Flow Boiling and Condensation Experiment Flight Hardware Development

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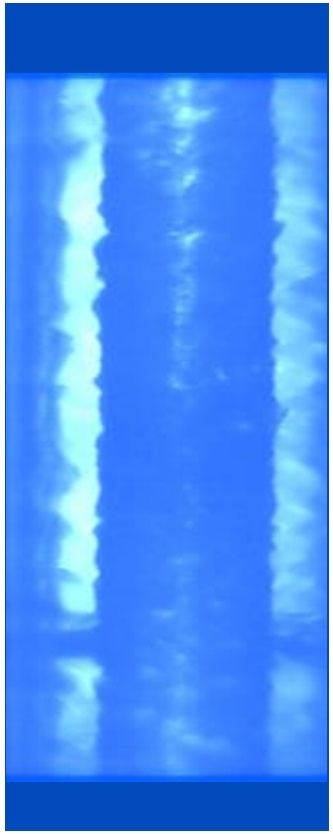

Flow Boiling and Condensation Experiment (FBCE)

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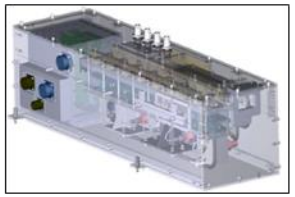
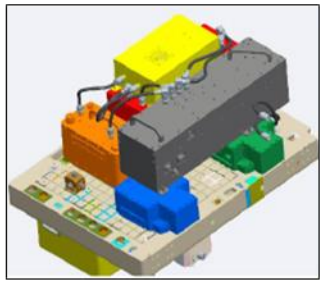
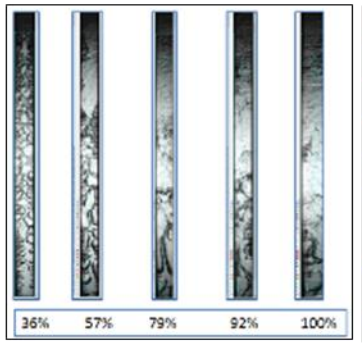
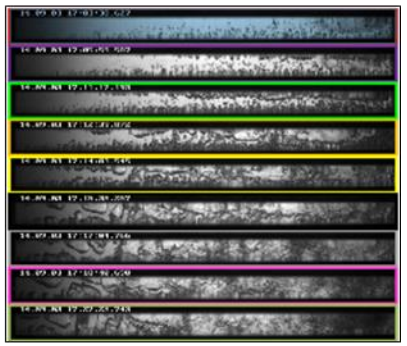
GRC Project Manager: Andrew Suttles, NASA GRC
GRC Project Scientist: Dr. Henry Nahra, NASA GRC
Customers/Adopters (Push): AP1, TSES1, Nuclear Power/Propulsion, Thermal Control/Life Support, Chilldown for Cryo Propellant Management

Right to left: Flow Boiling Imaging (Horizontal orientation, 1g); Flow Boiling Imaging (vertical up-flow orientation, low g-Aircraft); Integrated FBCE system on FIR optics bench; Flow Boiling Module Teat Assembly









Objectives

- Develop an integrated two-phase flow boiling/condensation facility for the International Space Station (ISS) to serve as primary platform for obtaining two-phase flow and heat transfer data in microgravity.
  - Obtain flow boiling and flow condensation databases in long-duration microgravity environment.
  - Develop experimentally validated, mechanistic model for microgravity flow boiling critical heat flux (CHF) and flow condensation and dimensionless criteria to predict minimum flow velocity required to ensure gravity-independent CHF.

Experimental Approach

- Study influence of microgravity on two-phase transport phenomena.
- Control variables: temperature, pressure, flow rate.
- Diagnostics: Pressure transducers, thermocouples, high-speed imagery.

Relevance/Impact

- The Rankine cycle is one of the most viable options for space application because of its high power output per unit mass or unit volume.
- TSES1: Conduct research to address issues for active two phase flow relevant to thermal management.
- AP1: Reduced-gravity multiphase flows, cryogenics and heat transfer database and modeling, including phase separation and distribution (i.e.. flow regimes), phase-change heat transfer, pressure drop and multiphase system stability.

Project Development Approach

- Protoflight flight hardware – Flight-functional ground unit for development testing.
- Fluids Integrated Rack (FIR) Subrack Payload Facility.
- Developed, integrated, and operated in-house by GRC Engineering.

Estimated ISS Resource Requirements

Accommodation (carrier)	Fluid Integrated Rack (FIR)
Upmass (kg) (w/o packing factor)	165 kg (estimated - dry)
Volume (m^3) (w/o packing factor)	0.2 m^3 (estimated)
Power (kw) (peak)	2500W (estimated)
Crew Time (hrs) (installation/operations)	8 hrs for install (estimated) runs autonomous / Inc 65-69
Autonomous Operation	12 months
Launch/Increment	**First Available in Increment 62**

Flight FBM test module in assembly

Award	SCR	RDR	PDR	CDR	FHA	Ops
6/15/2011	11/2011	2/2014	3/2015	1/2018	5/2019	9/2020

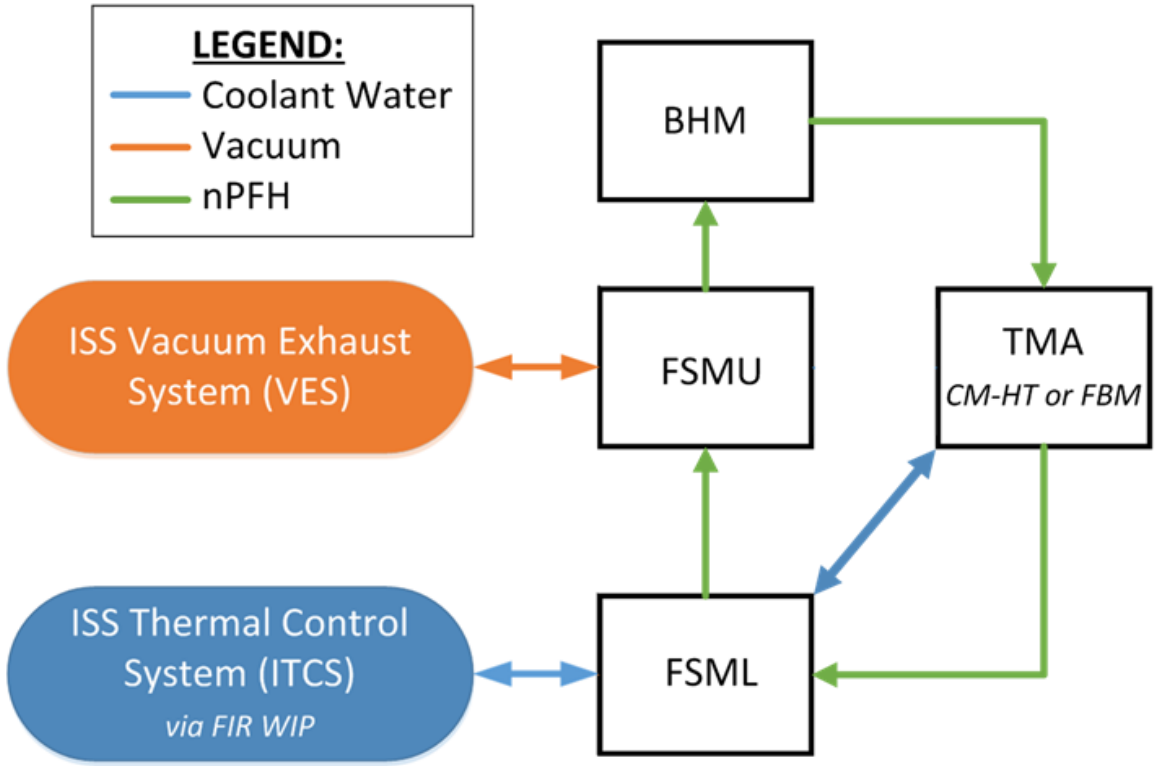
FBCE System Overview

FBCE Modules:

- **BHM** – Bulk Heater Module
- **FSMU** – Fluids System Module - Upper
- **FSML** – Fluids System Module - Lower
- **RDAQM 1** – Remote Data Acquisition Module 1
- **RDAQM 2** – Remote Data Acquisition Module 2
- **TMA** – Test Module Assembly (1 of 2 installed):
  - **FBM** – Flow Boiling Module
  - **CM-HT** – Condensation Module - Heat Transfer

