NTP CERMET Fuel Development Status

Marvin W. Barnes¹

¹Metals Engineering Division, NASA Marshall Space Flight Center

Nuclear and Emerging Technologies for Space (NETS) 2017 Orlando, FL
Presentation Overview

NTP CERMEN'T FUEL DEVELOPMENT
• GE710 Program
• NTP CERMET Fuel Development

CERMET FABRICATION USING TUNGSTEN POWDER COATING AND SPARK PLASMA SINTERING
• Background
• Tungsten Powder Coating
• Spark Plasma Sintering
• Experimental Approach
• Results
• Conclusions
GE710 Program

• Extensive CERMET fuel development program
  – Over 15 million invested from May 1962 to Sept 1968
  – Operated fuel element fabrication line for reactor-sized fuel elements
  – Successfully fabricated 40+ W-60vol%UO$_2$ fuel elements for qual testing
    • Conducted over 300,000 hours of qualification testing

• 710 fabrication approach
  – Press and sinter W-UO$_2$ compacts
  – Machine cooling channels
  – Stack compacts
  – Weld tubes for cooling
  – Weld external cladding

AEC Research and Development “710 High Temperature Gas Reactor Program Summary Report” GEMP-600; Vol I; 1969
NTP CERMET Fuel Development

• Hybrid GE710 Approach
  – GE710 approach with modern fabrication processes
    • Spark Plasma Sintering
    • Tungsten Powder Coating

• FY16 Development Efforts
  – Fabricated W-dUO$_2$ compacts using Spark Plasma Sintering and Tungsten Powder Coating
  – Phase I SBIR – Bonding tungsten CERMET compacts
  – Phase I SBIR - Electrolytic method for tungsten coating

NTP CERMET Fuel Development

**FY17 Development Efforts**
- Developing process to fabricate subscale surrogate elements from compacts
- Optimizing compact fuel element environmental testing (CFEET) apparatus
- Initiating multiscale modeling task
- Tungsten electron beam welding study

**FY18 Planning**
- SPS fabricate compacts with particles provided by BWXT
- Hot hydrogen screening of W-dUO$_2$ compacts and subscale fuel segments
CERMET Fabrication using Tungsten Powder Coating and Spark Plasma Sintering

Marvin W. Barnes¹, Dr. Dennis Tucker¹, Lance Hone² and Steven Cook²

¹Metals Engineering Division, NASA Marshall Space Flight Center
²Center for Space Nuclear Research

Nuclear and Emerging Technologies for Space (NETS) 2017 Orlando, FL
Background

• Past efforts focused on consolidating blended tungsten powder and uncoated $\text{dUO}_2$ particles
  – Poor quality feedstock
    • Large particle size distribution
    • Non-spherical particles - agglomeration
    • Need for coated particles
  – Particle segregation/non-uniform distribution of $\text{UO}_2$ within W matrix
  – Low density/ partial consolidation
  – Fuel element distortion
  – Explored CVD coating
    • Complex process due to the need to fluidize particles

• Developed W powder coating
  – Non compatible with past consolidation methods
  – Led to SPS

• Small amount of CIF funding augmented by NTP Project

Tungsten Powder Coating

• Straightforward approach to particle coating
• Conducted experiments with 6 different organic binders
• Coating Process
  – Blend W powder, dUO₂ particles, and binder
  – Stir mixture above binder drop point on hot plate for 5 min
• Not as uniformly coated as CVD coated particles

Spark Plasma Sintering

- Rapid Consolidation/Sintering
- Net-shape/Near Net-Shape Parts
- High Density Parts
- Simple Process

1. Pictures courtesy of UC Davis and Substech
Experimental Approach

- Utilized SPS system at CSNR to sinter W/UO₂ samples
  - Used W powder coated particles
- Sintered 24 samples at 1600C, 1700C, 1750C, 1800C, and 1850C peak temperatures
- 20-minute dwell time at peak temperatures; Pressure of 50 MPa
- Measured density and SEM
- TEM, hardness, and further SEM planned
- CFEET testing planned
### Results

- **Density**
  - Increased with peak sintering temperature
  - Near theoretical density

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Thickness (mm)</th>
<th>Diameter (mm)</th>
<th>Average Density (g/cm³)</th>
<th>Percent of Theoretical (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NASA-SPS-1850C-001</td>
<td>5.90</td>
<td>19.93</td>
<td>14.2</td>
<td>99.5</td>
</tr>
<tr>
<td>1800C-001</td>
<td>5.45</td>
<td>19.95</td>
<td>14.1</td>
<td>98.5</td>
</tr>
<tr>
<td>1800C-002</td>
<td>5.94</td>
<td>19.96</td>
<td>14.1</td>
<td>98.6</td>
</tr>
<tr>
<td>1800C-003</td>
<td>5.57</td>
<td>19.91</td>
<td>14.1</td>
<td>98.5</td>
</tr>
<tr>
<td>1800C-004</td>
<td>6.03</td>
<td>19.91</td>
<td>14.0</td>
<td>98.3</td>
</tr>
<tr>
<td>1800C-005</td>
<td>5.60</td>
<td>19.93</td>
<td>14.0</td>
<td>98.2</td>
</tr>
<tr>
<td>1750C-001</td>
<td>6.10</td>
<td>19.89</td>
<td>14.1</td>
<td>98.7</td>
</tr>
<tr>
<td>1750C-002</td>
<td>6.15</td>
<td>19.90</td>
<td>14.0</td>
<td>98.2</td>
</tr>
<tr>
<td>1750C-003</td>
<td>5.60</td>
<td>19.96</td>
<td>14.1</td>
<td>98.7</td>
</tr>
<tr>
<td>1750C-004</td>
<td>5.70</td>
<td>19.90</td>
<td>14.1</td>
<td>98.7</td>
</tr>
<tr>
<td>1700C-001</td>
<td>6.00</td>
<td>19.90</td>
<td>14.0</td>
<td>98.1</td>
</tr>
<tr>
<td>1700C-002</td>
<td>6.40</td>
<td>19.93</td>
<td>14.0</td>
<td>98.1</td>
</tr>
<tr>
<td>1700C-003</td>
<td>5.93</td>
<td>19.90</td>
<td>13.9</td>
<td>97.6</td>
</tr>
<tr>
<td>1700C-004</td>
<td>6.00</td>
<td>19.96</td>
<td>14.0</td>
<td>98.2</td>
</tr>
<tr>
<td>1600C-001</td>
<td>6.10</td>
<td>19.90</td>
<td>13.9</td>
<td>97.2</td>
</tr>
</tbody>
</table>

Results

- Density

Max Temp vs % Theoretical Density

![Graph showing the relationship between Max Temp (°C) and % of Theoretical Density. The data points range from 97.0% to 100.0% density at various Max Temp values. The trend line indicates an increasing relationship.]
Results

- SEM
  - Improved microstructure
  - UO₂ particles more uniformly dispersed
  - Cross-section depicts some particle elongation

Results

- Energy-dispersive X-ray spectroscopy (EDS)
  - No unexpected phases
Conclusions

• Improved mechanical properties and microstructure
• Further characterization needed and planned
  – Mechanical Properties
  – Thermal Properties
  – Chemistry
• Develop process to form elements from compacts
  – Stacking
  – Bonding
  – Cooling channel formation
  – Cladding