

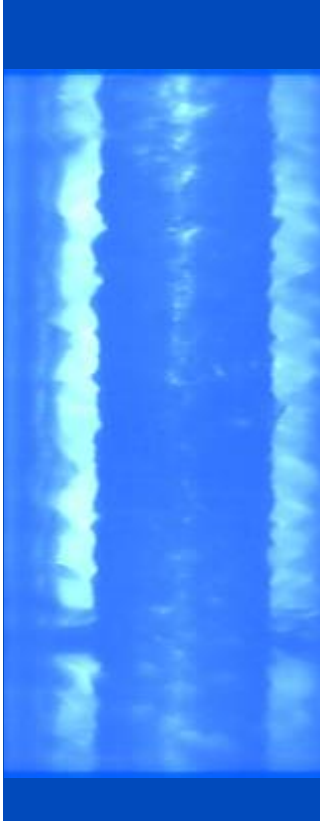


Flow Boiling and Condensation Experiment Flight Hardware Development

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Gravitational and Space Research

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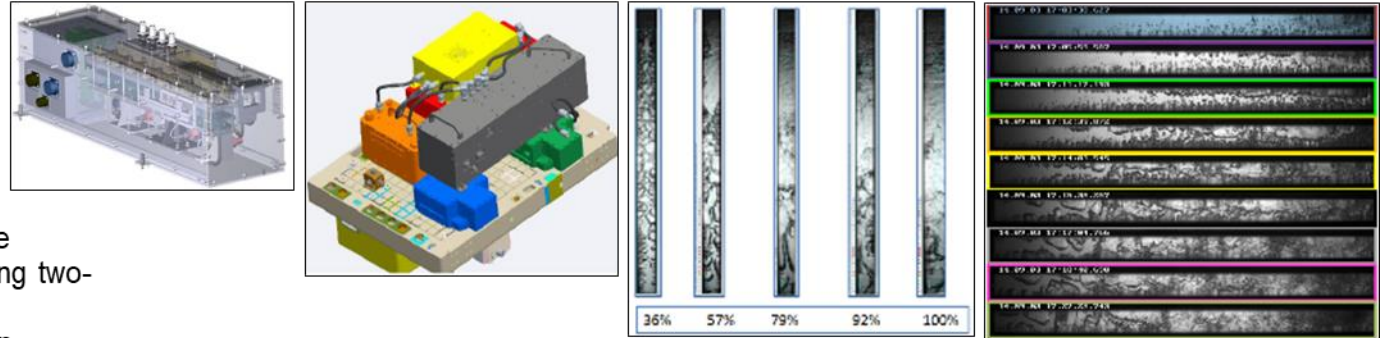




Flow Boiling and Condensation Experiment (FBCE)

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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 (m³) (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



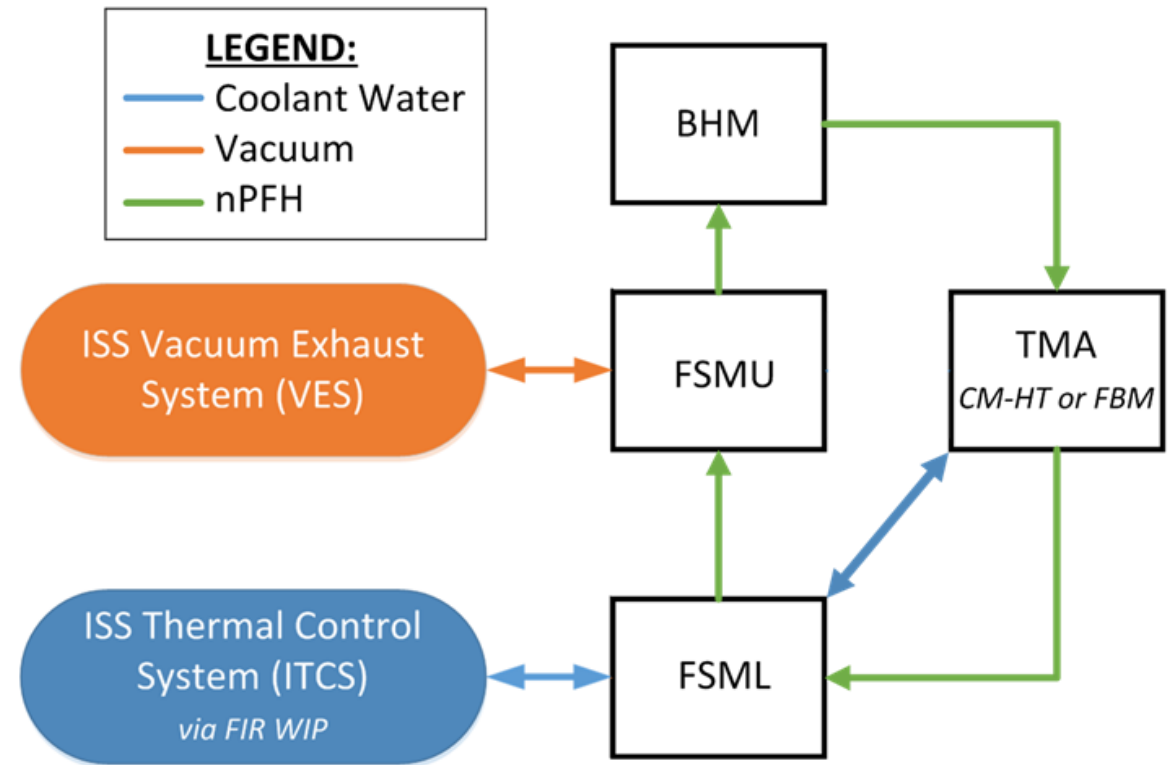
FBCE System Overview

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)

