# NASA GRC Cathode Development: Challenges and Future Work


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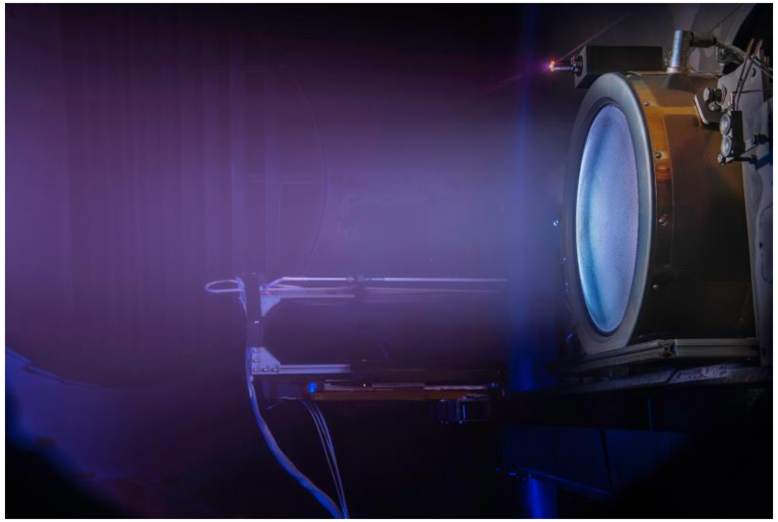
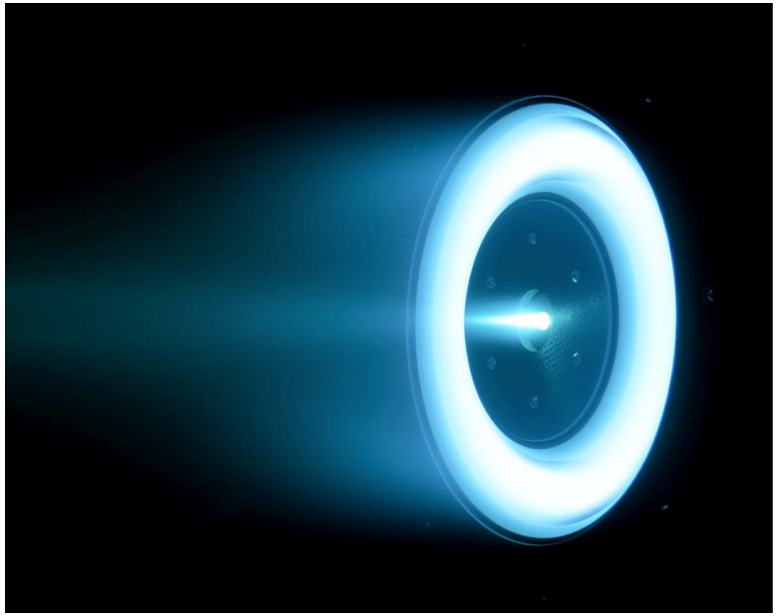
# Background

- Hall thrusters, gridded ion thrusters, and other electric propulsion systems require cathodes for operation.
- These charts will introduce some of the development, testing, and background on cathode work at NASA Glenn Research Center and will highlight challenges and possible forward work.
- Recent thruster projects include the Advanced Electric Propulsion System (AEPS) project with the Engineering Test Unit (ETU-2) thruster and the NASA's Evolutionary Xenon Thruster Commercial (NEXT-C) project with the Double Asteroid Redirect Test (DART) flight mission.
- Typical cathode insert configuration is BaO/Al2O3/CaO impregnated W (BaO).

NEXT-C, DART Flight Thruster

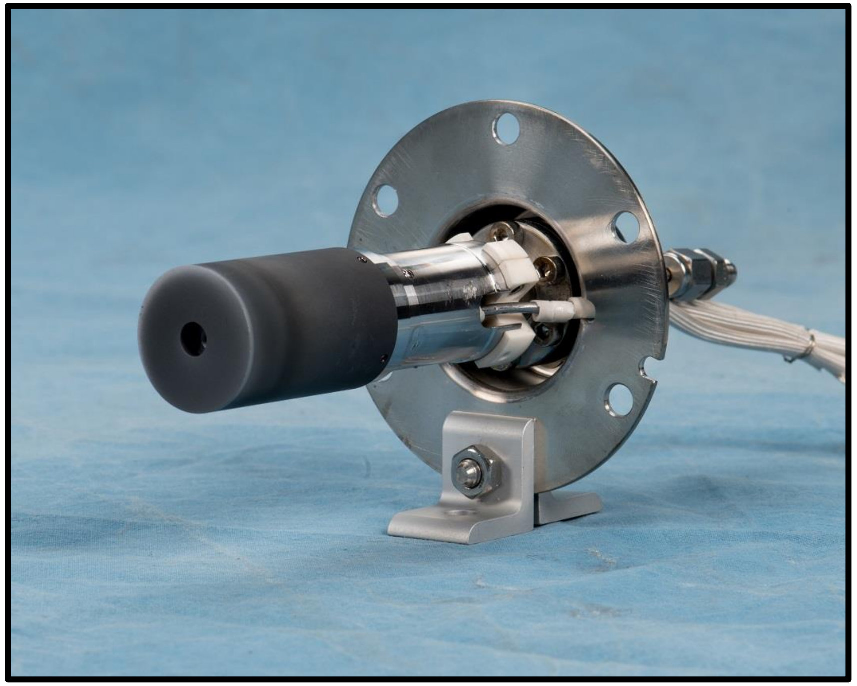


AEPS, ETU-2 Thruster

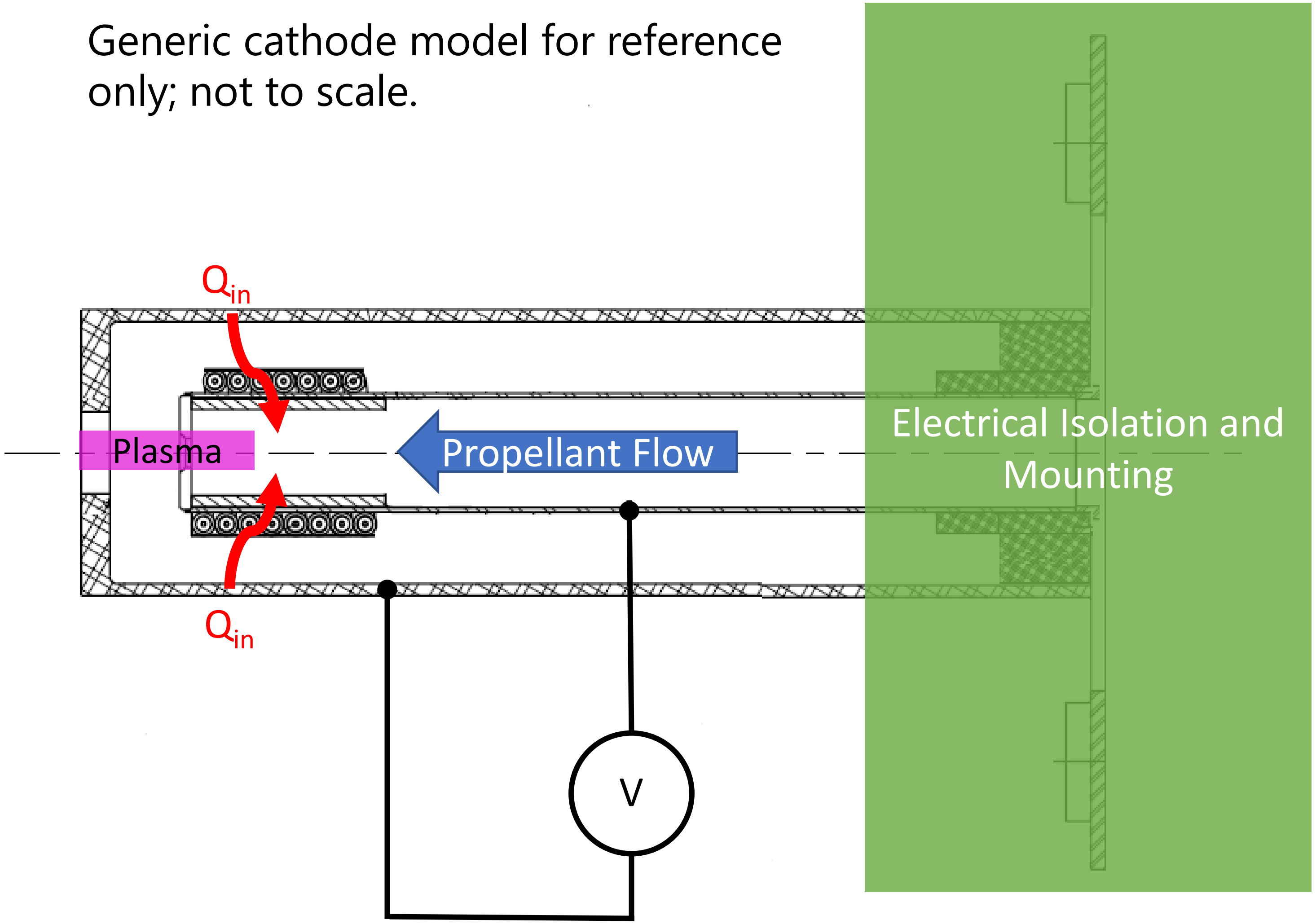


# Typical Cathode Components

NASA GRC Mark II



Generic cathode model for reference only; not to scale.



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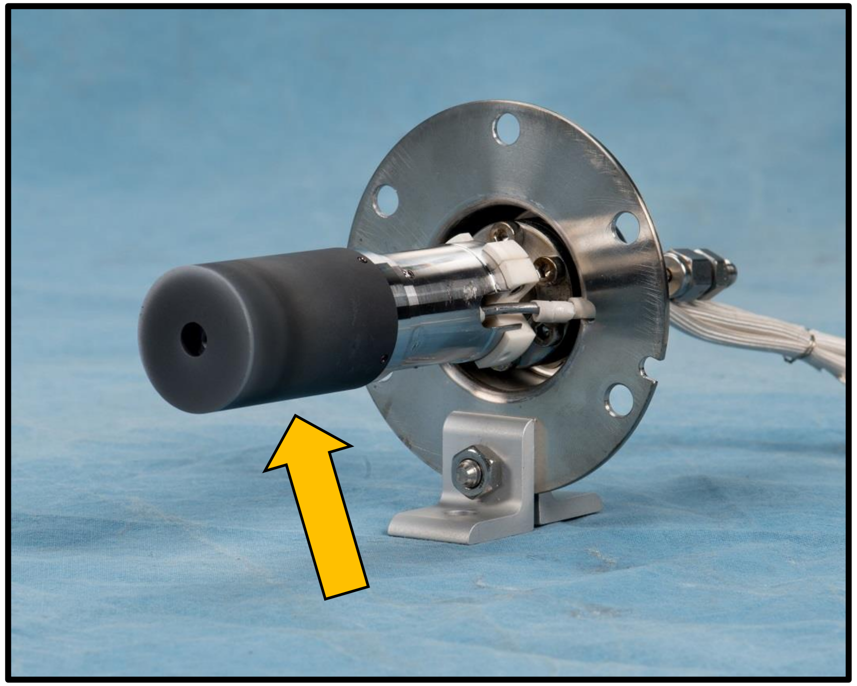

