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

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Background

• NTP fuels under development
  - W-60vol%UO₂ CERMET
  - W coated UO₂ spherical kernels
  - W coolant channel, perimeter, face clad
  - Inherent stability of W clad in hot H₂ minimize fuel erosion and fission product release during NTP operation

• HIP Manufacture Advantages
  - Near net-shape
  - Full scale
  - High density
  - Existing industrial base
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.
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
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 twist
  − Sufficient flow area for viable powder fill
**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 cut niobium HIP can components (43 min prod. Time)*

*Material Optimization*

*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)

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

- Can wall welded
- Mandrel rods stacked between spacer grids
- Enclose mandrel in wall
- Can top welded to can
- Vacuum leak check
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
• HIP can placed in can jig
• Jig placed in HIP furnace
• HIP schedule initiated
• Remove jig
• Weigh and measure can
Results

• 2013 HIP Trials
  – Circular 7 channel W-ZrO₂
  – Hex 61 channel, near full length W-ZrO₂: Fail
  – Circular slug W-dUO₂ x 2
  – Hex 7 channel W-dUO₂
  – Hex 61 channel, full length W-ZrO₂: 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
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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