National Aeronautics and Space Administration

Post-test Inspection of NASA's Evolutionary Xenon Thruster Long-Duration Test Hardware: Discharge Chamber

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Additional NEXT Publications

- LDT Companion Papers
  - Post-test Examination of NASA's Evolutionary Xenon Thruster Long-Duration Test Hardware: Discharge and Neutralizer Cathodes, AIAA-2016-4631
    - EP-09 4:00 – 4:30 PM on 7/25 in 250 D
  - Post-test Examination of NASA's Evolutionary Xenon Thruster Long-Duration Test Hardware: Ion Optics, AIAA-2016-4632
    - EP-09 4:30 – 5:00 PM on 7/25 in 250 D

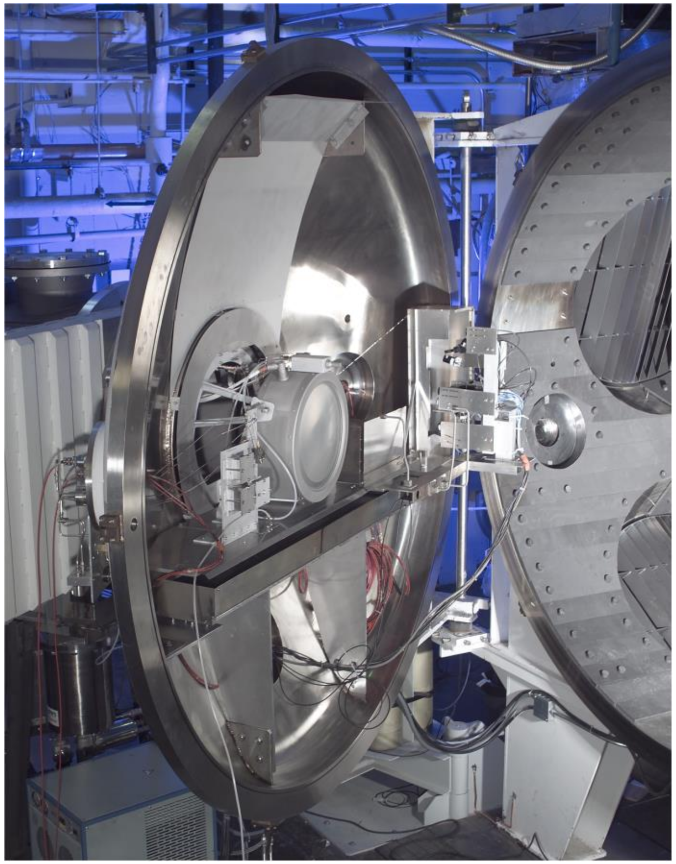
- Development and Validation of Autonomous Operational Sequences for the NEXT System, AIAA-2016-5077
  - ITAR-04 5:00 – 5:30 PM on 7/27 in 151 DE

- Status of the Development of Flight Power Processing Units for the NASA's Evolutionary Xenon Thruster - Commercial (NEXT-C) Project, AIAA-2016-4519
  - APS-01 10:30 – 11:00 AM on 7/25 in 150 DE

Presentation Outline

- NEXT Long-Duration Test (LDT) Background
- Discharge Chamber Magnetic Field Measurements
- Inspection of Discharge Chamber Mesh
- Discharge Chamber Flakes
- High-Voltage Propellant Isolators
- Insulators and Electrical Cabling
    - Screen-Anode Low Impedance Resolution
- Summary and Future Work

NEXT LDT Background



- Initiated as part of a comprehensive thruster service life assessment, utilizing both testing and modeling analyses, comprised of:
  - NEXT 2,000 h EM thruster wear test
  - NEXT thruster service life model development
  - NEXT PM1R thruster and propellant management system wear test
  - NEXT LDT
- Goals of the NEXT LDT
  - Qualify the NEXT thruster propellant throughput capability to an initial value of 450 kg
  - Validate the thruster service life models
  - Characterize thruster performance over test duration
  - Measure critical thruster component erosion rates
  - Identify unknown life-limiting mechanisms

- Objective to demonstrate 450 kg throughput redefined after completion in December 2009 to test-to-failure of thruster or voluntary test termination

