Propulsion System Development for the Iodine Satellite (iSAT) Demonstration Mission

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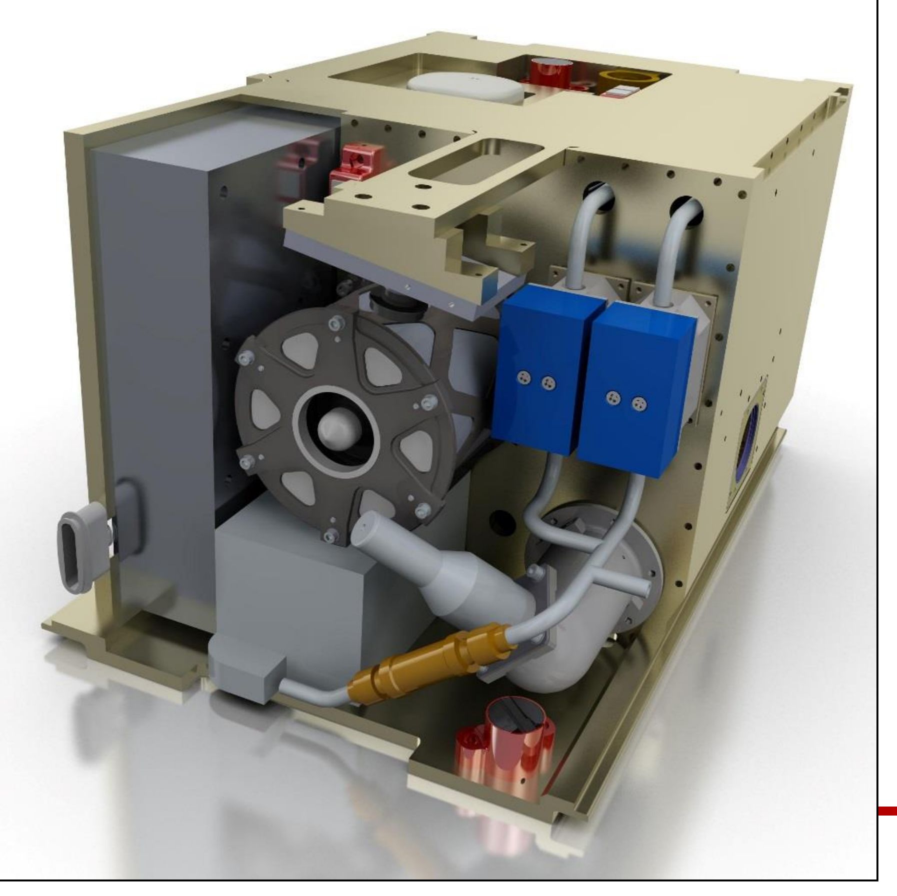
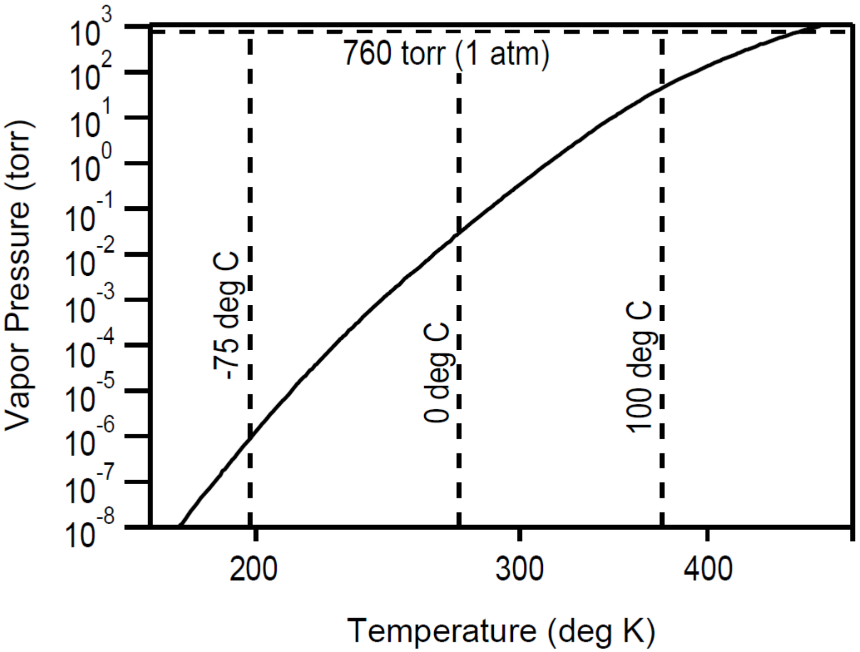
Motivation

