Sustaining Phenolic Impregnated Carbon Ablator (PICA) for Future NASA Missions Including Discovery and New Frontiers

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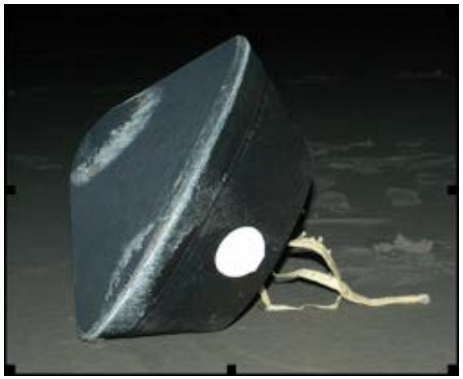
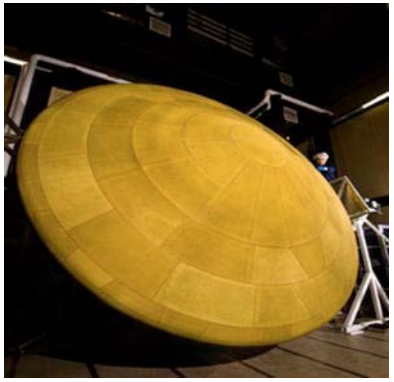
Background – PICA

State of the Art Low Density Carbon Phenolic Ablators

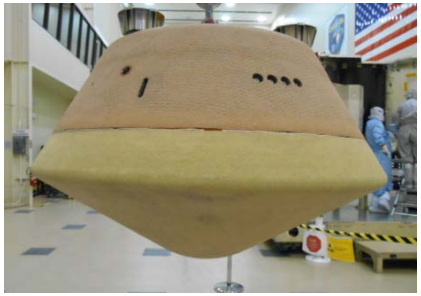
- **Phenolic Impregnated Carbon Ablator (PICA)**
  - First used as forebody single piece heatshield for Stardust
- **Low density coupled with efficient ablative capability at medium-high heat fluxes**
- **Since Stardust-**
  - Under the Orion program PICA was shown to be capable for both ISS and lunar return missions but was not selected as the baseline TPS
  - PICA was transitioned to Mars Science Lab (MSL) post CDR in a tiled configuration when the mission environments went beyond the capabilities of SLA561V
  - OSIRIS-REx sample return capsule as a single piece
  - Mars 2020 – Utilizing last of the “heritage” Sniace rayon based PICA



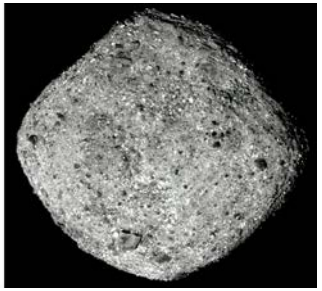
Stardust forebody TPS. (~0.8m diameter)



MSL Heatshield (4.5m diameter)



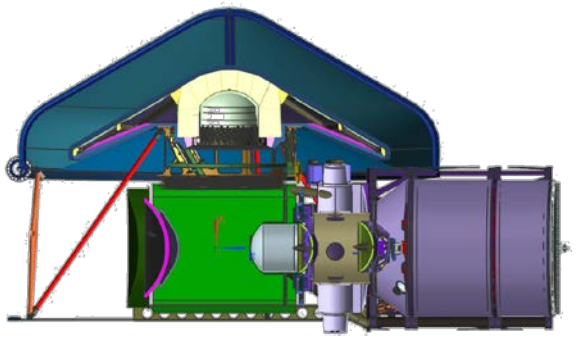
OSIRIS-REx forebody TPS. (~0.8m diameter)



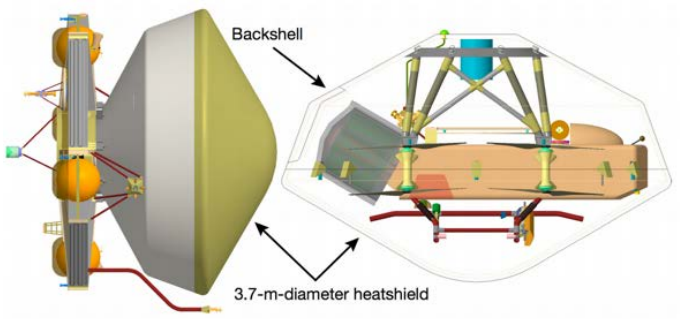
Bennu taken by the OSIRIS-REx spacecraft from a distance of around 50 miles (80 km).

