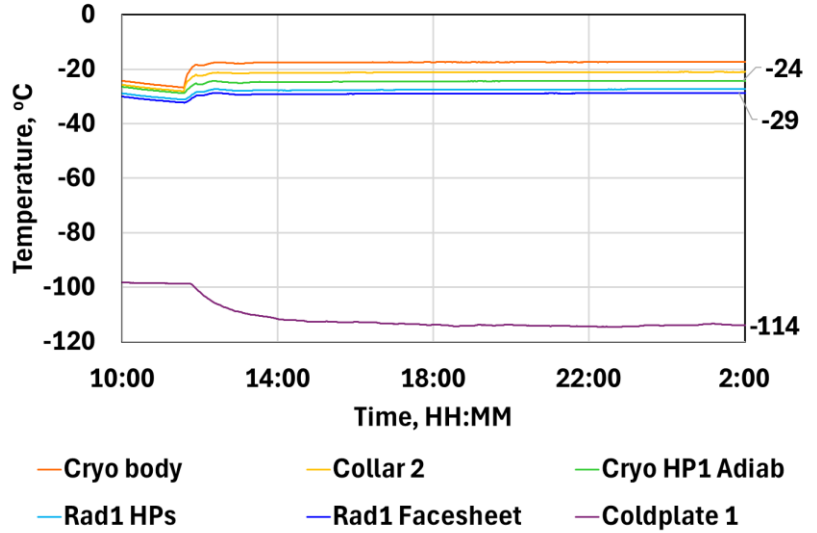


T_{cryo} = -17°C

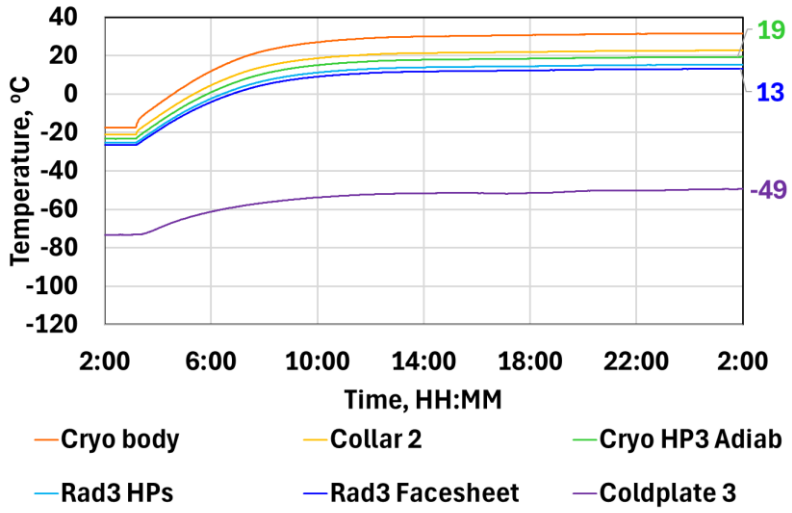
Q_{cryo_meas} = 73W

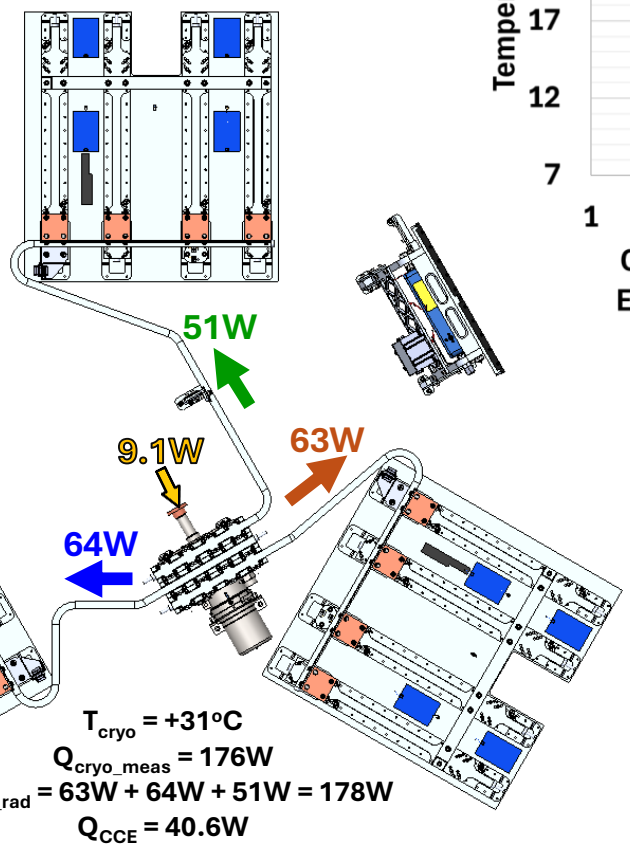
Q_{cryo_rad} = 35W + 28W + 26W = 89W

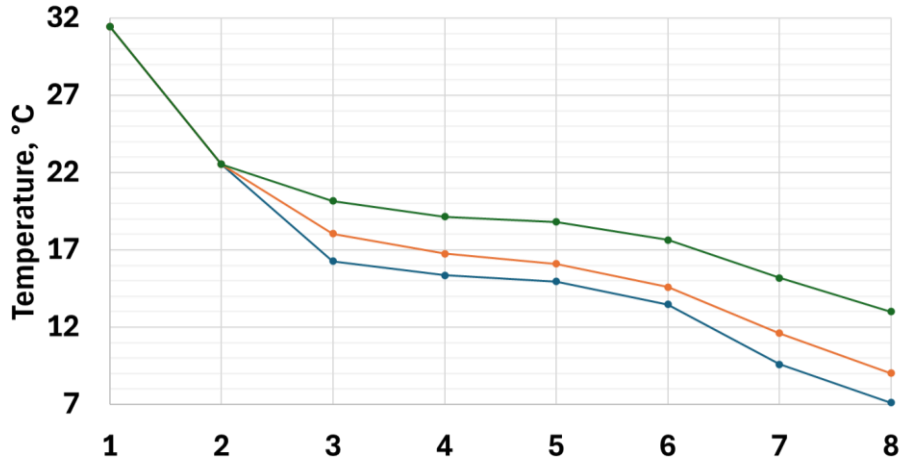
Q_{CCE} = 15.8W

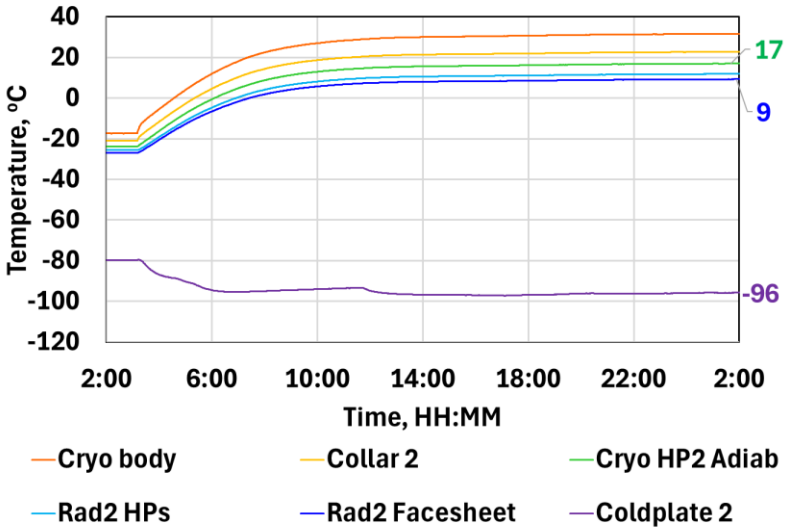


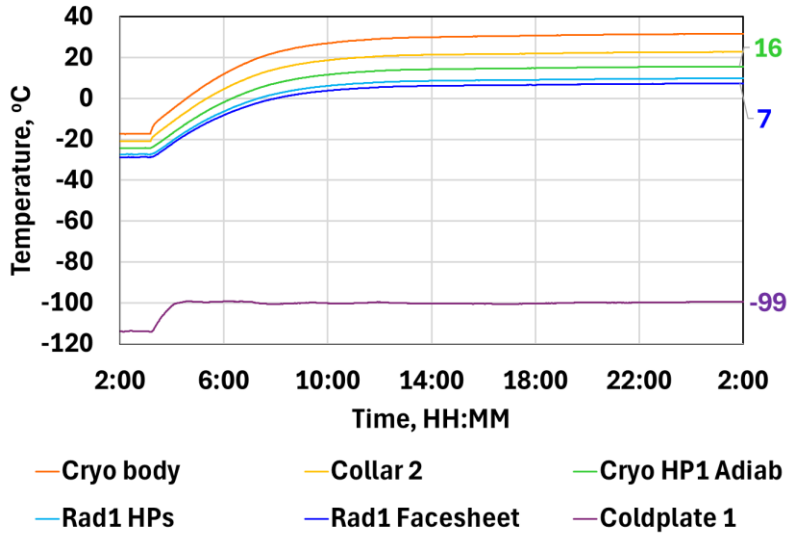
Nom Cold Op 1


Temperature, °C
40
20
0
-20
-40
-60
-80
-100
-120
2:00
6:00
10:00
14:00
18:00
22:00
2:00
Time, HH:MM
19
13
-49
Cryo body
Collar 2
Cryo HP3 Adiab
Rad3 HPs
Rad3 Facesheet
Coldplate 3