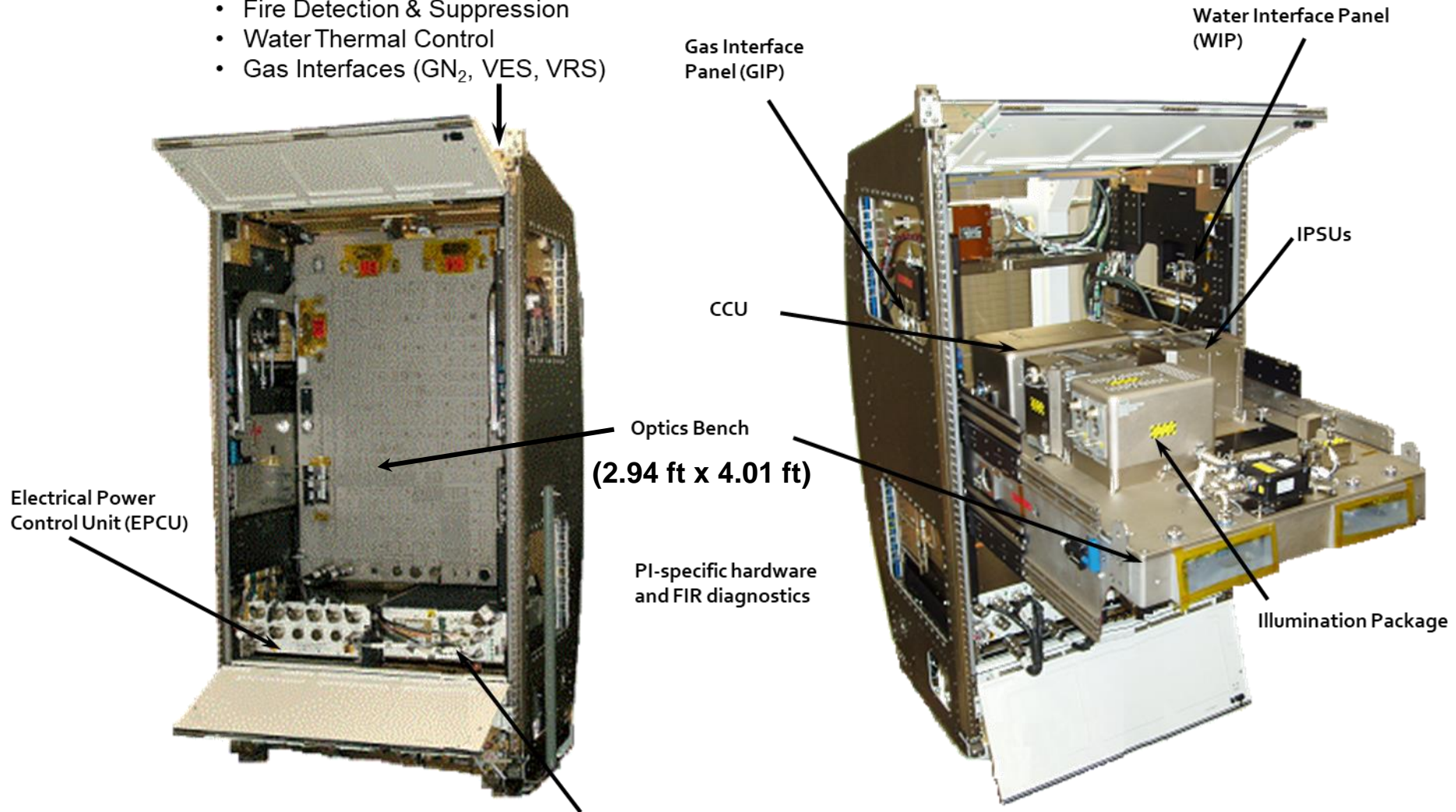




Fluid Integration Rack

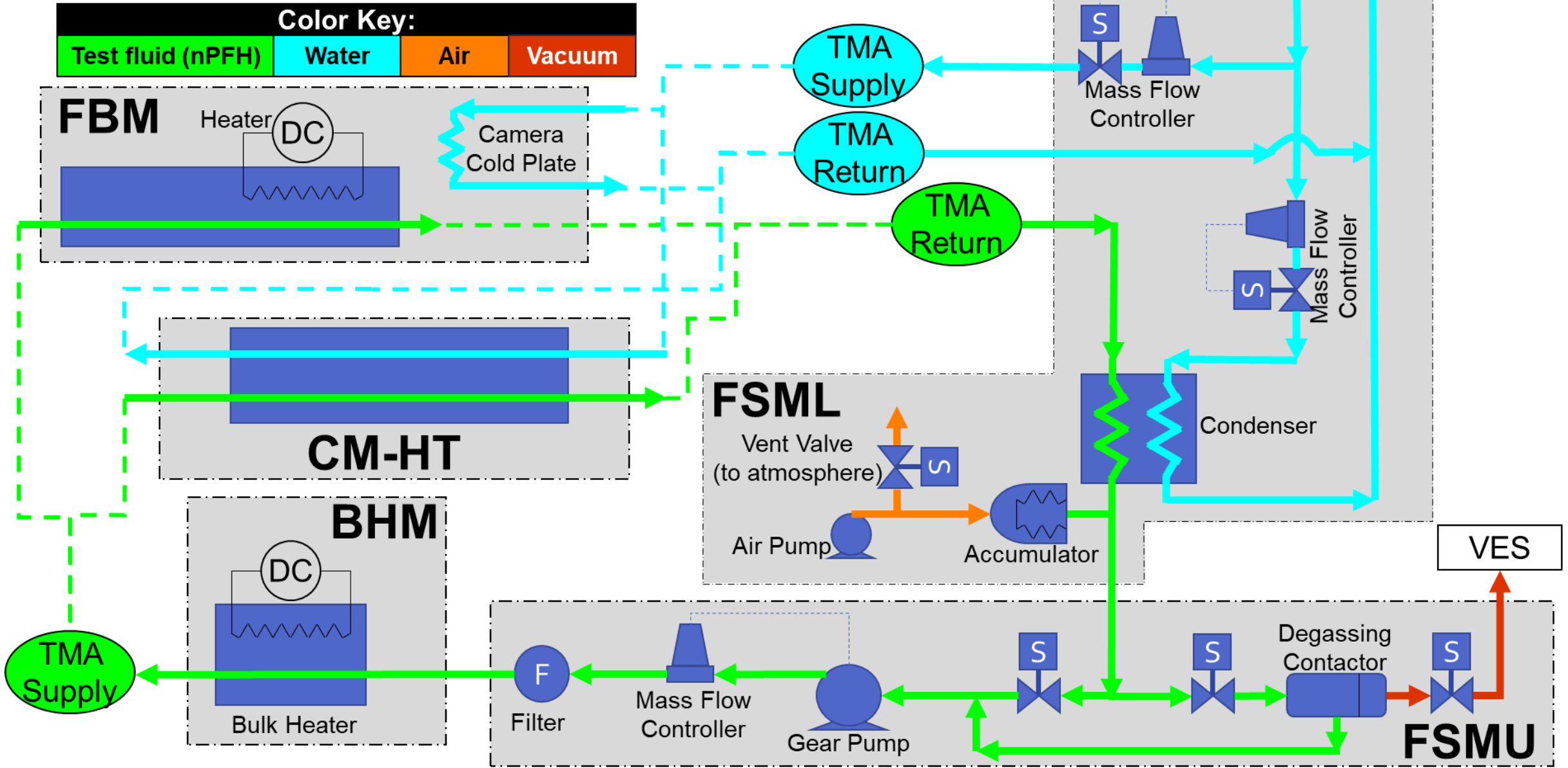
Environmental Control (ECS)

- Air Thermal Control
- Fire Detection & Suppression
- Water Thermal Control
- Gas Interfaces (GN₂, VES, VRS)