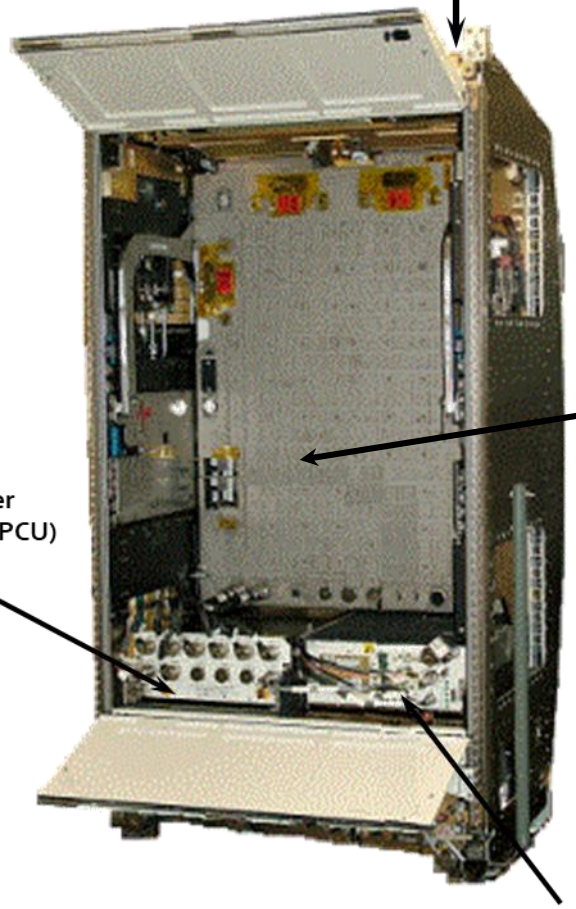
FIR Provided Hardware:

- SAMS – Space Acceleration Measurement System
- CCU – Confocal Control Unit (on back of rack)
- IPSU-CL – Imaging Processing Storage Unit – Camera Link (on back of rack)



Fluid Integration Rack

Environmental Control (ECS)
- Air Thermal Control
- Fire Detection & Suppression
- Water Thermal Control
- Gas Interfaces (GN_2, VES, VRS)

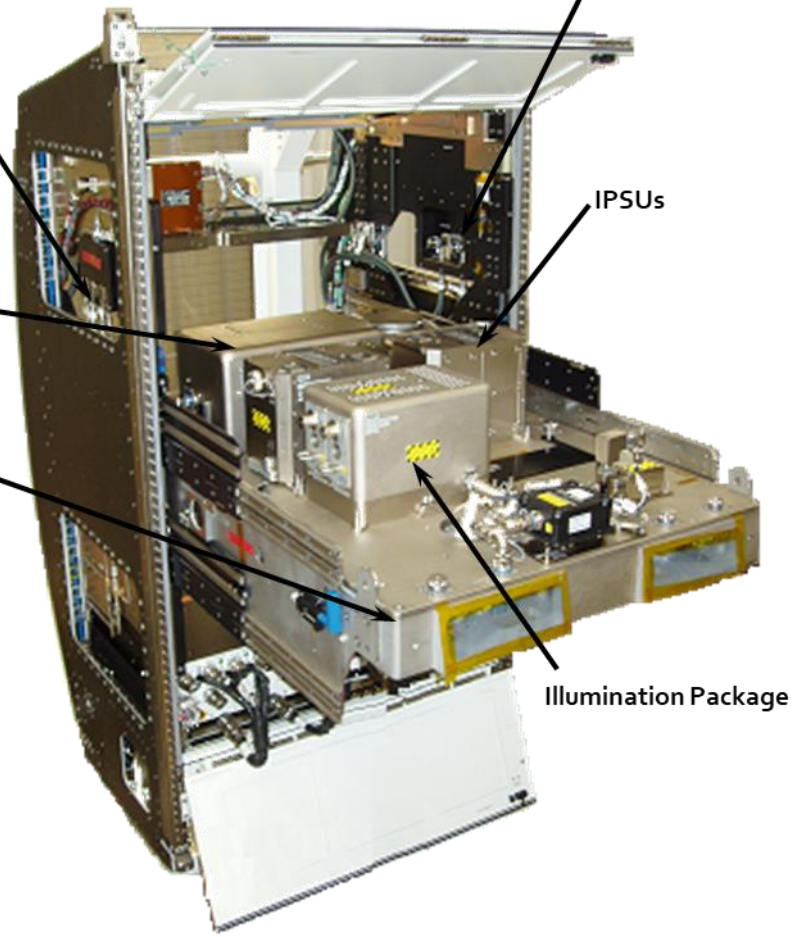


Electrical Power Control Unit (EPCU)

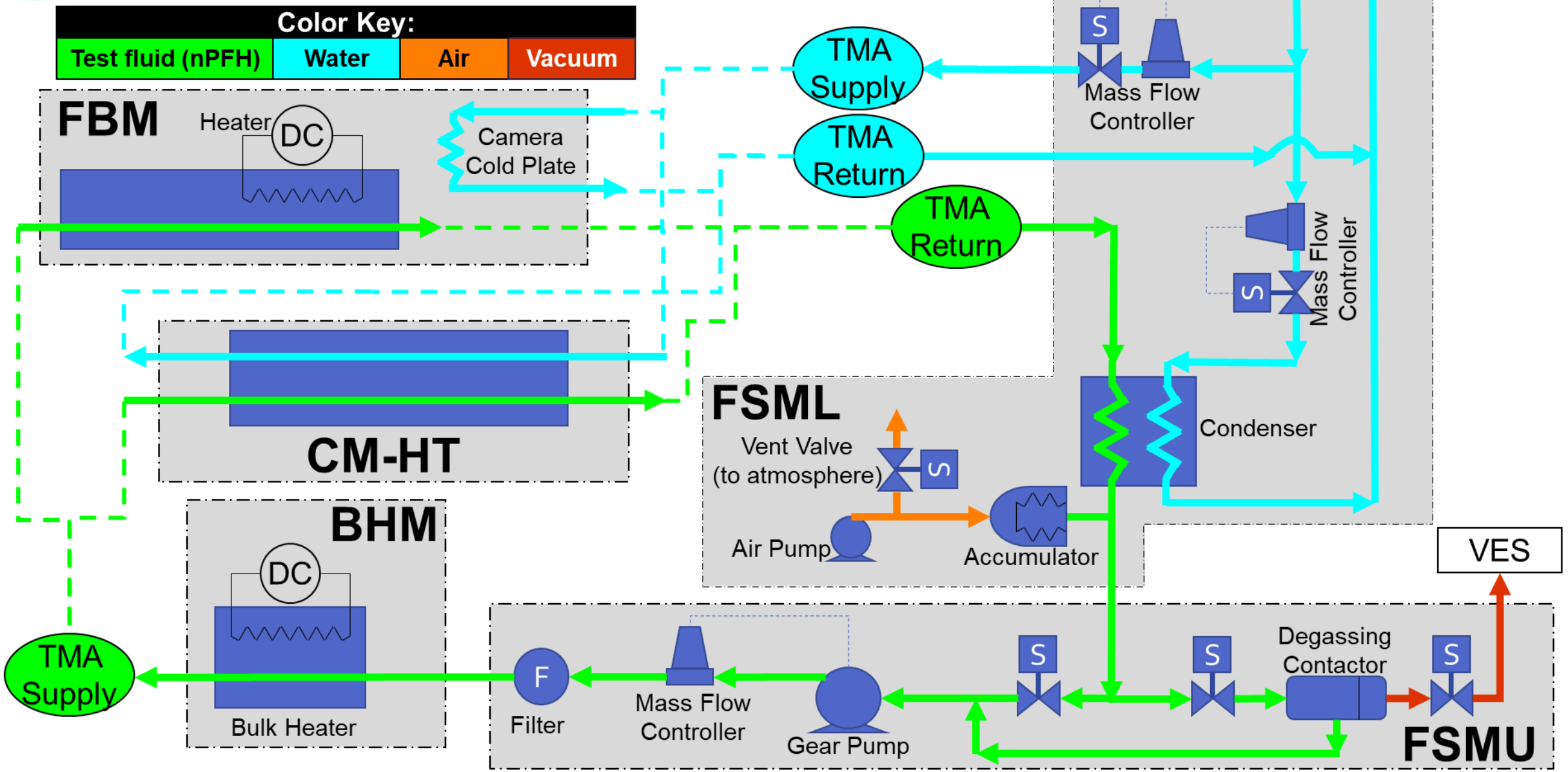
Optics Bench

(2.94 ft x 4.01 ft)