Future Needs for PICA-D*

- Mars Sample Return (MSR) Campaign
  - Sample Retrieval Lander (SRL):
    - Heatshield
  - Earth Entry Vehicle (EEV):
    - Backshell
    - Option for heatshield
- Dragonfly: Heatshield
- Future Discovery and New Frontiers missions:
  - Backshell and Heatshield



MSR EEV



Dragonfly

*PICA-D = Domestically (US) manufactured PICA utilizing Lyocell

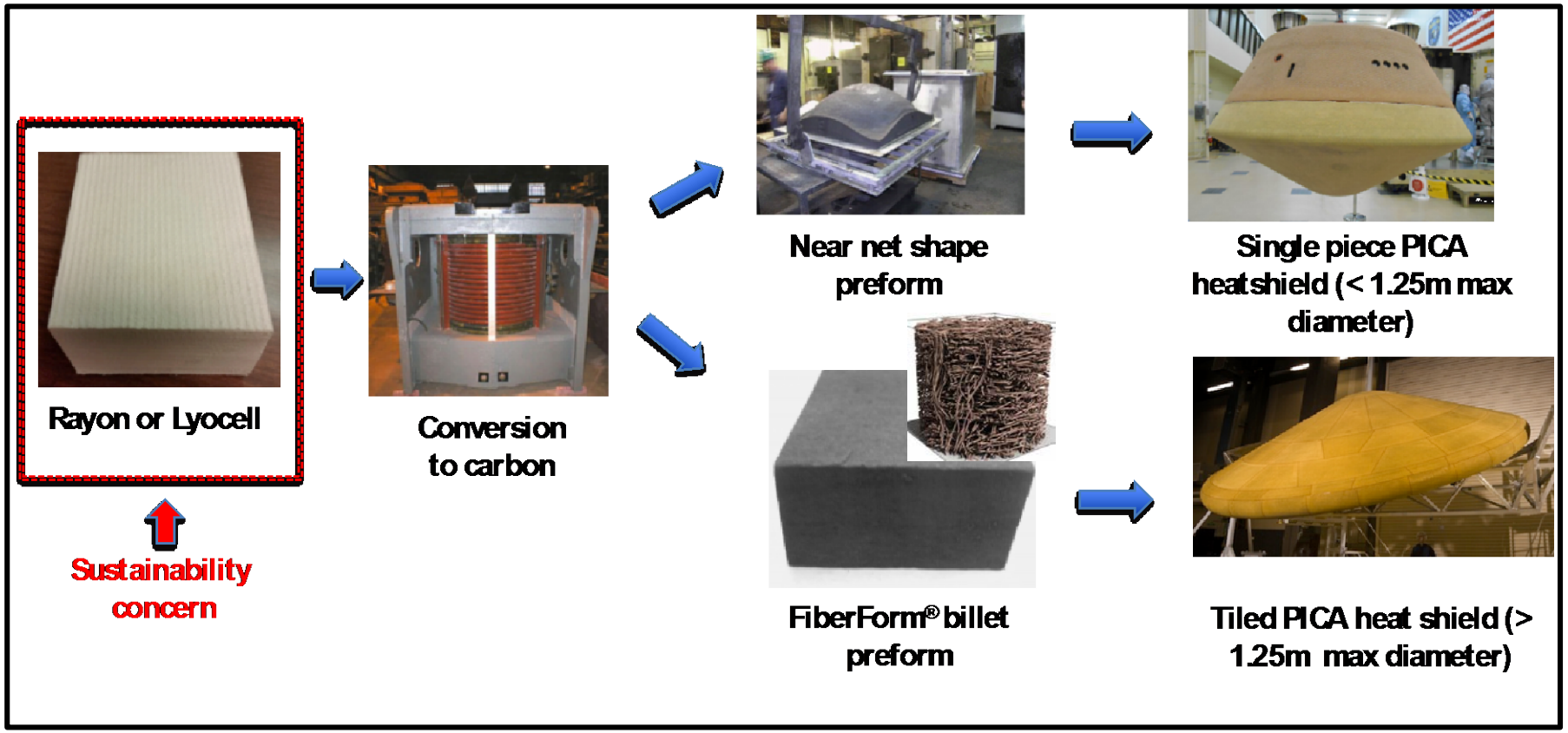
Challenges with PICA Sustainability

- In 2016 NASA learned that the “heritage” rayon used in PICA was ceasing production, leading to a flight-qualified PICA sustainability concern
  - Rayon precursor for PICA has become obsolete twice since the material was developed and used on Stardust
  - Manufacturing of Rayon is not environmentally friendly (no longer produced in US)
- Lyocell has been identified as a alternative to the rayon based precursor
  - Lyocell production is much more environmentally friendly
  - Lenzing – sister factories in US, Austria and UK able to provide the same Lyocell precursor – multiple supply routes alleviate future sustainability concern

Mission/ Project	Precusror type	Rayon Sustainability	Changes /Updates to PICA
Stardust - Near Net Shape (NNS)	Liberty rayon	US source – production ceased in the 90s	Developing process to fabricate singe piece Near Net Shape (NNS) cast part within the density specification required
Orion - billets	Multiple sources – settled on Sniace	Multiple international sources evaluated	Optimized densification process for billets, tested the bounds of the density specification and the influence on performance / properties
MSL- billets	Sniace rayon	international source – production ceased in ~ 2017	Leveraged Orion data to allow adoption on MSL
OSIRIS Rex - NNS	Sniace rayon	international source – production ceased in ~ 2017	Cast FiberForm preform density spec modified compared to Stardust. Phenolic level adjusted based on lessons learned from Orion/MSL
