VHITAL-160 Thruster Development Status

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Agenda

I. Bi TAL Overview

II. VHITAL Program Overview

III. Thruster Fabrication

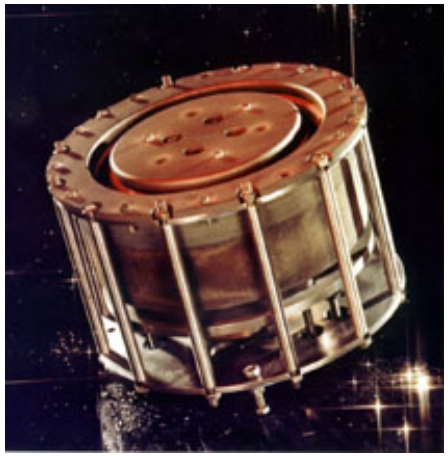
IV. Thruster Testing

Two Stage Bismuth-fueled Hall Thruster Technology is Attractive for High Power Missions

- Missions to the outer planets will require **high Isp and power**
- This technology has already **demonstrated excellent performance at high Isp**
  - >70 % efficiency at 25-36 kW and up to 8000 s
- It has **excellent growth potential**, having already demonstrated 140 kW operation at > 70% efficiency.
- **Bi propellant** offers many system level advantages over xenon.
- **Two Stage Hall thruster** technology is required for high Isp operation!
- **TsNIIMASH is the only source in the world** for this technology.
- Other SOA Hall thruster technologies cannot deliver the required performance!!

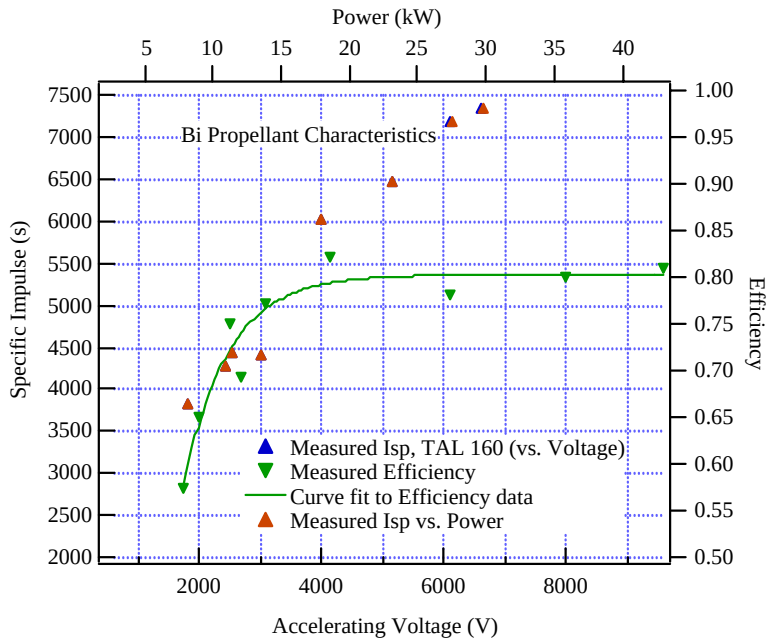
Metric	SOA Single Stage Hall Thrusters			SOA Two Stage TALs			Proposed Thruster	Competing Technology	
	Flight SPT 100	Flight TAL D55	SPT-1	D-80	TAL 160	TAL 200	VHITAL 160*	NEXIS	Li-LFA
Isp (s)	1600	1600	1600-3700	1293-4140	2000-8000	Š5200	6000-8000	6000-9000	4000-8000
Efficiency (%)	50	50	<60	>65	70	70	>70	75	60
Power (kWe)	1.35	1.35	1-3.2	0.7-8.7	~20-140	20-36	25-36	20-25	250-500
Mass						25	40	35	130
Throughput (kg)	~100	~80	?	?	?	?	36 kg/kW (goal)	2000	1 yr.
Propellant	Xe	Xe	Xe	Xe	Bi	Bi	Bi	Xe	Xe