NEXT LDT Background

- Decision to voluntarily terminate test was made in April 2013
- A comprehensive end-of-test performance characterization along with diagnostic repairs were performed prior to test termination in February 2014
- At end of test, thruster had demonstrated:
  - 51,184 hours of operation
  - 918 kg propellant throughput
  - 35.5 MN-s total impulse
- Thruster vented to atmosphere in April 2014, with post-test inspection beginning shortly thereafter

- Post-test inspection is presently nearing completion – this paper/presentation discusses pertinent results to-date of the discharge chamber as well as miscellaneous components such as the high-voltage propellant isolators (HVPIs) and electrical cabling
  - Results on other components are covered in companion papers

NEXT LDT Post-test Inspection

- Post-test inspection of NEXT LDT thruster hardware largely followed similar methods and procedures as what was used for NSTAR ELT
- Comparisons made (when appropriate) to results from several prior life tests
- Focus placed on previously identified failure modes, including:
  - Magnetic field degradation due to excessive temperatures
  - Poor flake retention of sputtered material
  - Deposition of sputtered material on insulators, including within HVPIs
- Also needed to resolve issues encountered during test, including an observed low impedance between the anode (discharge chamber) and screen grid

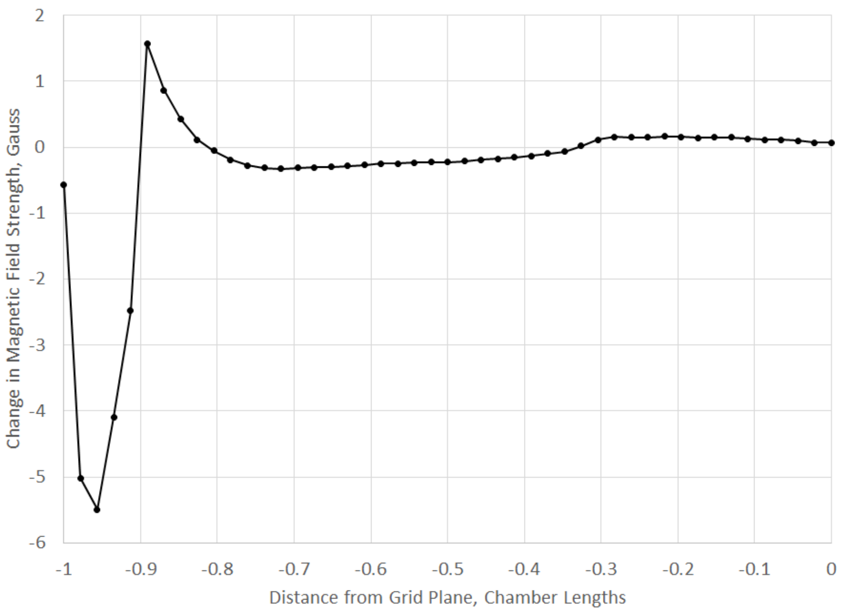
Magnetic Field Measurements

- Magnetic field measurements were taken with a 3-axis gaussmeter within the volume of the discharge chamber
  - Identical technique and equipment as pretest measurement

- Comparison of strength profile at chamber centerline indicates pretest and post-test measurements are all within 6 G of each other

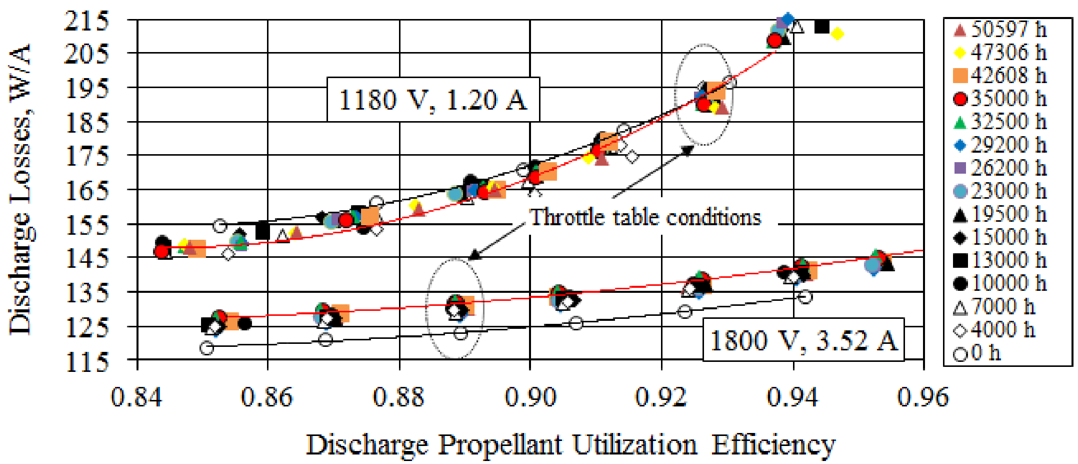
- Largest discrepancies occur furthest upstream where there are large B_{mag} and $\partial B/\partial z$
  - Position uncertainty, especially of z = 0, could lead to larger differences in this region

