The Manufacture of W-UO2 Fuel Elements for NTP Using the Hot Isostatic Pressing Consolidation Process

NASA Advanced Exploration Systems (AES) Program

Nuclear and Emerging Technologies for Space (NETS)
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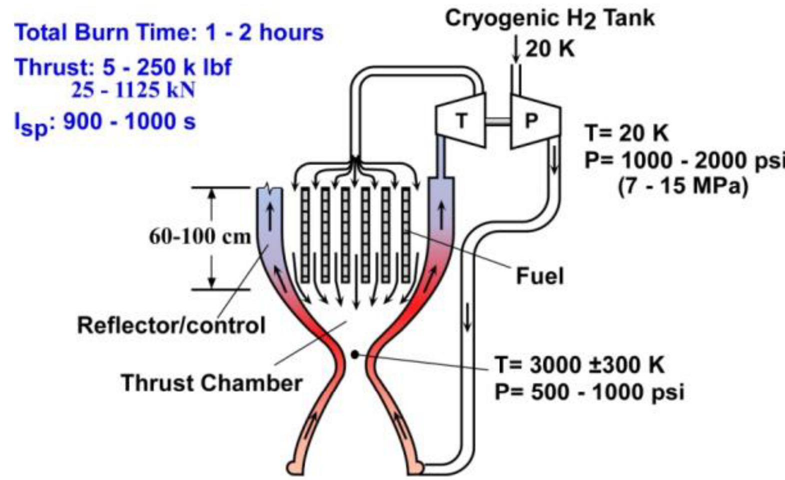
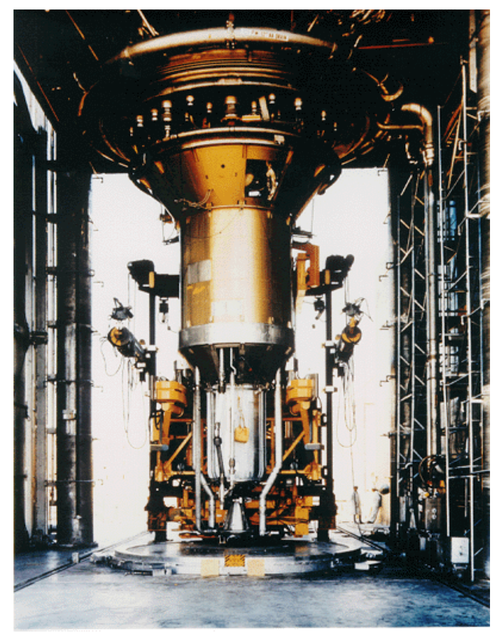
Presentation Outline

- Need for NTP fuel material development
- NCPS Task4 fuel design and fabrication
- Hot Isostatic Press (HIP) overview
- HIP element fabrication process
- NCPS Task 4 HIP development approach
- MSFC HIPed components and capabilities
- Conclusions

Need For NTP Fuel Material Development

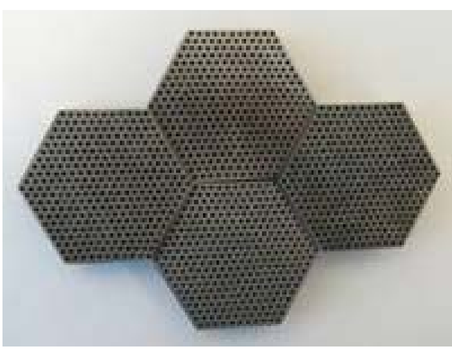
- NTP is attractive for space exploration
  - Higher Isp than traditional chemical rockets
  - Shorter trip times
  - Reduced propellant mass
  - Increased payload
- Significant work done on previous programs (Rover/NERVA, ANL, GE710)
  - Feasibility proven, but low TRL for current standards
- Lack of qualified fuel material is a key risk (cost, schedule, and performance)
- Development of stable fuel form is a critical path, long lead activity
- Nuclear Cryogenic Propulsion Stage (NCPS) Project
  - Advanced Exploration Systems Program FY12-14
  - Fuel Design and Fabrication Task