FBCE Fluid System Overview

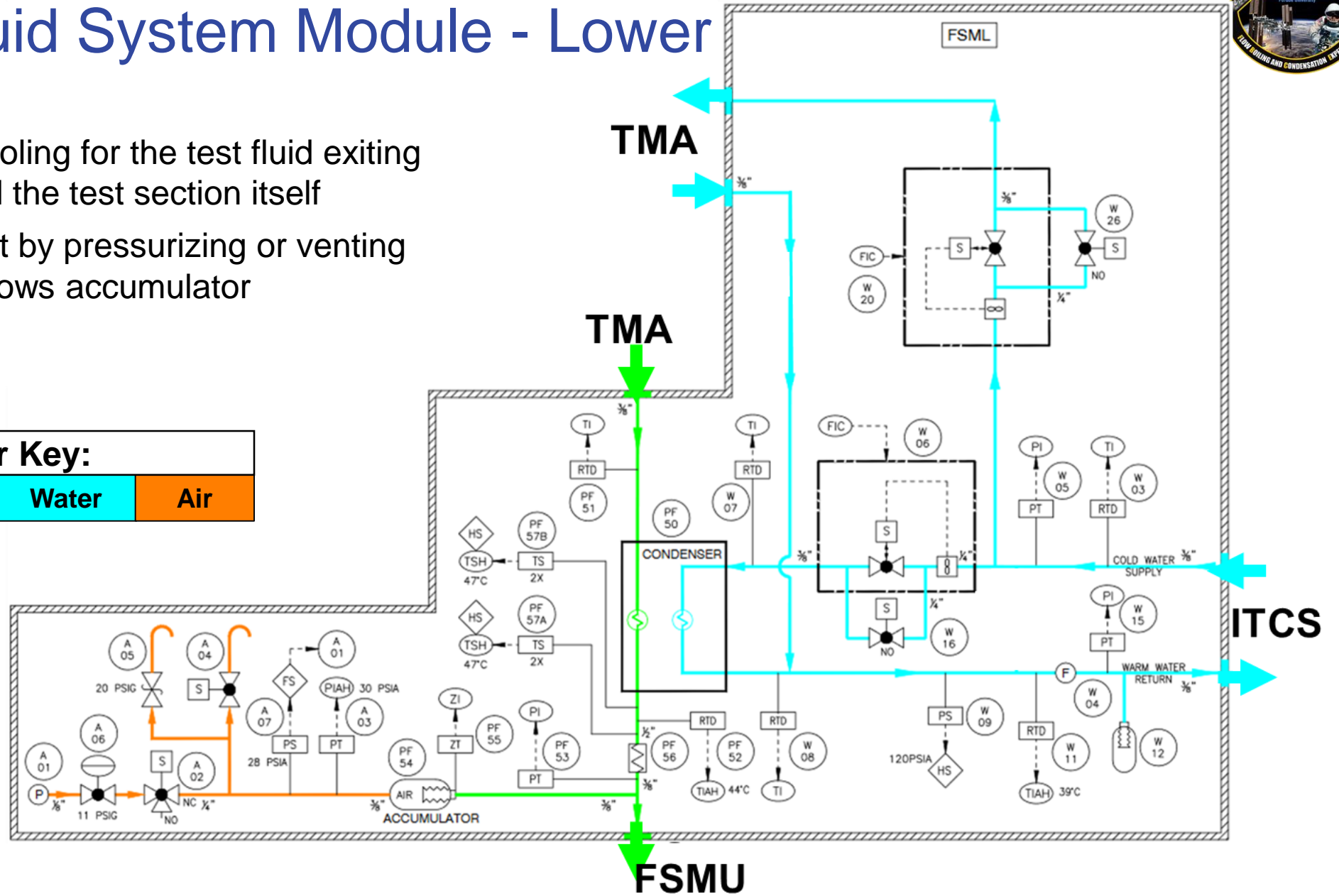




FBCE Fluid System Module - Lower

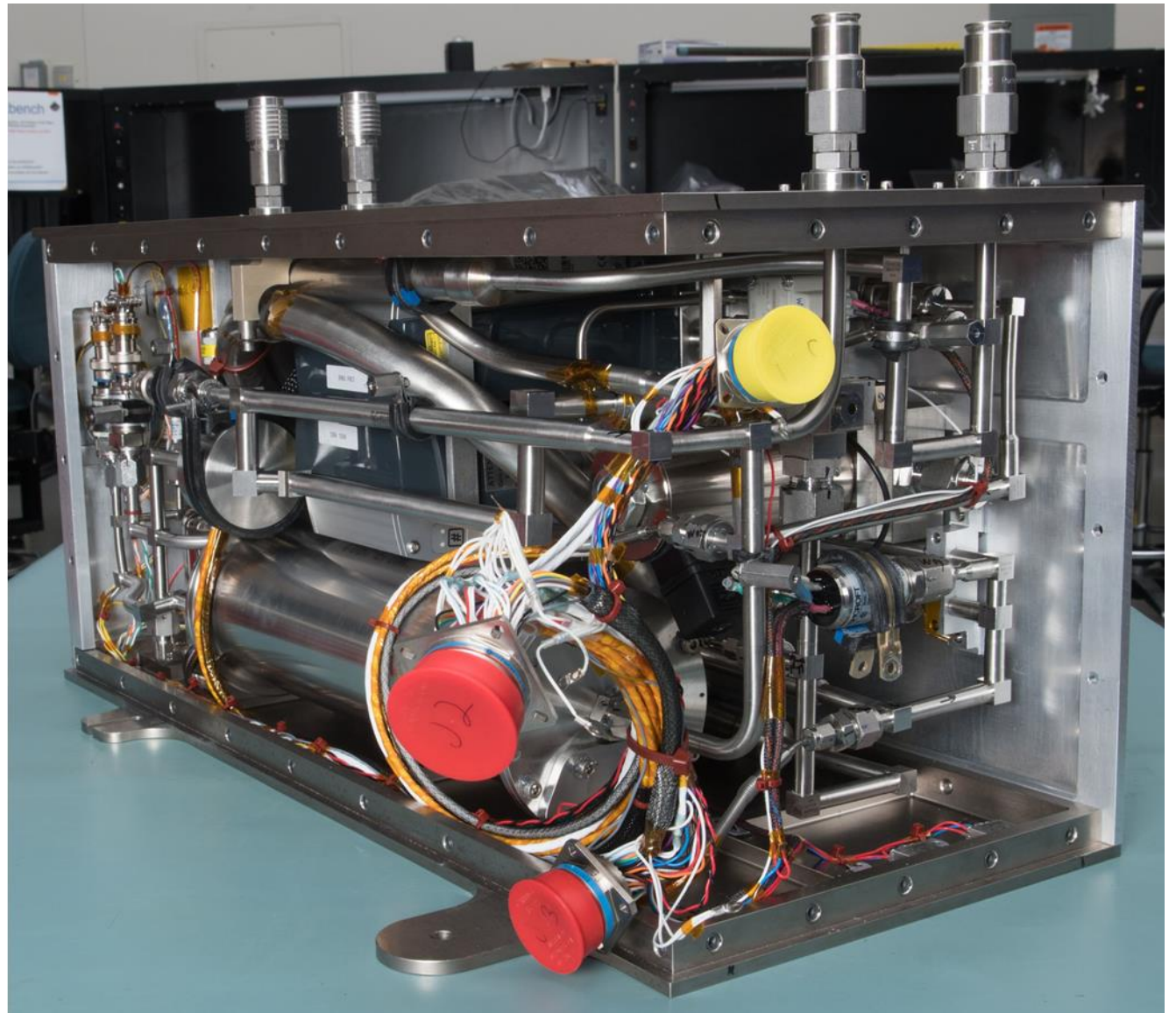
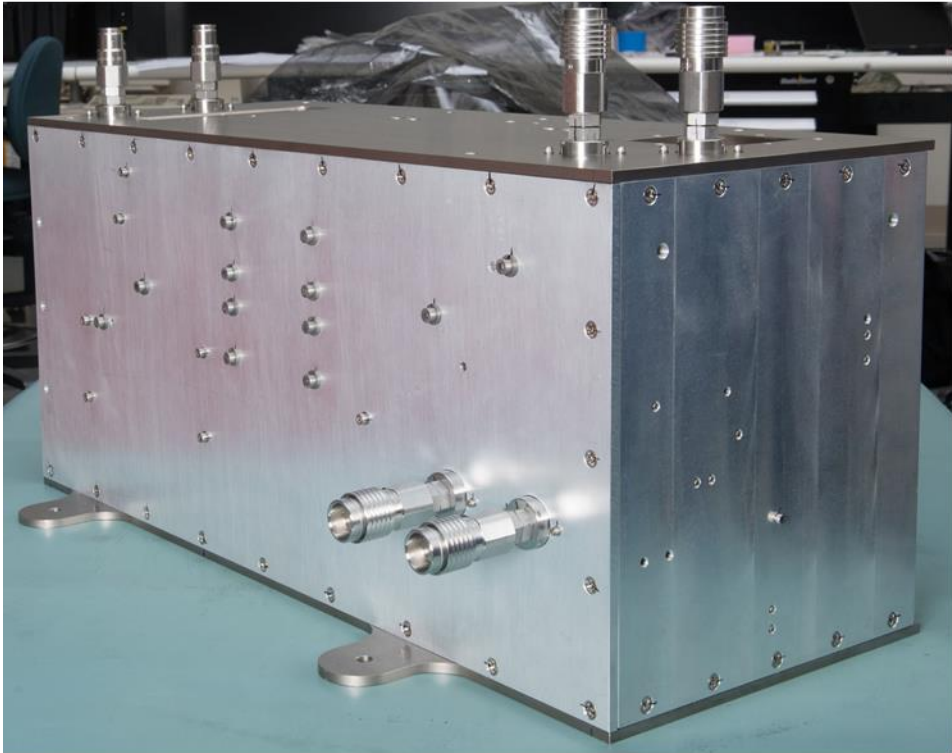
- Provides primary cooling for the test fluid exiting the test section, and the test section itself
- System pressure set by pressurizing or venting the air-side of a bellows accumulator