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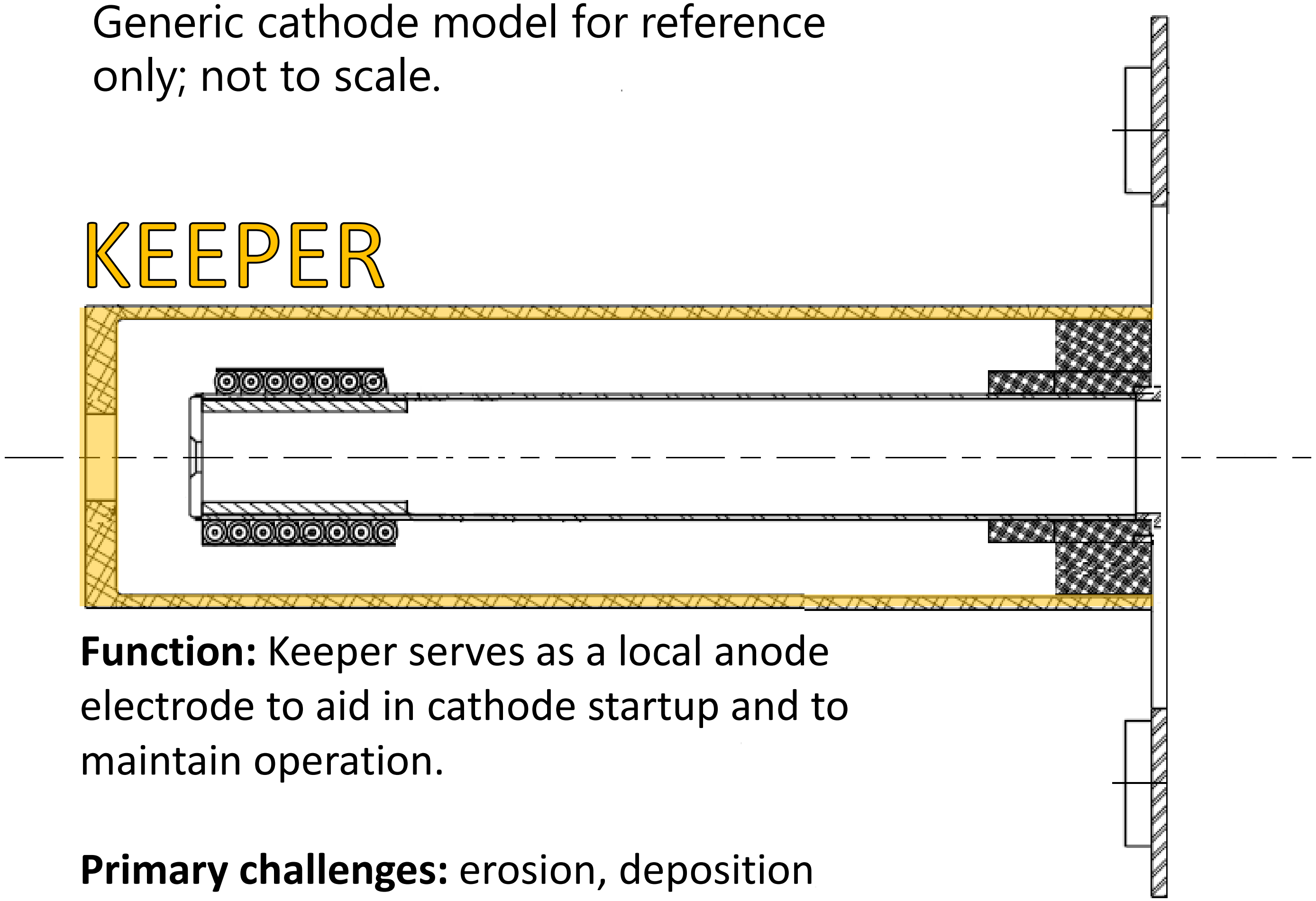


**Function:** Keeper serves as a local anode electrode to aid in cathode startup and to maintain operation.

**Primary challenges:** erosion, deposition

**Primary testing:** thruster life test or wear test

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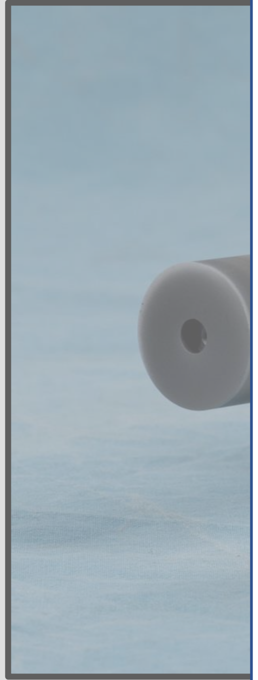
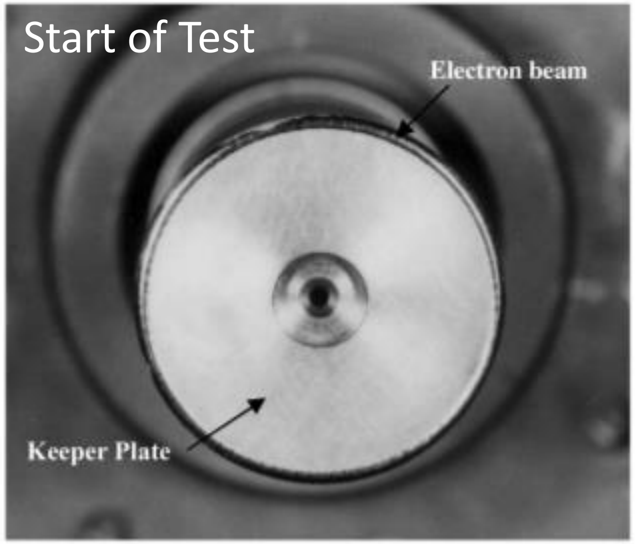
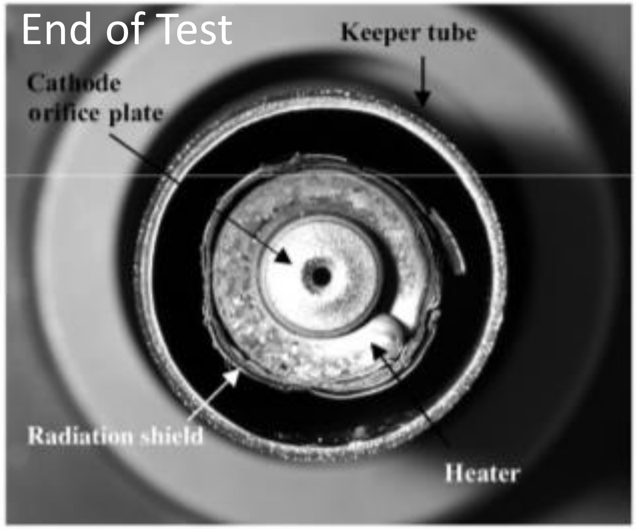


## N-STAR 30kh Life Test, Significant Erosion




A. Sengupta, J. Prop and Power 2009

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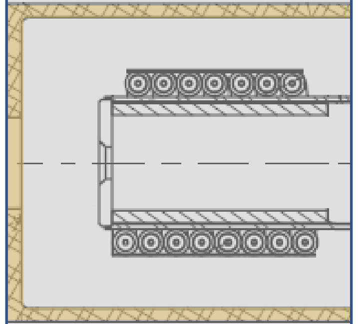
…only; not to scale

KEEPER



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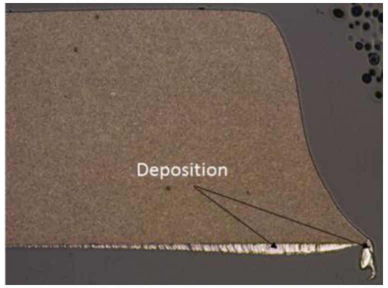
## NEXT 50kh Long Duration Test, Marginal Erosion and Deposition


R. Shastry, AIAA 2016

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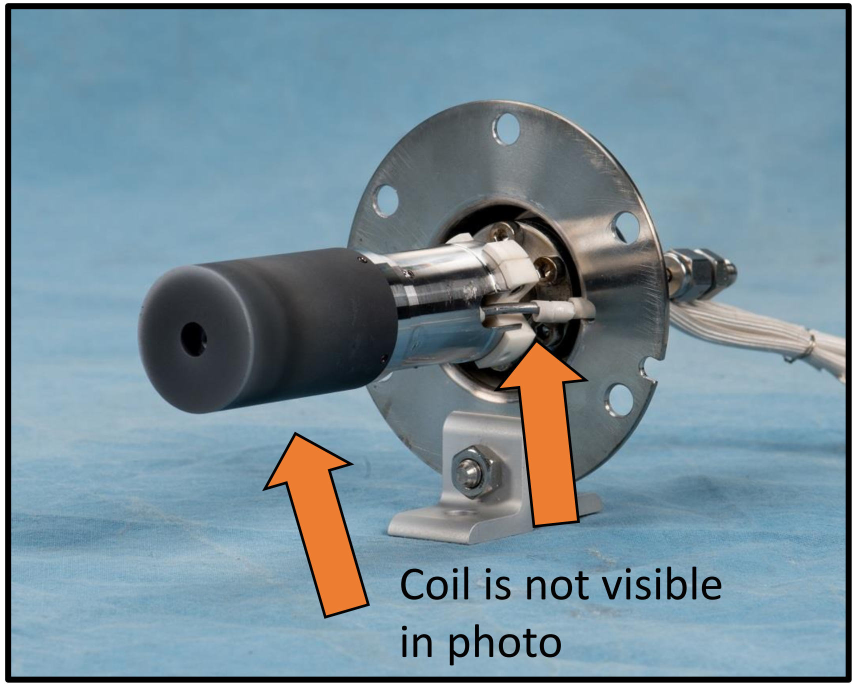


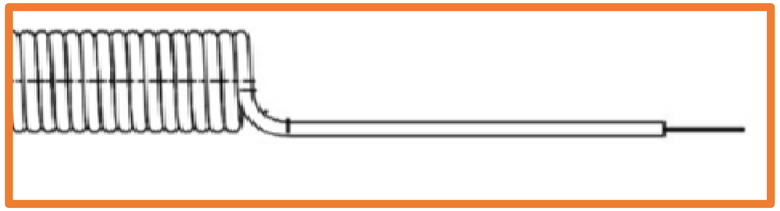

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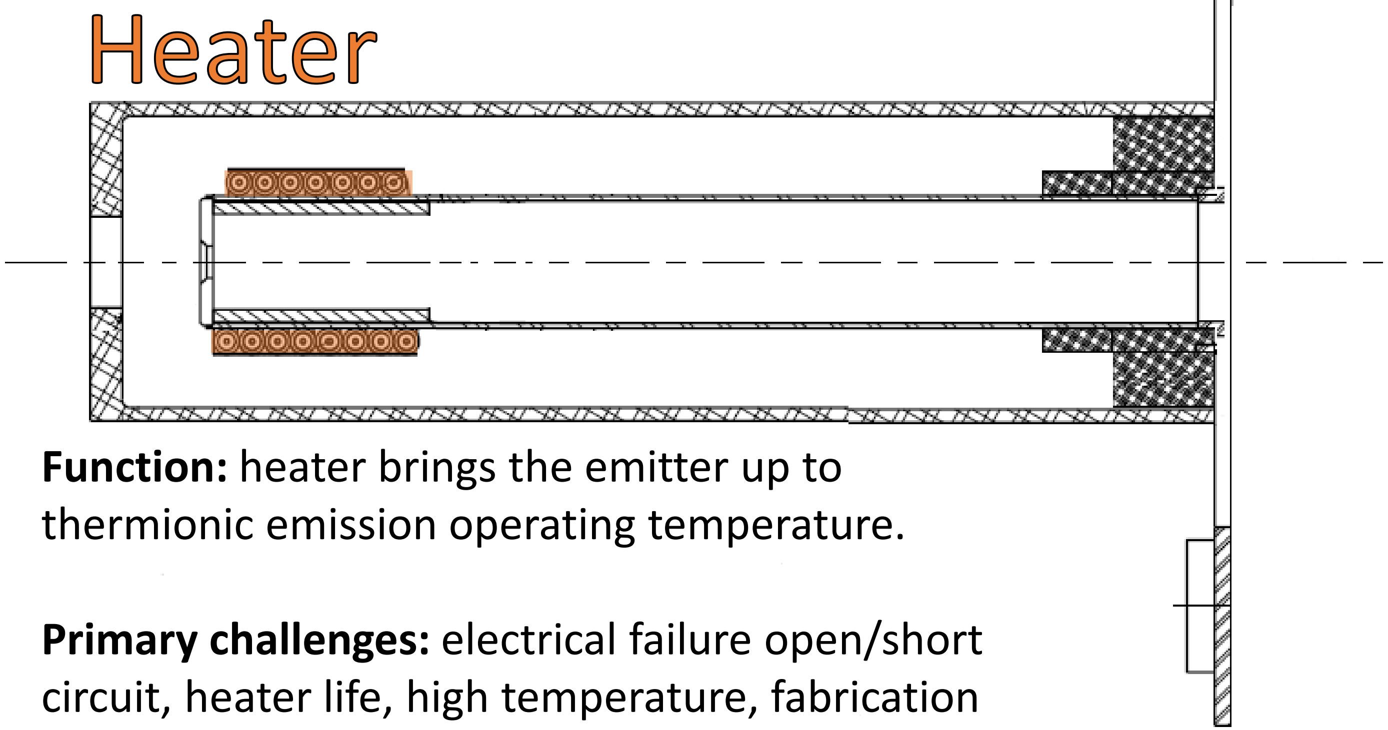