- iSAT – iodine satellite
- 12U (20x20x30-cm) CubeSat flight demo of a 200-W iodine-fed Hall effect thruster
- Purpose here is to describe development and testing of the propulsion system that will be flown

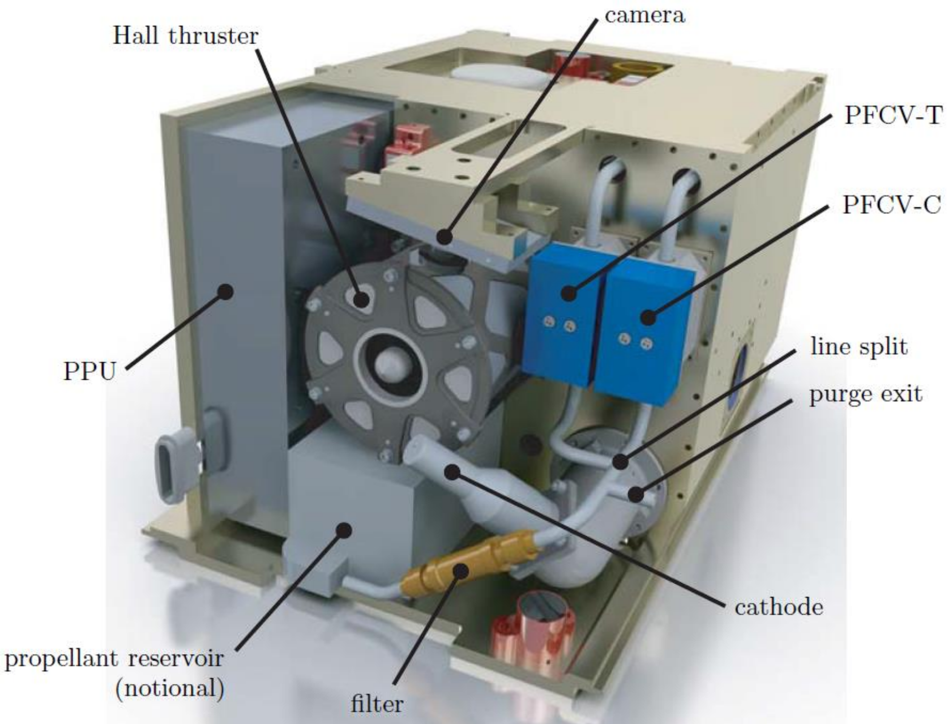


Motivation - continued

- Why iodine?
  - Stores as a dense solid with a low vapor pressure
  - High $\rho \cdot I_{sp}$ making it an enabling technology for near-term small satellite applications
  - Also provides potential systems-level advantages for mid-term higher power spacecraft propulsion
  - Propellant flow can be thermally-regulated, subliming at low temperature (<100 C) to yield a low pressure (~50 torr) gas source
  - Low power performance similar to SOA xenon Hall thrusters
  - Current-Voltage characteristics very similar between iodine and xenon-fed Hall thrusters
  - Cold surfaces in a vacuum chamber can be used to 'cryopump' propellant

