

National Aeronautics and
Space Administration



NTP CERMET Fuel Development Status

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for Space (NETS) 2017 Orlando, FL*



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Presentation Overview

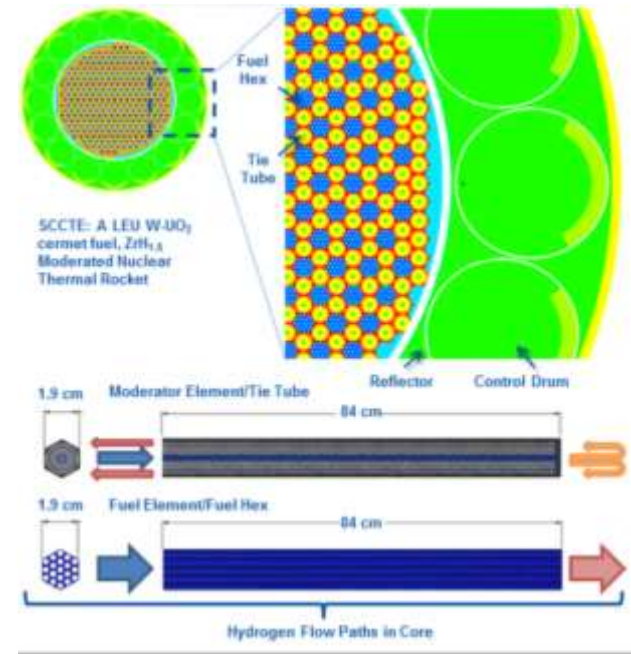


NTP CERMENT FUEL DEVELOPMENT

- 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

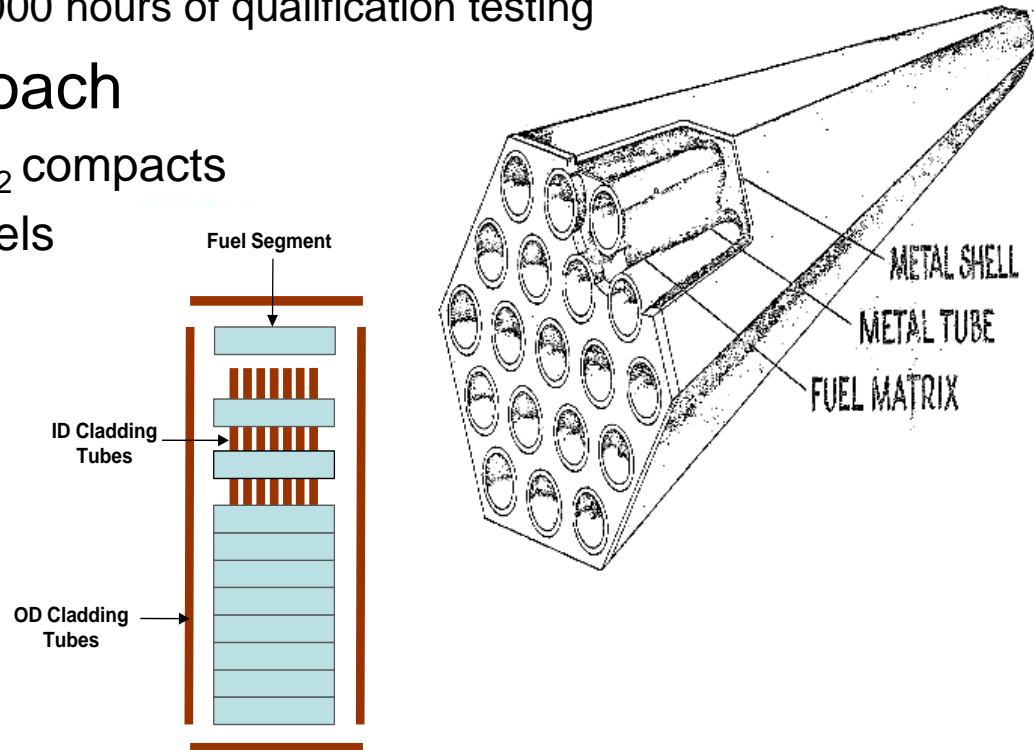




GE710 Program



- 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%UO₂ fuel elements for qual testing
 - Conducted over 300,000 hours of qualification testing
- 710 fabrication approach
 - Press and sinter W-UO₂ compacts
 - Machine cooling channels
 - Stack compacts
 - Weld tubes for cooling
 - Weld external cladding