Color Key:		
Test fluid (nPFH)	Water	Air





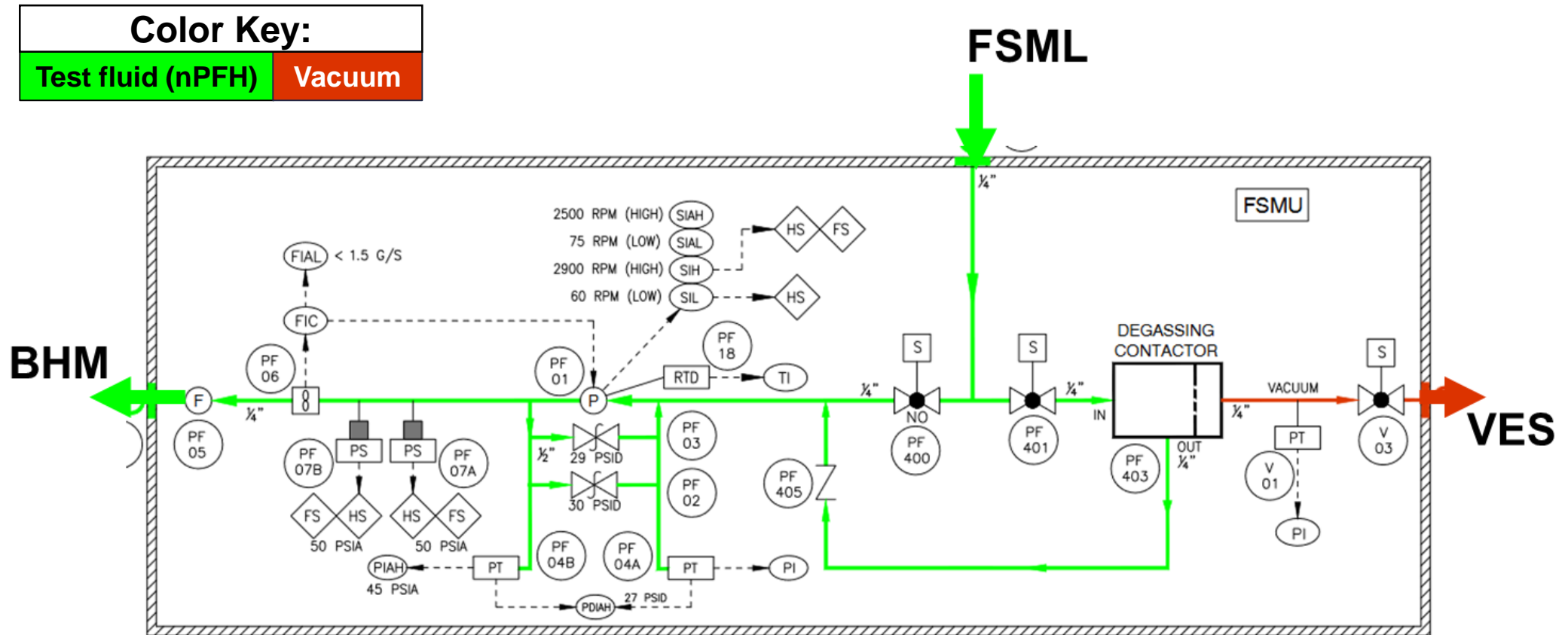
FBCE Fluid System Module - Lower





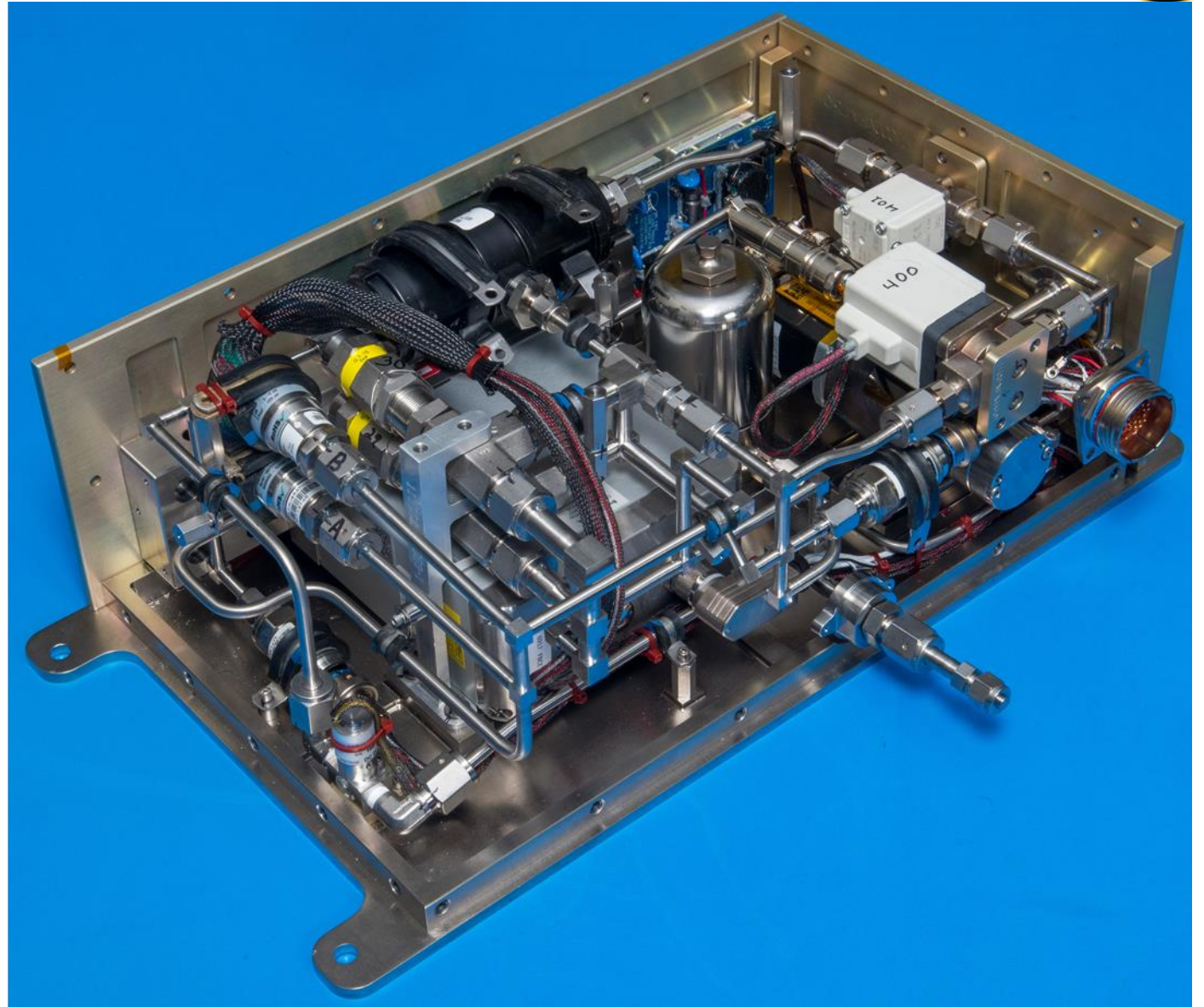
Fluid System Module - Upper

- 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





FBCE Fluid System Module - Upper

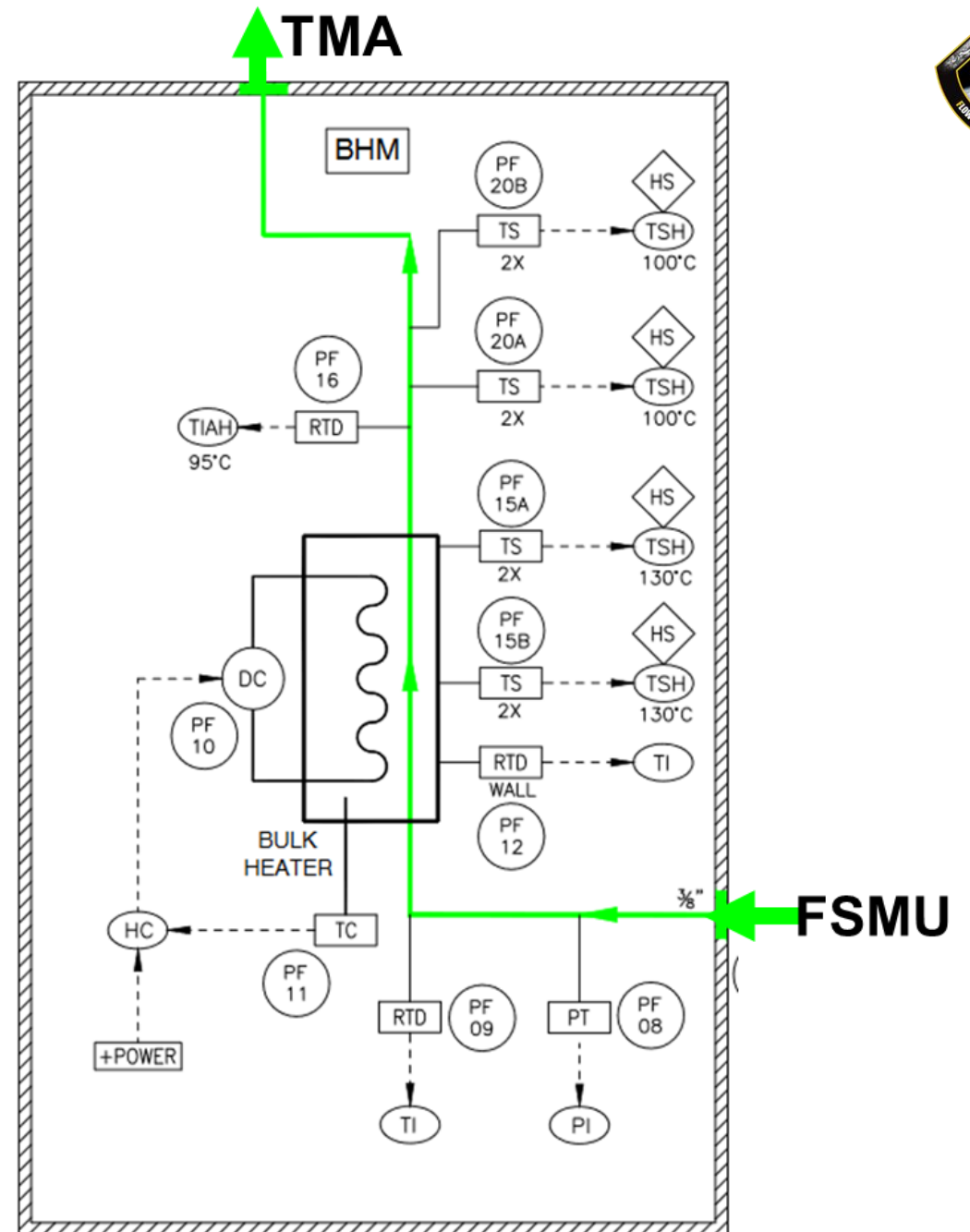




Bulk Heater Module