Two Stage TALs Developed and Demonstrated by TsNIIMASH



TAL 200
- -Radiative cooling up to 34 kW
- -Power: 10-34 kW
- -Isp: 2000-5200 s

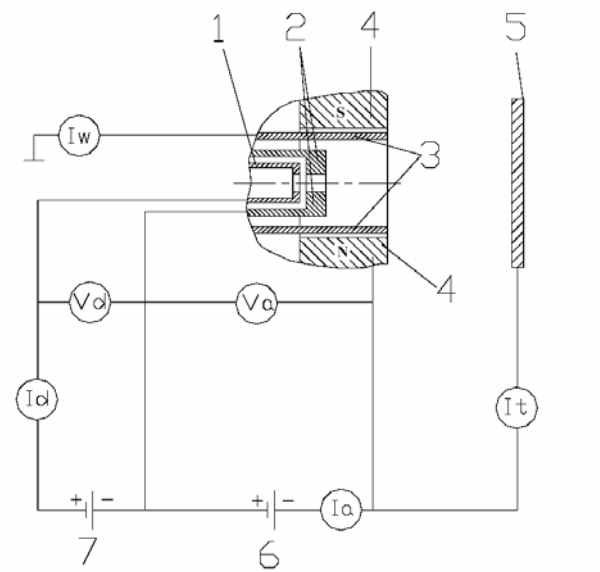
TAL 160
- -water cooled up to 140 kW
- -Power: 20-140 kW
- -Isp: 4000-8000 s

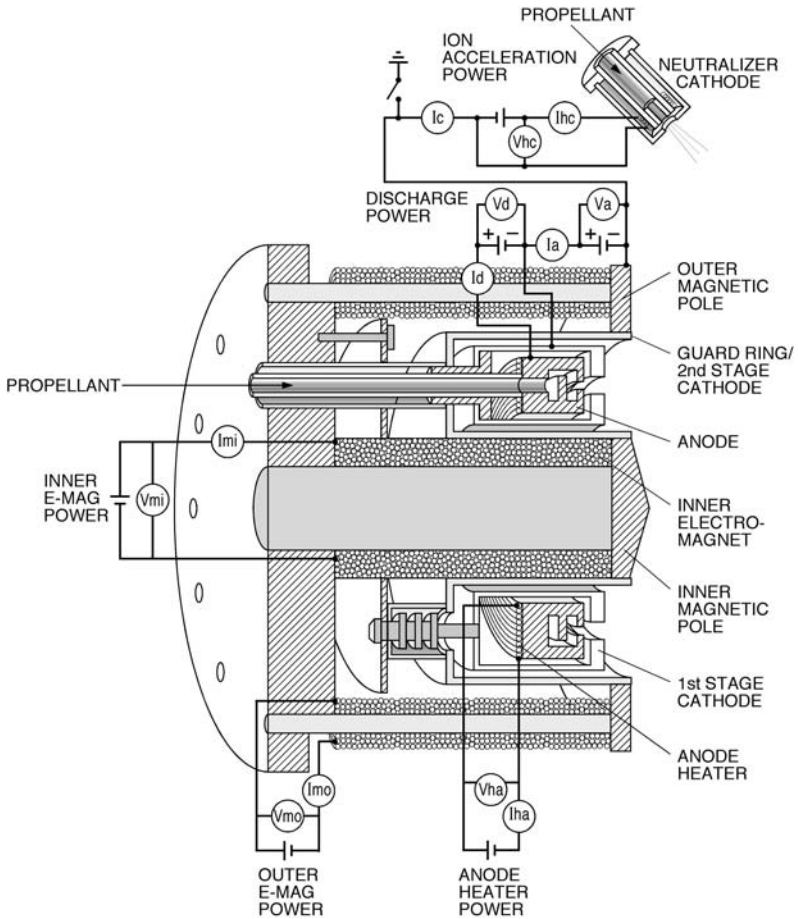


Thrusters demonstrated increasing efficiency with voltage beyond 8000 V!