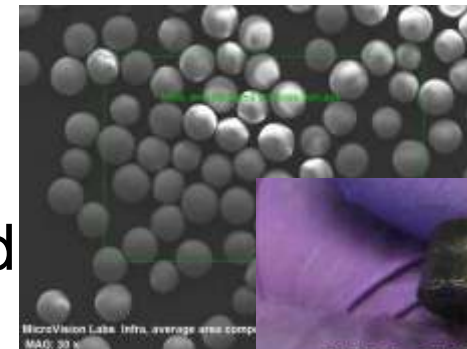
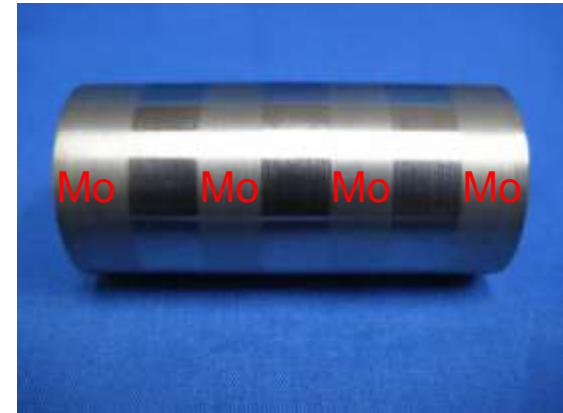




NTP CERMET Fuel Development



- Hybrid GE710 Approach
 - GE710 approach with modern fabrication processes
 - Spark Plasma Sintering
 - Tungsten Powder Coating
- FY16 Development Efforts
 - Fabricated W-dUO₂ compacts using Spark Plasma Sintering and Tungsten Powder Coating
 - Phase I SBIR – Bonding tungsten CERMET compacts
 - Phase I SBIR - Electrolytic method for tungsten coating

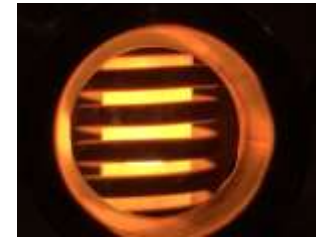




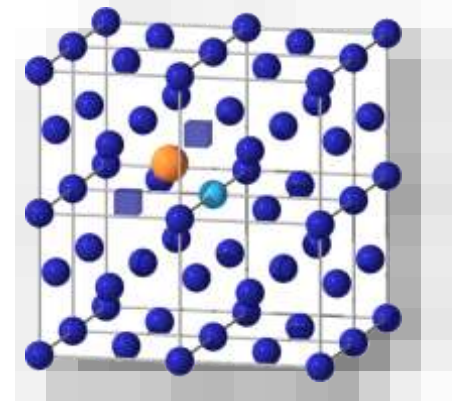
NTP CERMET Fuel Development



- 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-dUO₂ compacts and subscale fuel segments



CFEET Testing



Multiscale Modeling

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CERMET Fabrication using Tungsten Powder Coating and Spark Plasma Sintering

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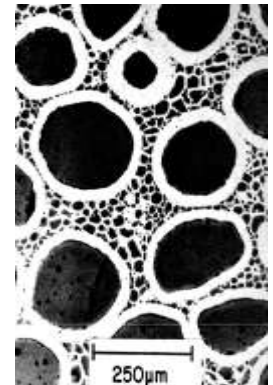
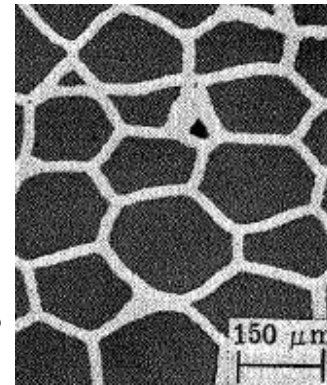
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Background