- Analysis of the volumetric map as a whole shows no sign of magnetic field degradation



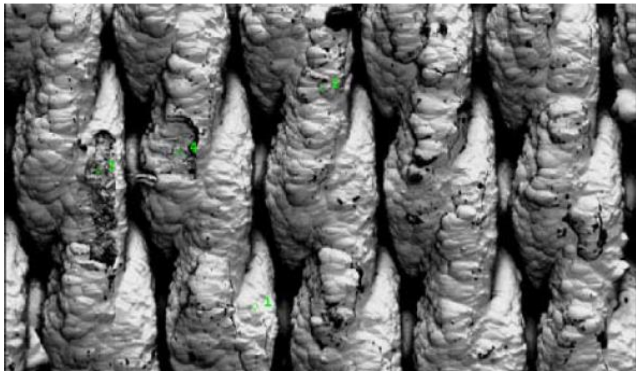
Magnetic Field Measurements

- Measurements of magnetic field strength were also made at various azimuthal locations along each magnet ring, similar to pretest measurements
  - Measurement was found to be sensitive to relative probe angle and location along discrete magnets
  - These factors were varied until the strength was maximized, yielding a repeatable measurement – however, pretest measurements were not taken this way
- When comparing maximum values along each ring, pretest and post-test measurements agree to within ± 6%, with post-test being higher most of the time
- All measurements consistent with thruster discharge performance data, indicating no magnetic field degradation

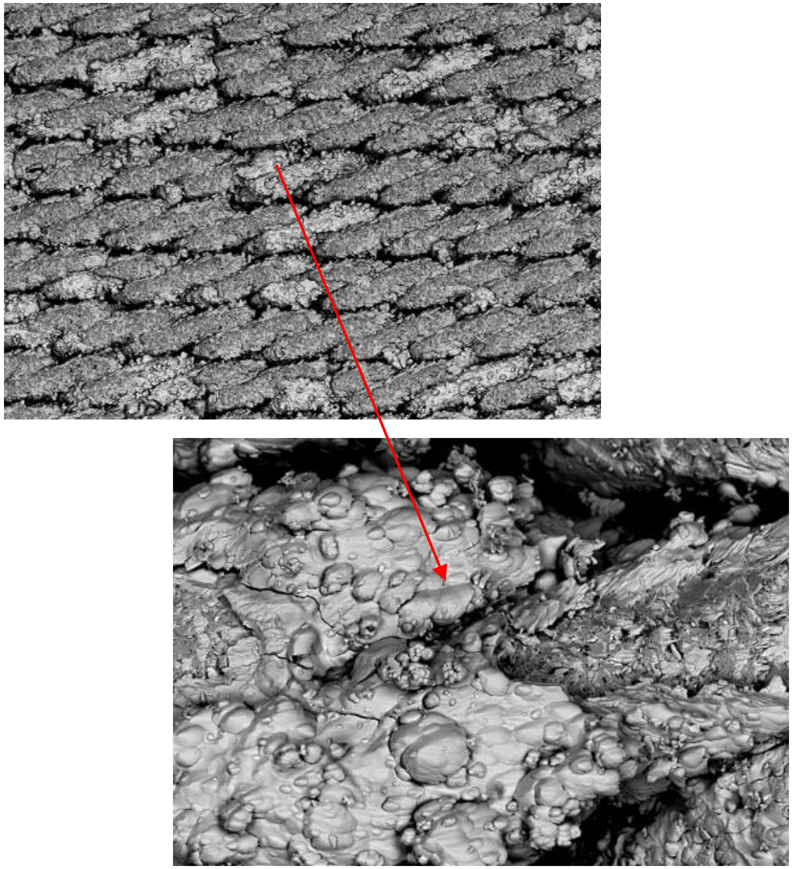


Discharge Chamber Mesh

- Discharge chamber mesh samples were removed at various axial locations and a fixed azimuthal location (axisymmetry of deposition assumed)
- Deposition coating evident in photomicrographs of mesh
- Energy dispersive x-ray spectroscopy indicates this coating is primarily grid material, although numerous nodules within mesh had high carbon content
- Similar results were found in NSTAR ELT