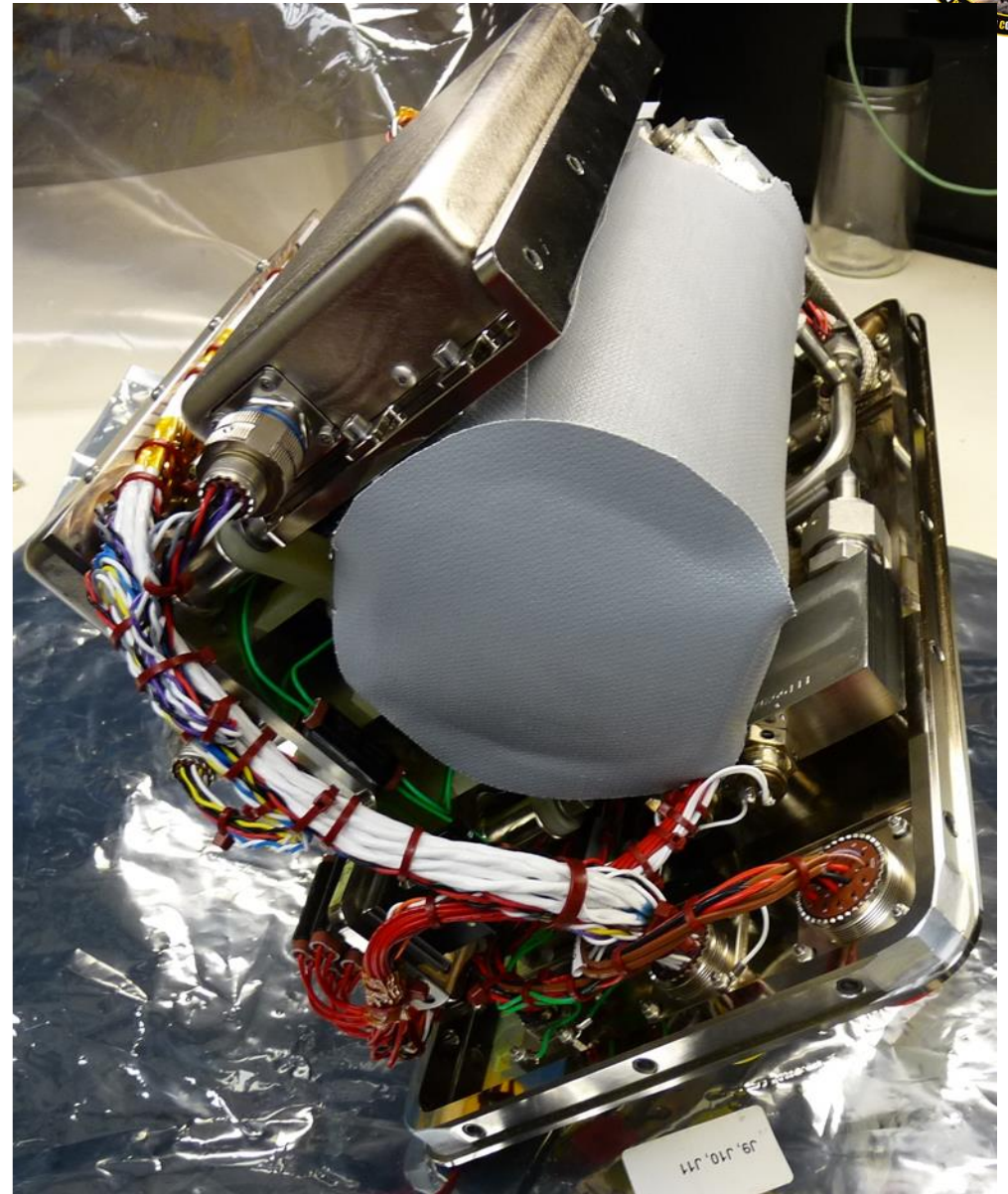
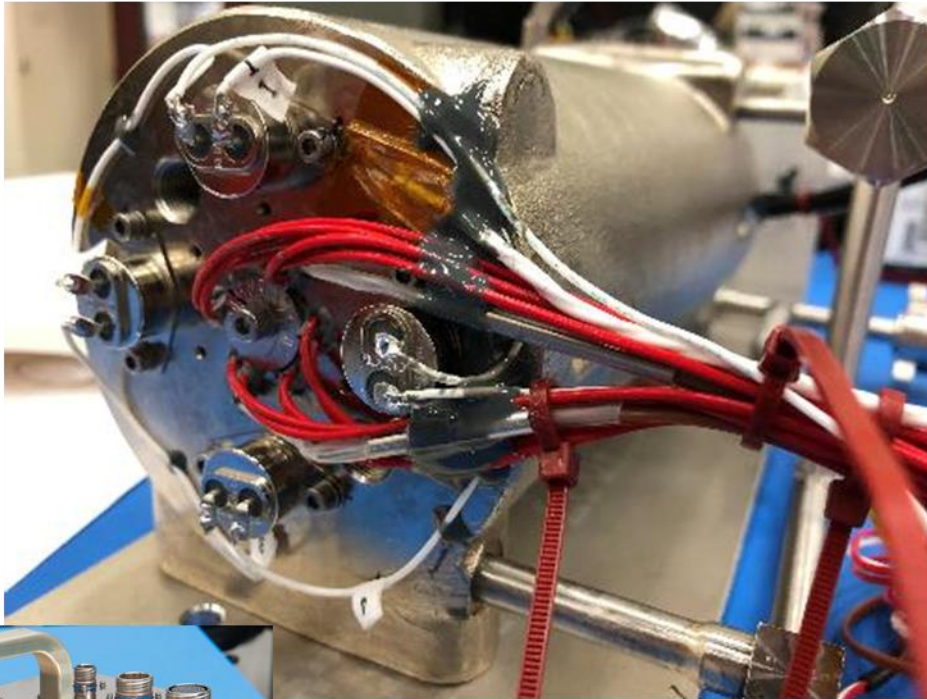
- Primary source of heating to condition test fluid to required test section inlet conditions
- Three 120V primary heaters and three 28V booster heaters can be operated at any time, with backup heaters available
- Multiple safety devices in place to prevent overheating of the test fluid