- Past efforts focused on consolidating blended tungsten powder and uncoated dUO_2 particles
 - Poor quality feedstock
 - Large particle size distribution
 - Non-spherical particles - agglomeration
 - Need for coated particles
 - Particle segregation/non-uniform distribution of 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

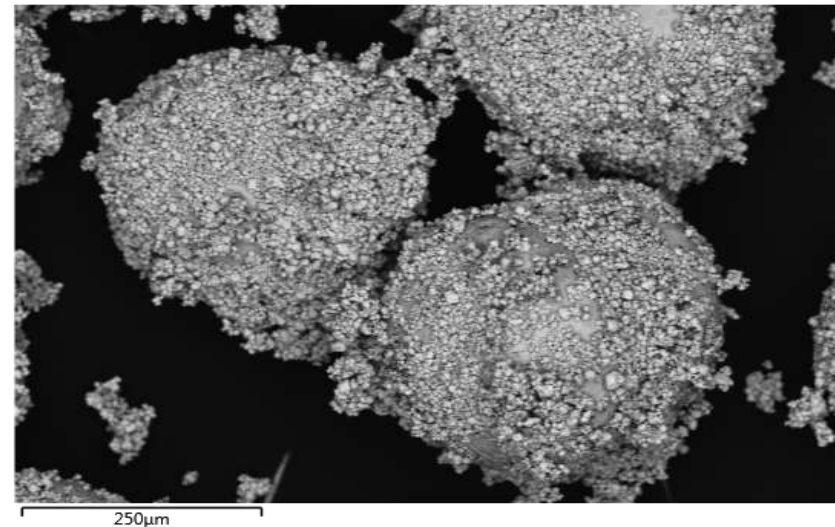
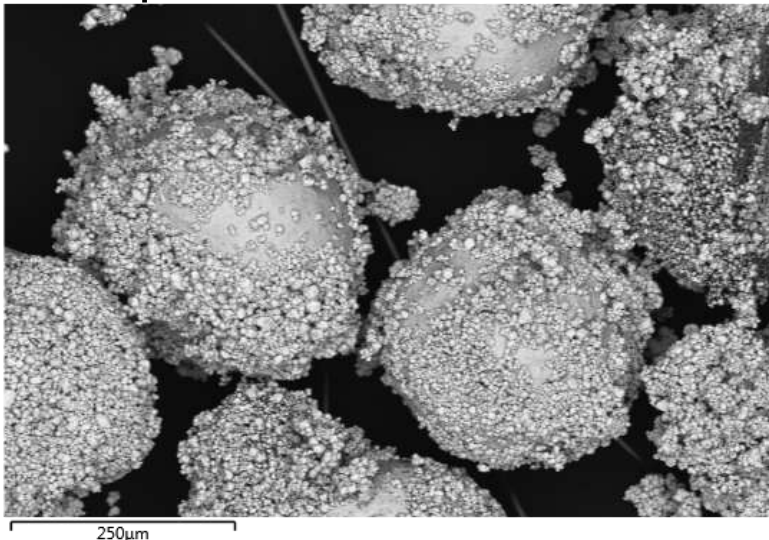
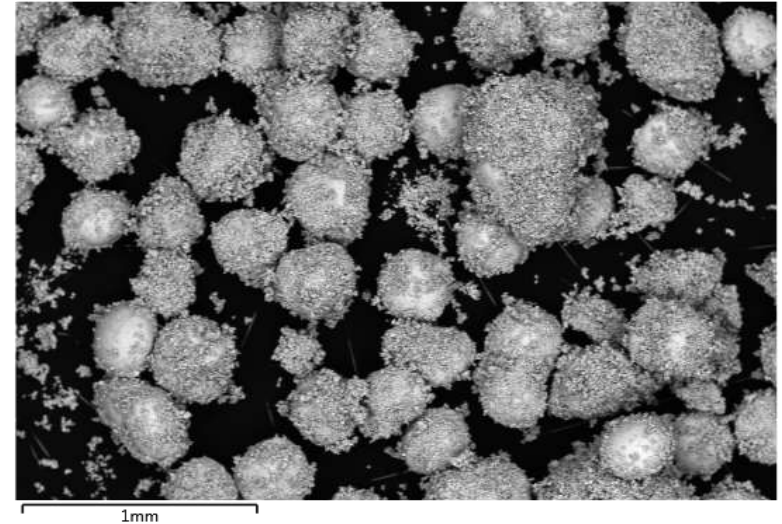