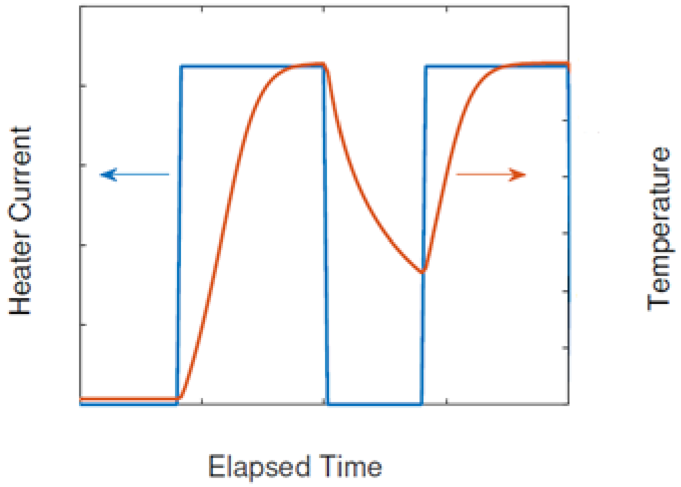

**Function:** heater brings the emitter up to thermionic emission operating temperature.

**Primary challenges:** electrical failure open/short circuit, heater life, high temperature, fabrication

**Primary testing:** cyclic life testing

# NEXT-C Heater Cyclic Testing, Variability in Electrical Failures

## Typical Cycle Profile

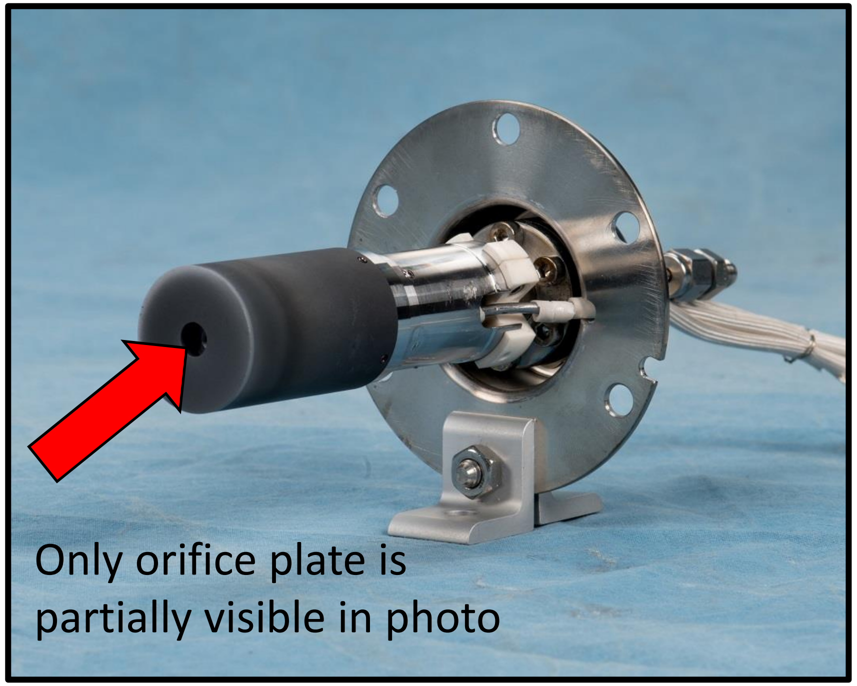



| Heater Position | Heater Size | Development Heaters | | Flight Heaters | |
|---|---|---|---|---|---|
| | | Total Cycles | Failure Mode | Total Cycles | Failure Mode |
| 1 | 0.25" | 21,479 | Shorted | 13,976 | Open |
| 2 | 0.25" | 25,117 | Open | 29,003 | Open |
| 3 | 0.25" | 27,700 | Shorted | 13,613 | Shorted |
| 4 | 0.5" | 19,059 | Open | 15,758 | Open |
| 5 | 0.5" | 33,551 | Shorted | 10,578 | Open |
| 6 | 0.5" | 21,626 | Open | 19,988 | Shorted |

N. Arthur, AIAA 2019
T. Verhey NASA/TM-2018-219730

# Typical Cathode Components

NASA GRC Mark II

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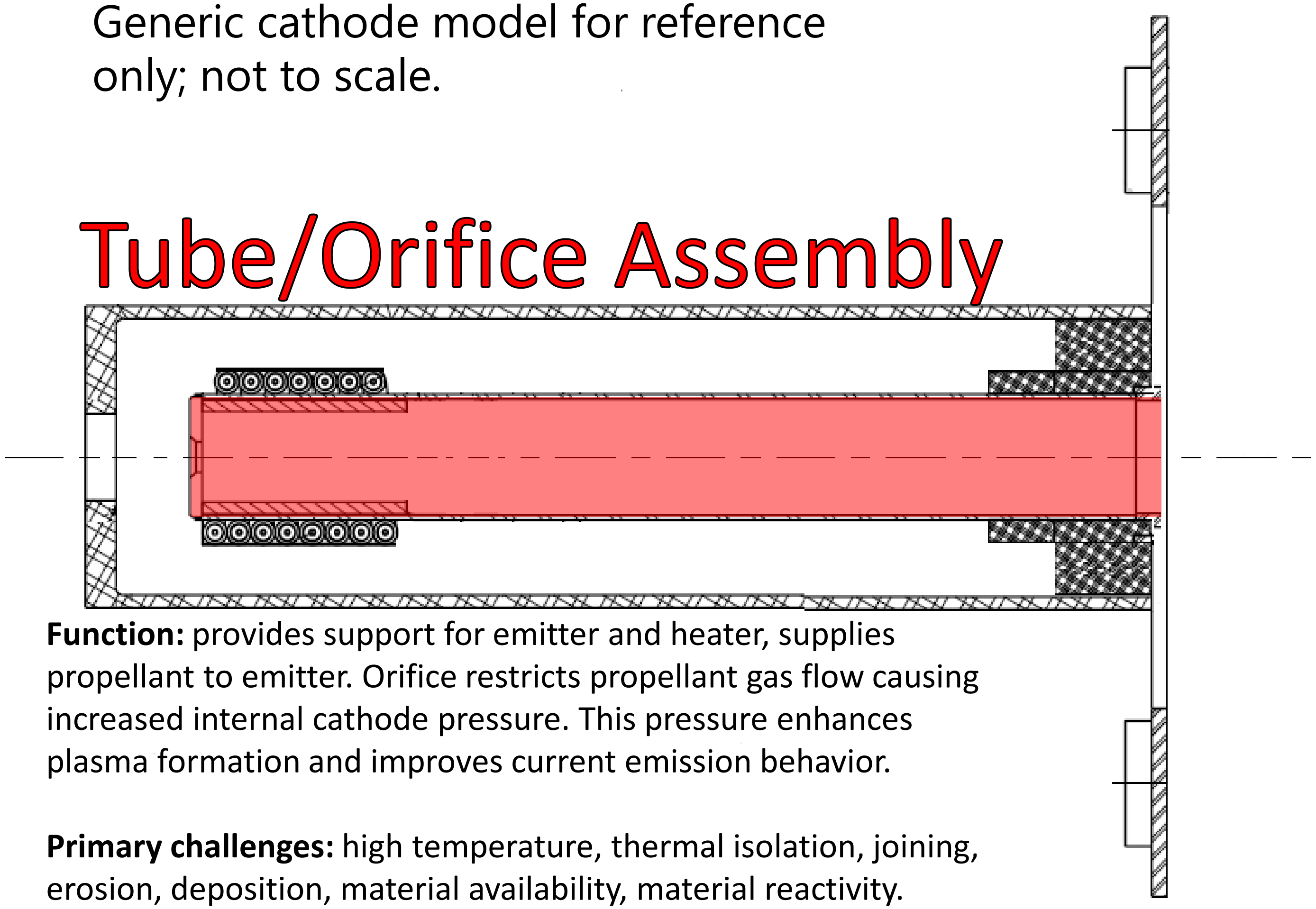
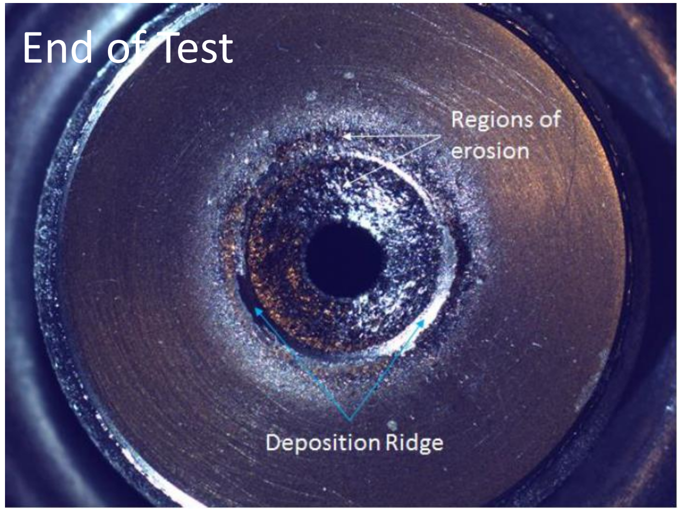


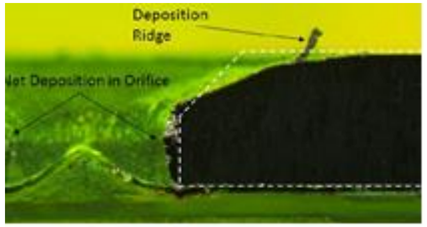

**Function:** provides support for emitter and heater, supplies propellant to emitter. Orifice restricts propellant gas flow causing increased internal cathode pressure. This pressure enhances plasma formation and improves current emission behavior.

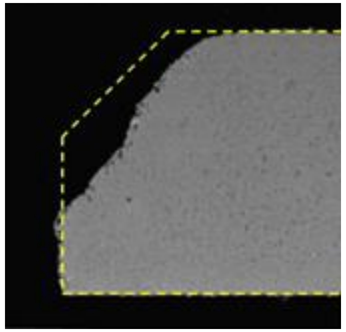
**Primary challenges:** high temperature, thermal isolation, joining, erosion, deposition, material availability, material reactivity.

**Primary testing:** thruster life test, wear test, leak checking.

## NEXT 50kh Life Test, Erosion and Deposition

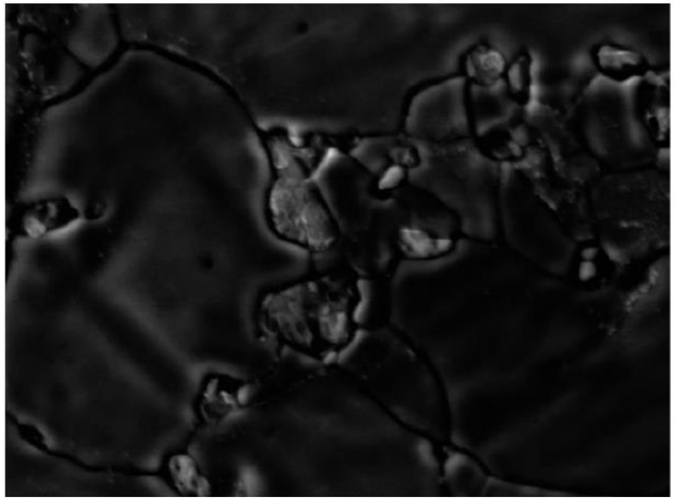


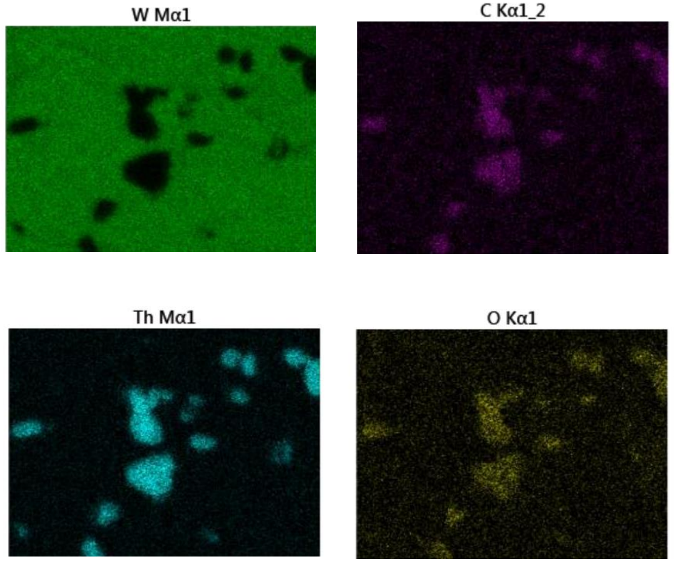



R. Shastry, AIAA 2016

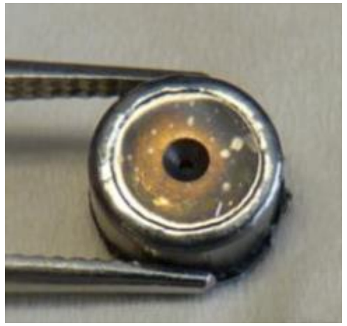
## Thoriated Tungsten, Difficult to source

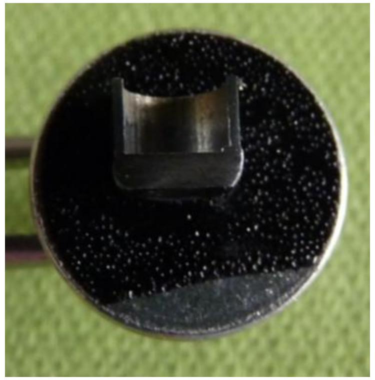





J. Mackey, Personal Records

## Joining of Orifice Plate, Welding Challenges





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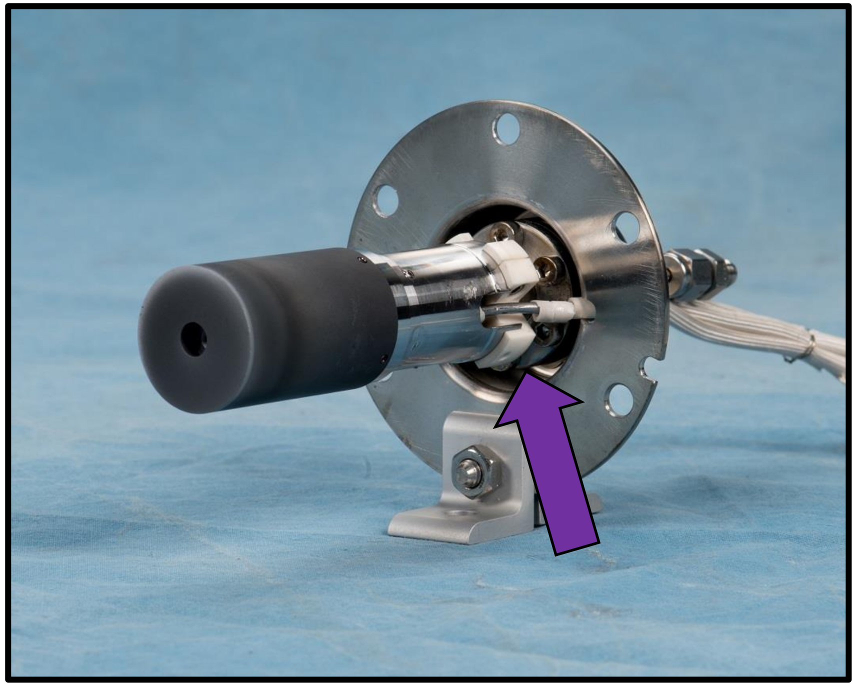