Color Key:
Test fluid (nPFH)





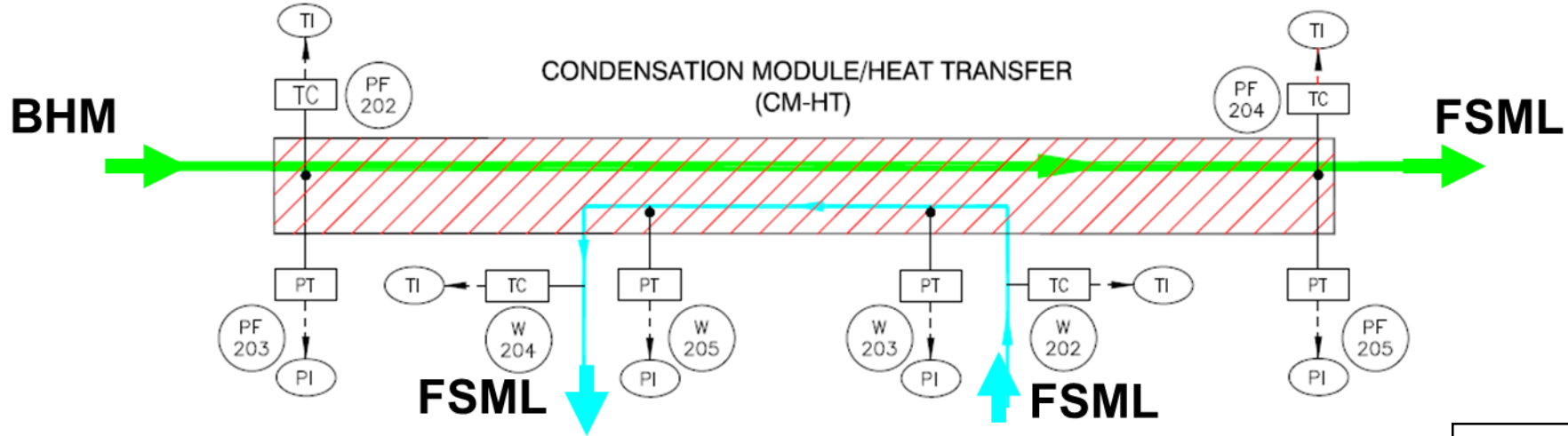
FBCE Bulk Heater Module





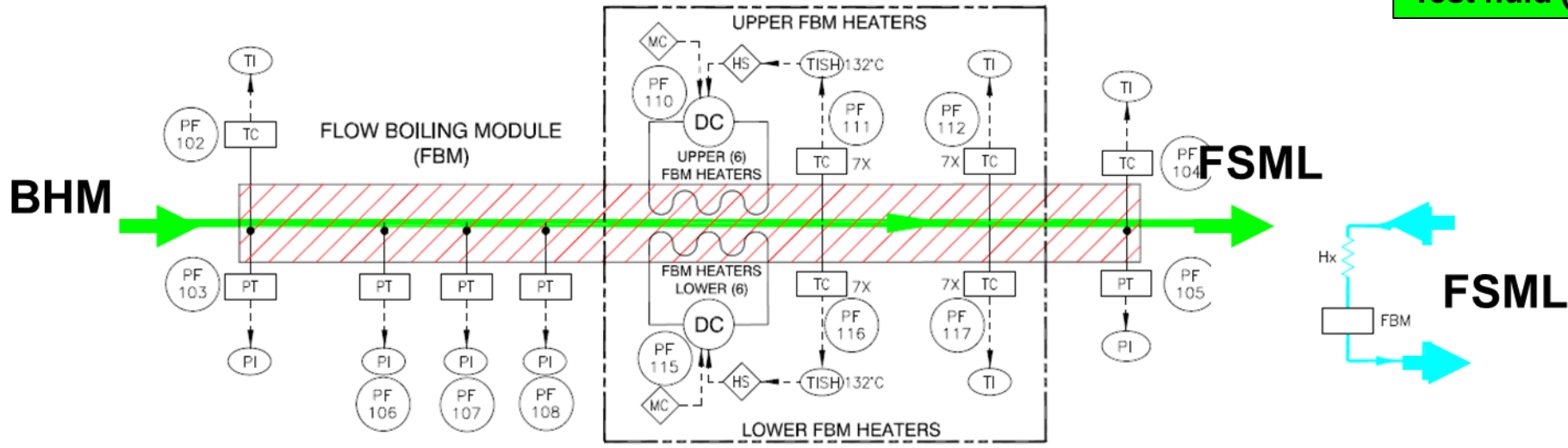
Test Module Assemblies

Condensation Module - Heat Transfer (CM-HT)