Tungsten Powder Coating



- Straightforward approach to particle coating
- Conducted experiments with 6 different organic binders
- Coating Process
 - Blend W powder, dUO_2 particles, and binder
 - Stir mixture above binder drop point on hot plate for 5 min
- Not as uniformly coated as CVD coated particles

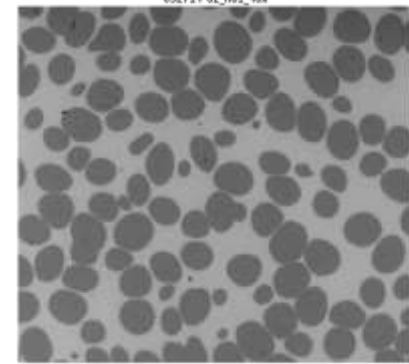
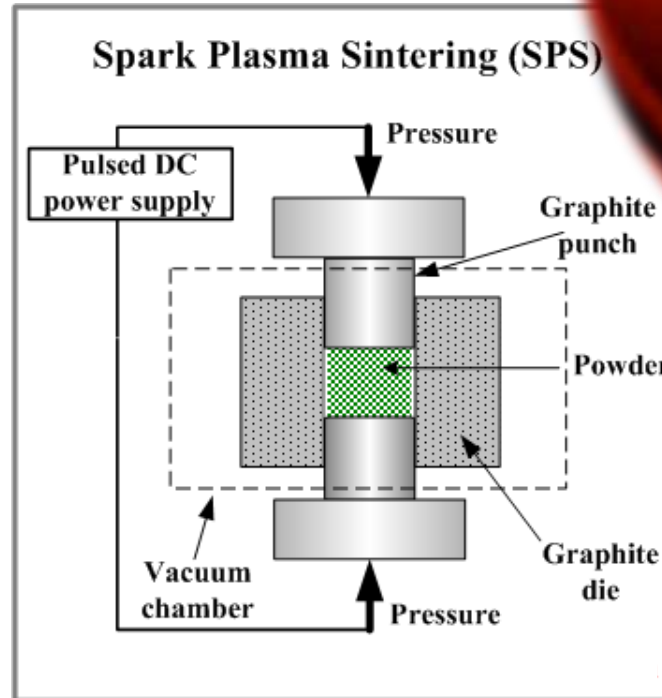
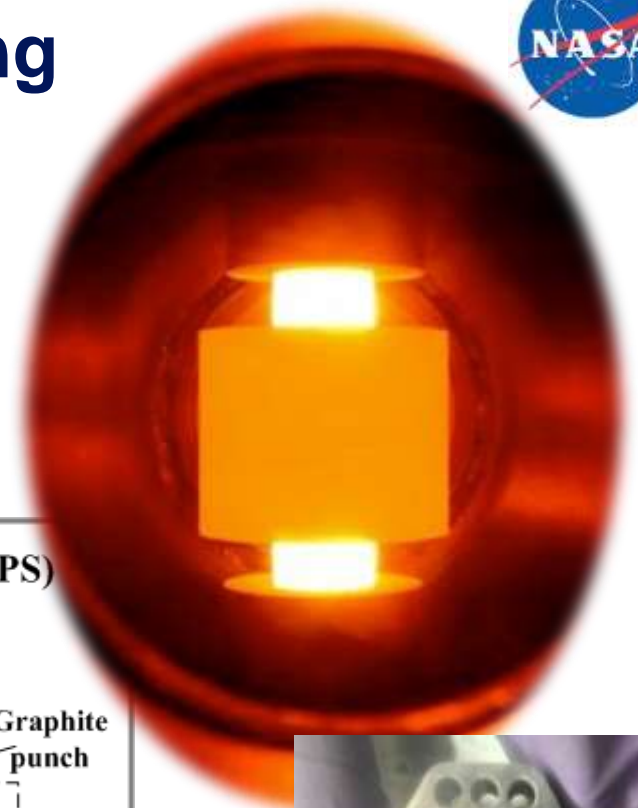