M2020 - billets	Sniace rayon	international source – production ceased in ~ 2017	Leveraged MSL
PICA-D - billets	Lyocell	Domestic/international sister plants. Greener processing	Orion/MSL density specification range
PICA-D - NNS	Lyocell	Domestic/international sister plants. Greener processing	Leveraged OSIRIS Rex/MSL density specification range

PICA Manufacturing Overview

Role of Rayon/Lyocell in PICA Manufacturing



- Chopped, graphitized rayon/Lyocell - based carbon fiber slurry-cast into either block (billet) or single piece heatshield preforms
- Single piece cast heatshields have fiber oriented to optimize (minimize) through-thickness thermal conductivity
- Lightweight phenolic sol-gel matrix is infiltrated into preform

Establishment of PICA-D as a Replacement for Heritage PICA

- **FY17 - SMD-PSD funded NASA Ames to manufacture & perform limited property/aerothermal characterization of Lyocell-based PICA (PICA-D)**
  - Fiber Processing, billet fabrication, single piece heatshield preform fabrication, conversion to PICA (billets and single piece preform)
  - PICA property testing and arc jet testing
- **FY17 task with limited testing indicated PICA-D had good potential as a replacement for heritage PICA**
  - Material properties and aerothermal performance in family with “heritage” PICA
- **FY18/FY19 – further efforts to characterize and extend the capability of PICA-D and establish Lyocell PICA as a replacement for heritage PICA**
  - Establishing PICA-D as a replacement will allow missions to utilize PICA-D without having to address further sustainability risks.
  - Establishing extended capability of PICA-D will allow Sample Return Missions with higher entry speed and larger size that were not considered before.
    - Extended aerothermal operational capability
    - Larger single piece heatshield manufacturing