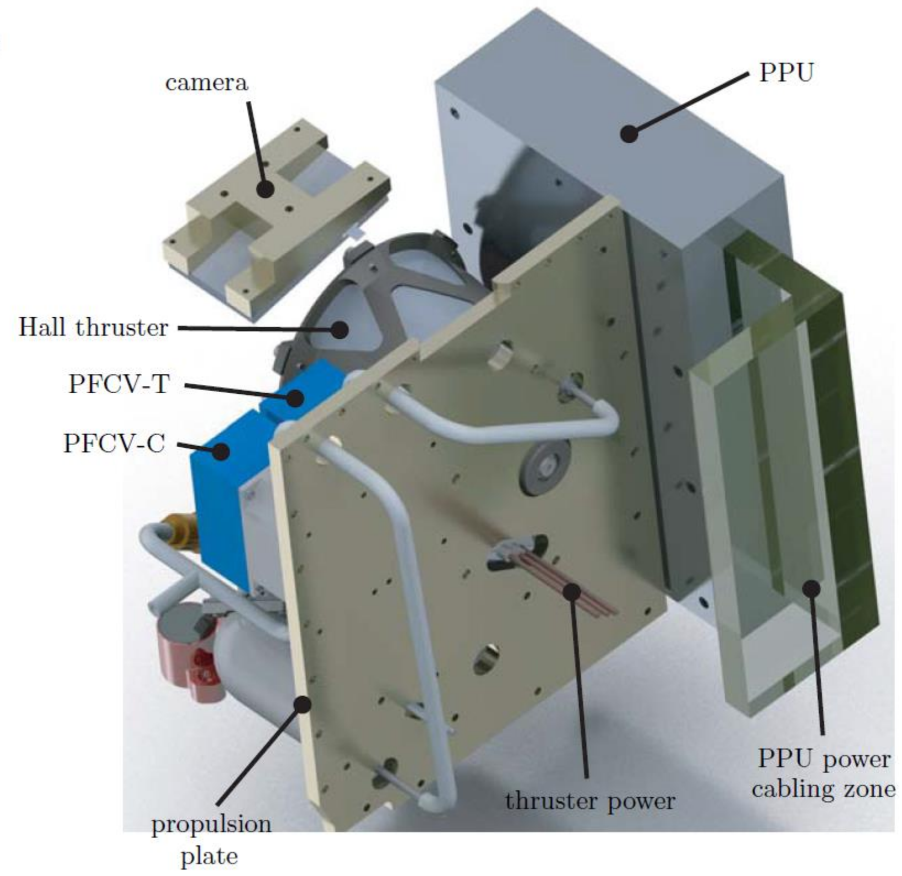


Propulsion System - General



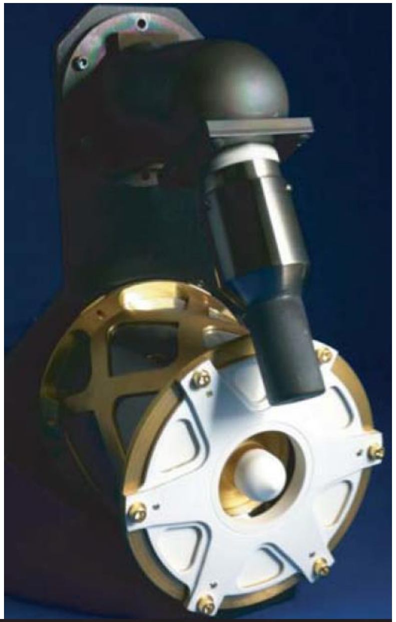
Aft Looking Forward

Propulsion Plate from Front Side



Thruster & Cathode

- Thruster
  - Version of Busek BHT-200 Hall thruster modified for iodine compatibility (BHT-200-I)
  - BHT-200 was first American Hall thruster to fly in space (US Air Force TacSat-2, 2006)
  - Lab testing at 200-W and higher has shown xenon vs. iodine efficiency approx. equal at same operating conditions
  - Lower measured plume divergence with iodine than xenon
- Cathode
  - Typical BaO cathode cannot be used with iodine propellant
  - Baseline is $12CaO\text{-}7Al_2O_3$ electride emitter cathode
  - Electride cathode initiated w/little to no heating – systems-lelve power savings for mission
  - In general, LaB_6 cathode also iodine-compatible, but requires more power to initiate discharge – could be used on less power-starved missions