Spark Plasma Sintering



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



1. Pictures courtesy of UC Davis and Substech
2. R.C. O'Brien, S.K. Cook, L.C. Hone. "Fabrication of depleted UO₂-W Cermet Fuel Elements via Spark plasma Sintering: Advances and Progress Made", Stennis Space Center, MS : s.n., 2014. Nuclear and Emerging Technologies (NETS).



Experimental Approach



- Utilized SPS system at CSNR to sinter W/ UO_2 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
- CFEEET testing planned





Results



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

Specimen	Thickness (mm)	Diameter (mm)	Average Density (g/cm ³)	Percent of Theoretical (%)
NASA-SPS-1850C-001	5.90	19.93	14.2	99.5
1800C-001	5.45	19.95	14.1	98.5
1800C-002	5.94	19.96	14.1	98.6
1800C-003	5.57	19.91	14.1	98.5
1800C-004	6.03	19.91	14.0	98.3
1800C-005	5.60	19.93	14.0	98.2
1750C-001	6.10	19.89	14.1	98.7
1750C-002	6.15	19.90	14.0	98.2
1750C-003	5.60	19.96	14.1	98.7
1750C-004	5.70	19.90	14.1	98.7
1700C-001	6.00	19.90	14.0	98.1
1700C-002	6.40	19.93	14.0	98.1
1700C-003	5.93	19.90	13.9	97.6
1700C-004	6.00	19.96	14.0	98.2
1600C-001	6.10	19.90	13.9	97.2