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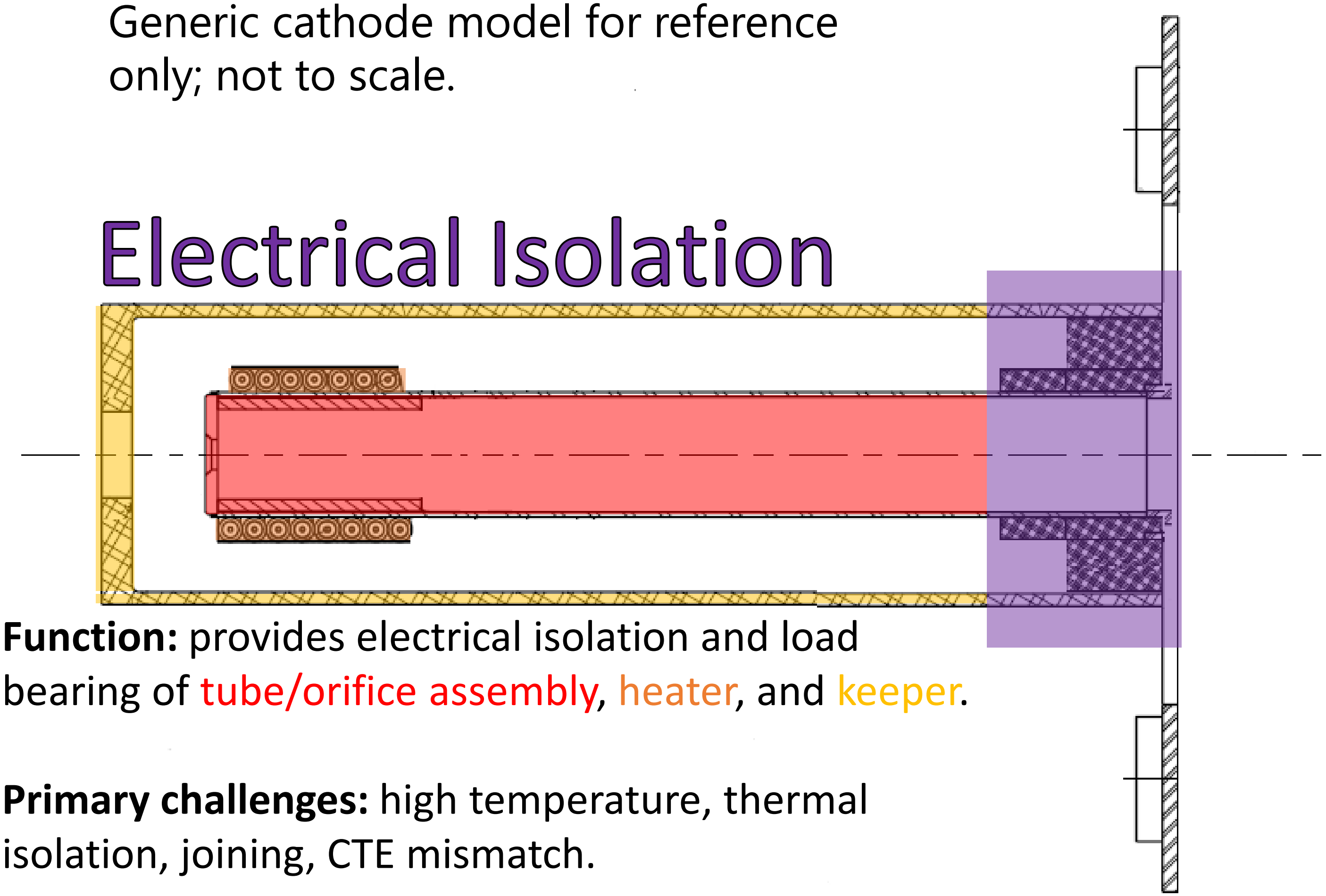


**Function:** provides electrical isolation and load bearing of tube/orifice assembly, heater, and keeper.

**Primary challenges:** high temperature, thermal isolation, joining, CTE mismatch.

**Primary testing:** thruster life test, wear test, mechanical testing.

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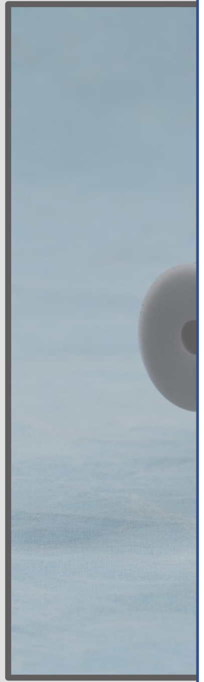
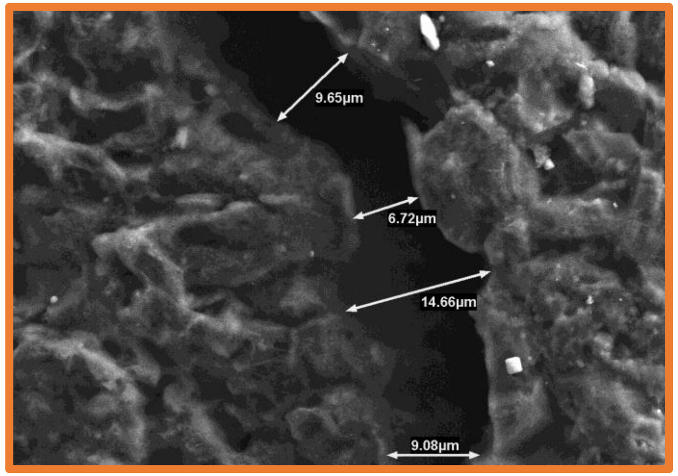
NASA GRC



## Thermal Challenges, CTE mismatch during brazes

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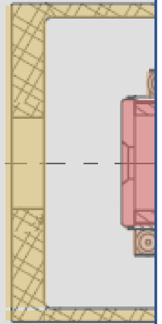

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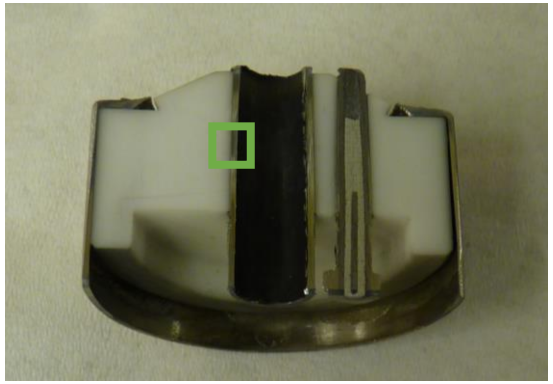
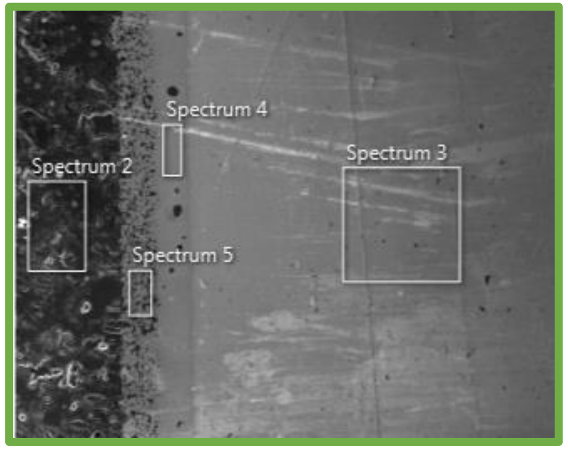
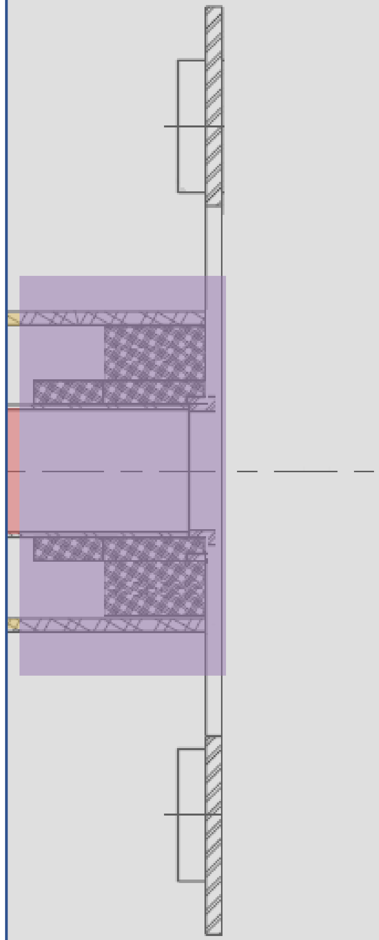
## Joining/Brazing Challenges, Alumina to Mo/Re






J. Mackey, Personal Records



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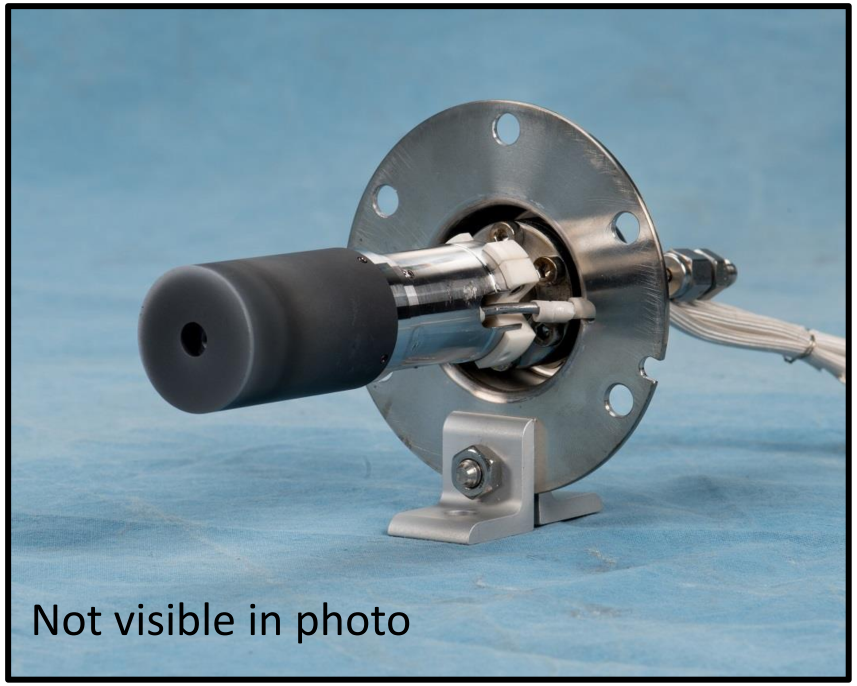