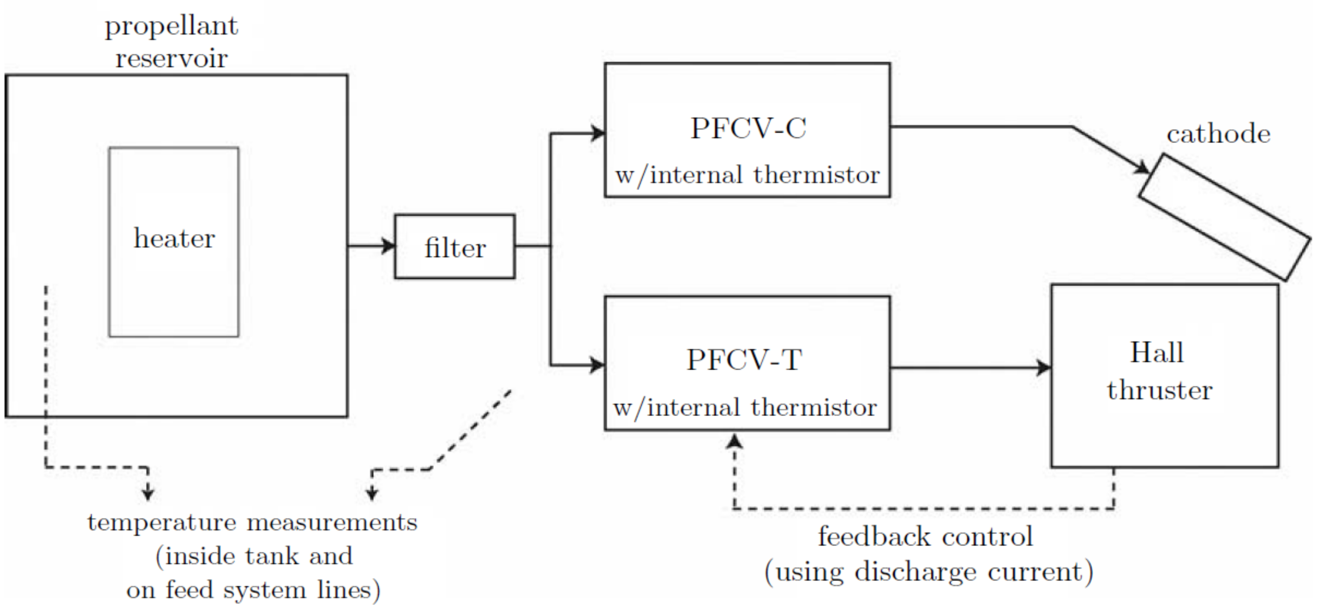


PPU

- Thruster Power
  - Power for main discharge, magnetic circuit, and cathode operation
  - 28 VDC input voltage
  - Efficiency >90% at 200W thruster operation
  - Capability to change magnetic circuit polarity
  - Capability to ignite electride cathode (objective to ignite without heater power)
  - Capability to provide heater power to condition/state a cathode
- Feed System Control and Monitoring
  - Control one latch valve
  - Control two proportional flow control valves
  - Monitor 4-10 temperature sensors
  - Monitor 1-3 pressure transducers
  - Feed System heater control for four (4) independent heater ‘zones’