PI-specific hardware and FIR diagnostics



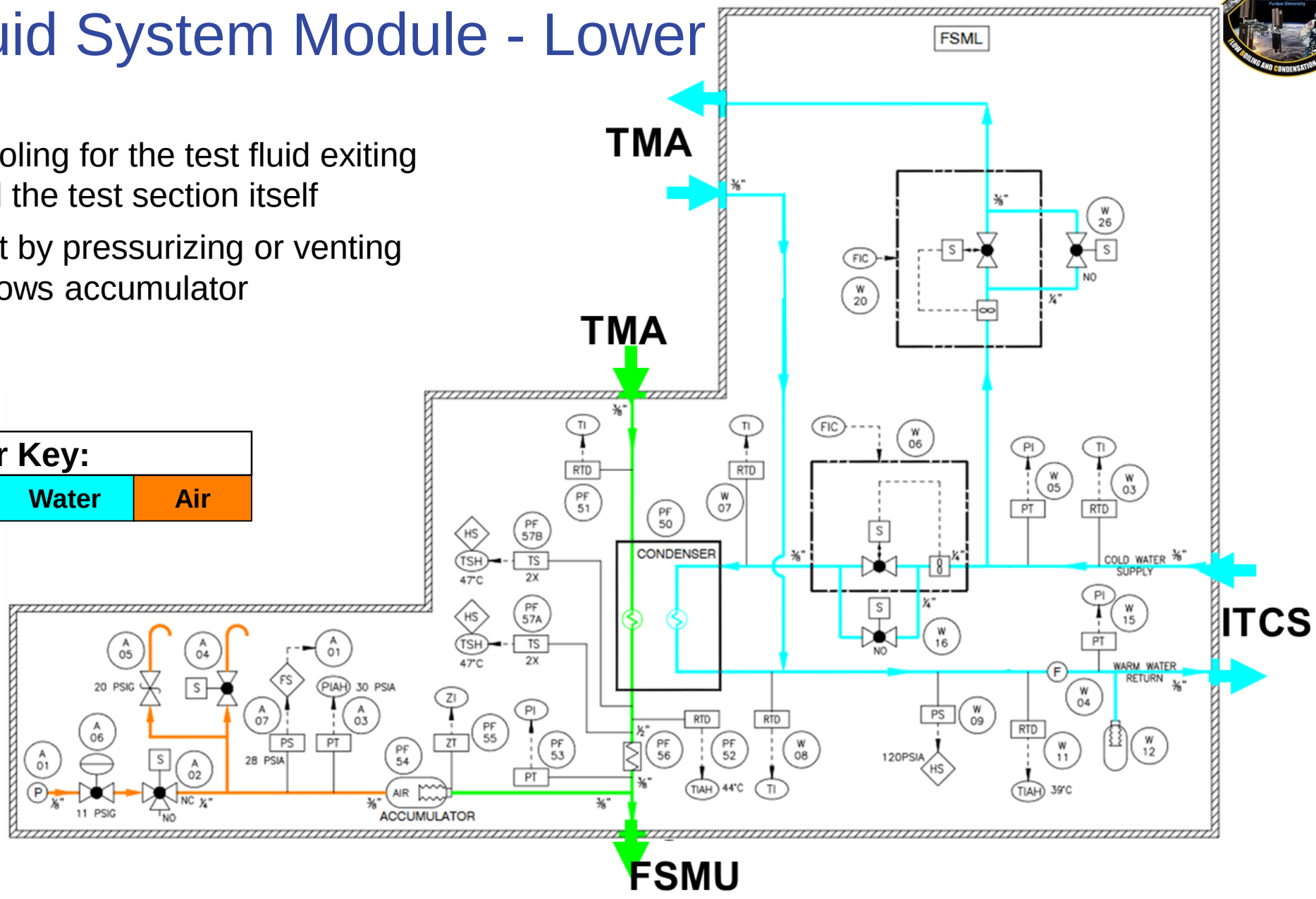
FBCE Fluid System Overview



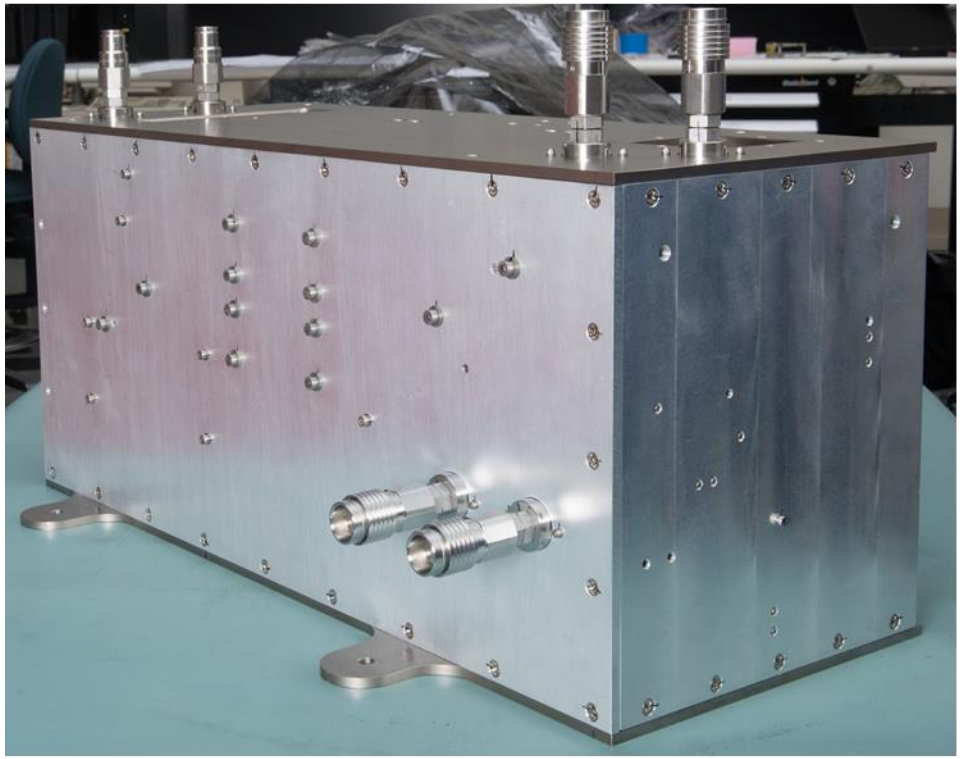
FBCE Fluid System Module - Lower

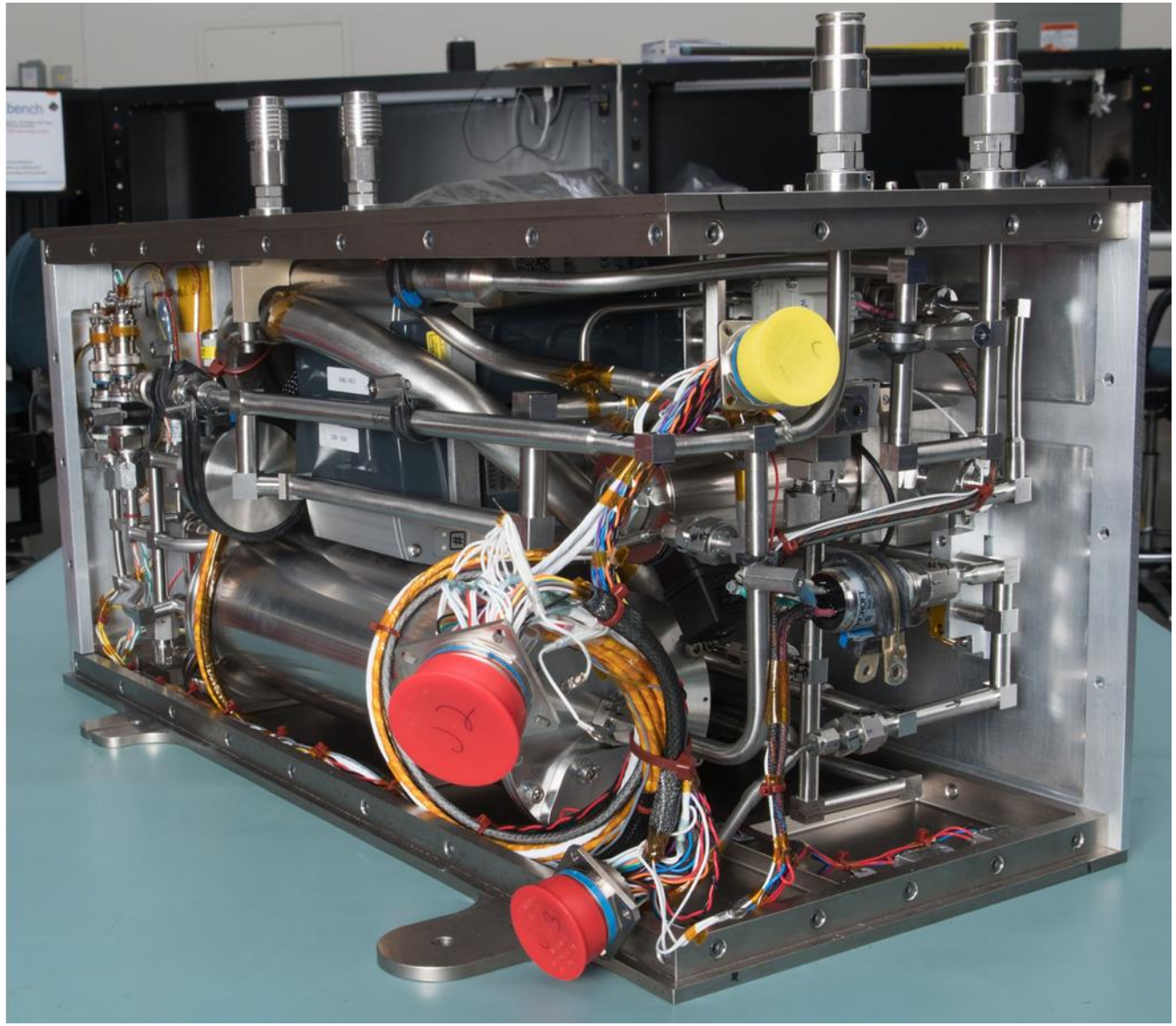
- Provides primary cooling for the test fluid exiting the test section, and the test section itself
- System pressure set by pressurizing or venting the air-side of a bellows accumulator

