Design Evolution of Hot Isostatic Press Cans for NTP Cermet Fuel Fabrication

NASA Advanced Exploration System (AES) Project

NETS
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Background

- NTP fuels under development
  - W-60vol%UO_2 CERMET
  - W coated UO_2 spherical kernels
  - W coolant channel, perimeter, face clad
  - Inherent stability of W clad in hot H_2 minimize fuel erosion and fission product release during NTP operation

- HIP Manufacture Advantages
  - Near net-shape
  - Full scale
  - High density
  - Existing industrial base

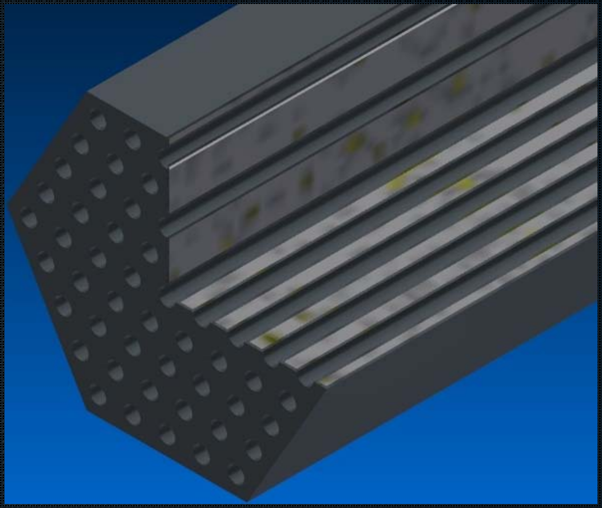
331 and 7 channel fuel samples

HIP Furnace

Problem & Objective

- Fuel Element Constraints
  - Fully encapsulated fuel kernels
  - Long length
  - Numerous coolant channels
  - Integral claddings
  - Limited to refractory alloys (Nb, Ta, Mo)
  - Powder metallurgical constraints

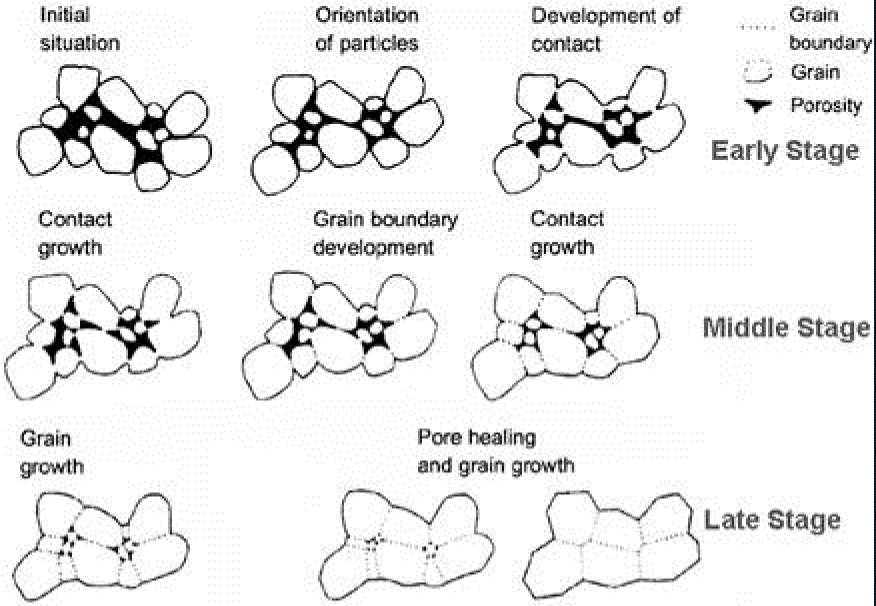
- Develop a sub-scale and full-scale HIP cans that can be used to fabricate NTP fuel elements for process development and fuel element evaluation.