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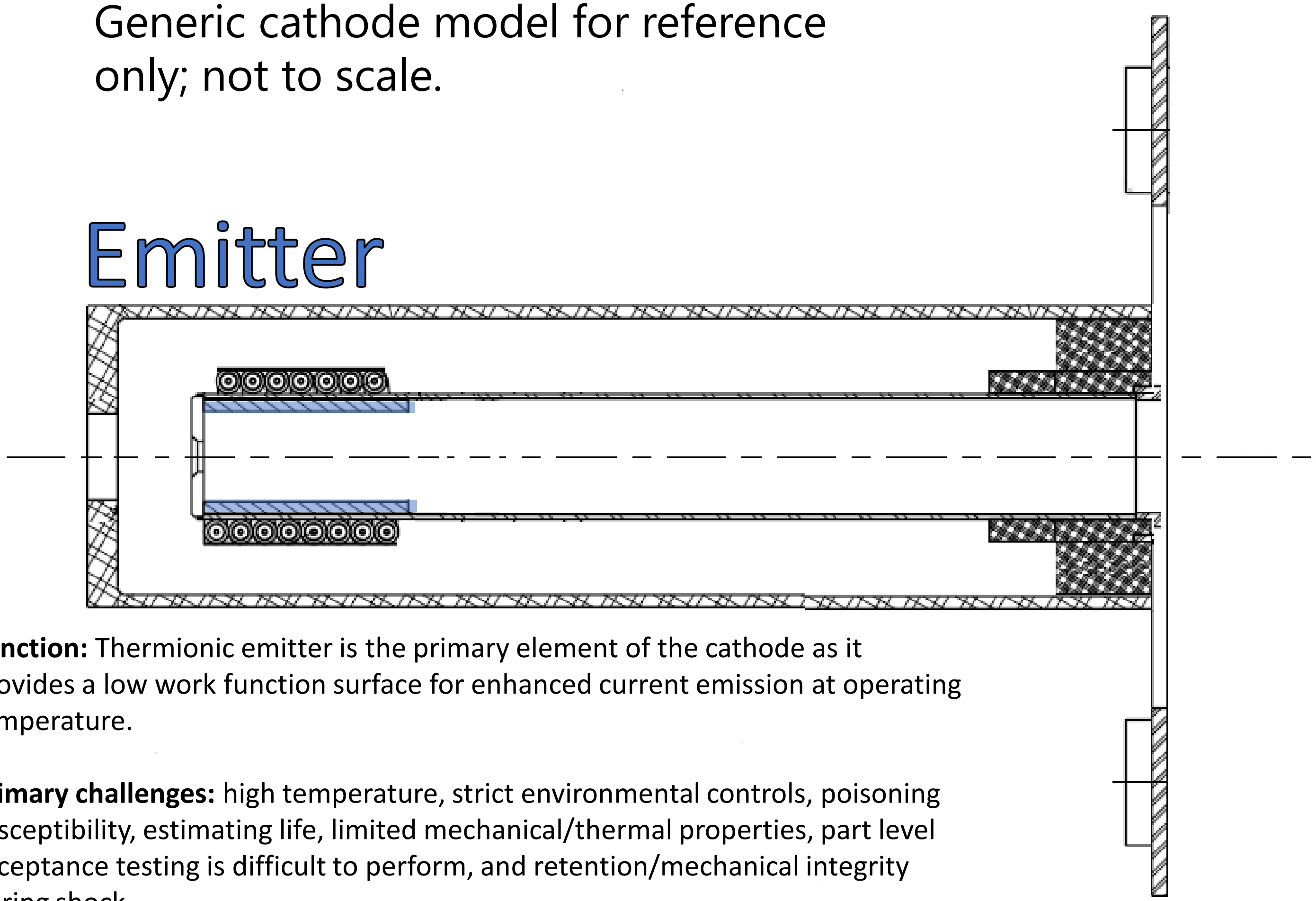
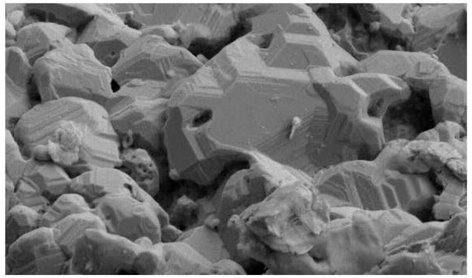



**Function:** Thermionic emitter is the primary element of the cathode as it provides a low work function surface for enhanced current emission at operating temperature.

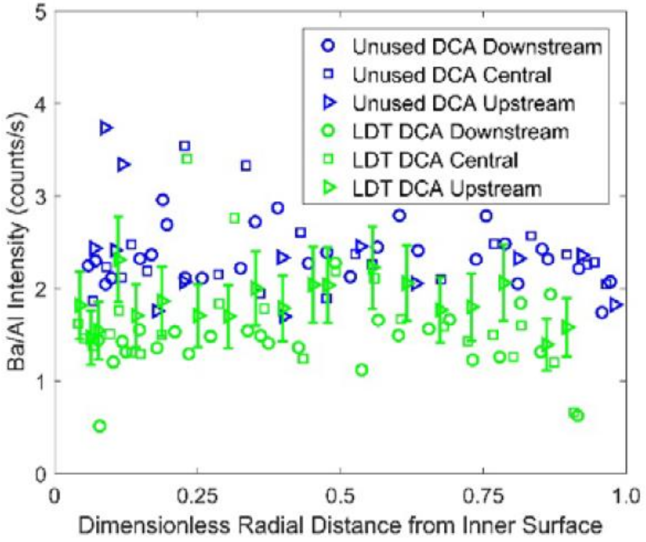
**Primary challenges:** high temperature, strict environmental controls, poisoning susceptibility, estimating life, limited mechanical/thermal properties, part level acceptance testing is difficult to perform, and retention/mechanical integrity during shock.

**Primary testing:** plasma measurements, emitter temperature distribution, environmental exposure and life testing.

## NEXT 50kh Long Duration Test (LDT), Emitter Life

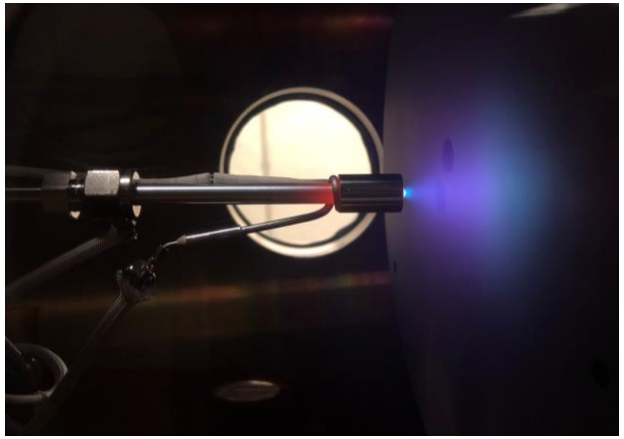


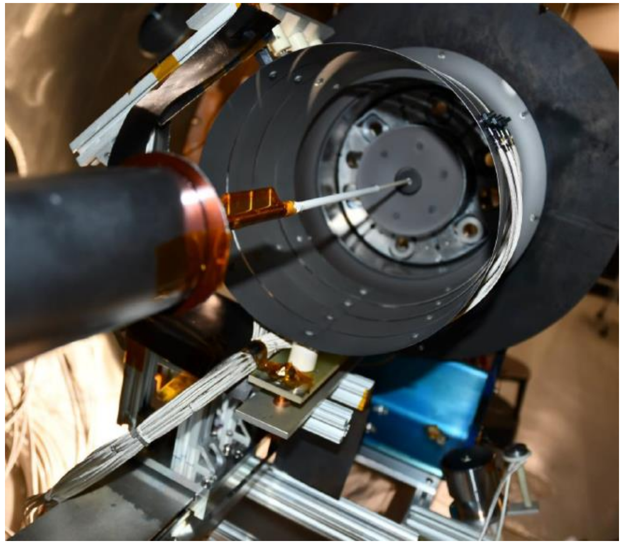
### Ba Content after 50kh

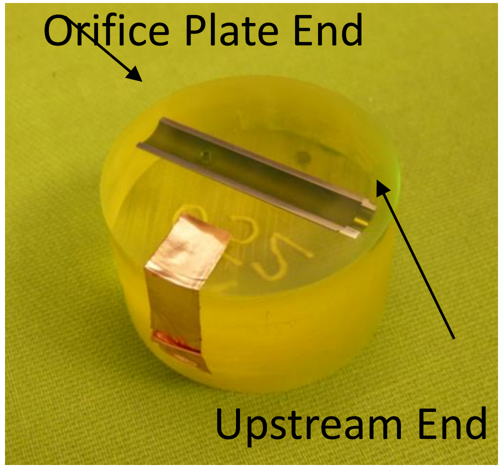



J. Mackey, NASA/TM-2017-219713

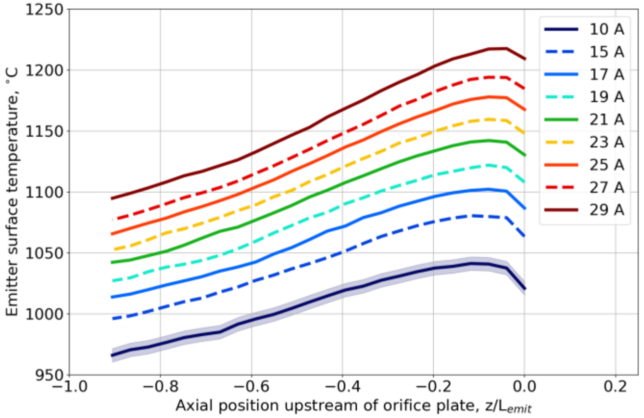
## Cathode Plasma Probing, Environmental Exposure Studies, Temperature Profile Studies, Testing performed at cathode level instead of component level








### Emitter Temperature Profile




T. Gray, Personal Records

S. Hall, NASA/TM In Press

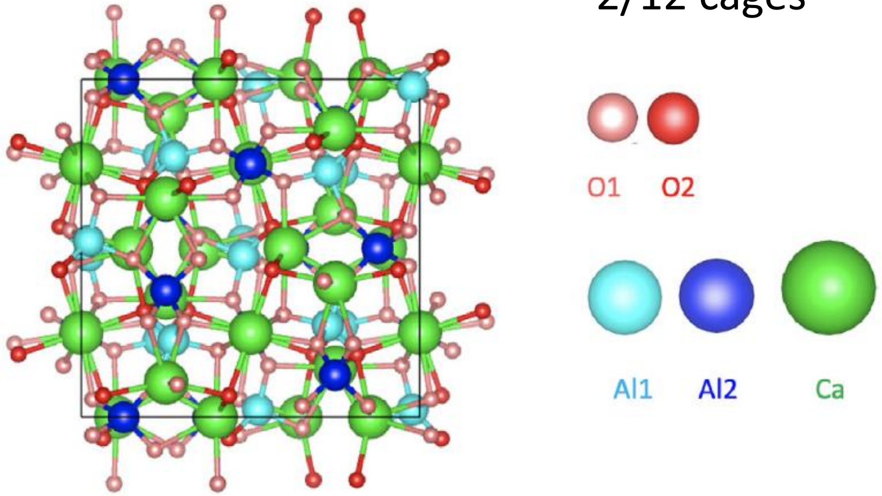
environmental exposure and life testing.

# Forward Research

- BaO based cathodes are a proven technology and are well established on several large projects (AEPS, NEXT-C).
- Large projects would likely accept only marginal design changes and improvements, however smaller projects may accept more significant design changes.
- Emitter insert challenges such as high temperature and poisoning sensitivity drive many of the design challenges for the entire cathode assembly.
- Furthermore, research for alternative propellants, such as iodine, require alternative insert materials
- Lower temperature insert materials may be beneficial to future projects, specifically ones using alternative propellants.
- Ca-Al-O based electride (C12A7) is a potential candidate for research.
    - C12A7 promises to be a chemically stable compound, does not require high temperature, less susceptible to poisoning, and less susceptible to environmental factors.

## C12A7 Crystal Structure

Oxygen ion fills 2/12 cages




Unit cell contains 12 cages $[Ca_{24}Al_{28}O_{64}]^{4+}$

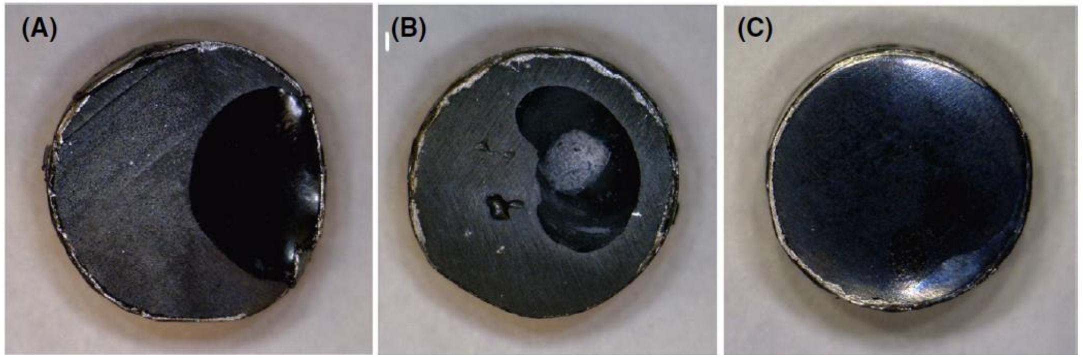
Electron fills 4/12 cages

A. Sayir, J. Am. Ceram. Soc. 2021

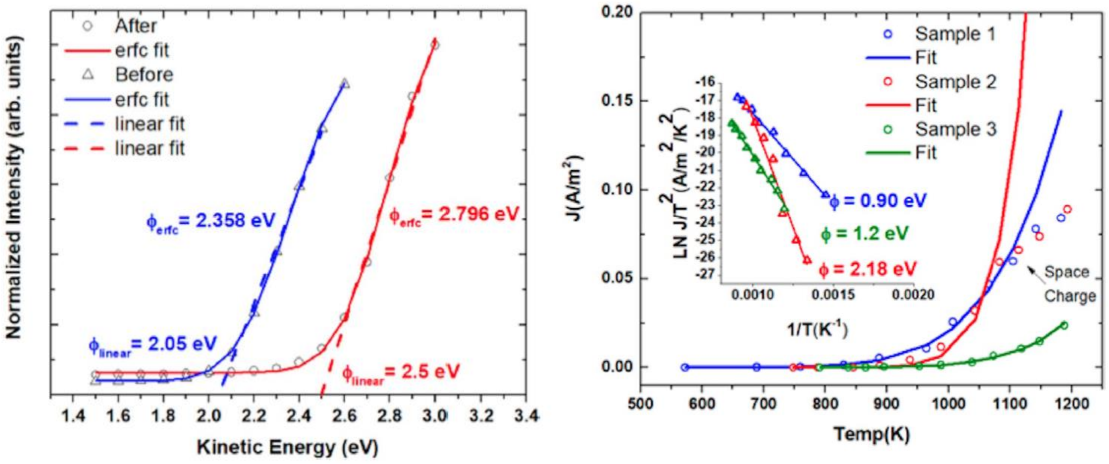
# C12A7 Research

- C12A7 electrides have been successfully synthesized and characterized but further work is required to understand and implement C12A7 into cathodes.
- Purity, electrical properties, thermal properties, and mechanical properties vary both within and between research groups, requiring the need for additional work.
- Implementation into full electric propulsion cathodes is limited, as a result limited test data exists to determine feasibility.