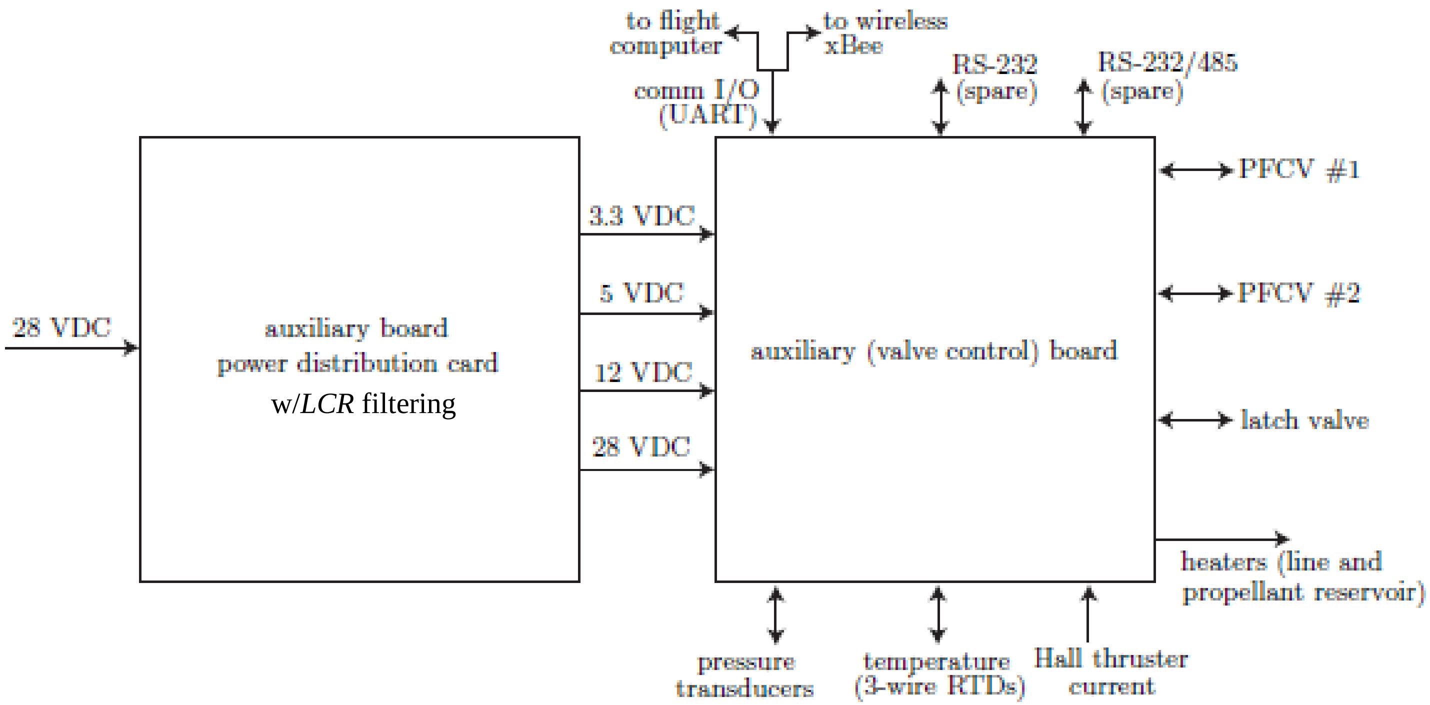
Feed System

- ¼" Hastelloy tubing, welded throughout
- 40 micron Hastelloy filter
- Two (2) Vacco PFCVs (independent control of cathode and anode flowrates
- Tank loading of 0.7 kg I_2 with starting ullage volume of 20%



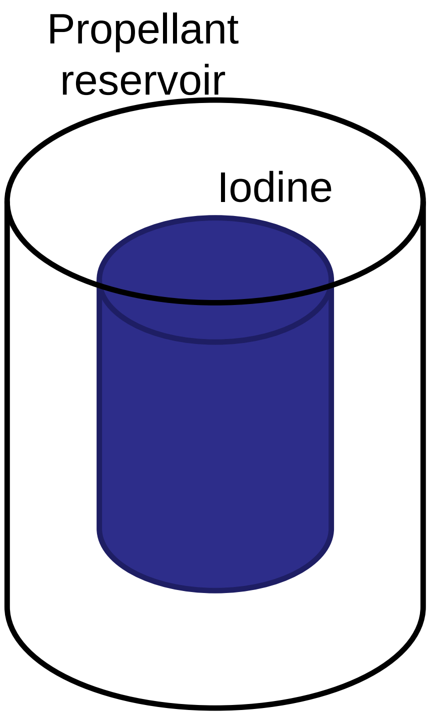
Feed System Control and Monitoring

- Auxiliary board to operate valves and monitor systems in lab (in lieu of PPU)
- Power distribution card to provide power at correct voltages
- Functionality to be incorporated into PPU



Reservoir – Thermal Modeling

- Reservoir – cylinder of 85.5 mm height, 31.75 mm diameter
- 100 g of iodine, cylindrical shape, equidistant from all sides
- 2.88 W of heater input power



- Iodine heated by
  - Radiation-only: ~ 1.5 orbits to heat iodine
  - Conduction-only: > 9 orbits to heat iodine

Table 2. Material properties for the thermal model of the reservoir.

component	material	thermal conductivity (W/(m-°C))	density (kg/m^3)	specific heat (J/(kg-°C))	IR emissivity
propellant reservoir	titanium	7.1 @ 25°C	4428.8	539.6 @ 25°C	0.2
propellant (solid)	iodine	0.449	4940	429	0.8
propellant (gaseous)	titanium	0.004351	4930	217.6	–
insulation	aluminized black kapton	0.1557 @ 25°C	1449.6	1001.5 @ 25°C	0.03 **Solar Absorptivity** 0.12