Two-Stage Anode Layer Thruster Technology

- Developed at TsNIIMASH in Russia (1960's-1985)
- Tested on Pb, Tl, Cd, Cs, Ca, and **Bi**
- Ion generation region is separated from acceleration region to limit electron back-streaming through the accelerating layer.
- Split of ionization between acceleration and ion production region is optimized to maximize overall efficiency.
- Two stage configuration enables effective ionization at current densities much lower than in single stage Hall thrusters.





Bismuth Propellant Offers Many Advantages Over Traditional Propellants

	Bismuth	Xenon	Lithium
Density (kg/m^3) at 20 C	9780 (solid)	2000 (supercritical, 2800psi, 40 C)	535 (solid)
Cost ($/kg)	75	2000	137
Atomic Mass	208.98	131.29	6.94
Ionization Potential (eV)	7.287	12.13	5.39

ADVANTAGES

1. High Density
2. Low Cost
3. Condensability at room temperature
4. Low ionization potential
5. High atomic mass

20,000 kg	Bismuth	Xenon	Lithium
Cost ($M)	1.5	40	2.7
Tank Volume (m^3)	2	10	37

PAYOFF

1. Small spacecraft tank volumes and mass.
2. Low cost for propellant for flight and ground testing.
3. High thruster power testing at low vacuum chamber pump speeds.
4. High efficiency thrust.

VHITAL Phase B Program Objectives

1. Resurrect the Russian two-stage Bi-TAL technology

2. Fabricate a Radiatively cooled 2-stage Bi-Fed TAL (VHITAL160)

3. Demonstrate and Validate VHITAL Performance on Bi at 25 kW (6000s) and 36 kW (8000 s)

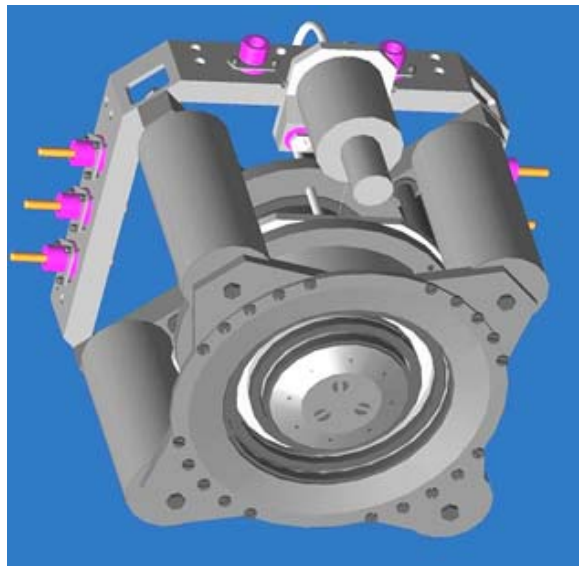
4. Develop component-level technologies for a flight-like Bi feed system

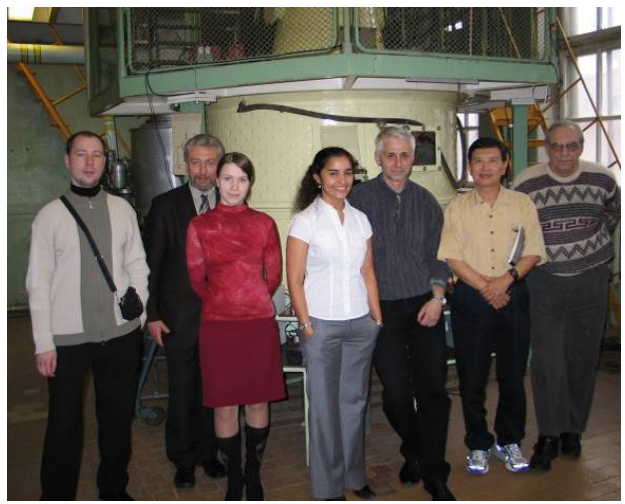
VHITAL Team

- Stanford University (PI)
  - Thruster Life Assessment
- JPL (Co-I's)
  - Program management and Feed System Development
- TsNIIMASH-Export
  - Thruster Design Analysis, Fabrication and Acceptance Testing
- University of Michigan: (Co-I)
  - Life and Contamination Assessment Modeling
- Colorado State University: (Co-I)
  - Lifetime Diagnostics: CRDS
- NASA MSFC:
  - Liquid Metal Feed System (tank, EM pump, flow sensor)
- Energy Science Laboratories Inc:
  - Vaporizer Fabrication