Investigation of C12A7




C12A7 Work Function




J. Mackey, J. Am. Ceram. Soc. 2021

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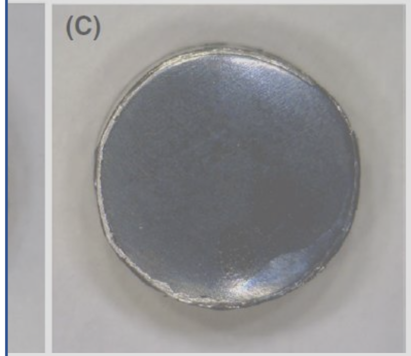
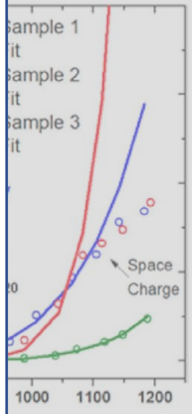
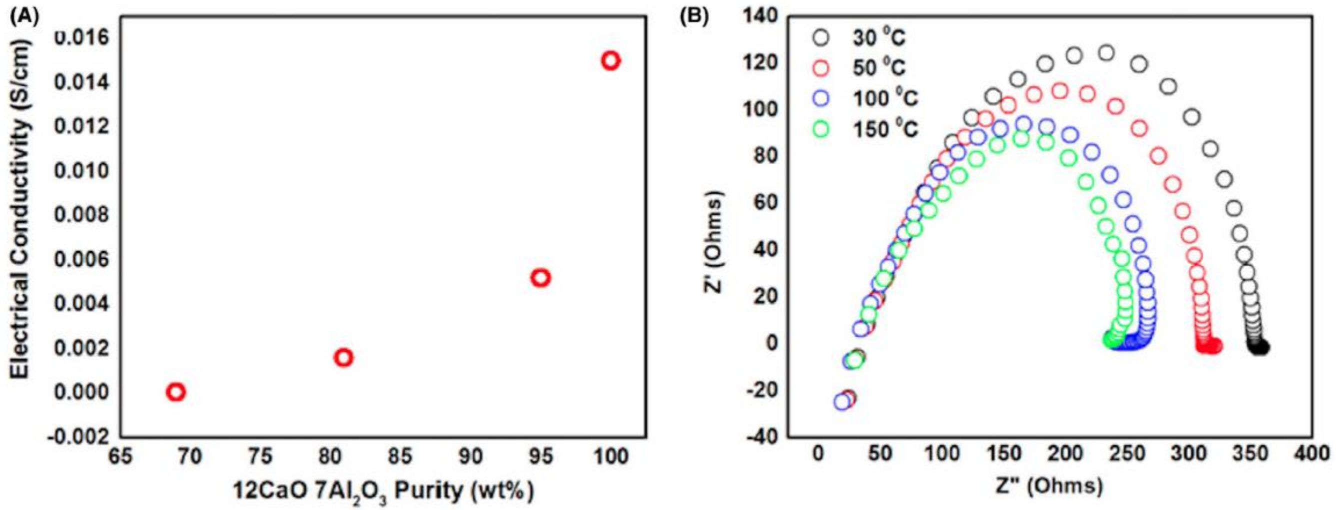



Work Function

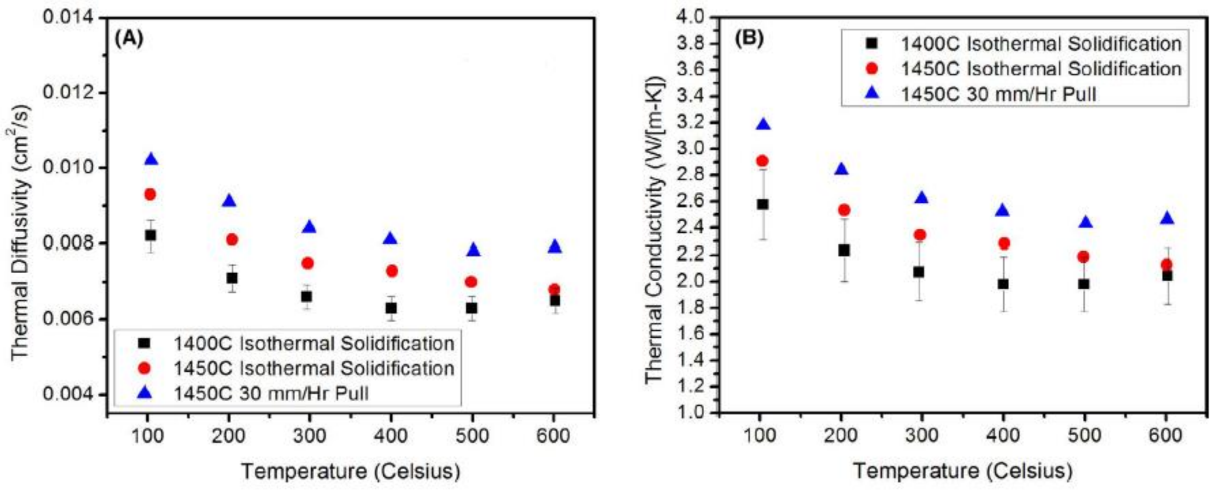


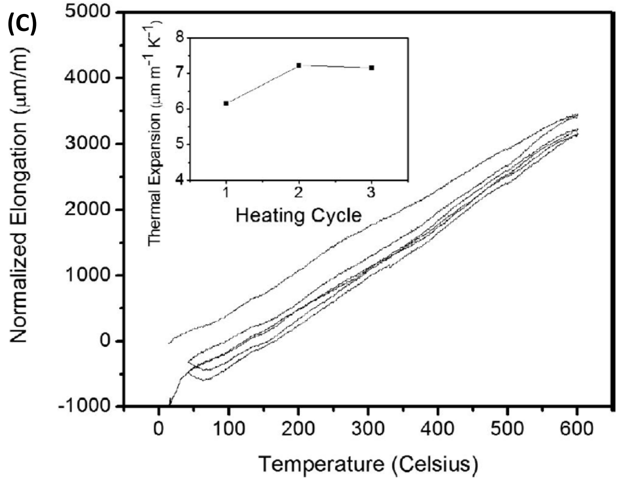

## C12A7 Electrical Properties




A. Sayir, J. Am. Ceram. Soc. 2021

## C12A7 Thermal Properties

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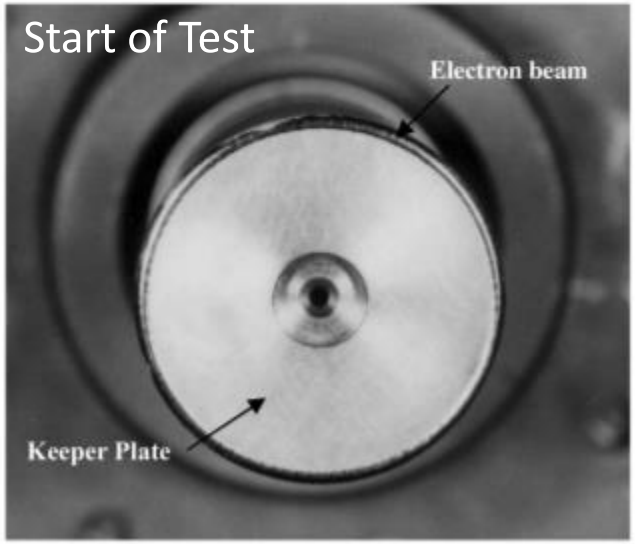
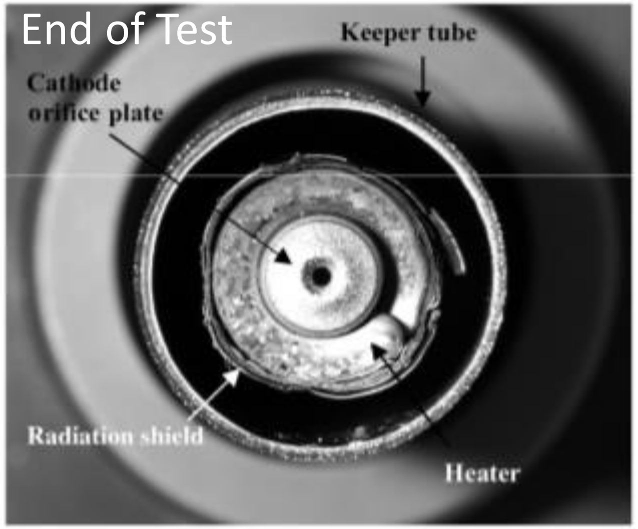
# Summary

- Primary challenges with existing BaO cathode technology:
  - Heater (predicting life, meeting life requirements)
  - Orifice Plate (material joining challenges, Thoriated Tungsten sources)
  - Electrical Isolation (material joining challenges, CTE mismatch)
  - Emitter (environmental controls, predicting life, component acceptance testing)
- Many of the highlighted challenges are a result of the high temperatures that are required for BaO cathodes.
- Novel lower temperature emitter materials could eventually be used to reduce many of the challenges.
- C12A7 electride is a promising emitter material, but limited cathode level development exists.

# Backup Charts

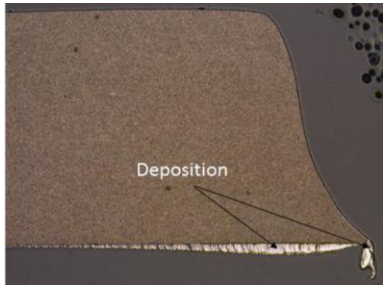
## N-STAR 30kh Life Test, Significant Erosion



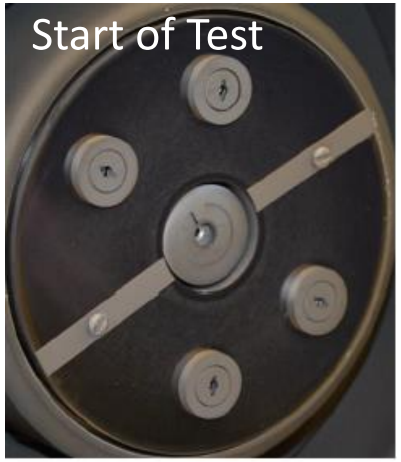

A. Sengupta, J. Prop and Power 2009

## NEXT 50kh Long Duration Test, Marginal Erosion and Deposition

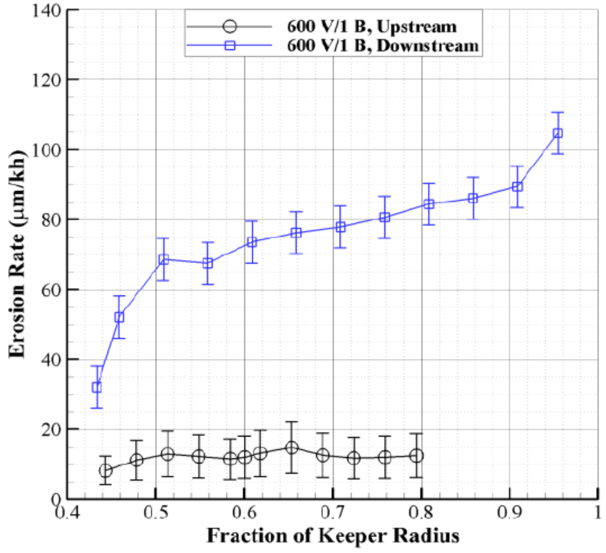




R. Shastry, AIAA 2016

## AEPS 250 h Wear Test, Marginal Erosion Position Dependent




Keeper Erosion Rates




J. Frieman, J. Appl. Phys 2021

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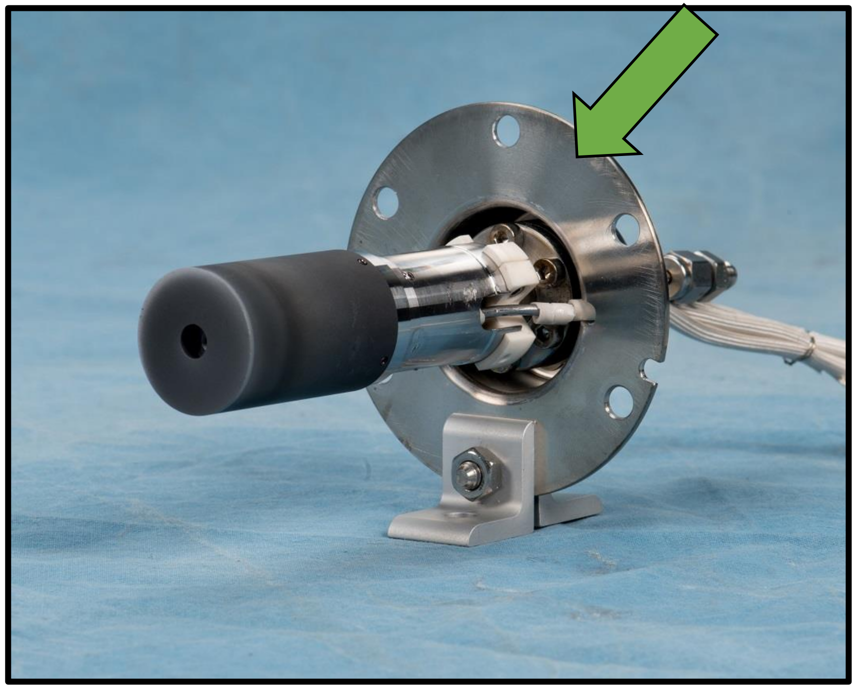
NASA GRC Mark II