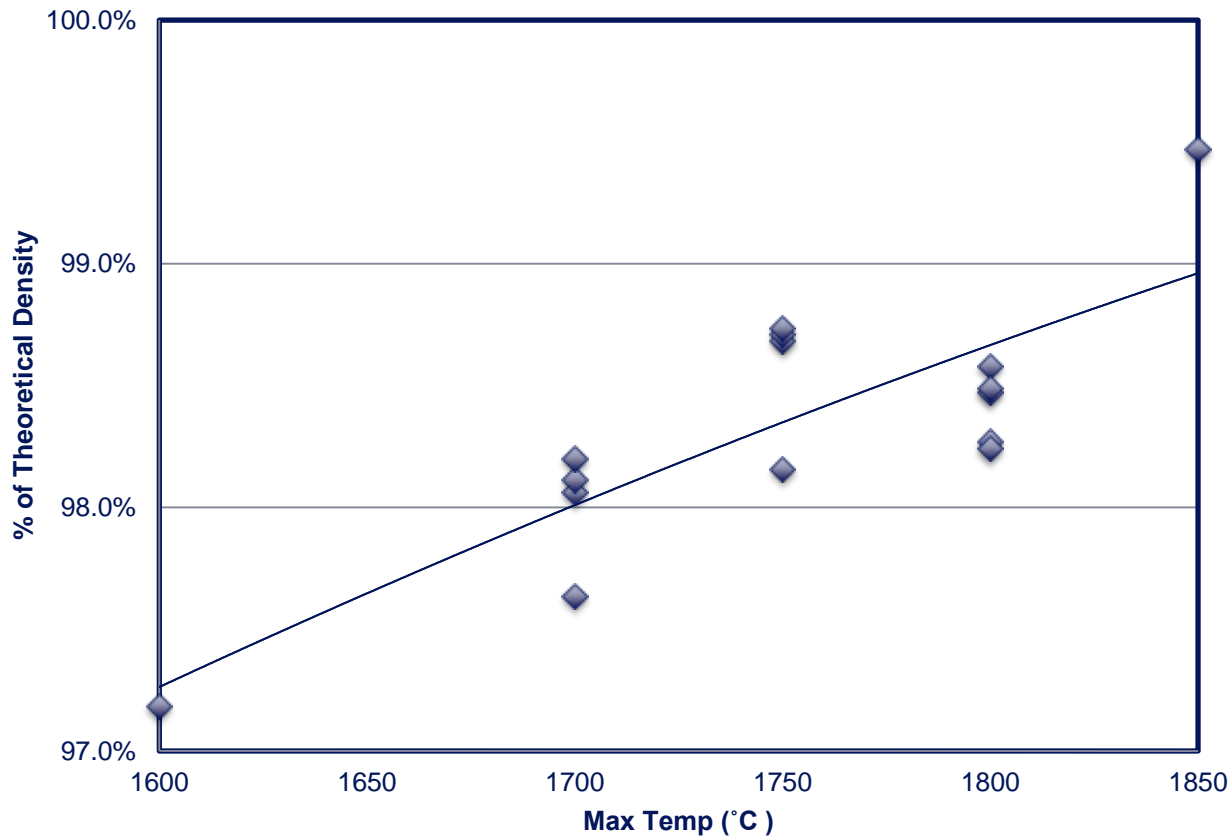


Results



- Density

Max Temp vs % Theoretical Density

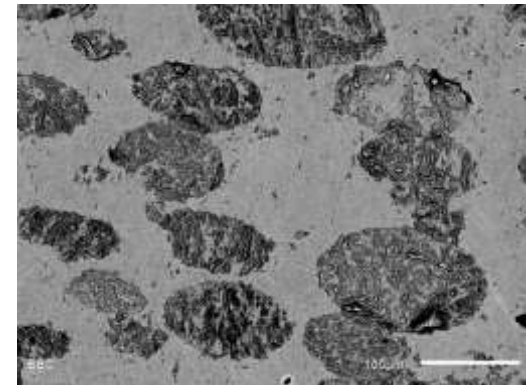
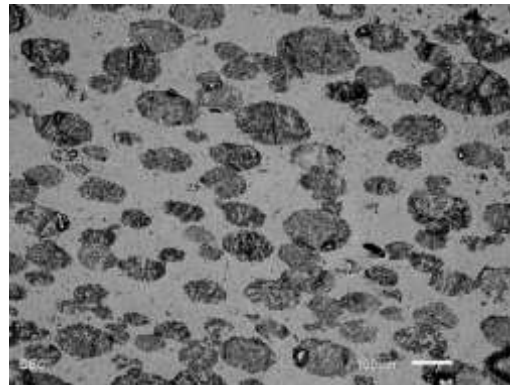
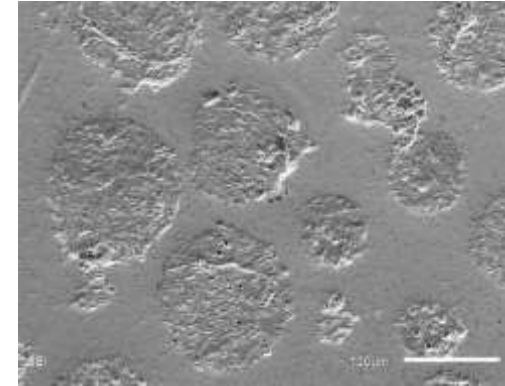
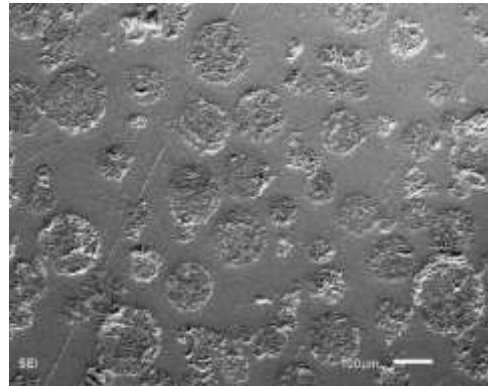
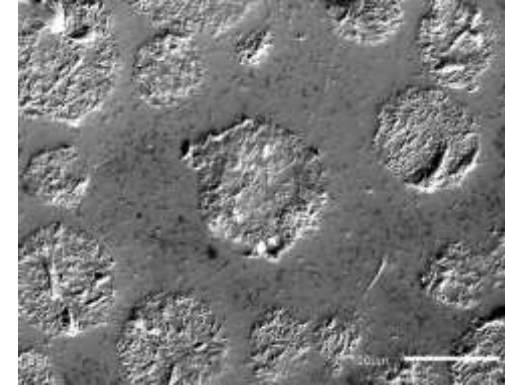
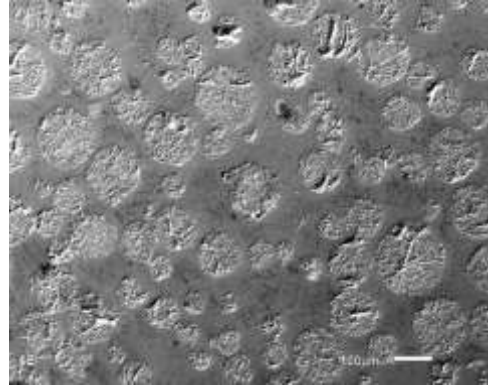