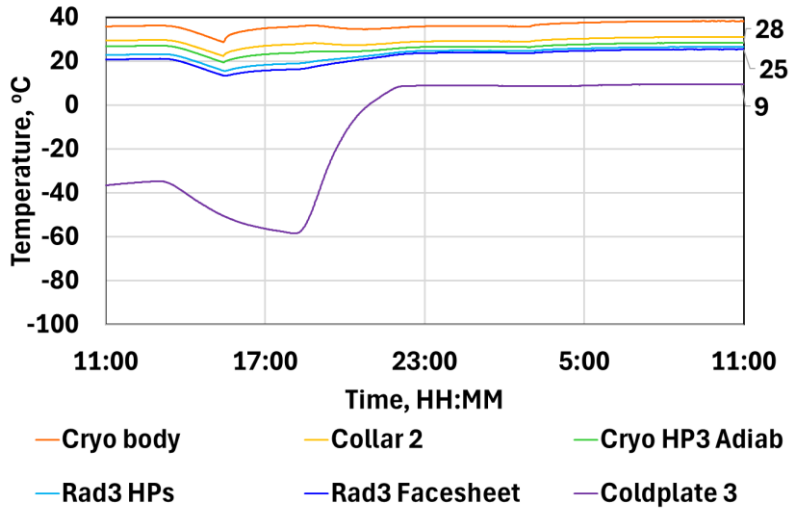

51W
9.1W
63W
64W
T_{cryo} = +31°C
Q_{cryo_meas} = 176W
Q_{cryo_rad} = 63W + 64W + 51W = 178W
Q_{CCE} = 40.6W

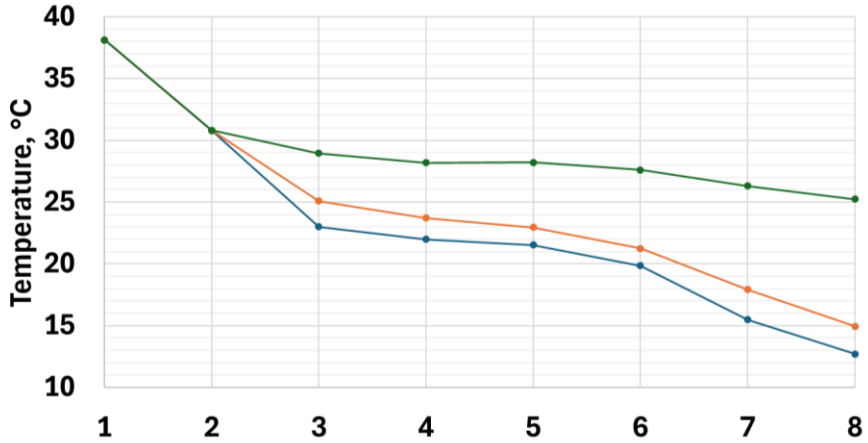

Temperature, °C
32
27
22
17
12
7
1
2
3
4
5
6
7
8
CHRS Component, 1 - Cryocooler, 2 - Collar, 3 - Cry HP Evap, 4 - Cryo HP Adiab, 5 - Cryo HP Cond, 6 - Adapters, 7 - Rad HPs, 8 - Rad Facesheet


Temperature, °C
40
20
0
-20
-40
-60
-80
-100
-120
2:00
6:00
10:00
14:00
18:00
22:00
2:00
Time, HH:MM
17
9
-96
Cryo body
Collar 2
Cryo HP2 Adiab
Rad2 HPs
Rad2 Facesheet
Coldplate 2