From NSTAR ELT*

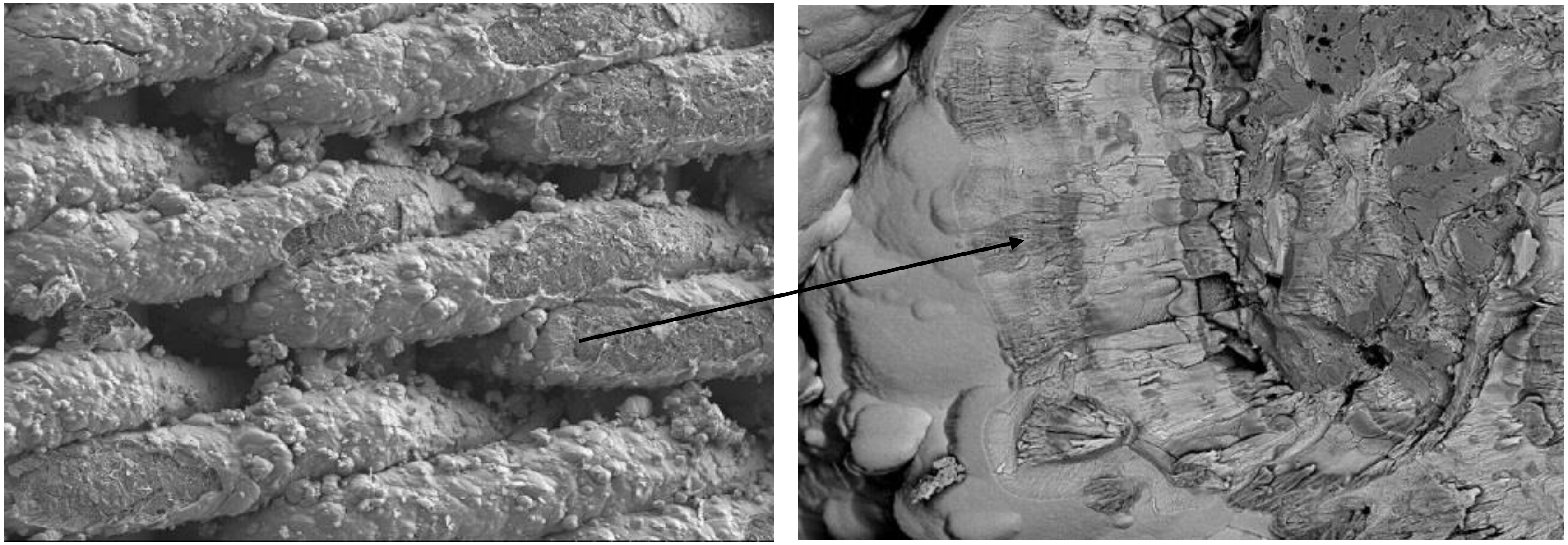


From NEXT LDT

*Image from Sengupta, A., et al., "The 30,000-Hour Extended-Life Test of the Deep Space 1 Flight Spare Ion Thruster," NASA/TP 2004-213391, March, 2005.

Discharge Chamber Mesh

- Samples of discharge chamber mesh further upstream showed deposition with broken edges
  - Could be due to spalling or handling of sample during inspection
- Broken edge shows layered deposition
  - Backscattered electron image indicates light layers are primarily grid material and darker layers have more carbon content
- Estimate of deposition thickness from broken edge ~ 15 µm, which is well below estimated maximum deposition thickness that can be retained by mesh



Discharge Chamber Flakes

- A large number of flakes were found at the bottom of the discharge chamber
  - Similar result to NSTAR ELT
- Numerous samples were taken, and a total of ~ 3.1 grams of material was collected from the discharge chamber
- Many of the largest flakes exhibited a semi-circular shape
  - Radius of curvature of these flakes indicate they had come from the accelerator grid apertures – similar result to NSTAR ELT
- Flakes were comprised of a combination of grid material and carbon