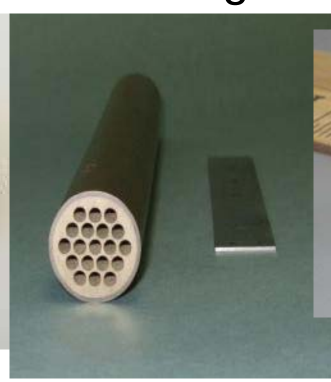


NCPS Task 4- Fuel Design / Fabrication

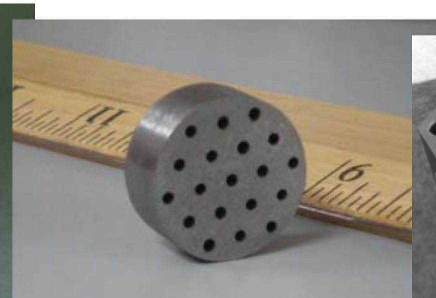
- Goals
  - Mature CERMET and Graphite based fuel materials
  - Develop and demonstrate critical technologies and capabilities
- Objective
  - Along with other NASA centers and DOE, optimize manufacturing processes to develop an NTP fuel material
    - Idaho National Laboratory (INL)
    - Oak Ridge National Laboratory (ORNL)
  - Fabricate CERMET, graphite composite and advanced carbide fuel element samples with depleted uranium fuel particles
  - Complete mechanical and thermal property testing to develop an understanding of the process/property/structure relationship
  - Perform full scale element testing of CERMET and graphite fuels



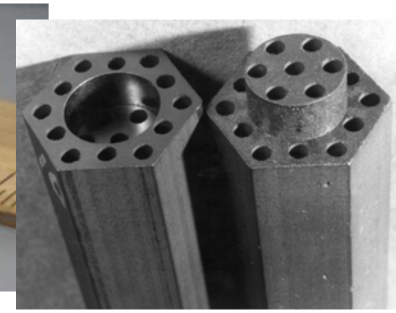
331 Channel Hex Demo (MSFC)



19 Channel HIP Demo (MSFC)



19 Channel PECS Demo (INL)



Graphite Composite Fuel Element (Rover/NERVA)

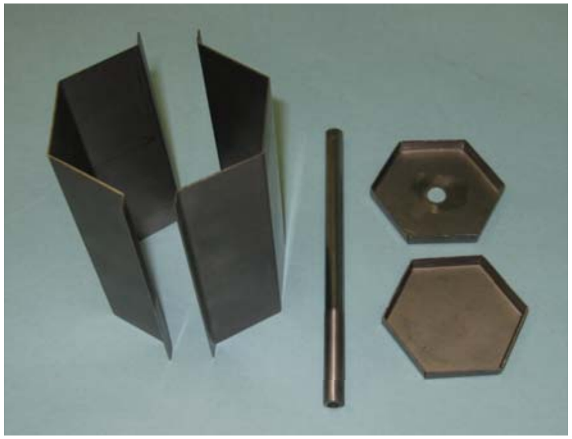
Hot Isostatic Pressing (HIP) Consolidation Process

- Net shape or near net shape processing
  - Integral HIP bonded claddings
  - Internal geometries
- Minimal post HIP processing
  - HIP can removal
  - Removal of mandrels to achieve internal geometries
- Powder metallurgy fabrication process
- Ability to produce high density components
  - >99% theoretical density

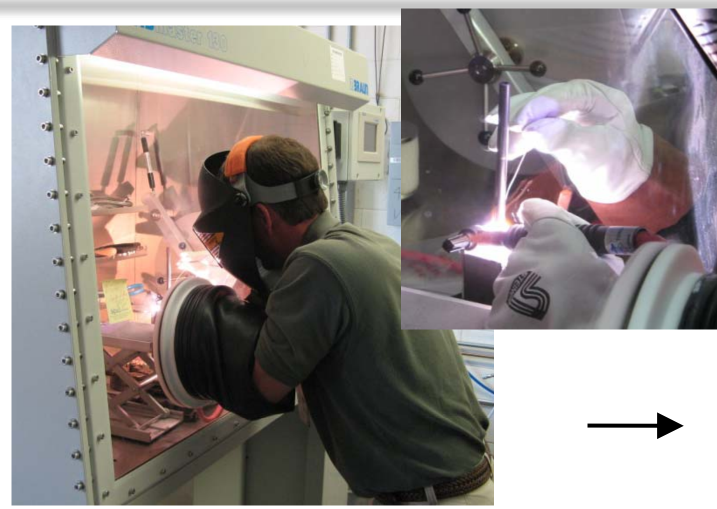
American Isostatic Presses Inc. HIP unit