Color Key:		
Test fluid (nPFH)	Water	Air



FBCE Fluid System Module - Lower

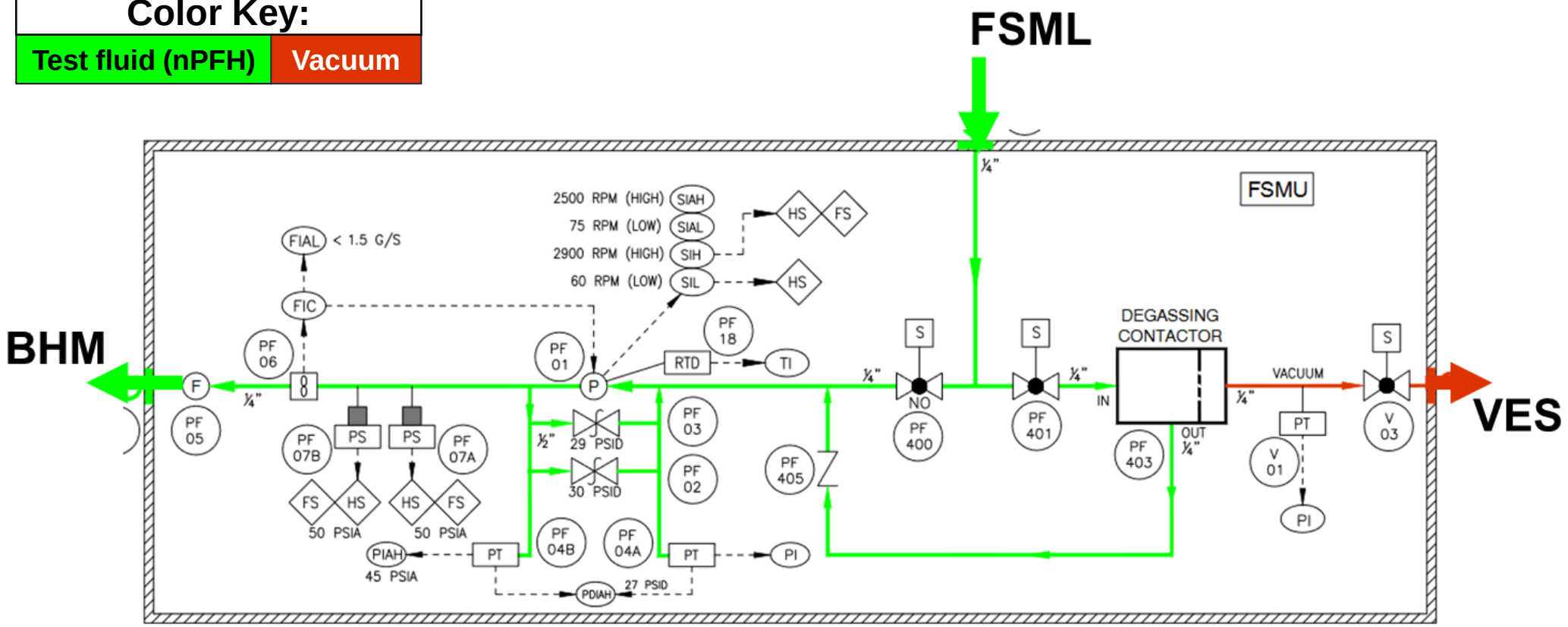




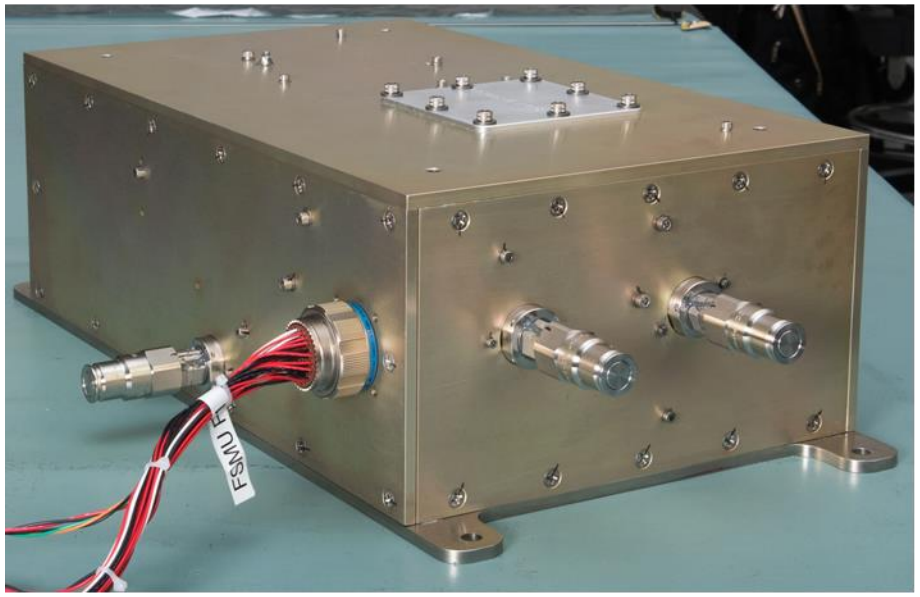
Fluid System Module - Upper

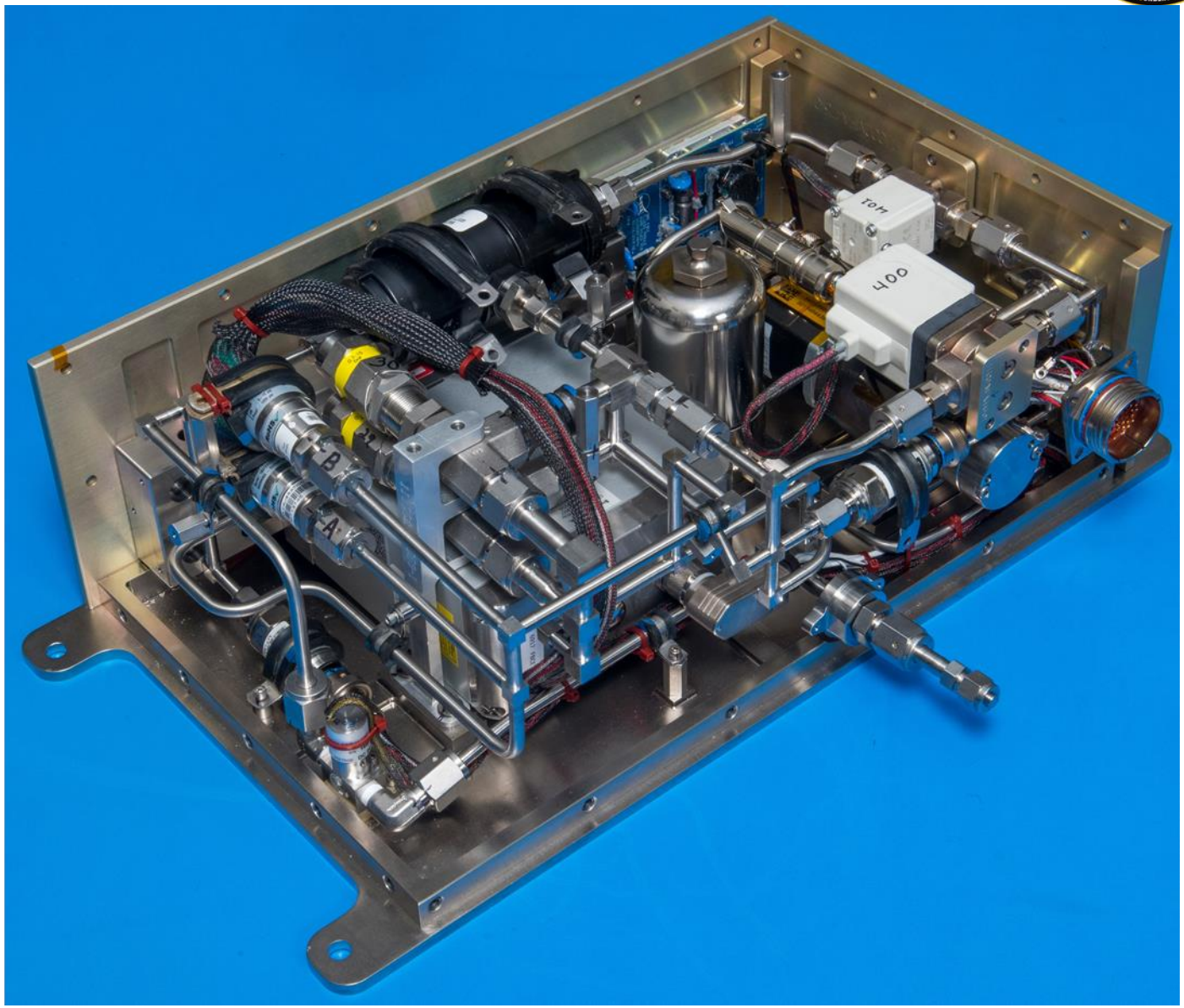
- Mass flow controller drives a gear pump to provide flow throughout the closed loop system
- Multiple controls in place to prevent over-pressurization
- Degassing contactor removes dissolved gases from test fluid when membrane exposed to vacuum