Results



- SEM
 - Improved microstructure
 - UO_2 particles more uniformly dispersed
 - Cross-section depicts some particle elongation





Results

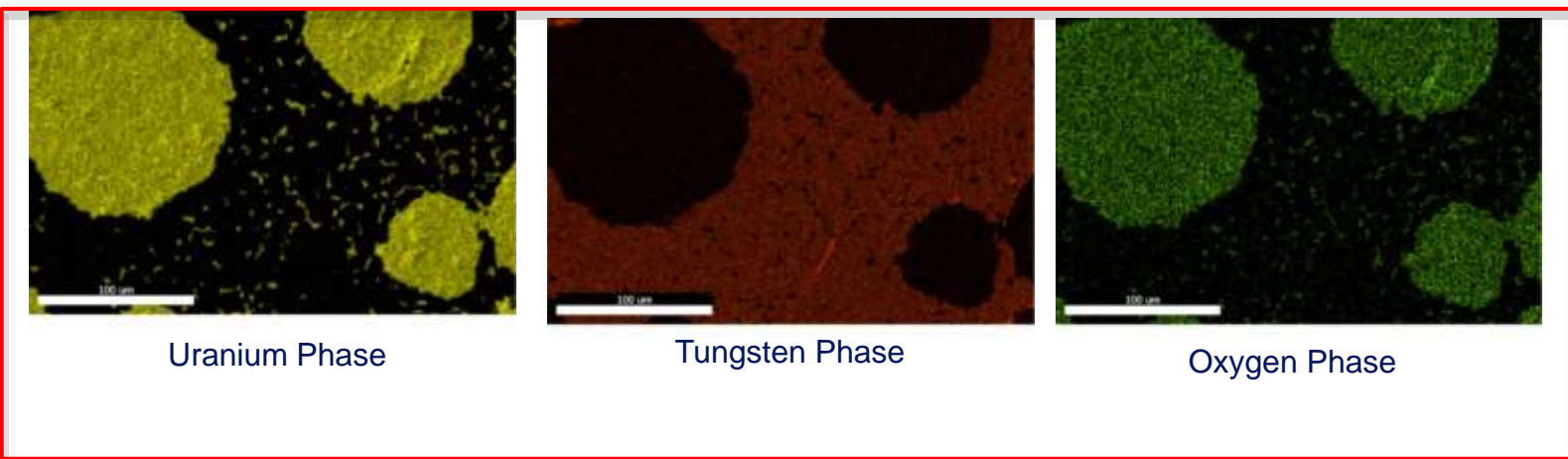


- Energy-dispersive X-ray spectroscopy (EDS)
 - No unexpected phases



Uranium Phase

Tungsten Phase



Uranium Phase

Tungsten Phase

Oxygen Phase



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