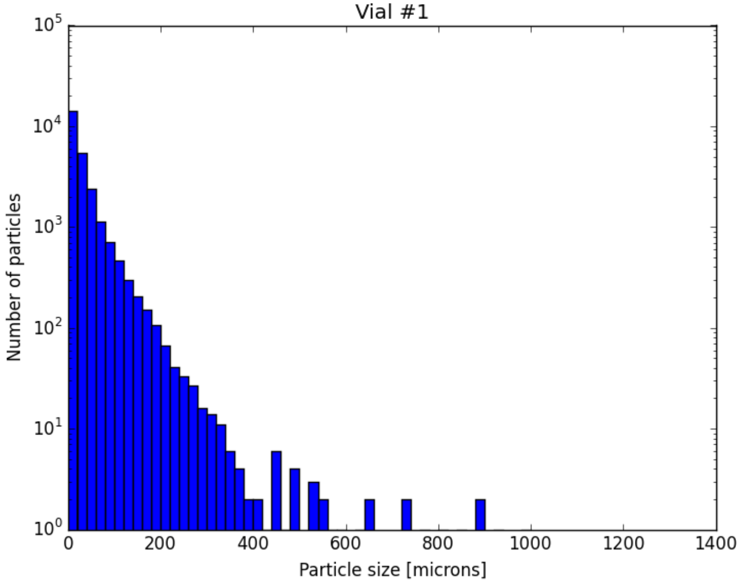
From NEXT LDT

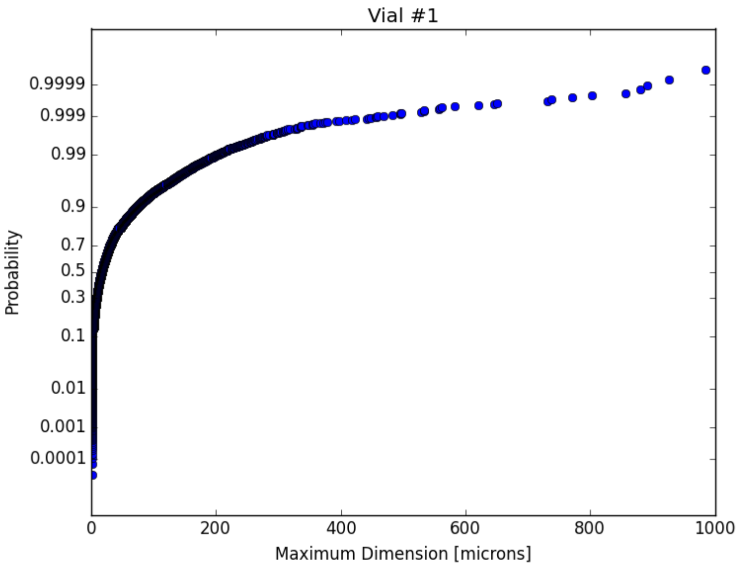
From NSTAR ELT*

*Image from Sengupta, A., et al., "The 30,000-Hour Extended-Life Test of the Deep Space 1 Flight Spare Ion Thruster," NASA/TP 2004-213391, March, 2005.

Discharge Chamber Flakes

- Samples of flakes from different axial locations were analyzed to determine size distributions
  - Need to quantify likelihood of forming flakes large enough to short grids
- Histograms indicate that 99% of flakes have a largest dimension < 200 µm
- However, flakes do exist that are large enough to cause a grid-to-grid short
- NSTAR ELT also found large flakes, but determined that these flakes originated from the facility so should not be an issue in flight
  - Similar analysis on large flakes for NEXT LDT is presently underway

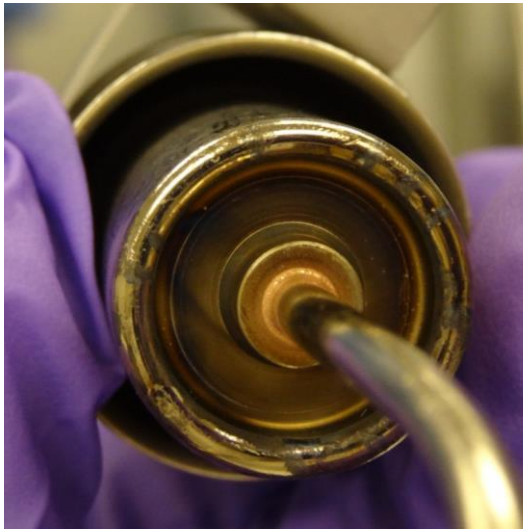




High-Voltage Propellant Isolators

- HVPIs for both main and discharge cathode lines were inspected for leaks and impedance degradation