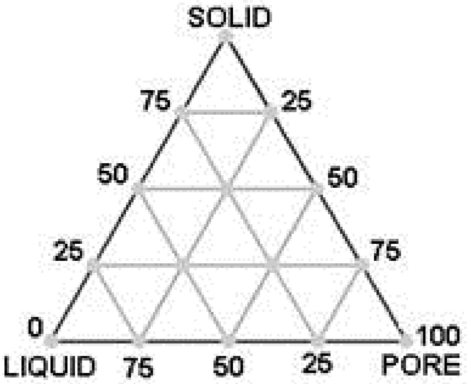
61 channel cermet fuel element concept (ANL-200 reference)

Consolidation

- Powder Characteristics
  - Appropriate coarse, medium and fine grain distribution
  - Green packing density drives shrinkage/dimensional tolerance
- Sinter Temperature
  - 80% of powder melting temperature
- Pressure
  - >15 ksi for consolidation onset
- Atmosphere
  - Compatible with can: argon
- Time
  - T /P ramp rates and hold times influence microstructure



Consolidation process

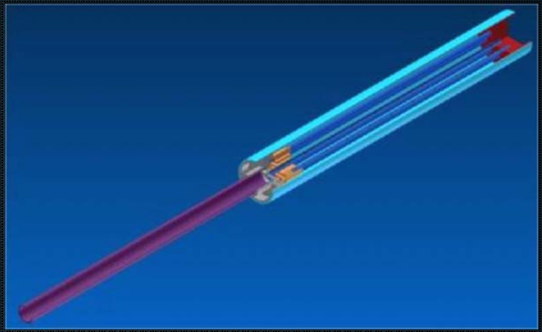


Ternary phase diagram

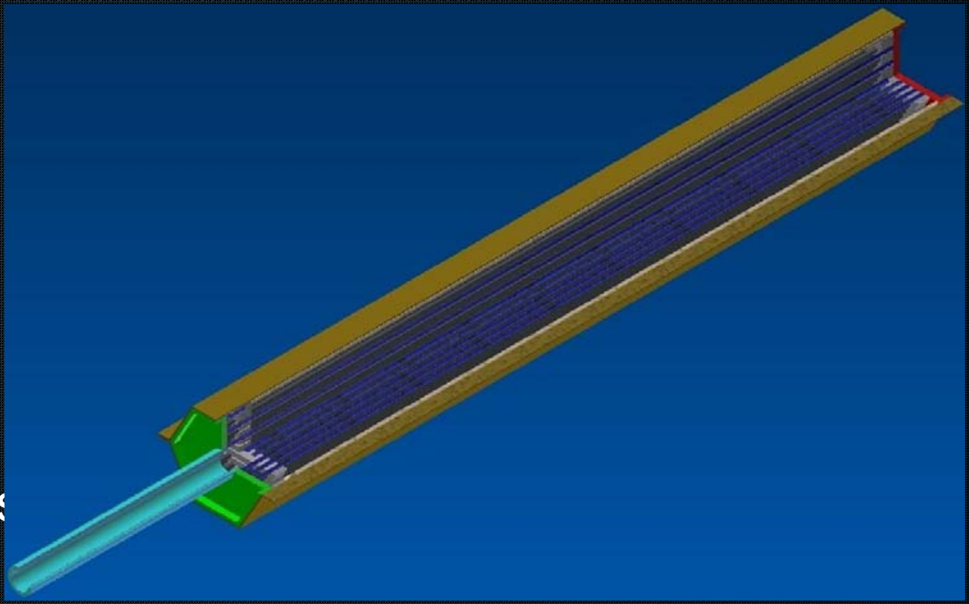
HIP Can Design

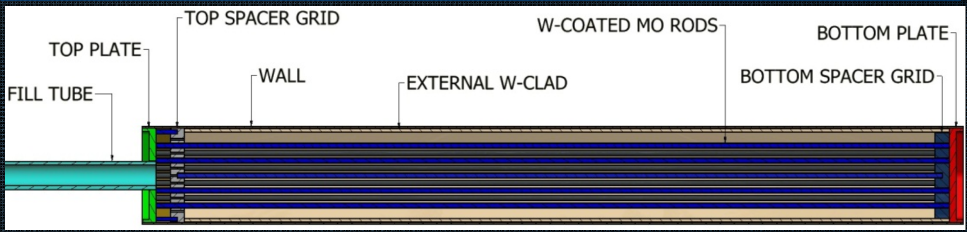
- Design features
  - Complex hexagonal can/mandrel geometry
  - 19-61 channels
  - 50-100 cm length
  - Perimeter clad
  - Coolant channel & face clad

- Design constraints
  - 10-20% shrinkage
  - Channels must not bow or twis
  - Sufficient flow area for viable powder fill