Thruster Development Program

- Thruster Program Led By TsNIIMASH Export
  - Bi-test facility demonstration with refurbished pre-existing D160
  - Design and Fabrication of the VHITAL160 thruster
  - Design and fabrication of gravity fed LM feed system
  - Design and fabrication of Bi-fed neutralizer cathode
  - Acceptance testing of the VHITAL 160 at TsNIIMASH at 25 and 36kW
  - Participate in functional testing at JPL

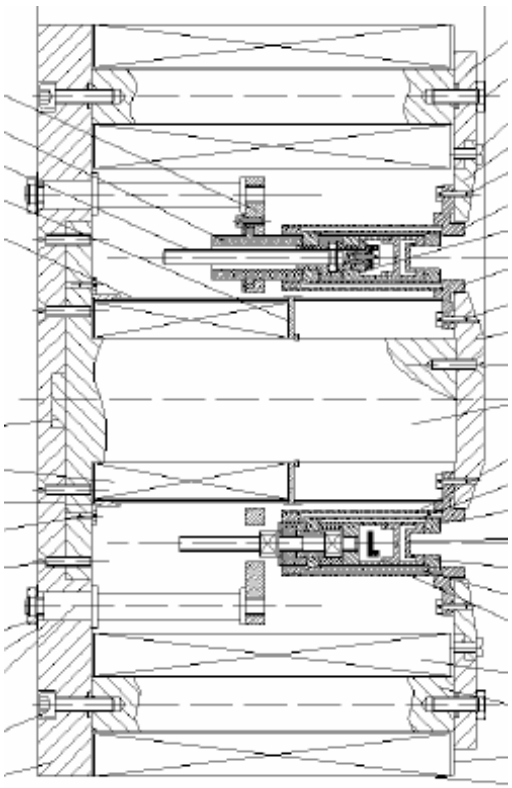


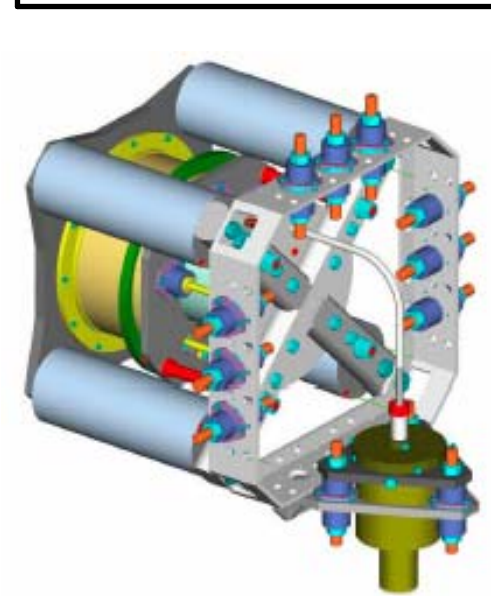


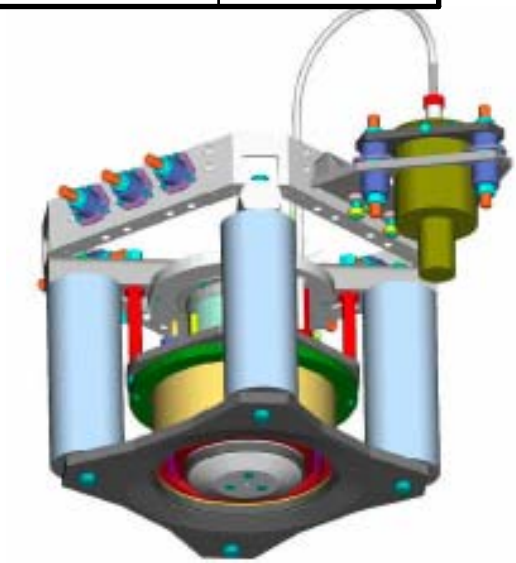
The VHITAL160 Thruster

- VHITAL160 is a two-stage Bi-fed TAL Utilizes the existing channel geometry of the D160 and the radiative cooling scheme of the D200