Color Key:	
Test fluid (nPFH)	Vacuum



FBCE Fluid System Module - Upper

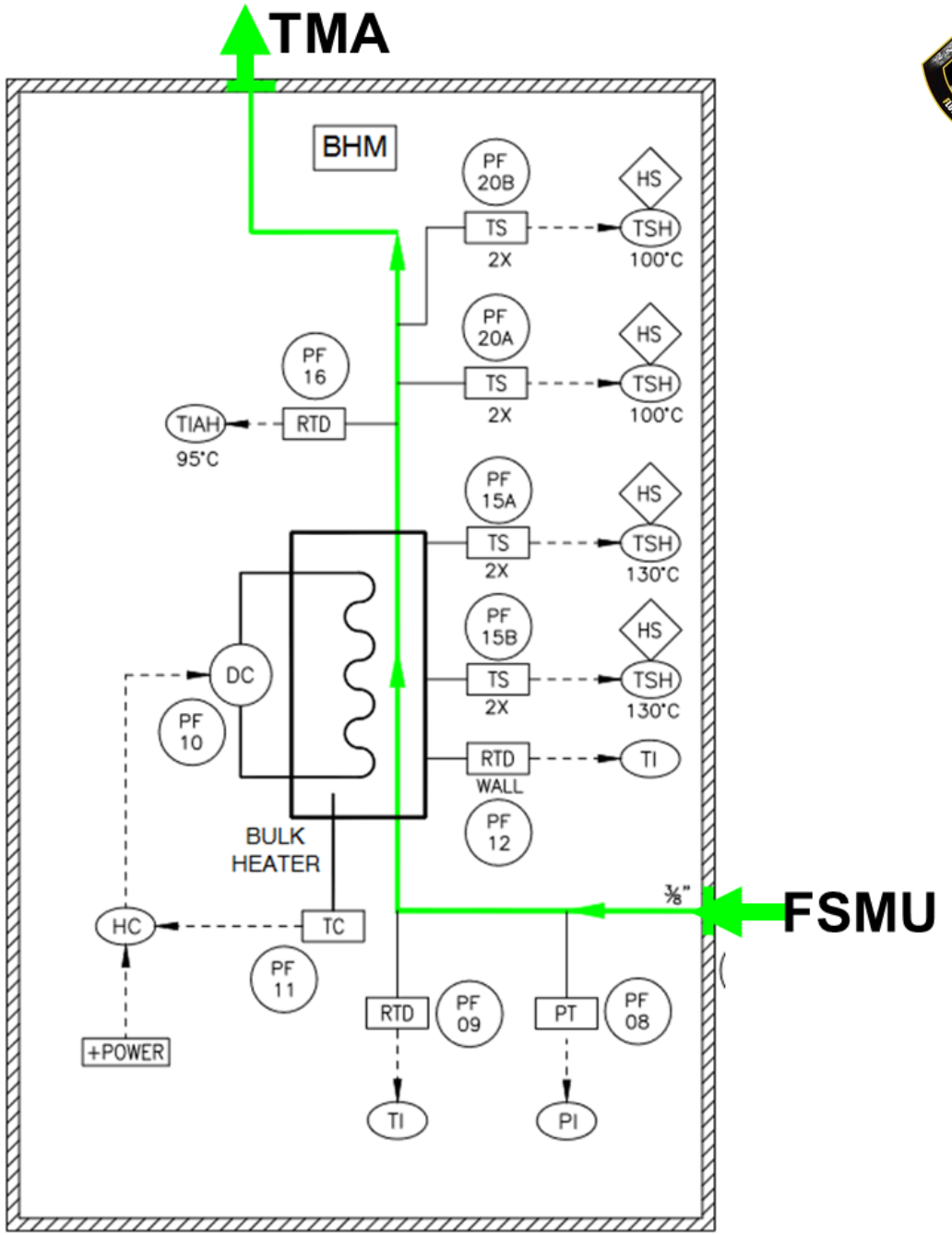




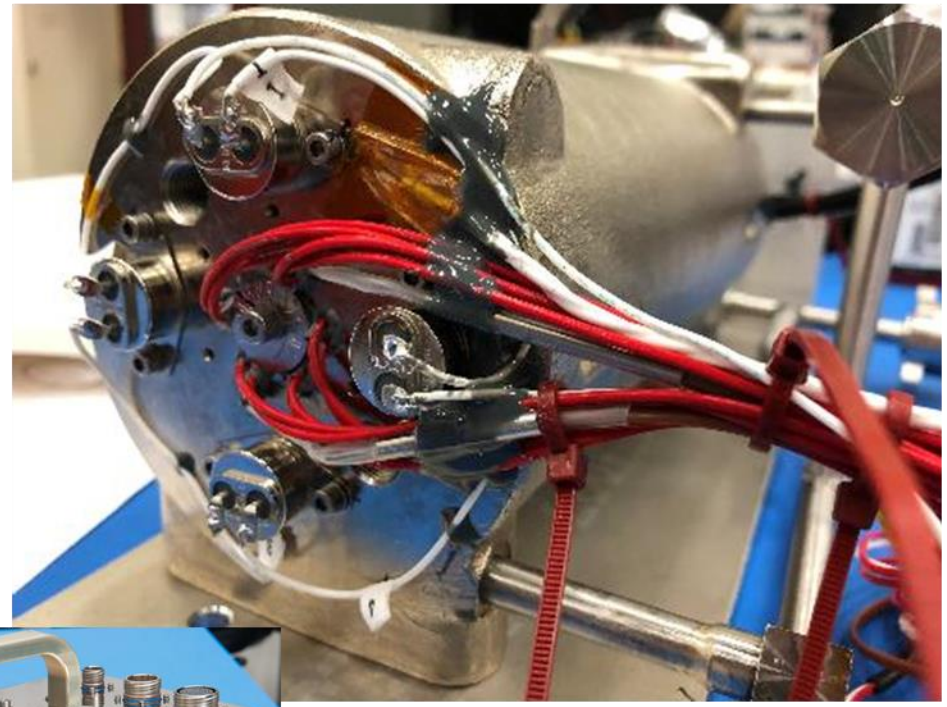
Bulk Heater Module

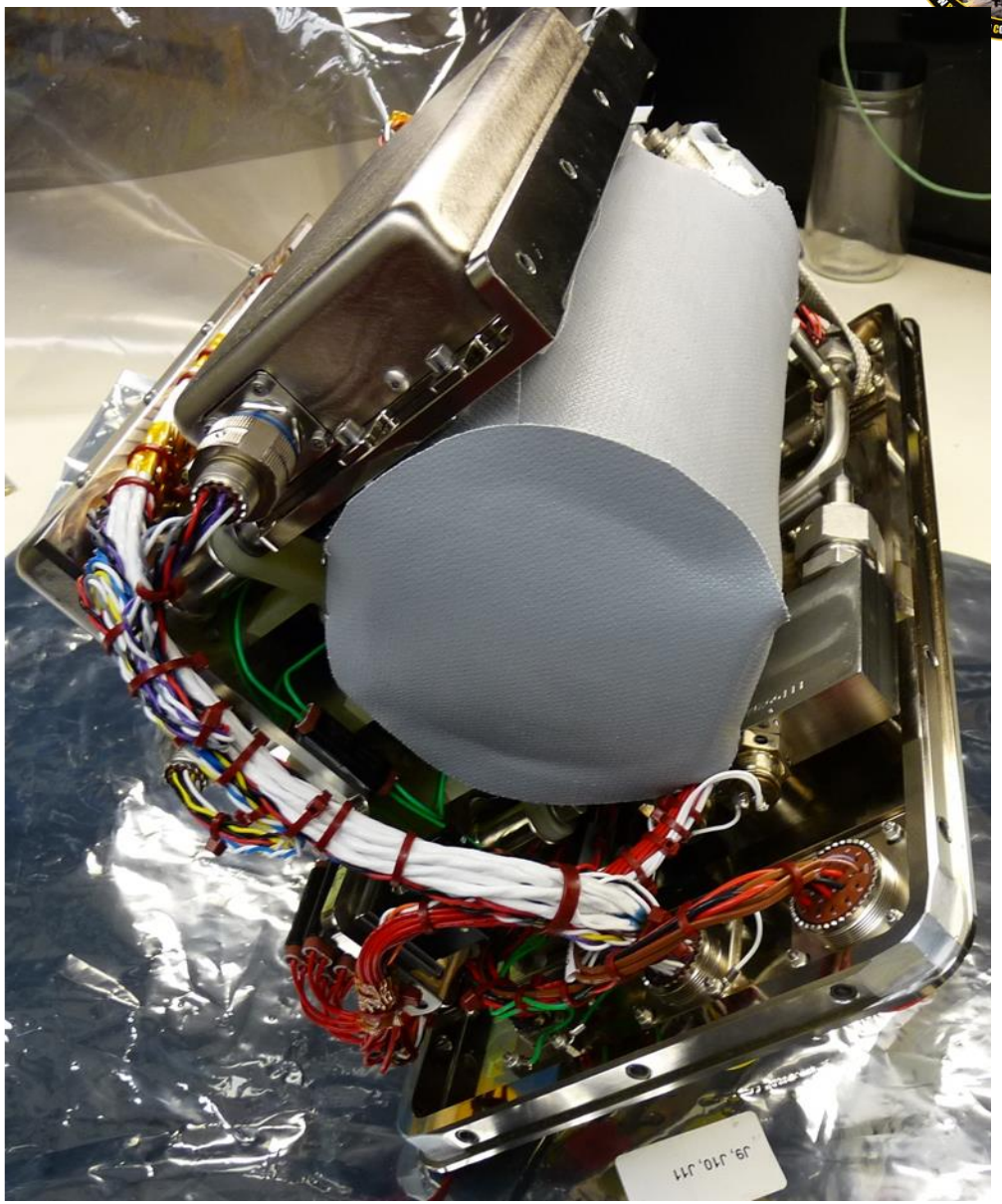
- Primary source of heating to condition test fluid to required test section inlet conditions