- No leaks were found, and both HVPIs had impedances > 300 GΩ at 1800 V applied voltage



- Only visual change on casing was discoloration on downstream end of discharge cathode HVPI
  - Cause is unknown, but was not an issue

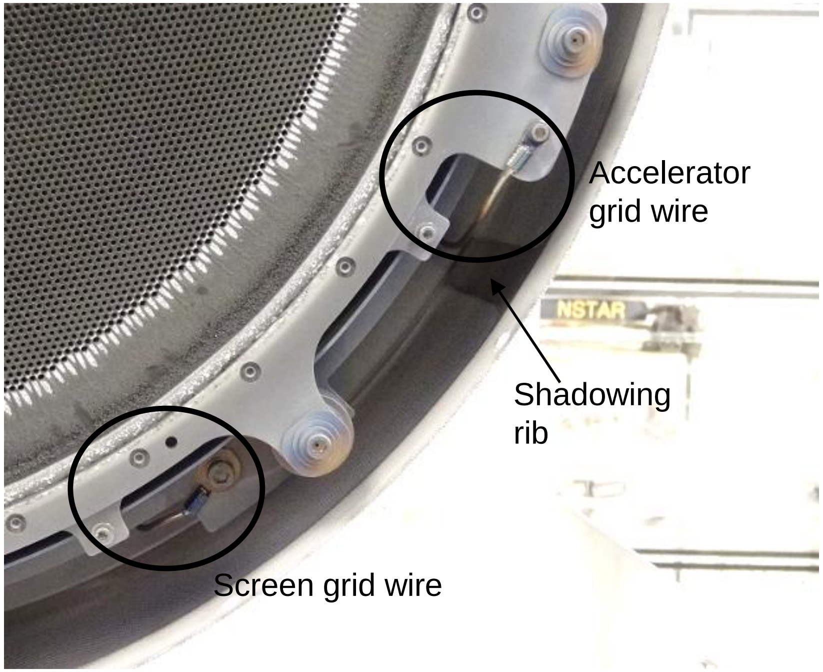
- Destructive disassembly of both HVPIs revealed all insulators to be clean with no signs of internal arcing

Insulators and Electrical Cabling

- Numerous insulators on thruster were inspected for signs of arcing or impedance degradation including:
  - Discharge cathode wiring insulators
  - Ion optics mounting isolators
  - Thruster gimbal insulators
  - Neutralizer cathode assembly mounting insulators
- All insulators were found to be in excellent condition with no signs of arcing
  - All impedances > 300 GΩ at maximum operating voltages
- All electrical cabling was also inspected for signs of arcing or breaks in insulation
- A few breaks in outer insulation jacket were found in the anode and accelerator grid cables, but inner insulation remained intact
  - Proper isolation from surroundings at maximum operating voltages was verified
- All other cabling was found to be intact with no signs of arcing

Screen-Anode Low Impedance

- Low impedance between screen grid and anode was observed during test, and dropped to 40-50 kΩ by the end of the test
- Cause was traced to deposition on screen grid wire as it passes through discharge chamber from rear of thruster (verified with resistance measurements)
- Elemental analysis indicated this deposition is primarily backsputtered carbon from the facility that had come through the perforated plasma screen
- Cylindrical plasma screen is solid in latest thruster design, so this issue is not expected to occur in flight or in future ground tests



Summary and Future Work

- Post-test inspection of the LDT thruster hardware is nearing completion

- Major findings
  - No sign of magnetic field degradation after 51 kh of operation
  - Deposition on discharge chamber mesh is ~ 15 µm, much less than the estimated maximum retainable thickness
  - Large amount of flakes found at bottom of discharge chamber, including certain large ones that had spalled from accelerator grid apertures
  - Size distributions of flakes indicate that 99% have largest dimensions less than 200 µm, much smaller than the grid gap
  - All insulators and electrical wiring inspected with no signs of arcing found
  - Screen grid-anode low impedance traced to deposition on screen grid wire from facility backsputtered material and should not occur in flight

- Future Work
  - Discharge chamber mesh samples will be sectioned to further analyze deposition
  - Chamber flakes will be more thoroughly characterized to quantify amount and size of flakes that originated outside of thruster

Questions?