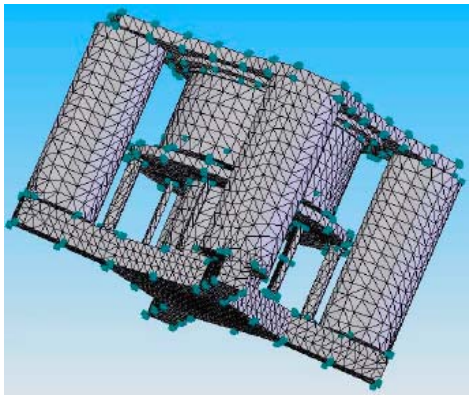
Parameter	Mode 1	mode 2
Specific Impulse (s)	6000	8000
Power (kW)	25	36
Flow Rate (mg/s)	9	11
Magnetic Induction (T)	0.2	0.2
Thruster (mN)	650	710
Thrust Efficiency (%)	78	79



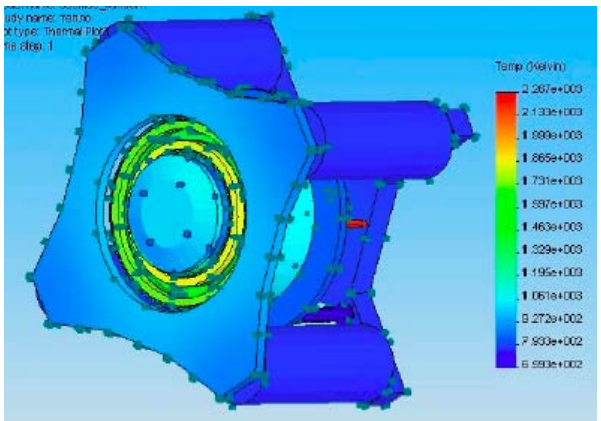




Thruster Design



Thermal model thruster mesh



Temperature distribution for
36 kW operation with heater

- **3-D thermal model developed and applied for design analysis with excellent results.**
  - Effective radiative cooling scheme at both critical operating points (25-36 kW) for limited material temperatures
  - Required temperatures attained for anode and both first and second stage cathodes with applied heating, with applied heating and discharge and in self-heating mode at 25 and 36 kW to prevent bismuth condensation.

- **Thermal and structural model coupled to show successful design.**
  - Thermal expansion expected to be within tolerances without increased mechanical stress, distortion or misalignment.

- **Surface breakdown voltage analysis shows that breakdowns should not occur.**

•Tverdokhlebova, S., and Tverdokhlebov, O., "VHITAL-160 Thermal Model Building and 3D Thermal Model ," IEPC-2005-108.

VHITAL-160 Fabrication

- **VHITAL 160 Thruster parts fabrication**

VHITAL-160 and Thruster Parts

Central magnetic core

Molybdenum spares for anode

☑ Set of guard ring

☑ Side magnetic coils

VHITAL-160 Fabrication

Feed System

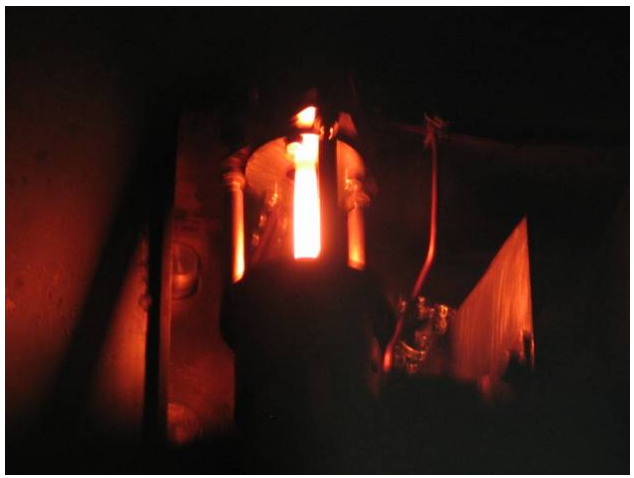
- **Feed System**
  - Evaporator (vaporizer) and propellant tank design for correct flow rate
  - Moly tube and coupling to thruster to minimize heating requirements and provide stable flow
- **Checkout testing**
  - Thermal expansion expected to be within tolerances
  - Optimize pre-heat and cool down cycles
  - Determine flow rate current calibration