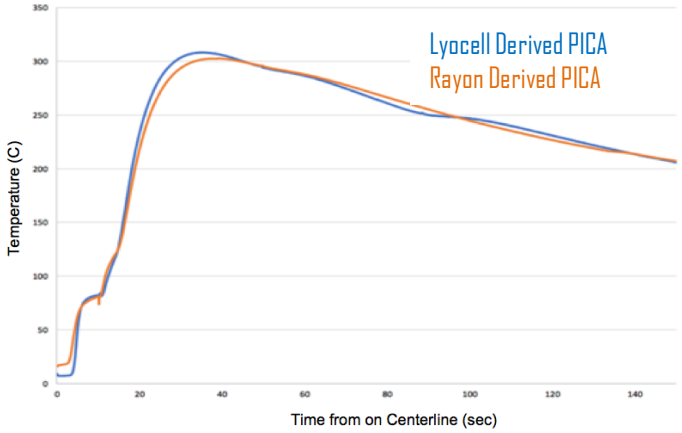
PICA-D Arc Jet Testing

Runs in Air 2017

Recession Comparison

Material	Average centerline recession (1550W/cm² and 1.3 atm)	Average centerline recession (400W/cm² and 0.3atm)	Average centerline recession (220W/cm² and 0.08atm)
Lyocell PICA	4.0mm	6.02mm	3.79mm
Rayon PICA	4.2mm	5.97mm	3.89mm

Example in-depth TC Trace @ 1550W/cm²



Run condition very relevant for proposers considering PICA as a forebody or backshell material

Runs in N_2 2018/19

Heat Flux = 140 W/cm², Pressure= 14 kPa

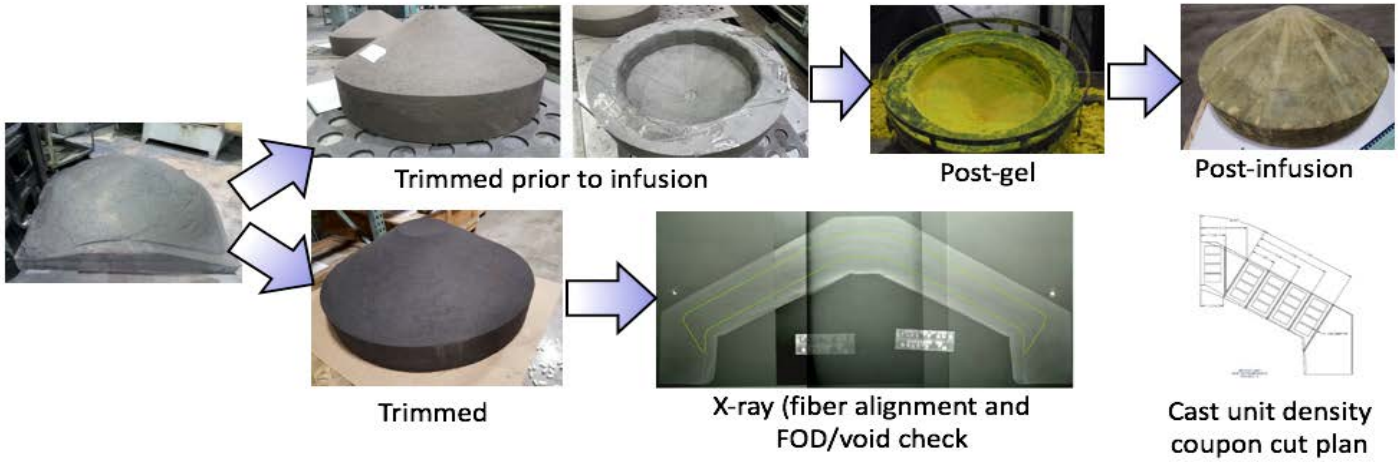
Heat Flux = 260 W/cm², Pressure= 19 kPa

- Previous testing of PICA with RTV seams was only done in air under MSL and Orion programs
- In support of Dragonfly Phase A study, PICA-D built 2 wedge shear models with RTV seams for testing in a nitrogen environment

For a Given Test Condition (Same Run Time) Initial Results Indicate that Recession and In-depth Temperature Between a Lyocell-Derived PICA and a Heritage Rayon-Derived PICA are Comparable, in both Oxygen and Nitrogen.