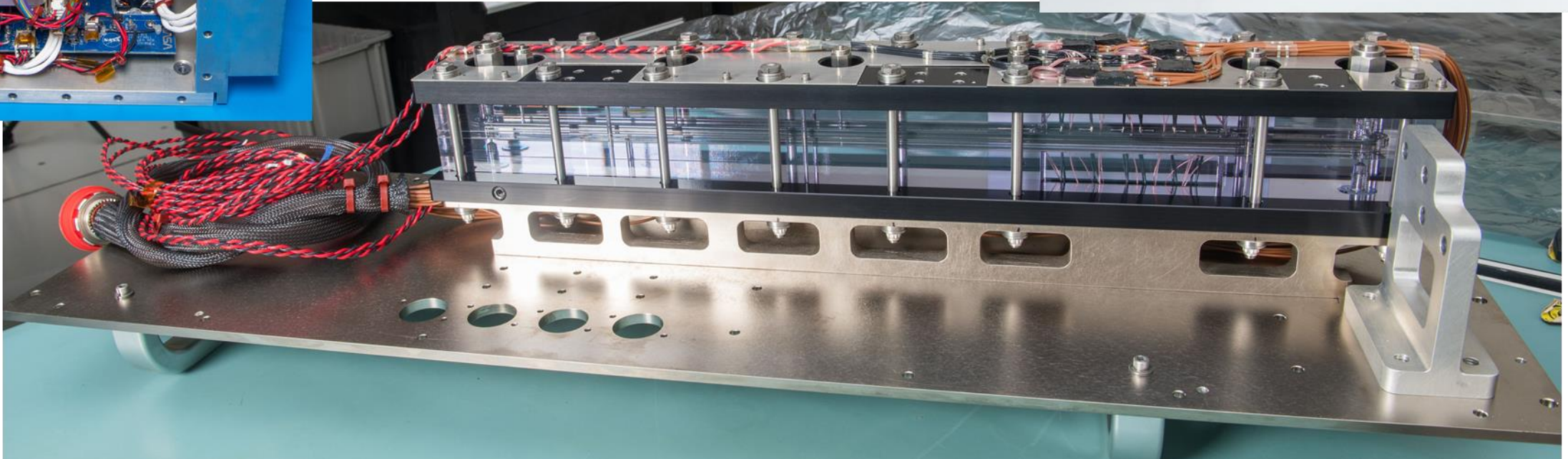
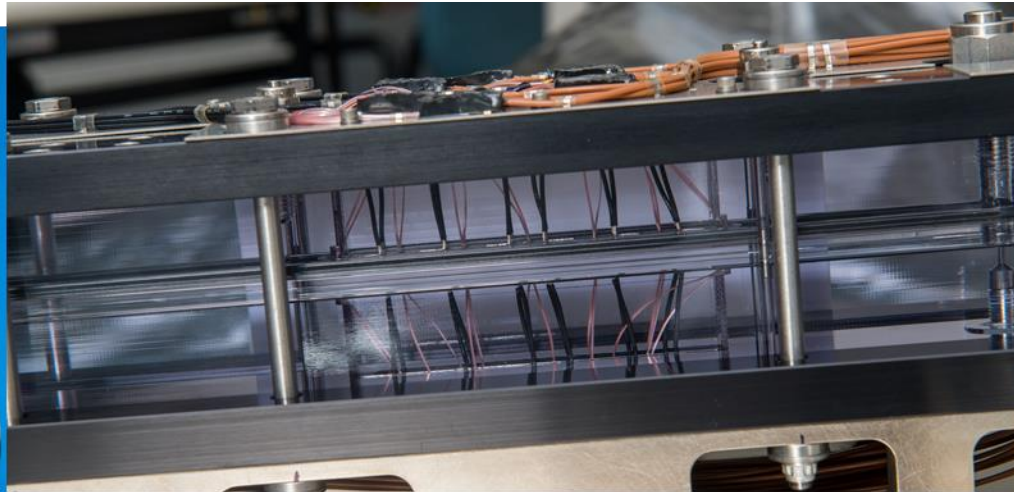
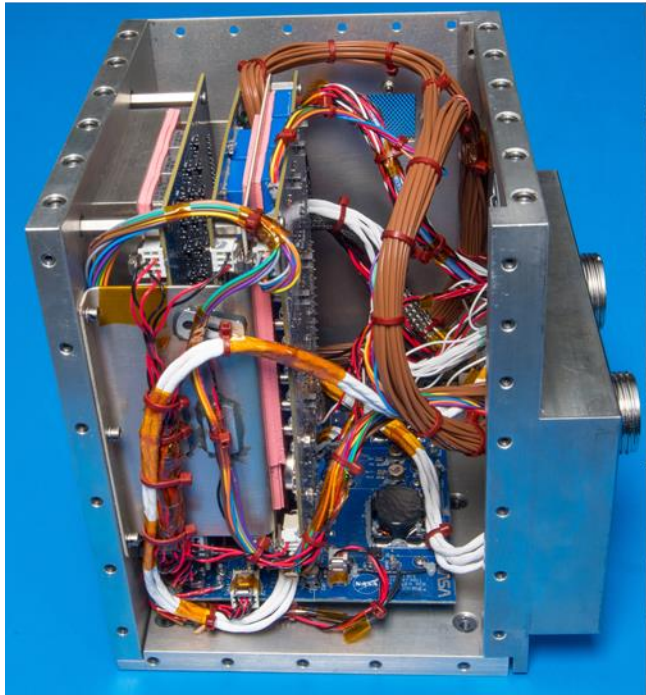
Flow Boiling Module (FBM)

Color Key:	
Test fluid (nPFH)	Water





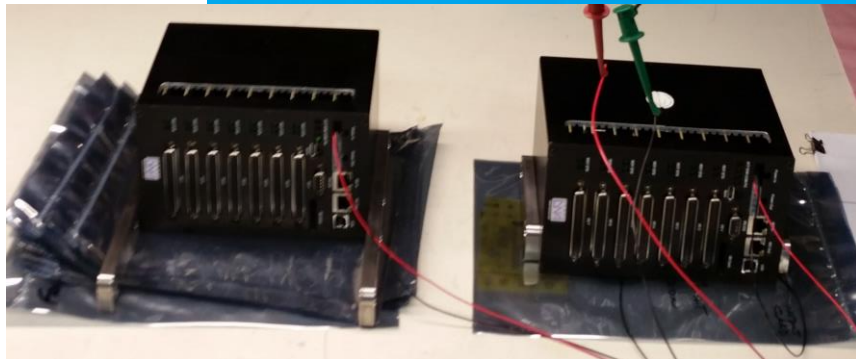
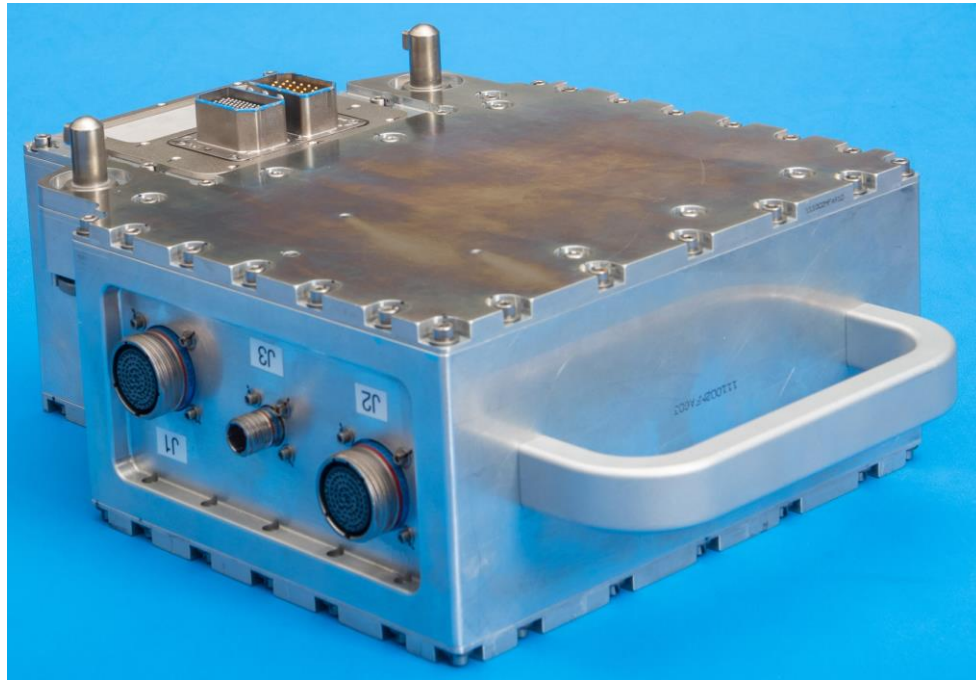
FBCE Flow Boiling Module