Temperature, °C
40
20
0
-20
-40
-60
-80
-100
-120
2:00
6:00
10:00
14:00
18:00
22:00
2:00
Time, HH:MM
16
7
-99
Cryo body
Collar 2
Cryo HP1 Adiab
Rad1 HPs
Rad1 Facesheet
Coldplate 1

Nom Hot Op 1





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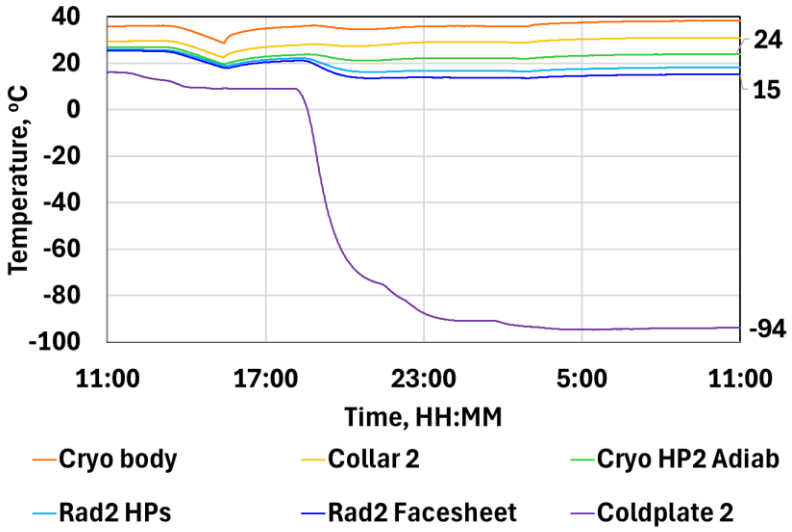
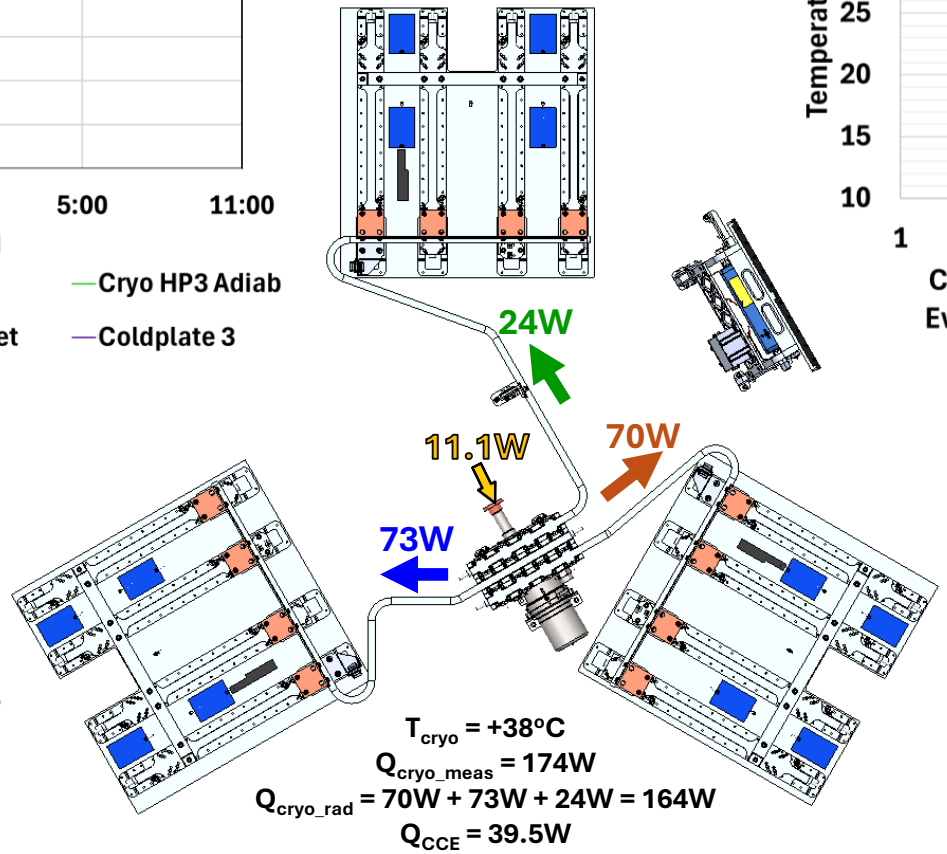
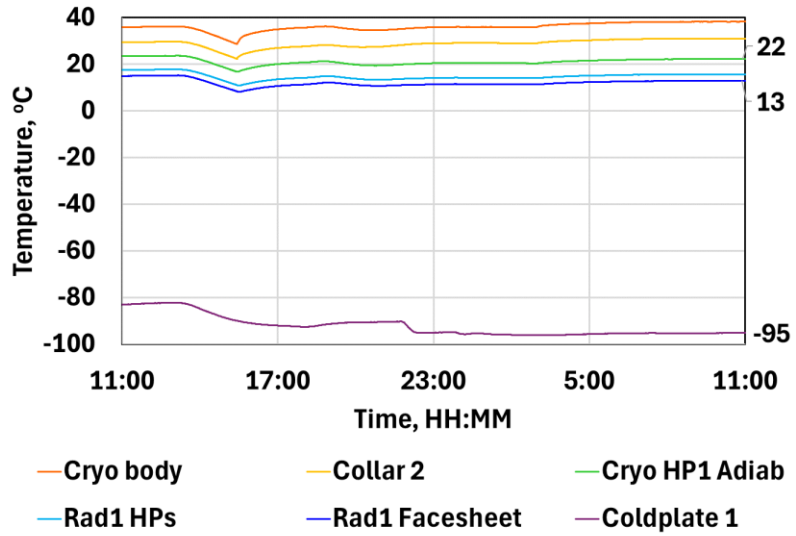
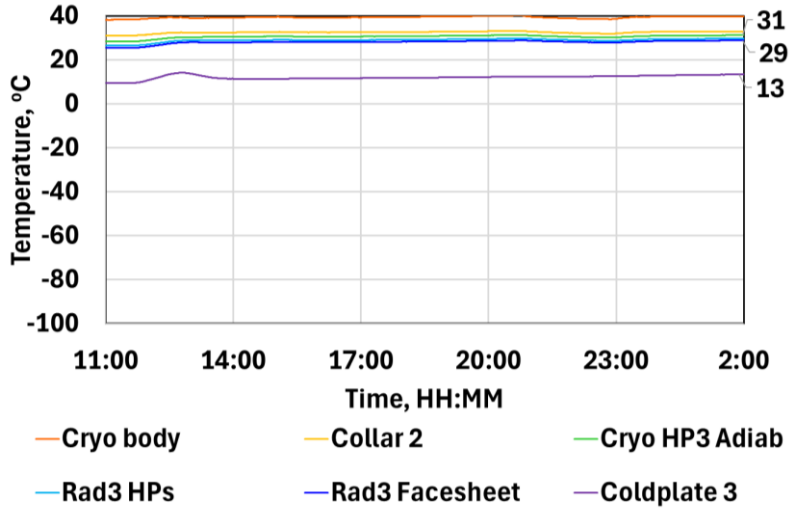
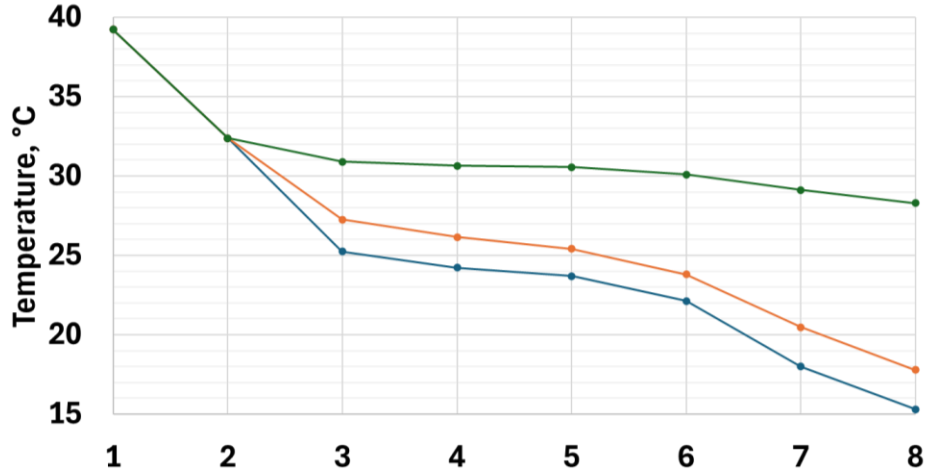