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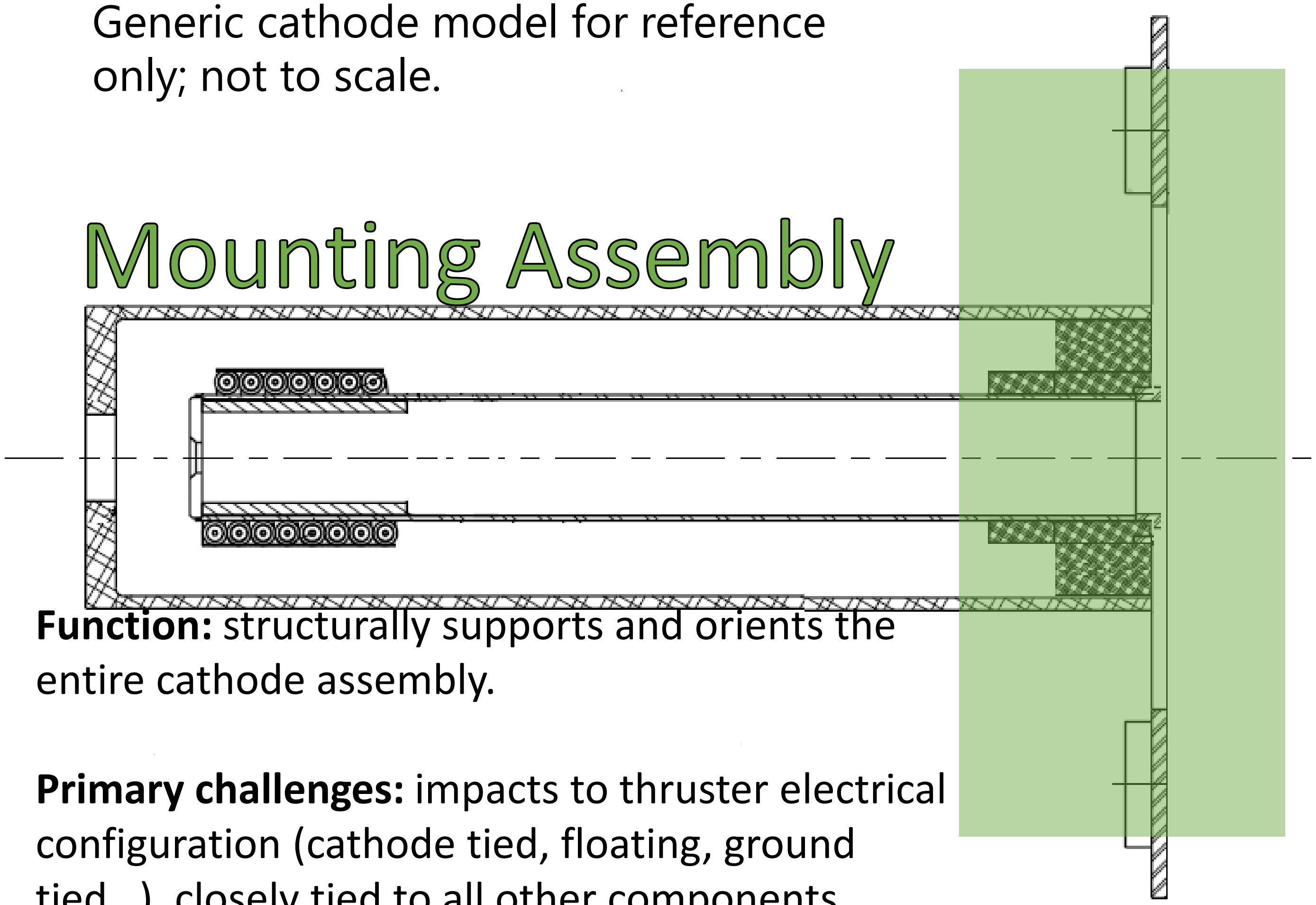


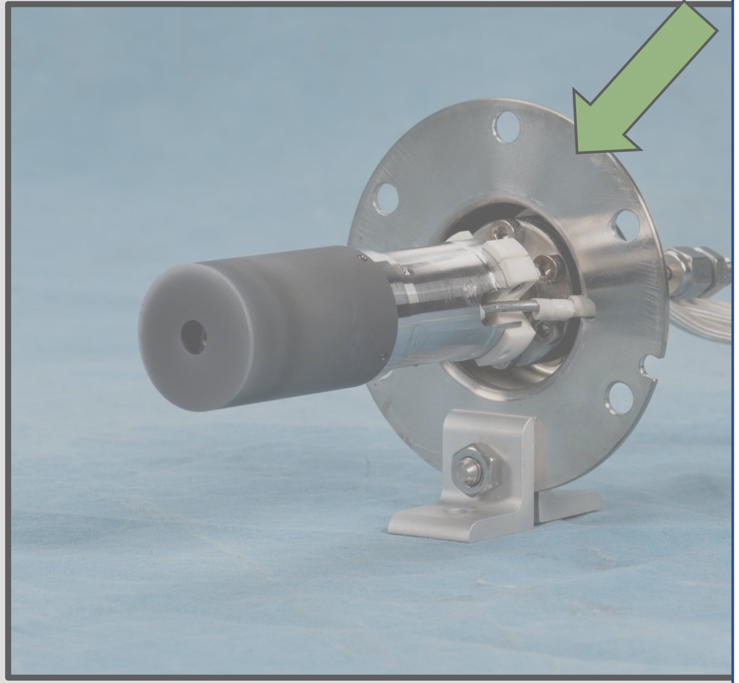

**Function:** structurally supports and orients the entire cathode assembly.

**Primary challenges:** impacts to thruster electrical configuration (cathode tied, floating, ground tied…), closely tied to all other components.

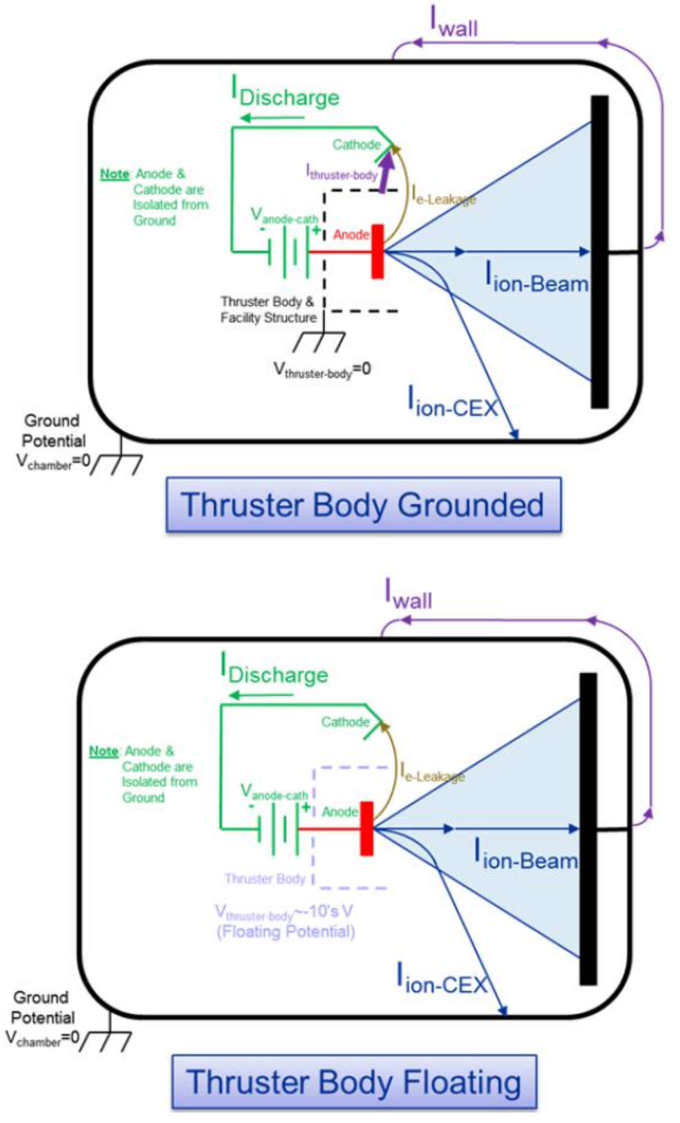
**Primary testing:** thruster life test and wear test.

# Typical Catho

NASA GRC Mark II



AEPS Thruster Electrical Configuration




P. Peterson, AIAA 2016

for reference

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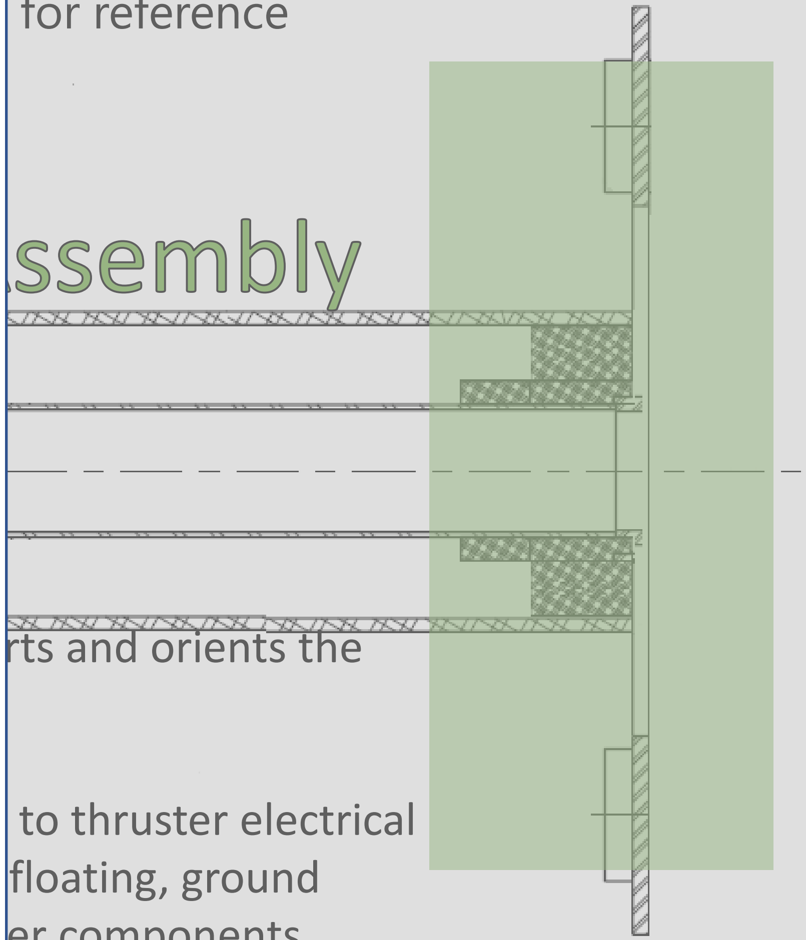

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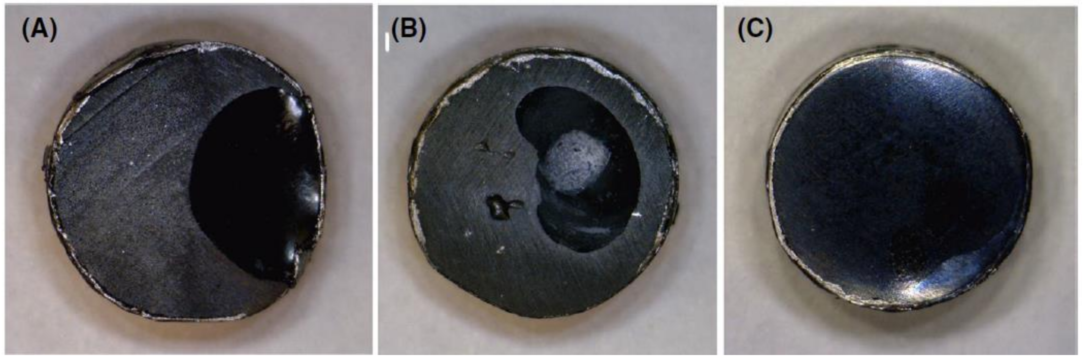
to thruster electrical
floating, ground
er components.