Anode Distributor

Cracked Vaporizer

VHITAL-160 Fabrication

Bi-fed Lab6 Neutralizer Cathode



Pre-heat with heater

- **Neutralizer Cathode**
  - Bi-Fed Lab6 emitter cathode
  - Brazed assembly with integrated feed system for melting and vaporizing Bi
  - 2-5 mg/s Bi flow
  - 2-5A neutralizer current
- **Checkout Testing**
  - Pre-heated neutralizer with heater supply to melt Bi and demonstrate Bi flow

Acceptance Testing Matrix

Value	Mode 1	Mode 2
Power N, W	25000	36000
Specific impulse I_{sp}, s	6000	8000
Discharge voltage U_d, V	150	150
Discharge current I_d, A	6	5
Accelerating voltage U_a, V	4750	8400
Accelerating current I_a, A	5.0	4.2
Bi mass flow rate, mg/s	11	9
Magnetic induction, B, tesla	0.2	0.2
Predicted Thrust, F, mN	650	710
Predicted Thrust efficiency, η	0.78	0.79

Test Facility

- TsNIIMASH Vertical test facility
  - 1.8m diameter by 1.3 length
  - 2 diffusion pumps provides ~E-5 torr base pressure
  - Floating beam target to measure ion current
  - Thruster mounted at top on HV flange
  - Pendulum thrust stand for thrust measurement
  - Before/after propellant tank weight measurement for flow rate
- HV isolated supplies for thruster and feed system
  - 500V discharge supply, 10kV accel supply
  - High current, magnetic and heater power system

VHITAL-160 test facility

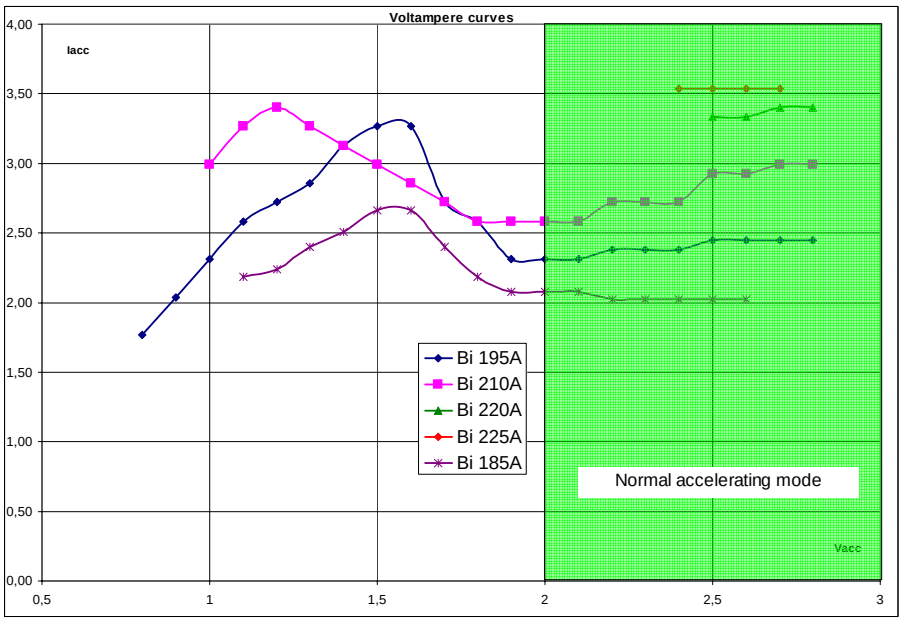
Thruster mounted in test Facility

VHITAL-160 on HV flange

D-160 Testing

- Demonstrated stable operation from 1-5A and 1-2 kV (up to 22.5 kW) without neutralizer
  - Demonstrated anomalous mode below 1.5kV
  - Demonstrated stable discharge
- Thruster measurement consistent with previous data
  - Difficulties with operating with Bi stem from expansion as it solidifies