- HIP parameters
  - Chamber temperatures ~70% of material melting point
  - Chamber pressures range from 15- 35 ksi
  - Cycle times 2- 6 hours

Net Shape HIP Fabrication Process

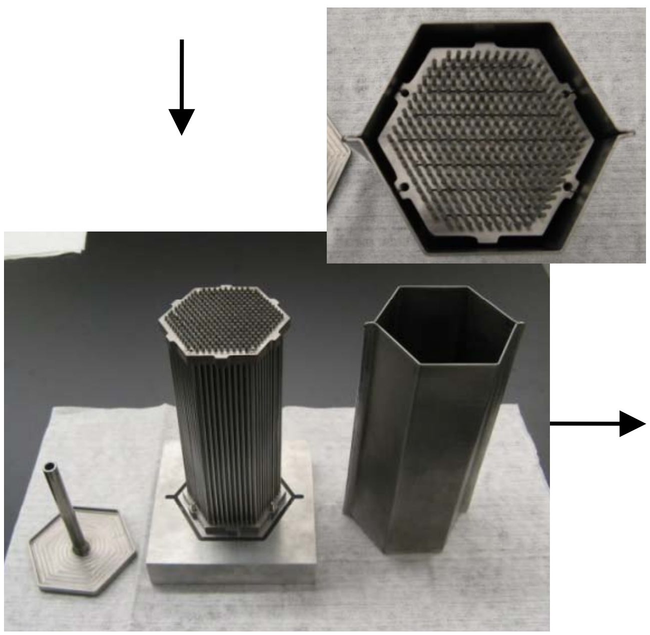


Hexagonal HIP can components

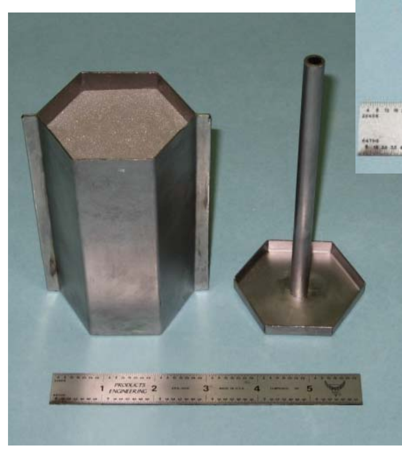


Final closeout weld

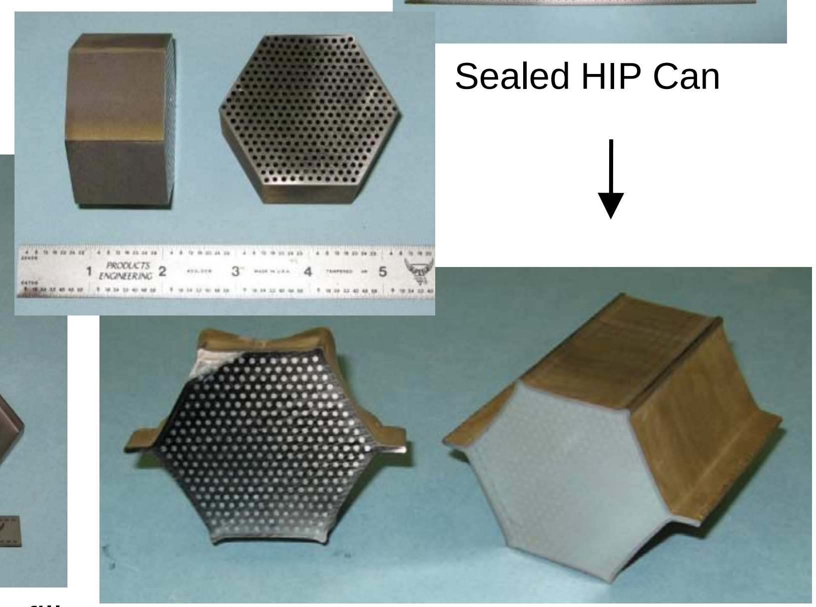
Sealed HIP Can



Mo Mandrel assembly



HIP can after powder fill



Can assembly after HIP cycle

NCPS Task 4 HIP Development Approach

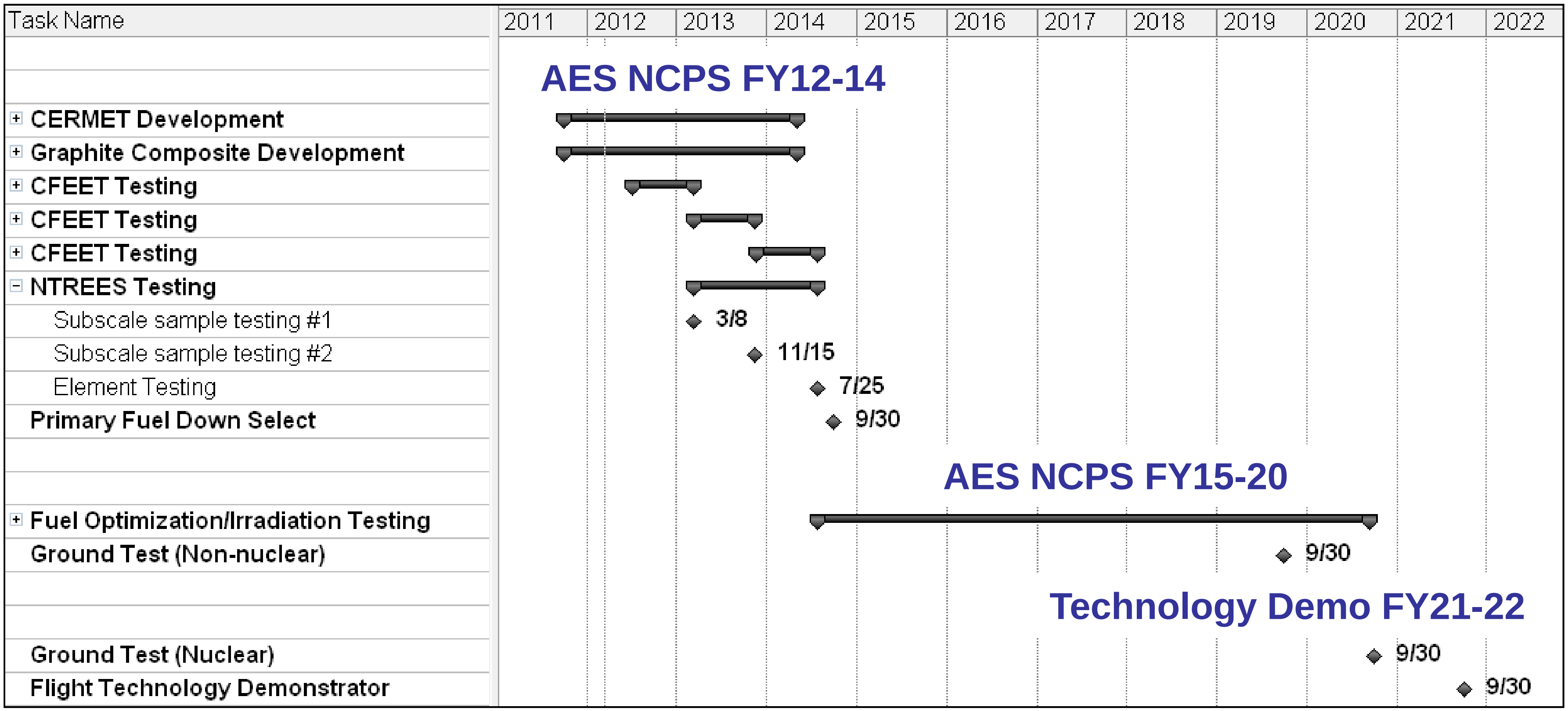
- HIP fabrication of W-UO2 CERMET fuel elements
  - Compositions and forms based on proven heritage materials and processes
  - Mono and mixed sized fuel particles ranging from 5um- 100um
- Material characterization
  - Characterization to evaluate microstructure, density, grain size, and chemistry
  - Material testing to include tensile, thermal conductivity, CTE and fatigue/ fracture
  - Surrogate fuel particles will be used in early development, CeO_2
- Hot Hydrogen Testing
  - Sample will be tested in static and flowing H_2 environment to evaluate material performance
  - Evaluate fuel mass loss, microstructure, claddings, particle coatings and stabilizers
  - Small scale sample testing, 0.5”- 1” diameter x 1” – 3” long (CFEET)
  - Large scale element testing, prototypic element dimensions, 1.09” ftf x 16.8” long, 61 channels