Materials Compatibility

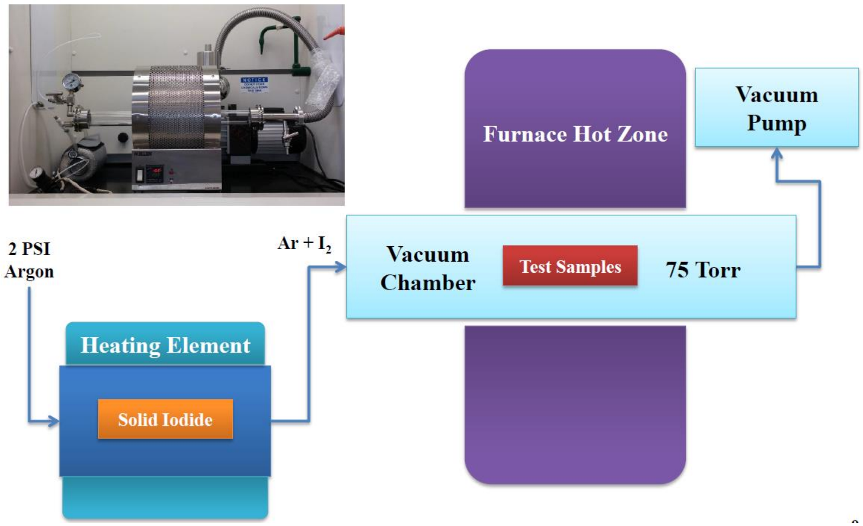
- Iodine compatibility with feed system, thruster, and spacecraft materials
- Little literature data on iodine exposure at the relevant conditions
- Two sets of experiments undertaken to better-quantify exposure in iSAT conditions

Systems	Metal or Alloy	Base Elements	Dry Iodine Vapor @ 25°C	Dry Iodine Vapor @ 100°C	Dry Iodine Vapor @ 300°C, 0.53 atm (Corrosion Rate mm/year)	Dry Iodine Vapor @ 450°C, 0.53 atm (Corrosion Rate mm/year)
Nickel Alloys	Pure Nickel	Ni	Resistant	Resistant	0.27	1.2
	Inconel 600	Ni-Cr-Fe	Resistant	Resistant	0.107	0.54
	Inconel 625	Ni-Cr-Mo	Resistant	Resistant	0.057	No Data
	Hastelloy B	Ni-Mo	Resistant	Resistant	No Data	0.464
	Hastelloy C	Ni-Cr-Mo	Resistant	Resistant	0.056	No Data
Noble Metals	Pure Platinum	Rt	Resistant	Resistant	0	0.006
	Pure Gold	Au	Resistant	Resistant	0	0.024
Refractory Metals	Pure Tungsten	W	Resistant	Resistant	0	0.008
	Pure Molybdenum	Mo	Resistant	Resistant	0.003	0.033
	Pure Tantalum	Ta	Resistant	Resistant	0.005	0.88
Aluminum	Pure Aluminum	Al	Unusable	Unusable	Unusable	Unusable
Copper Alloys	Pure Copper	Cu	Resistant	Unusable	Unusable	Unusable
	Brass	Cu-Zn	Resistant	Unusable	Unusable	Unusable
Iron Alloys	Iron, Cast Iron, Steel	Fe	Resistant	Unusable	Unusable	Unusable
	316 Stainless Steel	Fe-Cr-Ni	Resistant	Resistant	0.4 (Estimated*)	2.1
	304 Stainless Steel	Fe-Cr-Ni	Resistant	Resistant	0.6 (Estimated*)	3.2