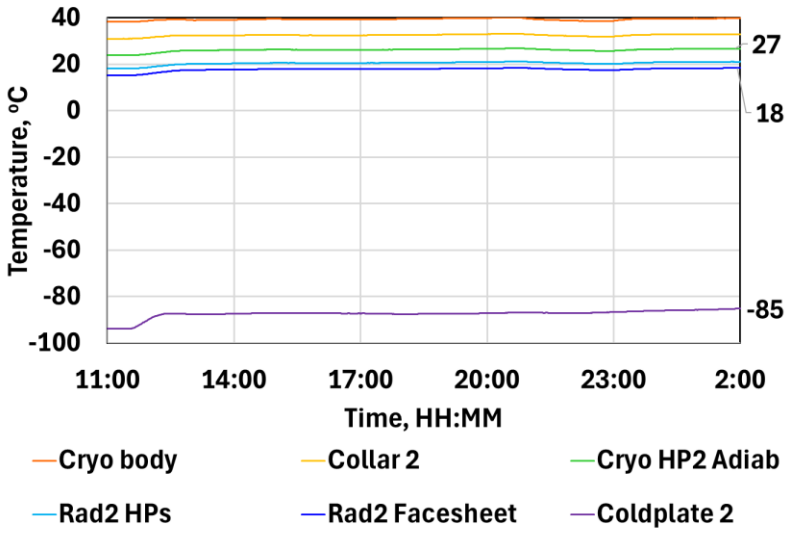


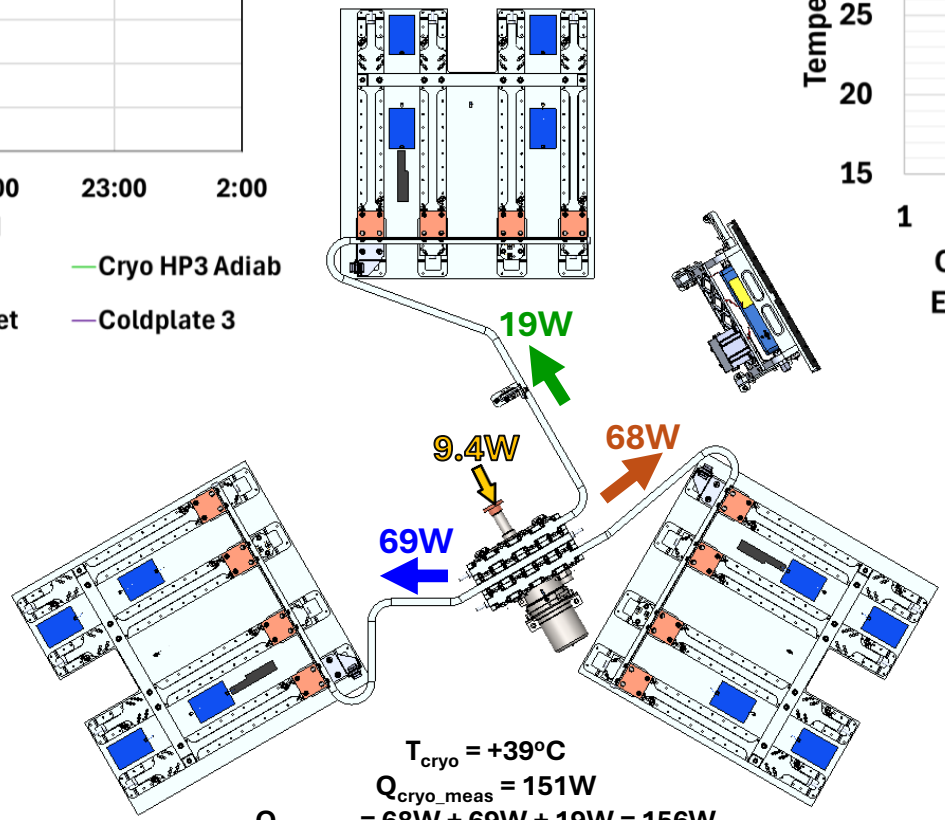


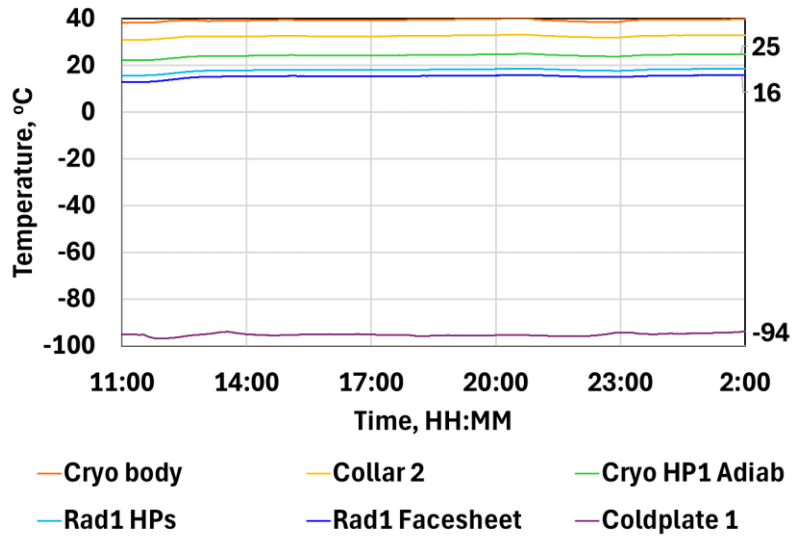
Worst Hot Op 2



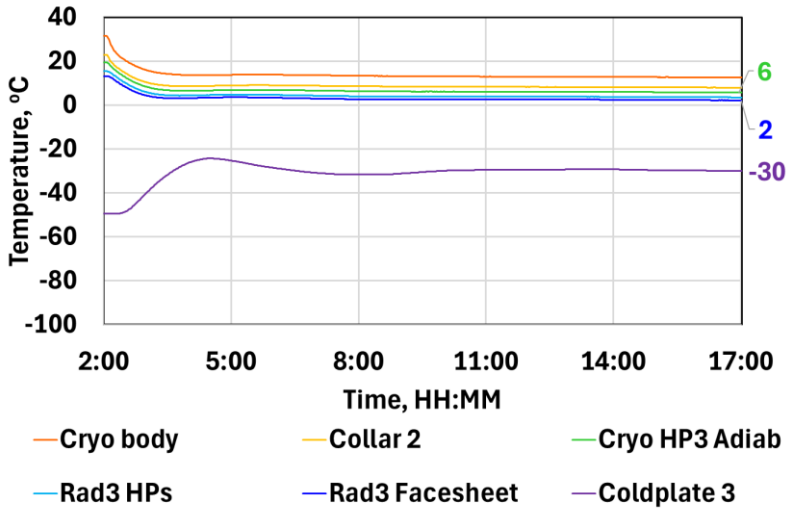


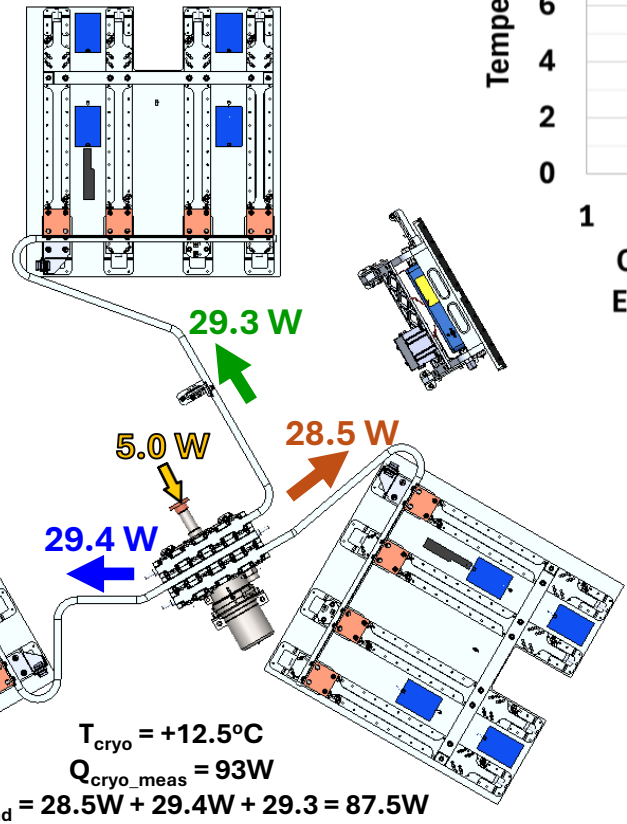


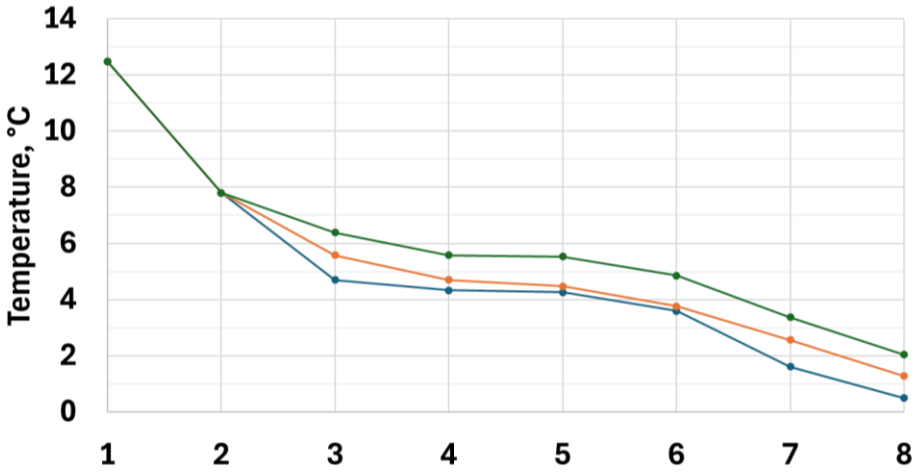


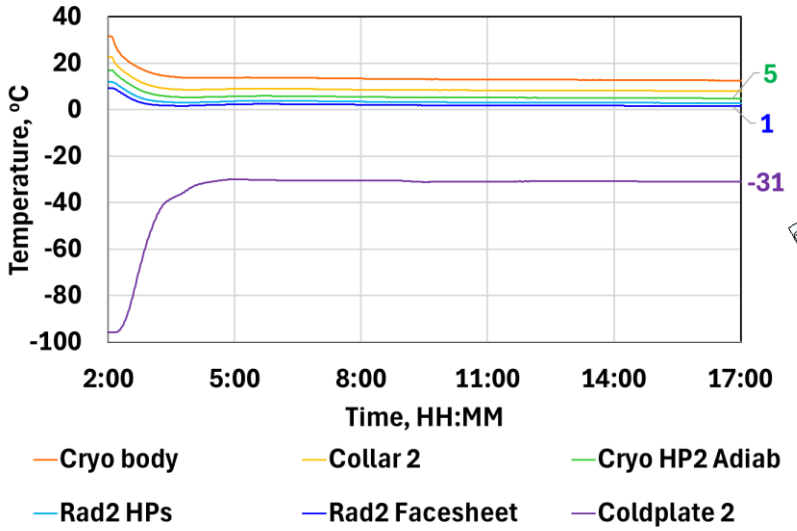