- Three 120V primary heaters and three 28V booster heaters can be operated at any time, with backup heaters available
- Multiple safety devices in place to prevent overheating of the test fluid

Color Key:
Test fluid (nPFH)



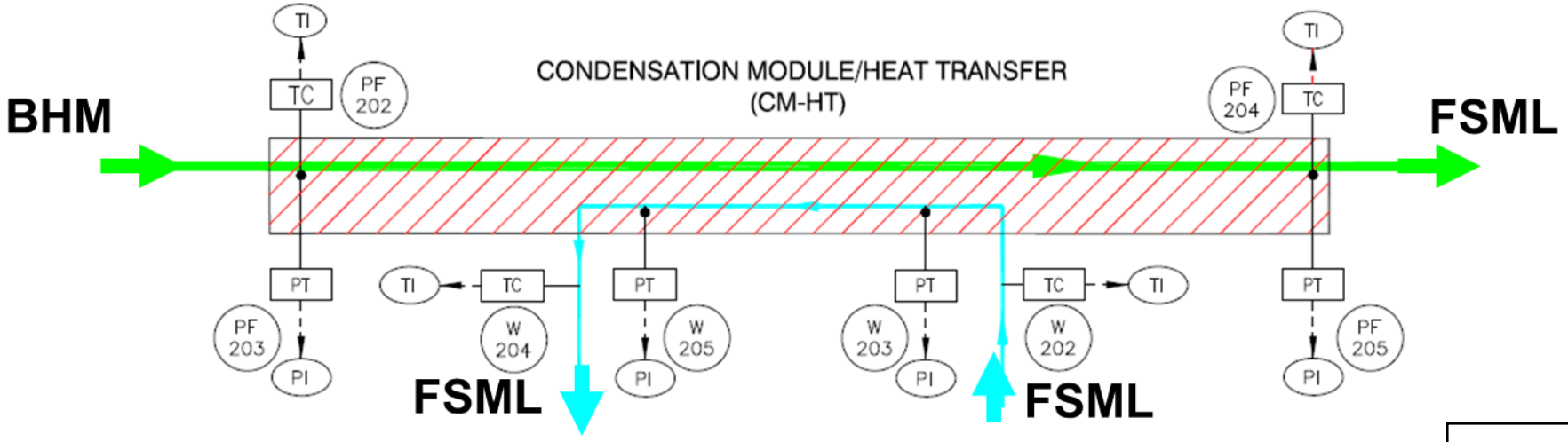
FBCE Bulk Heater Module



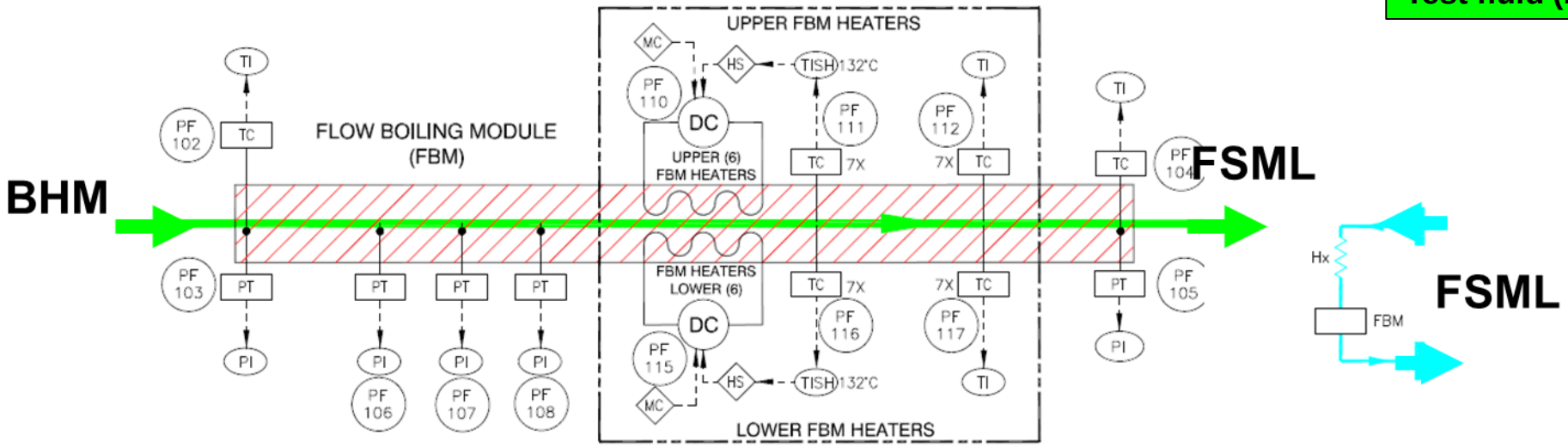


Test Module Assemblies

Condensation Module - Heat Transfer (CM-HT)