Circular 7 channel can design



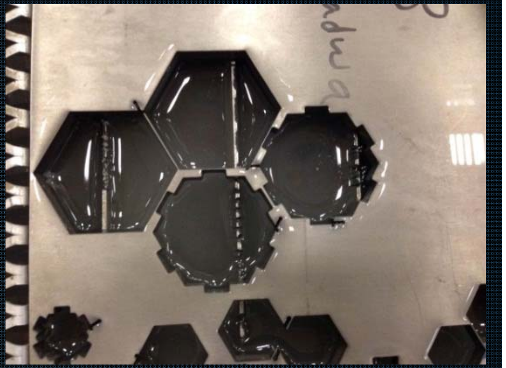


61 channel HIP can design (ANL-200 reference)

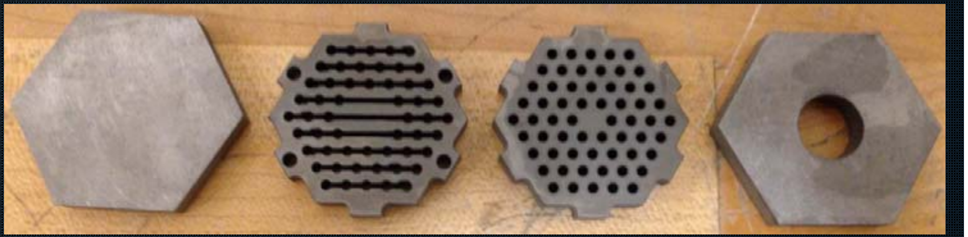
HIP Can Manufacture

- CNC milling
  - Specialized techniques for Nb
  - Time consuming
  - Expensive (time and materials)
- Water jet machining
  - Iterative development process
  - Non-specialized techniques
  - Significant time reduction
  - Sufficient dimensional tolerance
  - Minimal material waste
  - Minor milling required
- CNC sheet metal break
  - Axial tolerance difficult to achieve
  - Tolerance variation proportional to length

Water-Jet



Material Optimization



Water-jet cut niobium HIP can components (43 min prod. Time)

Can component fit-checks

Integral Clad

- Coolant channel clad
  - Vacuum plasma spray (VPS)
  - W onto Mo mandrel rods
  - Thickness uniformity and adhesion
  - Completed through a Phase I SBIR by Plasma Processing Inc. (PPI)

W coated Mo rods (EL-form)

- Perimeter Clad
  - Electro (EL)-form
  - W onto a graphite mandrel
  - High density and hermiticity
  - Developed under same PPI effort

External W clads (VPS)

Can Assembly

- Can wall welded
- Mandrel rods stacked between spacer grids
- Enclose mandrel in wall
- Can top welded to can
- Vacuum leak check

61 Channel Full Size HIP Can

7 Channel Subscale HIP Can

Weld in a argon glove box

Fill & Close-Out

- Can surface cleaned
- Can weighed and measured
- Can vibratory filled in a glove box
- Filled can weighed
- Can evacuated
- Fill tube crimped
- Seam weld and fill tube excess cut

61 channel near full scale HIP can: filled and closed out

HIP Operations

- HIP can placed in can jig
- Jig placed in HIP furnace
- HIP schedule initiated
- Remove jig
- Weigh and measure can

HIP Jig

Jig in furnace

Subscale Can Removal

Results

- 2013 HIP Trials
  - Circular 7 channel W-ZrO_2
  - Hex 61 channel, near full length W-ZrO_2: Fail
  - Circular slug W-dUO_2 x 2
  - Hex 7 channel W-dUO_2
  - Hex 61 channel, full length W-ZrO_2: Fail

- Failure Analysis
  - Wall cracking observed at can base
  - Significant reduction in ductility of HIP can coupons when compared to control samples
  - SEM/EDS revealed significant C embrittlement
  - Nb can interaction with graphite jig or furnace

W-dUO_2 filled HIP can

Failed HIP can

Conclusions

- HIP is viable for NTP fuel cermet fabrication
- Fundamental mechanisms are well understood
- Difficulty to meet NTP engine requirements proportional to length
- Design optimization highly iterative
- Significant opportunity for process and design improvement

Recommendations for Future Work

- Develop mitigation strategy to prevent Nb-C interaction
  - Mandrel coating?
  - Sacrificial getter foil?
- 19 channel Rover/NERVA geometry
  - Develop HIP can design
  - Fabricate prototype
  - Fabricate fuel element
- Optimize can designs
  - Finalize can geometry based on nominal green powder packing density
  - Establish fuel dimensional tolerance and NDE requirements
- Investigate methods for W can fabrication
  - Water jet of W sheet
  - VPS?
  - EL-forming?
  - Additive Manufacture?
  - Dip & HIP?

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- The opinions expressed in this presentation are those of the author and do not necessary reflect the views of NASA or any NASA Project.