Preliminary Hot Hydrogen Test Matrix

Sample Description (W-60 volume % UO2)	Specimen Geometry	Peak Temperature	Thermal Cycles	Environment
Uncoated UO2	CFEET Slug	2850K	10	Flowing H2
Uncoated UO2	CFEET 7-Hole ANL 200MW	2850K	10	Flowing H2
Uncoated w/clad	CFEET 7-Hole ANL 200MW	2850K	10	Flowing H2
Coated UO2	CFEET Slug	2850K	10	Flowing H2
Coated UO2	CFEET 7-Hole ANL 200MW	2850K	10	Flowing H2
Coated UO2 w/clad	CFEET 7-Hole ANL 200MW	2850K	10	Flowing H2
***Coated UO2 w/clad**	**Subscale NTREES ANL 200MW**	**2850K**	**10**	**Flowing H2**
Stabilized coated UO2 w/clad	CFEET 7-Hole ANL 200MW	2850K	10	Flowing H2
Optimized M&P #1	CFEET 7-Hole ANL 200MW	2850K	10	Flowing H2
***Optimized M&P #1**	**Subscale NTREES ANL 200MW**	**2850K**	**10**	**Flowing H2**
Optimized M&P #2	CFEET 7-Hole ANL 200MW	2850K	10	Flowing H2
***Optimized M&P #2**	**NTREES ANL 200MW Element**	**2850K**	**10**	**Flowing H2**

***NCPS fuel design and fabrication task milestone**

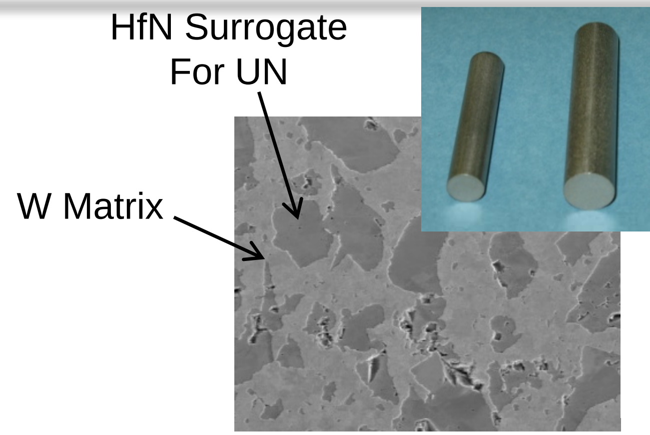
Notional Fuel Development Schedule



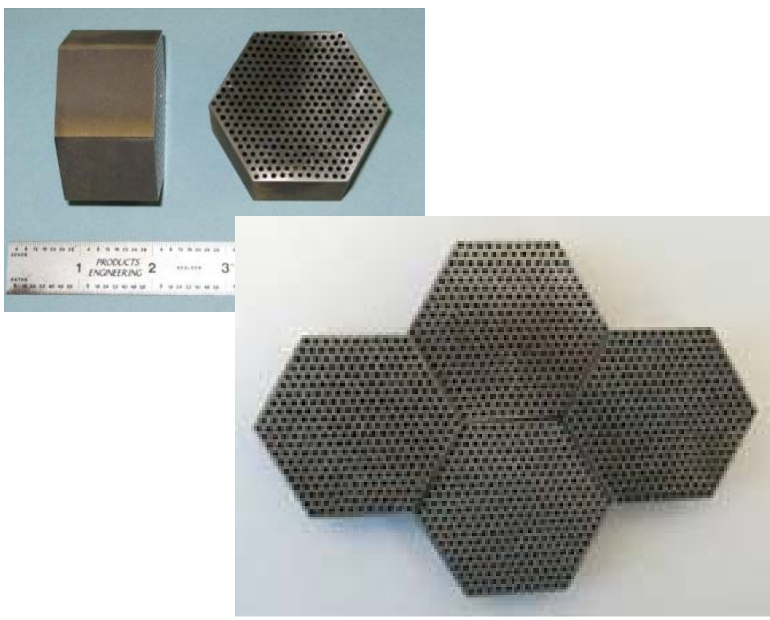
- Fuel down selection dependant on clear criteria and decisional analysis
- Fuel optimization and irradiation testing prior to ground test
- Nuclear systems are small engine technology demonstrators