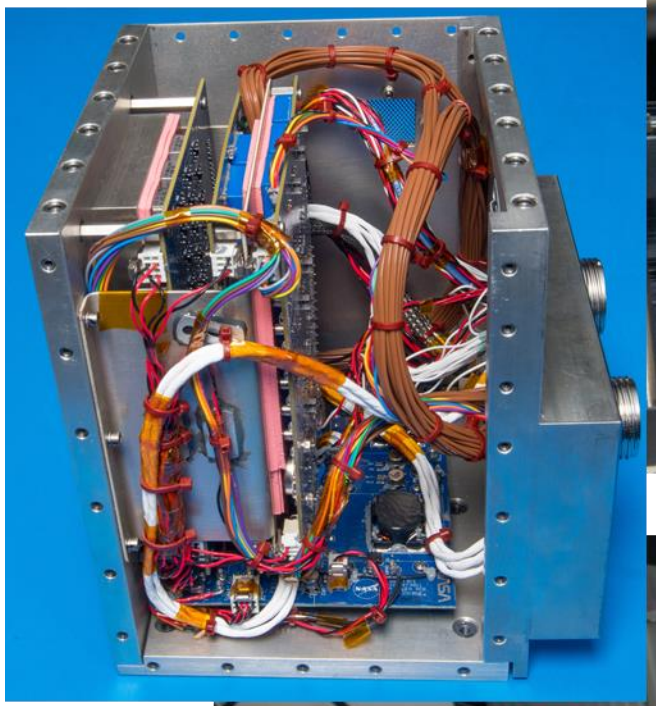


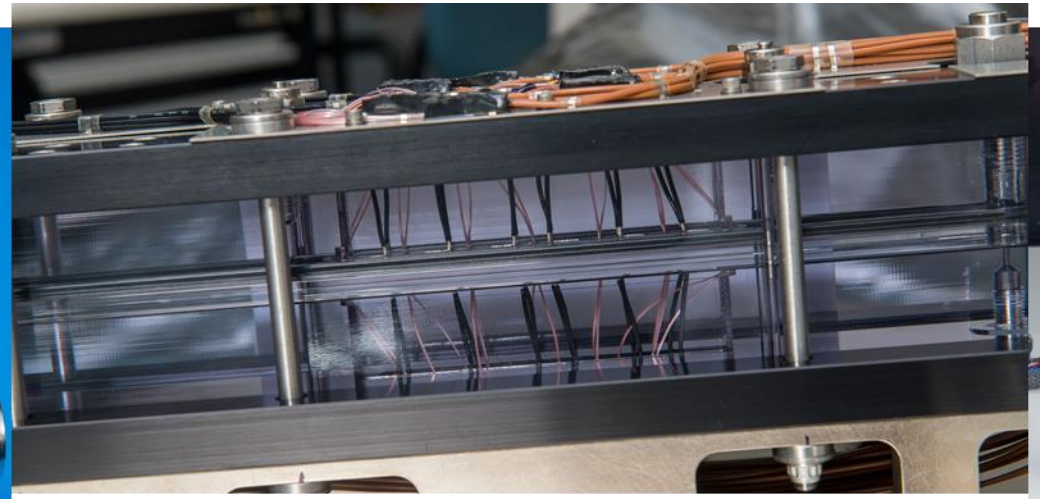
Flow Boiling Module (FBM)