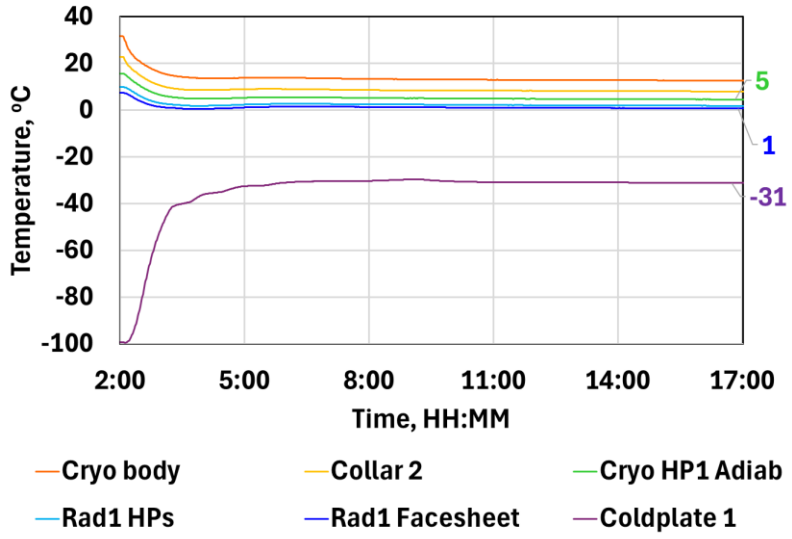
Uniform Cold Op



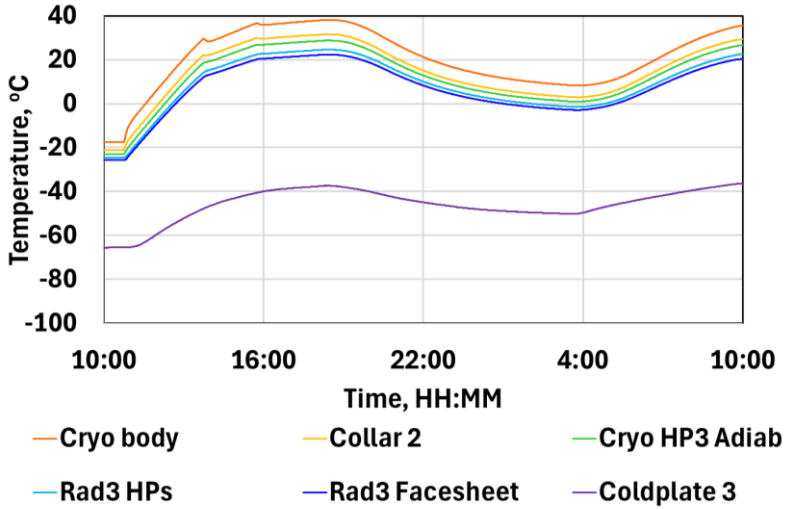


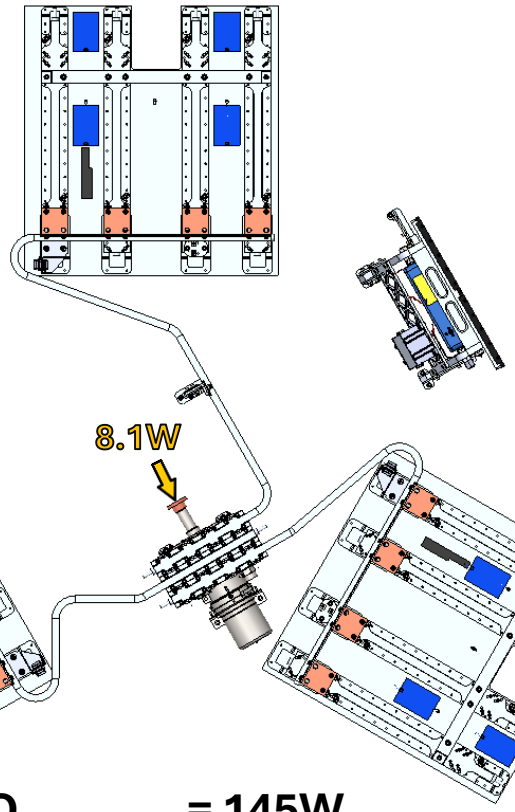


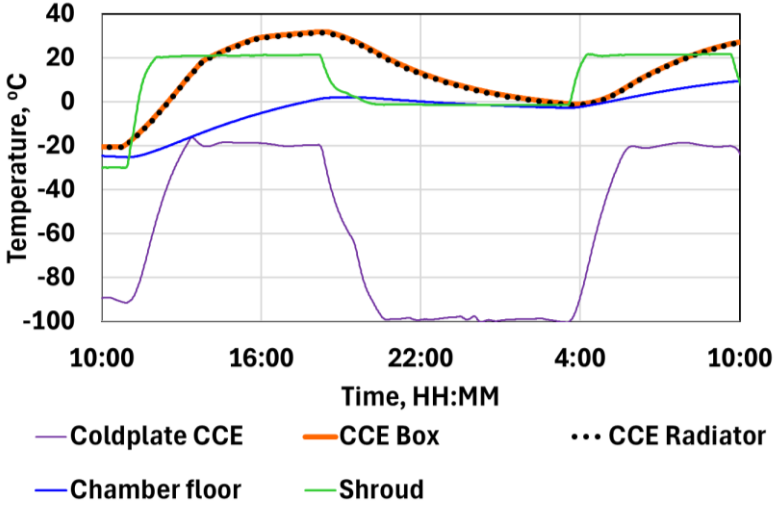


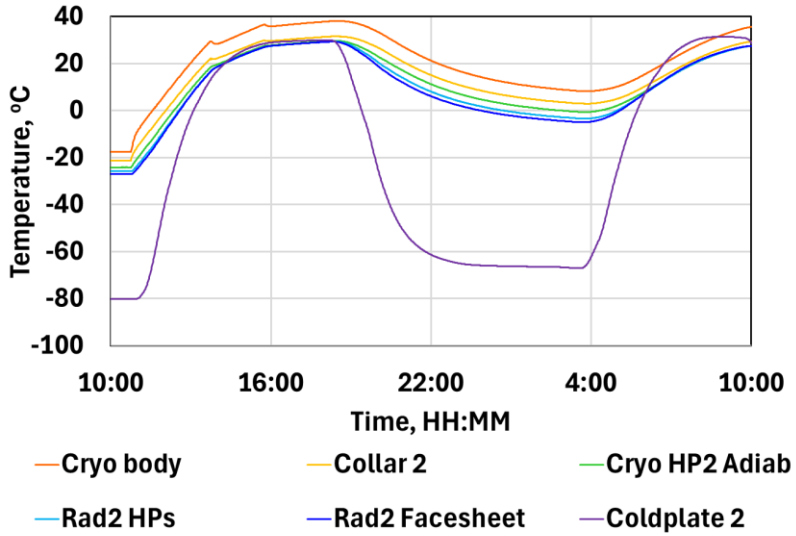


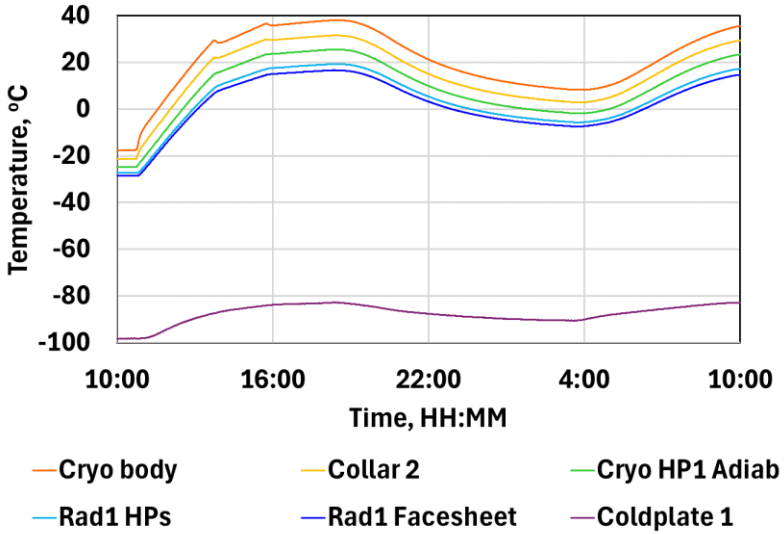
Nom Day-in-Life



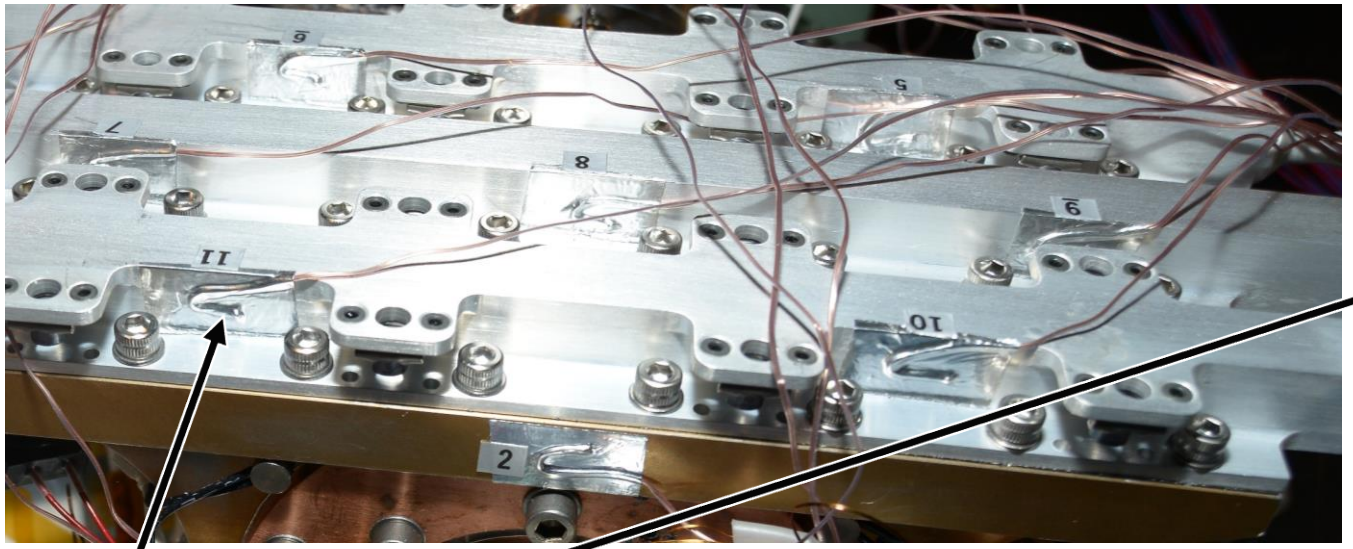