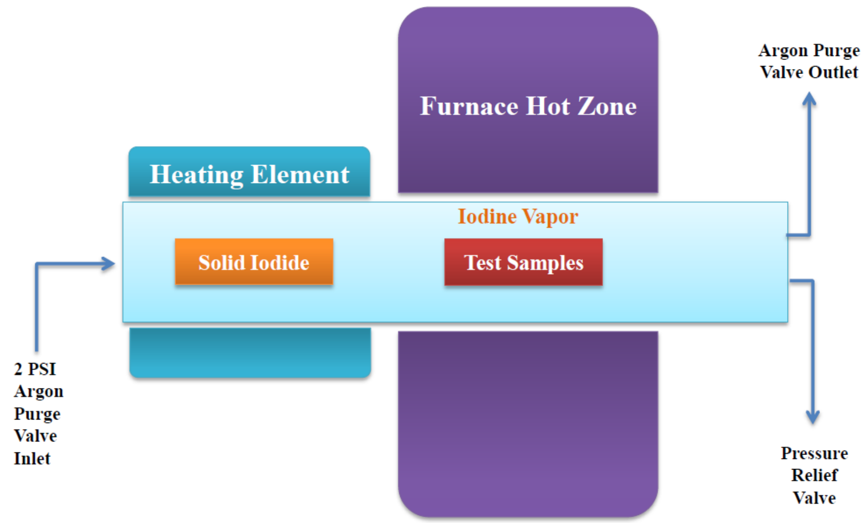
* Estimated corrosion rate at 300°C based upon extrapolation from 450°C data.

Materials Compatibility

Active Iodine Flow Test Setup

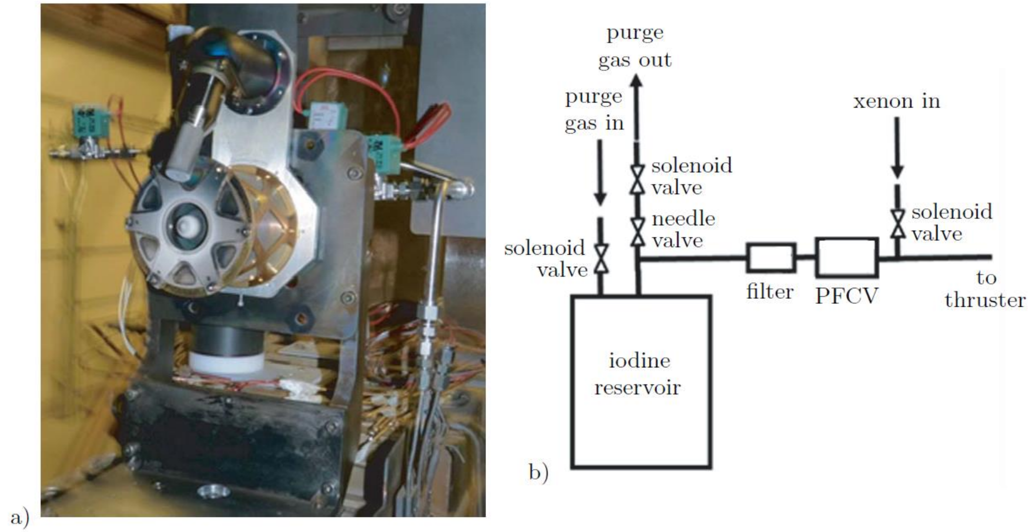


Passive Iodine Bath Test Setup



Material Category	Material Identification	1 Week Surface Condition	1 Week Thickness Change
Steel Alloys	304 Stainless Steel	Minor Darkening	None
	316 Stainless Steel	Minor Darkening	None
	4130 Alloy Steel	Minor Darkening	None
Aluminum Alloys	6061 Aluminum	Minor Darkening	None
	7075 Aluminum	Minor Darkening	None
	7075 Aluminum, Anodized	Minor Darkening	None
Copper Alloys	110 Copper	White Layer	Swelled
	Brass	Blackened	None
Titanium Alloys	Titanium 6-Al-4V	Minor Darkening	None
	Commercially Pure Ti	Minor Darkening	None

Propellant Loading / 80-hr Test



- Loading procedure – heating (before loading) followed by neutral gas purge to drive out oxygen, water vapor, and other volatile compounds

- 80-hr test at NASA-GRC to operate total mission throughput (anode on iodine)
- Performance measurements on xenon initially (baseline)
- Iodine feed to anode operated with reservoir, Vacco PFCV, and MSFC-developed auxiliary board
- Plume plasma measurements (Faraday probe, Langmuir probe) and materials coupons

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