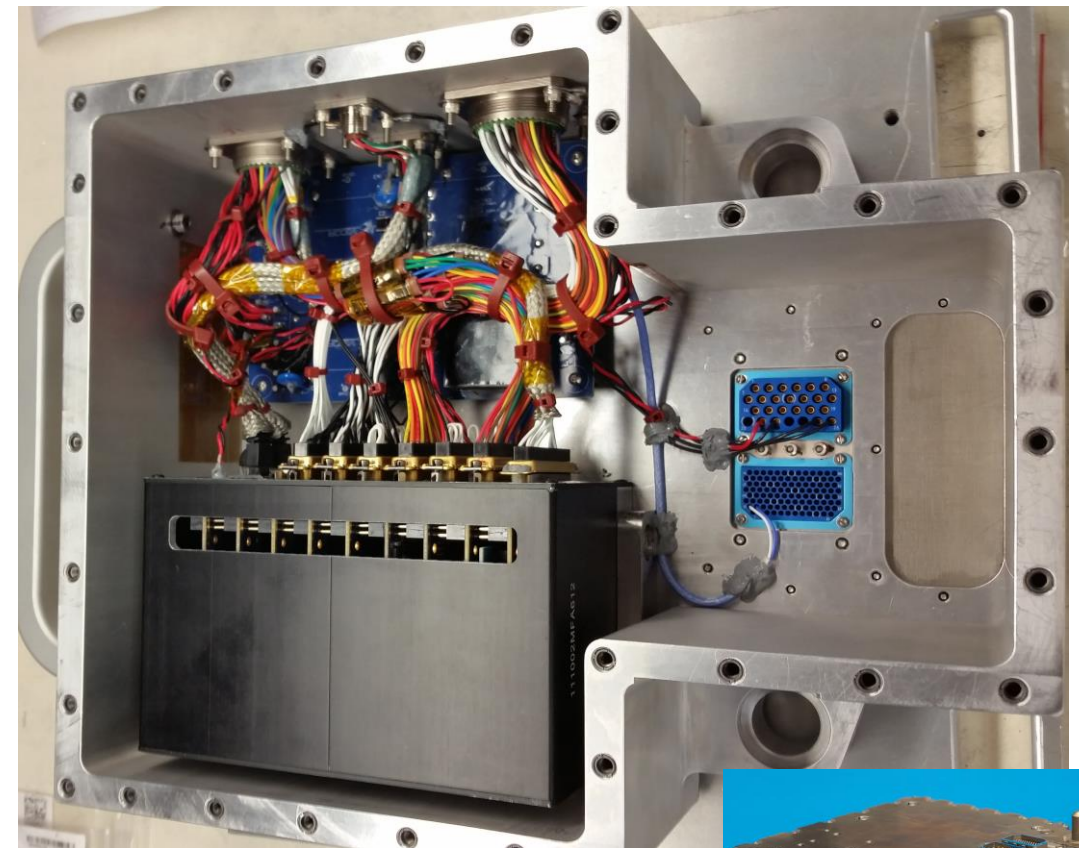
Remote Data Acquisition Modules

Remote Data Acquisition Module 1 (RDAQM1)



**UEI Data Cubes
[Thermocouple
Signal
Conditioning]**

Remote Data Acquisition Module 2 (RDAQM2)

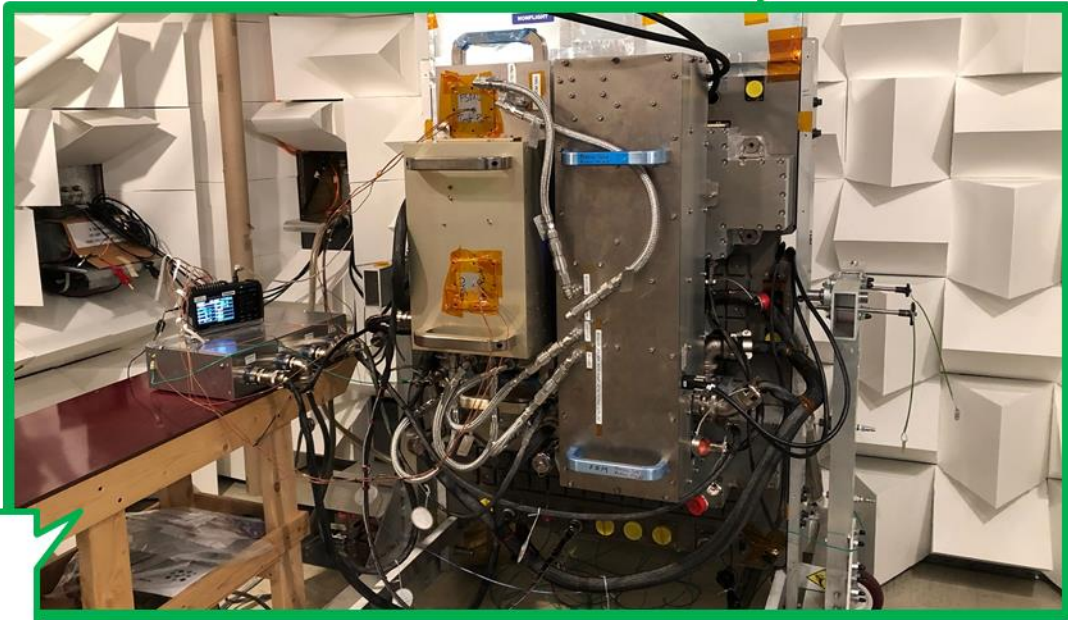
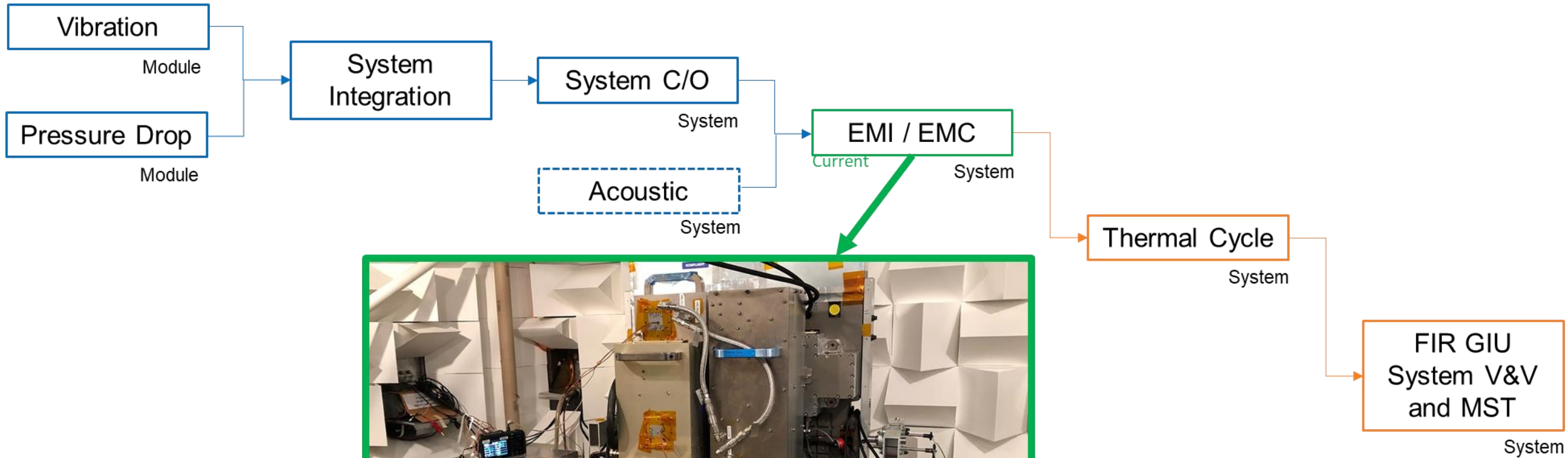


**UEI Data Cube and Custom Sensor
Supply Printed Circuit Board
[Signal Conditioning and Power
Distribution]**





Future Work: Environmental Testing



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 cm³ (36x48x19 in³)

**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
- Jesse deFiebre, Fluids Discipline Lead
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