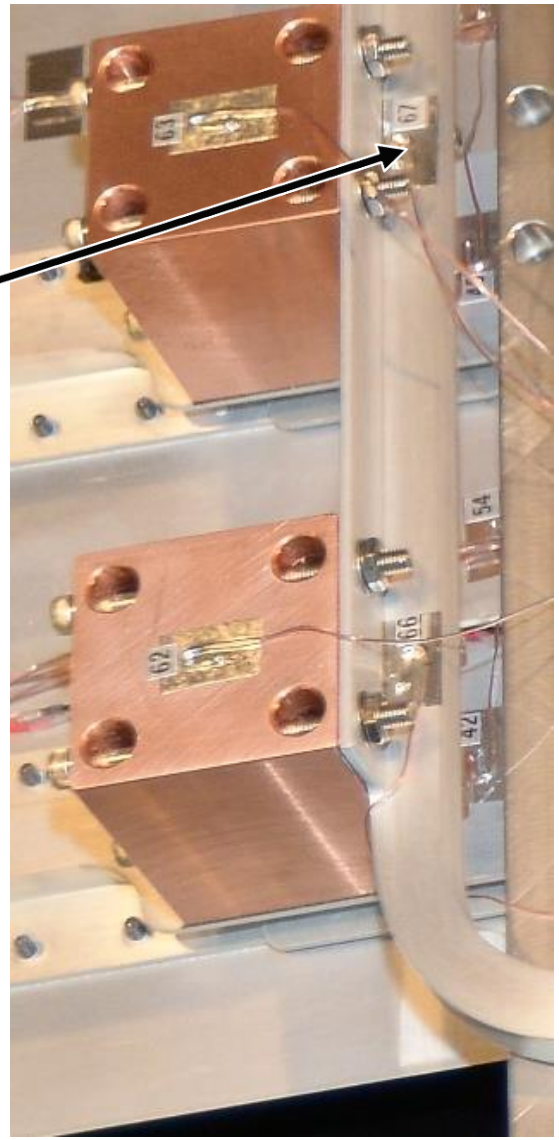






Conductances





- The evaporator and condenser temperatures were measured on the side.
- $C_{evap_cryo_side}$ = 7 ± 2 W/(in °C) – measured during the CHRS TVAC testing
- $C_{evap_cryo_interface}$ = 3 ± 0.5 W/(in °C) – converted based on previous HP testing
- $C_{cond_cryo_side}$ = 20 ± 5 W/(in °C) – measured during the CHRS TVac testing
- $C_{cond_cryo_interface}$ = 6 ± 2 W/(in °C) – converted based on previous HP testing
- $C_{radiator}$ = 10 ± 2 W/ °C – measured during the CHRS TVAC testing
- C_{CHRS} = 2.7 ± 0.5 W/ °C – measured during the CHRS TVAC testing
- **<u>The interafe conductances shall be used for modeling purposes</u>**