D160 running

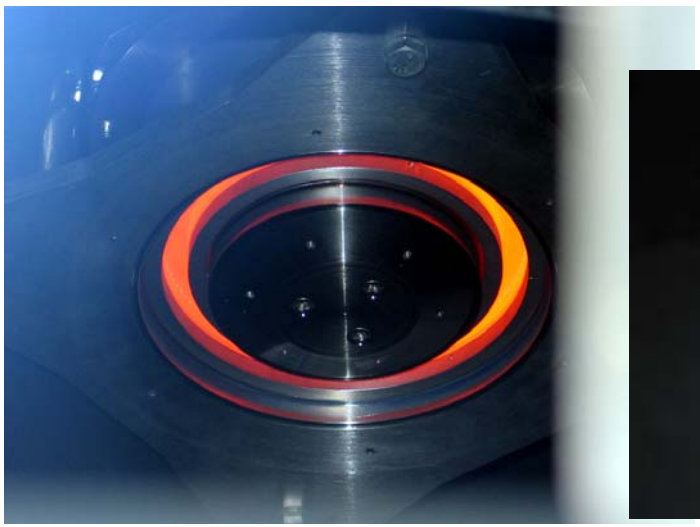


D160 Current Voltage Data

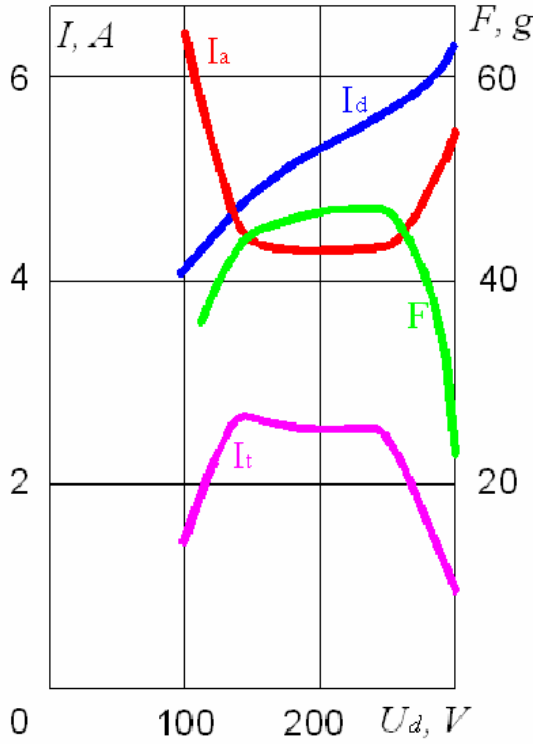
D160 post test

VHITAL-160 Testing

- Demonstrated stable operation from 1-5A and 1-4.5 kV (up to 22.5 kW) without neutralizer
  - Demonstrated anomalous mode below 1.5kV
  - Demonstrated stable discharge
- Thruster measurement consistent with previous data
  - Difficulties with operating with Bi stem from expansion as it solidifies



VHITAL-160 running at 22.5 kW with plasma beam



VHITAL160 Current Voltage Data

Summary

- TsNIIMASH Successfully resurrected with Bi-fed 2-Stage TAL with D160 testing this fall demonstrated up to 19kW operation
- VHITAL160 thruster, feed system, and neutralizer was fabricated out of modern high temperature materials to allow for radiative cooling scheme
- VHITAL160 thruster has been demonstrated up to 22.5 kW
- Novel and Flight-like feed System technologies have been fabricated and demonstrated

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