Lyocell Fiberform/PICA Billet and Near Net Shape Cast Processing

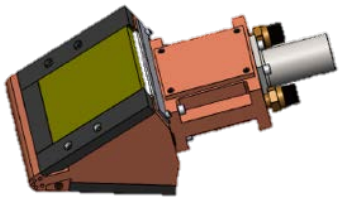
- 9 Fiberform billets manufactured in FY17 to optimize process (Lyocell)
- Additional billets fabricated in FY18 (property and arc jet testing)
- Fabricated 3 net-shaped Fiberform heatshield blanks (OSIRIS REx scale) in FY17
- Fabricated 4 net-shaped ~ 1.5m single piece FiberForm castings (FY18/19)
  - Converted one into 1.4 m PICA heatshield: characterization underway
  - Limited Non Destructive Evaluation (NDE) on the near net shape Fiberform unit to evaluate fiber alignment
- Significant number of lessons learned captured/implemented and substantial risk reduction achieved

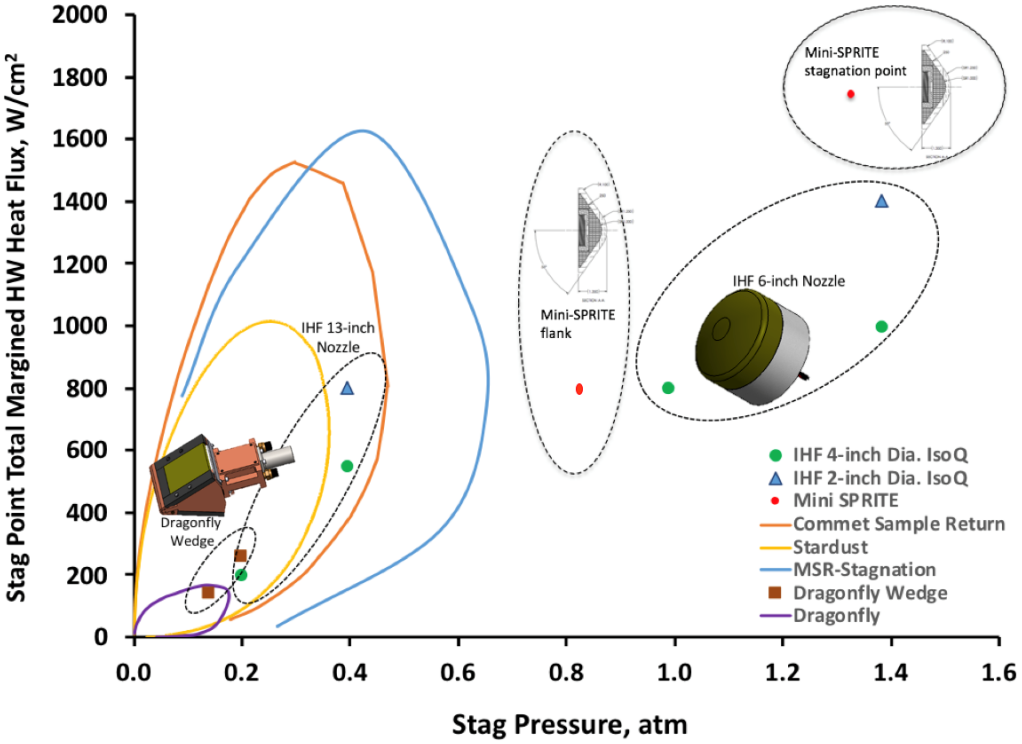


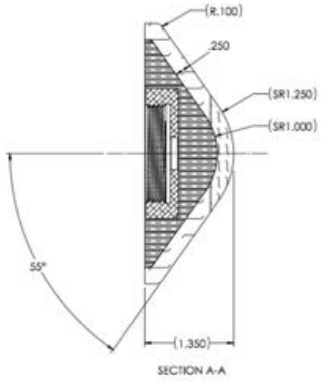
1.4m heatshield

Extended single piece heatshield manufacturing demonstrated

Test Campaign to Establish/Extend Capabilities







- **Arc jet campaign objectives**
  - Compare the thermal response and recession behavior of Lyocell derived PICA to rayon derived PICA
  - Initial look at any performance differences or off-nominal behavior in PICA-D
  - Establishing the extended capability of PICA-D will allow Sample Return Missions with higher entry speed that were not considered before

Summary

- **PICA has become a workhorse TPS for NASA and sustainment is essential**
- **NASA ARC / FMI are working together to address PICA rayon sustainability concerns**
- **Lyocell Based PICA (PICA-D) was manufactured and limited testing shows it to be a viable replacement for heritage rayon**
- **Scaled-up of single piece heatshield manufacturing also demonstrated**
- **Future NASA missions need PICA (SRL, MSR EEV and Dragonfly) and PICA sustainability effort will have a payoff for these missions**
- **Establishing the extended capability of PICA-D will allow Sample Return Missions with higher entry speeds and larger payload not considered before**