HIP Processing of NTP Fuel Elements at MSFC

- Demonstrated fabrication of Rover/NERVA 19 channel configuration
  - 1” dia. x 2” and 12” long
  - 19 channels, 0.125” diameter
- Demonstrated fabrication of ANL 2000MW Nuclear Rocket design
  - 2.81” flat-to-flat x 6” long
  - 331 channel, 0.067” diameter



CERMET (W/HfN)



331 channel hexagonal element demonstration

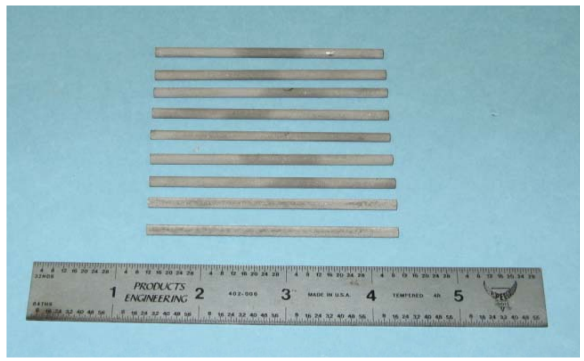
Net Shape Fabrication of W-HfN CERMETs

Net Shape HIP Fabrication Capabilities

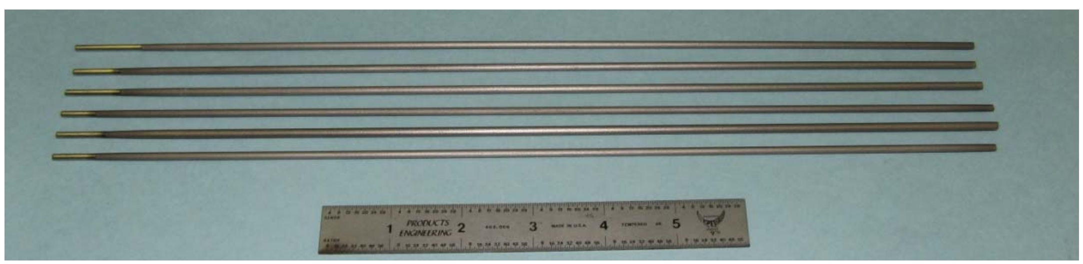
- Integral claddings on both OD and ID of net shape element
- W- 60Vol% ZrO_2 CERMET
- Two VPS W coated Mo mandrels, 0.010” thickness
- Two EL-Form W coated Mo mandrels, 0.010” thickness
- W OML Clad, 0.030” thickness