Lessons Learned from COSI CHRS TVAC

- **Heat pipe conductance assessment**
  a) The conductance based on HP side measurements is two to three times higher than based on the interface surfaces.
- **Not all Temperature Controlled Units (TCU) are the same.**
  a) One TCU was not capable reaching cold temperatures.
  b) Switched the test conditions between radiators. One radiator exposed to Sun.
- **Thermocouple (TC) mislabeling can happen when it is done in phases.**
  a) The first round of TC labeling was performed on one radiator that went back to vendor for TVAC testing, while the other two radiators were instrumented later.
- **Ground Support Equipment (GSE) can impact cryocooler operation.**
  a) The cooler could not be operated in vibration control mode due to vibration from TCUs and GSE other equipment.
  b) The cryocooler was operated in the manual vibration control mode. The heat removal was not affected.
  c) The primary causes were:
    i. noise on the accelerometer signal (resulting from the grounding scheme implemented),
    ii. a loosened and possibly damaged accelerometer cable,
    iii. and possibly background noise corrupting the accelerometer reading (due to frequency bleed or spectral leakage).

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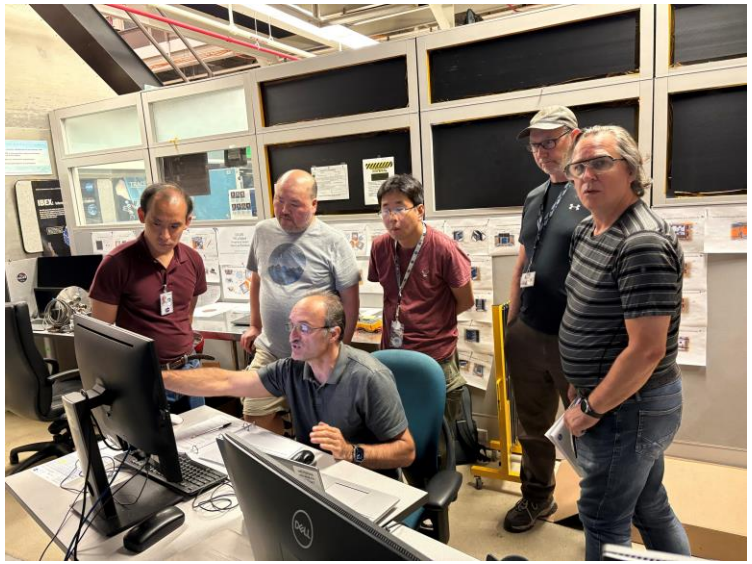
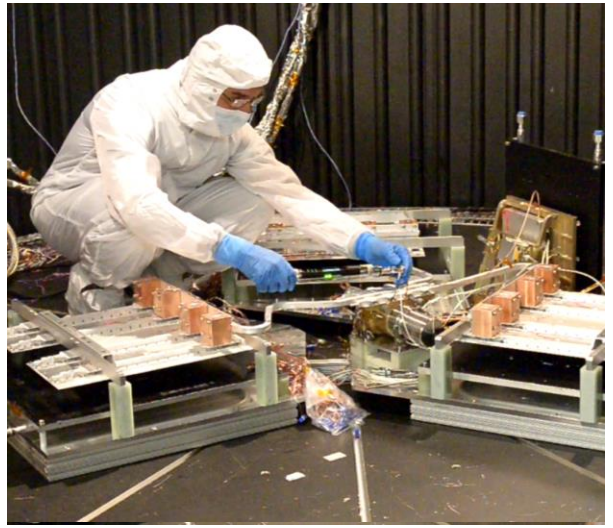
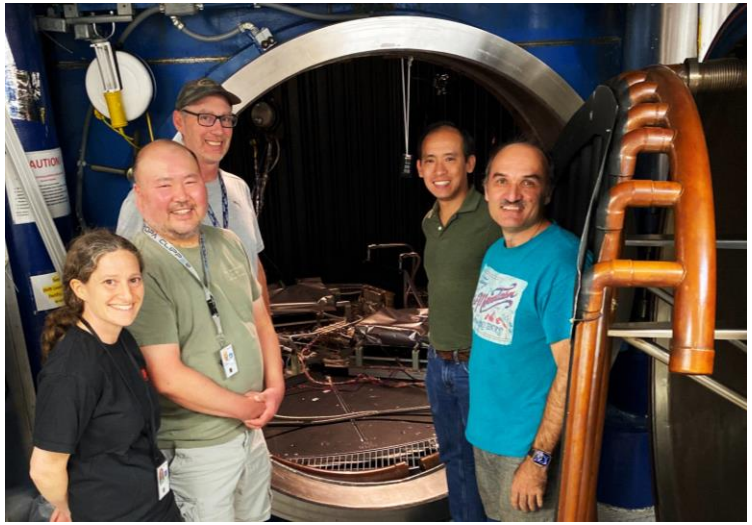
Acknowledgements

- Stuart Banks
- Robert Boyle
- Colton Cohill
- Hannah Goldberg
- Hak-Seung Lee
- James Rogers
- Albert Shih
- Buddy Taylor
- Howard Tseng







Abbreviations

- CAD – Computer Aided Design
- CCE – Cryocooler Control Electronics
- CHRS – Cryostat Heat Removal Subsystem
- COSI – Compton Spectrometer and Imager
- HP – Heat Pipe
- GSE – Ground Support Equipment
- MLI – Multi-Layer Insulation
- RHESSI – Reuven Ramaty High Energy Solar Spectroscopic Imager
- SMEX – Small Explorer mission
- TC – Thermocouple
- TRL – Technology Readiness Level
- TVAC – Thermal Vacuum