Backup

Lyocell – A Sustainable Precursor

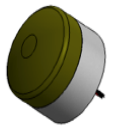
- Traditional rayon manufactured from wood pulp involves many steps and the conversion of wood pulp into rayon or regenerated cellulose results in toxic byproducts
  - rayon manufacturing was discontinued and is no longer a viable process in the US and Europe
- Lyocell - solvent spinning technique is simpler and more environmentally sound
  - uses a non-toxic solvent chemical that is 99% recycled in the manufacturing process
- Lenzing – sister factories in US, Austria and UK able to provide the same Lyocell precursor – multiple supply routes alleviate future sustainability concern

Refer to below links if interested in information on how fibers are made from wood pulp:
https://www.youtube.com/watch?v=tHdJGFv99fE
https://www.youtube.com/watch?v=14PZNgRoEUM

Test Campaign to Establish/Extend Capabilities

1

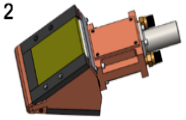
Drop-in replacement testing on 4in and 2in diameter stagnation models



- Objective: provide experimental evidence that PICA-D could be used with high confidence as a TPS material on variety of missions
- Testing from ~ 200 W/cm2 up to~ 1500 W/cm2 (cold wall) heat flux and 1.4 atm pressure
- AHF and IHF 6in nozzle tests
- Compare recession and in-depth temperature data with FIAT predictions
- Some, but limited, comparison to heritage (MSL) PICA is also planned

2

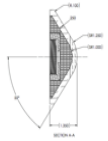
Exploring PICA-D performance limits through testing at extreme environments



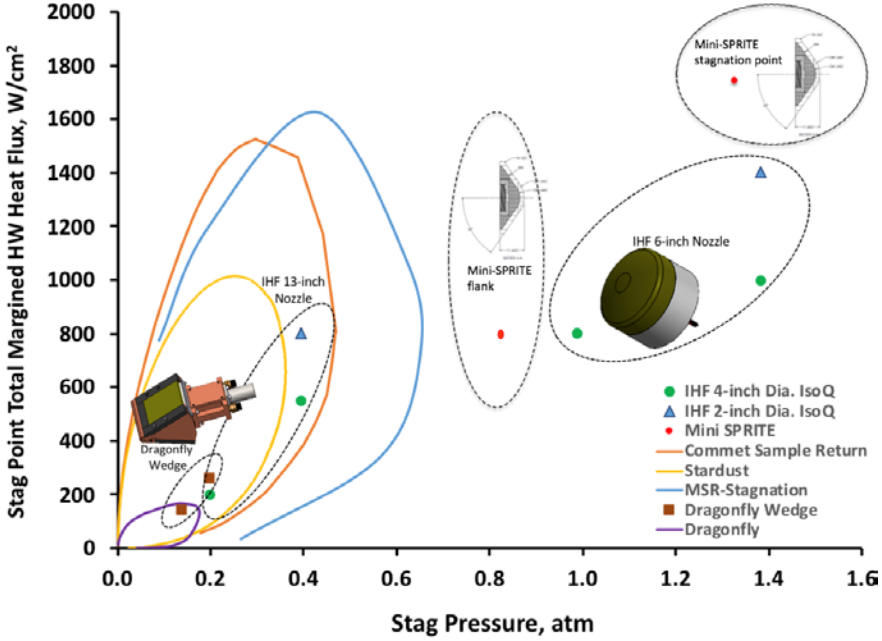
- Objective: expanding PICA limits and thermal performance modeling capability
- TBD condition, possibly ~ 1000 W/cm2, 0.8 atm pressure, 1400 Pa shear, wedge test model
- Testing at AEDC H2S facility

3

Exploring PICA-D performance limits through new test article design



- Objective: expanding PICA limits and thermal performance modeling capability
- Mini-SPRITE test model: ~2200 W/cm2 (cold wall) stagnation heating, 500 Pa shear on the flank
- IHF 6in nozzle test (limited number of coupons)



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