**Primary testing:** thruster life test and wear test.

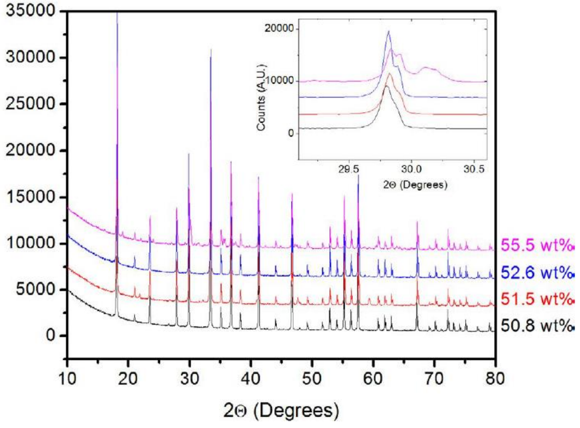
# C12A7 Research

- C12A7 electrides have been successfully synthesized and characterized but further work is required to understand and implement C12A7 into cathodes.
- Purity, electrical properties, thermal properties, and mechanical properties vary both within and between research groups, requiring the need for additional work.

Investigation of C12A7 phase purity




XRD

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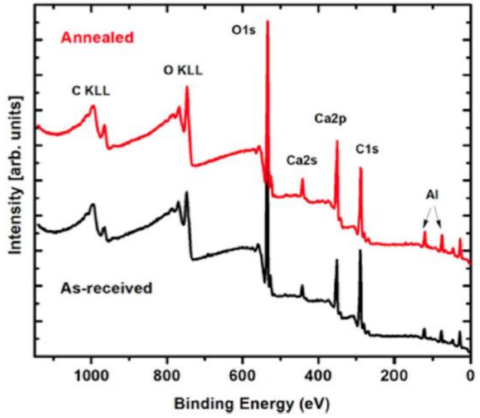


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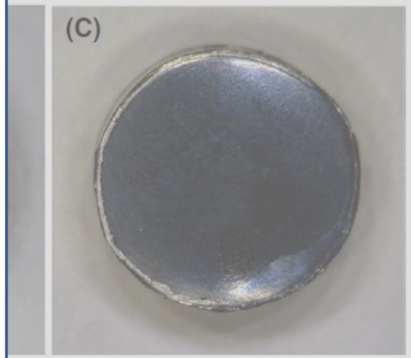
7 purity




XRD

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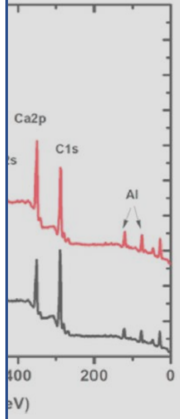
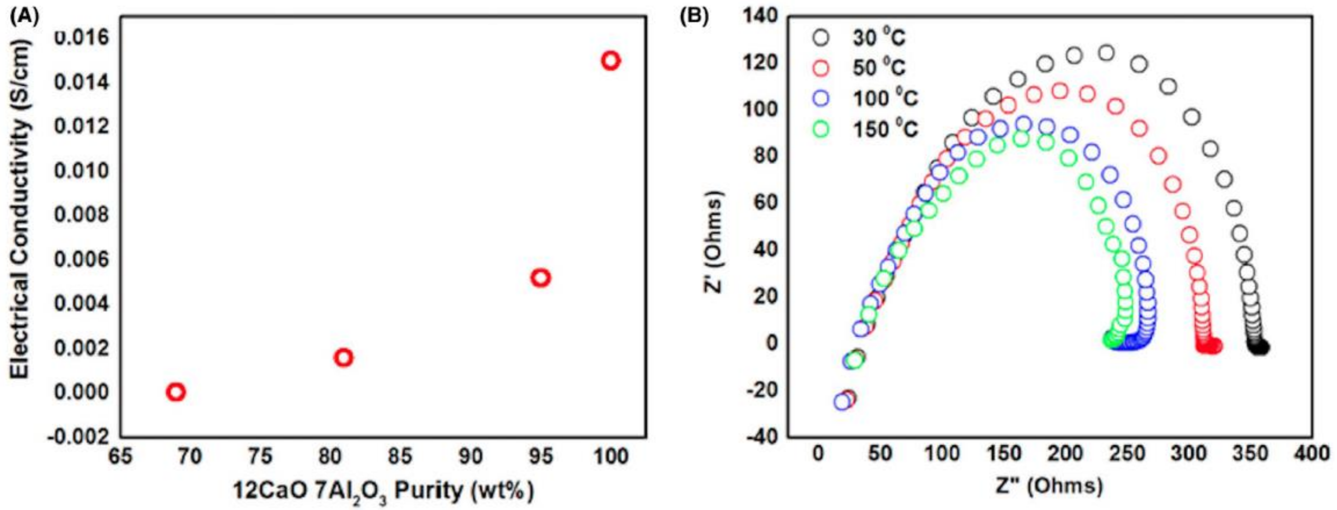



Electrical Properties

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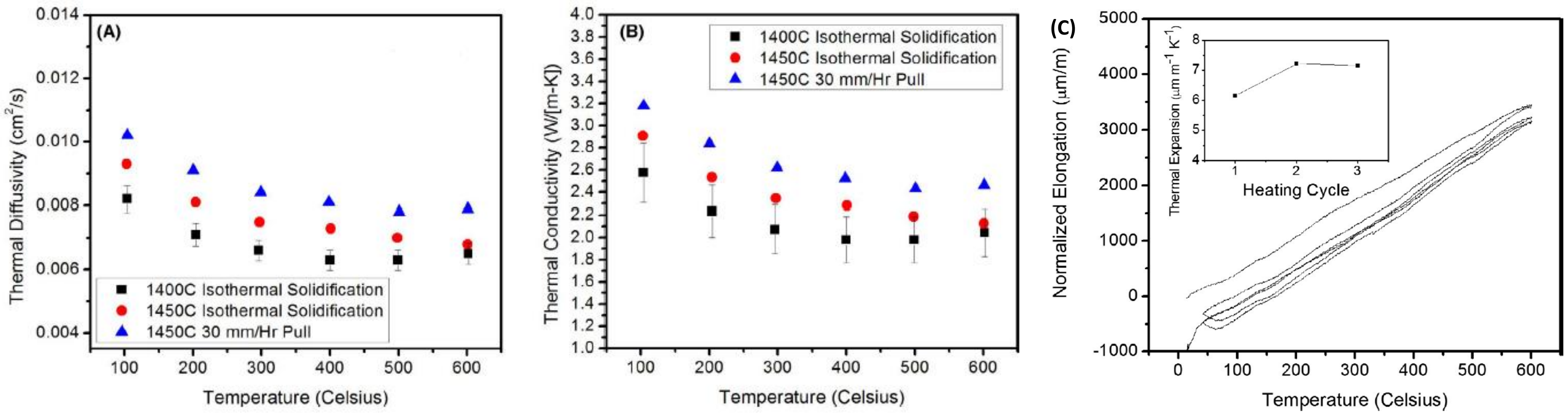
Thermal Properties

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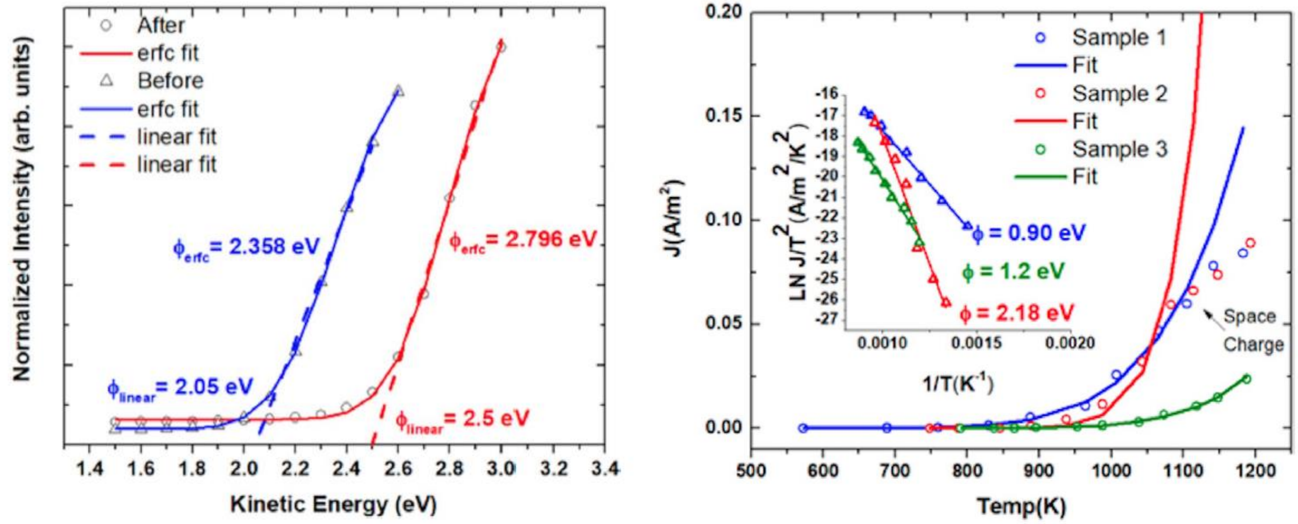
## Work Function

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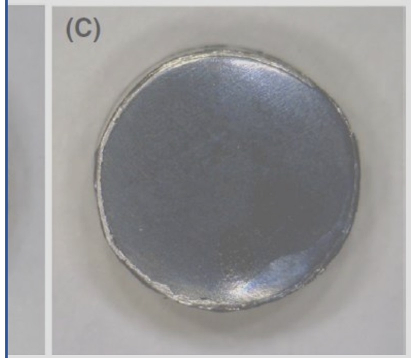
7 purity




XRD

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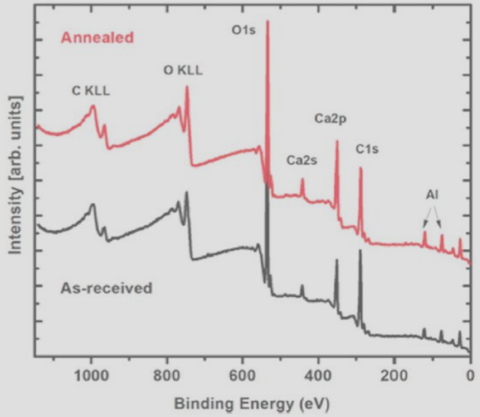


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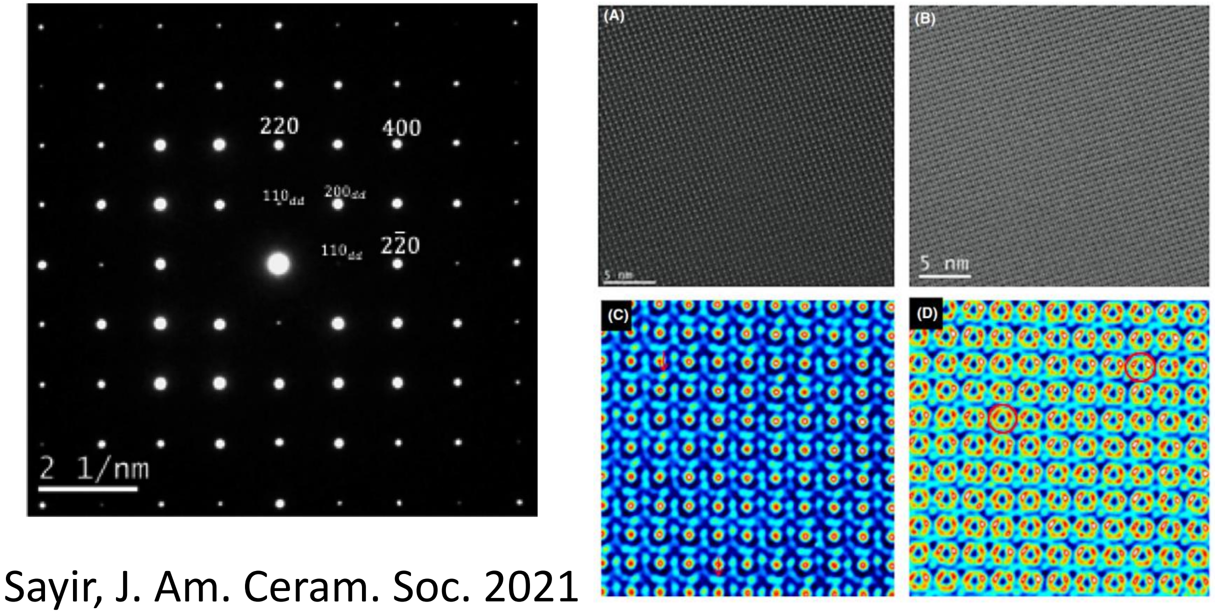
## Microstructure

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