HIP components prior to powder fill

VPS W and W-5Re cladding inserts

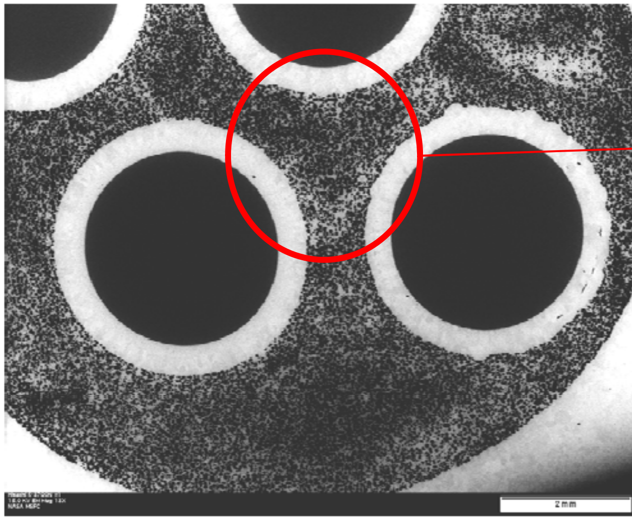


EL-Form W coated Mo Mandrels

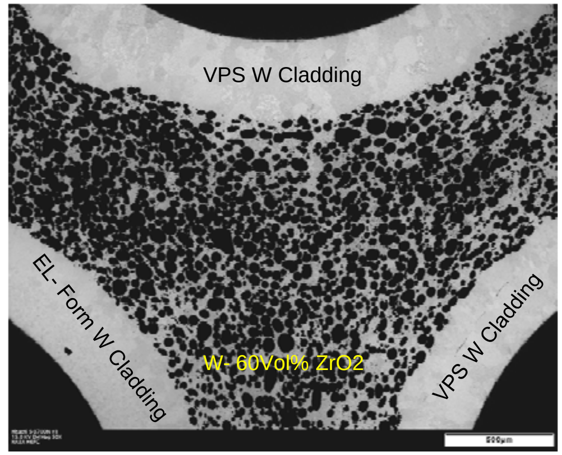


Vacuum Plasma Sprayed tungsten on Mo mandrels

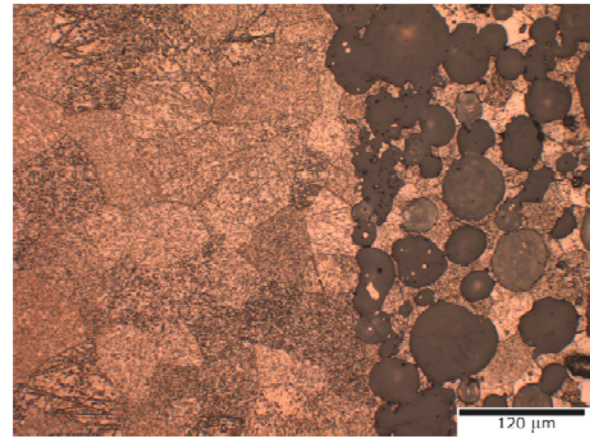
Integrally Clad Sample Micrographs
W-60Vol% ZrO2



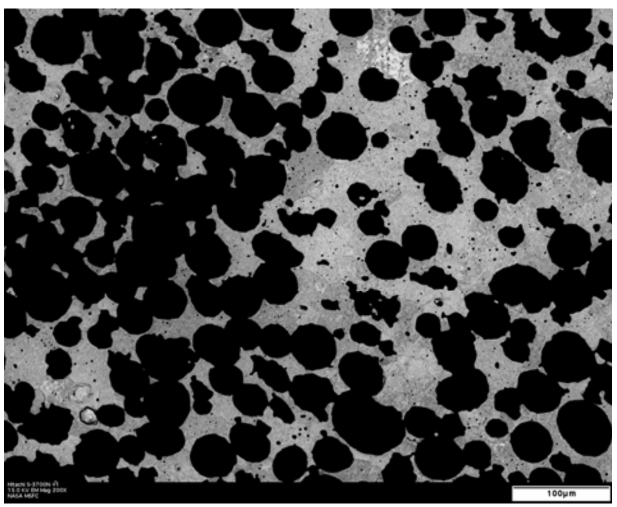
SEM image 13x



SEM image 50x

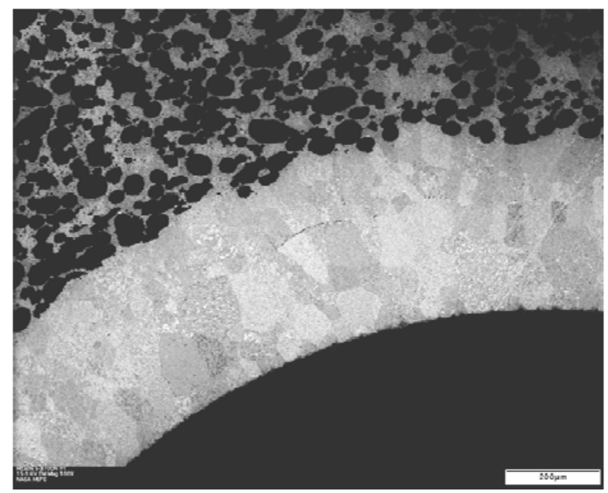


Optical image 200x,
OML Clad/ CERMET interface



SEM image 200x, ZrO2 (black particles)

SEM image 100x, W EL-Form interface



SEM image 100x, W VPS interface

Conclusions

- Lack of a qualified NTP fuel form and long lead item
- NCPS goal is to fabricate and test multiple fuels; CERMETs and graphite composites
- HIP development approach is defined
  - Sub scale and full length prototypic fabrication and testing
  - Uncoated, uncoated/clad, coated, coated/clad, stabilized, optimized
  - Acceptable risks
- MSFC has demonstrated the ability to HIP NS/NNS complex geometries with integral coolant channels and claddings
- Three years to fabricate, test and down select to a viable NTP fuel form
- NASA and DOE integrated fuel team to complete the large amount of work required for the NCPS Project