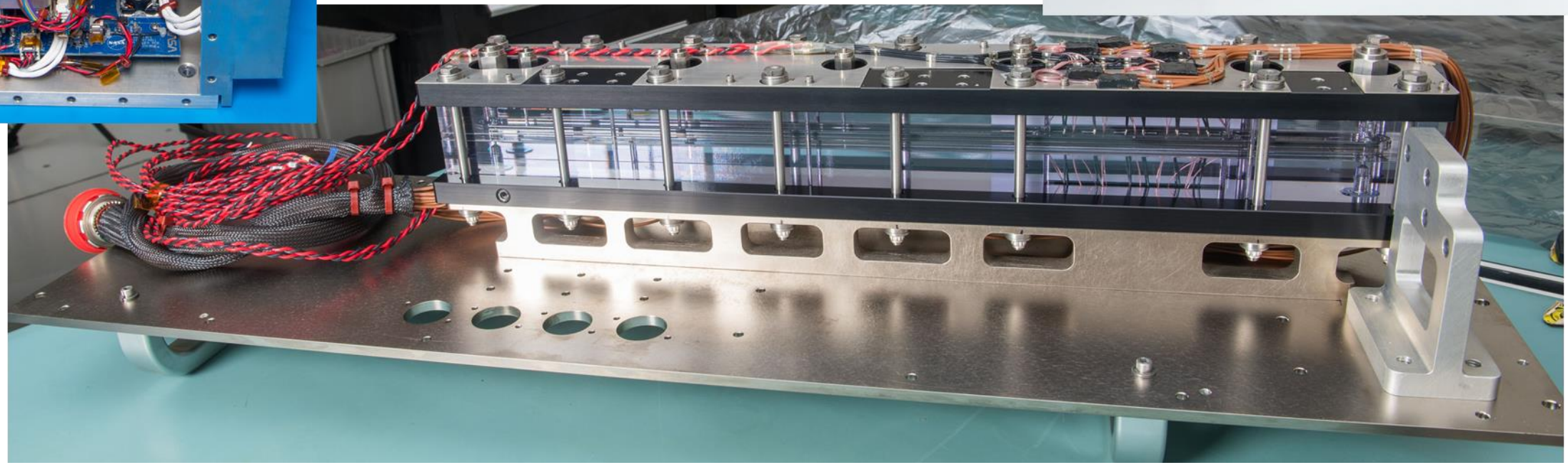


Color Key:	
Test fluid (nPFH)	Water

FBCE Flow Boiling Module

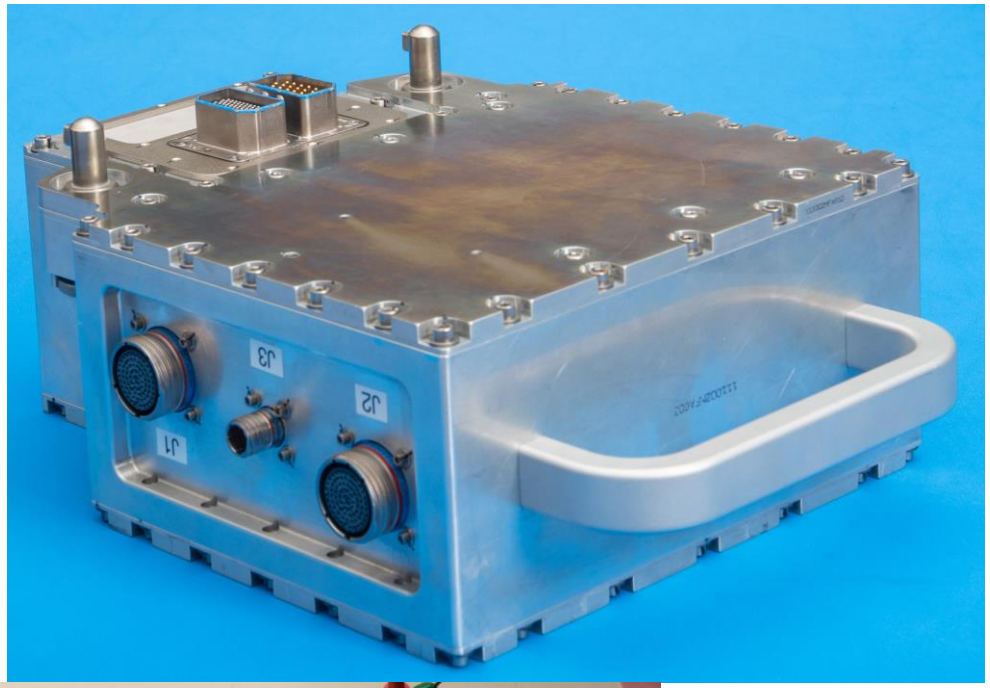


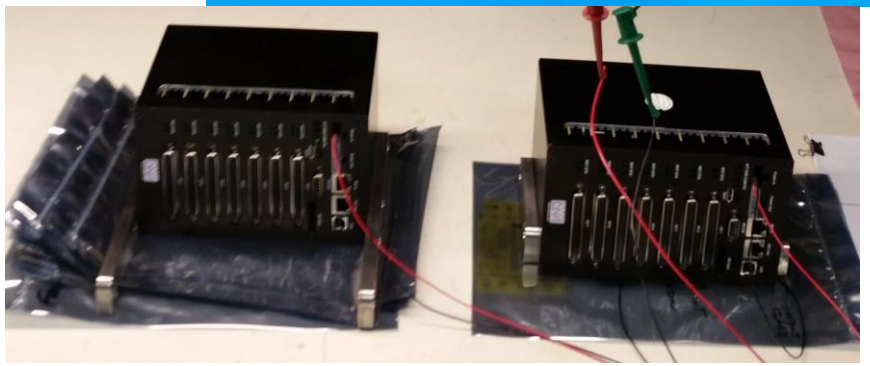




Remote Data Acquisition Modules

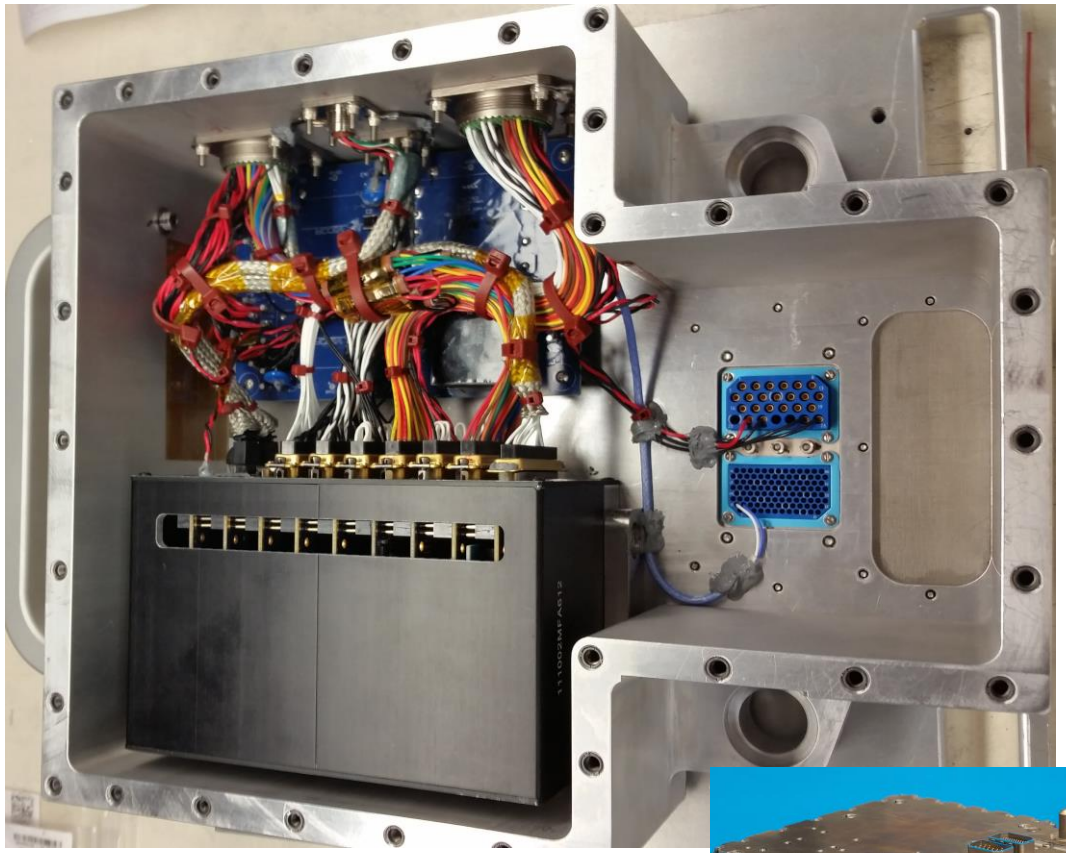
Remote Data Acquisition Module 1 (RDAQM1)





UEI Data Cubes [Thermocouple Signal Conditioning]

Remote Data Acquisition Module 2 (RDAQM2)



UEI Data Cube and Custom Sensor Supply Printed Circuit Board [Signal Conditioning and Power Distribution]

Future Work: Environmental Testing

Vibration
Module

Pressure Drop
Module

System Integration

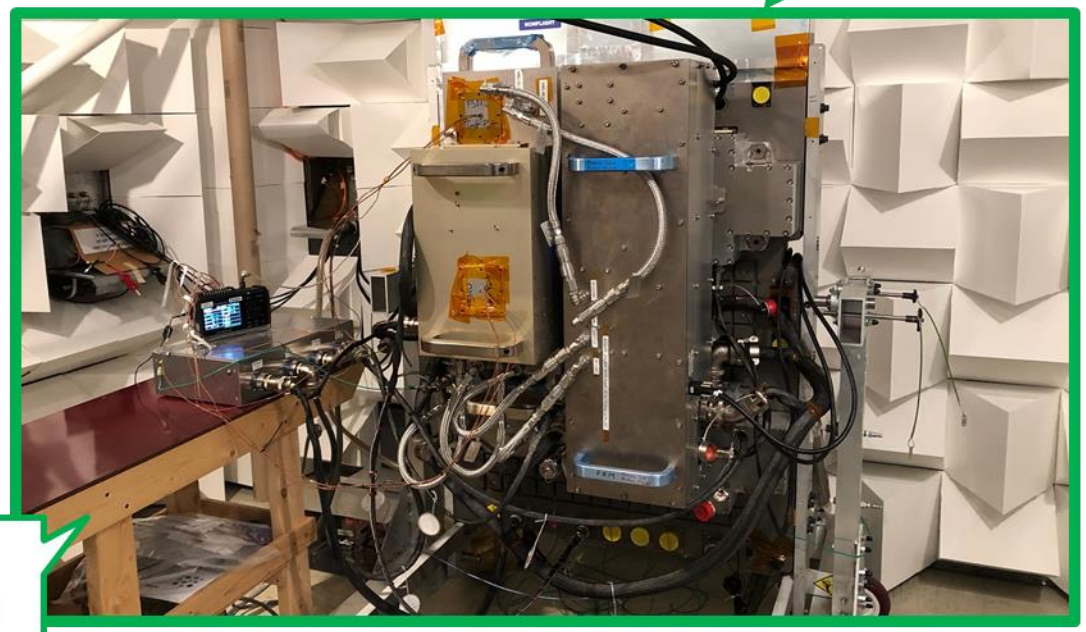
System C/O
System

Acoustic
System

EMI / EMC
Current
System

Thermal Cycle
System

FIR GIU System V&V and MST
System



FBCE in EMI Test Chamber

FBCE System Capabilities and Constraints*

- Capabilities:
  - Test Fluid: normal Perfluorohexane (nPFH)
  - Flow Rate to Test Section: 2 g/s – 40 g/s
    - 2 – 14 g/s for flow condensation experiments
    - 2 – 40 g/s for flow boiling experiments
  - Heat Delivery: up to 1540 W (BHM)
    - FBM additional heat delivery up to 340 W
  - Water Cooling to Test Section: up to 27 g/s
  - Water Inlet Temperature: 16 – 18°C (approximate)
  - Water Return Temperature: 40 – 49°C
  - Test Fluid Degassing Capability
  - Test Fluid Delivery to Test Section: subcooled, saturated, or two-phase mixture
- Constraints:
  - Available power to test section
  - Water cooling to test section limited by system pressure drop and flow required through condenser
  - Volume constraint: 91.44x121.92x48.28 cm^3 (36x48x19 in^3)

**NOTE: system capability numbers subject to change based on achieving finalized integrated system test results*

Acknowledgements

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Mark Sorrells, Verification and Validation Lead
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Dr. Jeffrey Mackey, Optics and TMA Lead
Rochelle May, Software Lead
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FBCE Project Support Team