Fabrication of depleted UO_2-W Cermet Fuel Elements via Spark Plasma Sintering: Advances & Progress Made

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Introduction: Under contract to Aerojet Rocketdyne, the Center for Space Nuclear Research (CSNR) has been developing the manufacturing processes for tungsten cermet fuels via Spark Plasma Sintering (SPS). This work has focused on the demonstration of the scalability of the SPS process to the production of Fuel elements for Nuclear Thermal Propulsion (NTP) reactors. Work performed in Fiscal Year (FY) 2011 demonstrated the capability to produce prototypic cermet fuel geometries by SPS. This was achieved by the production of tungsten cermets containing approximately 55 volume percent ($^{Vol}/_{O}$) CeO_2 as a surrogate for UO_2. Additions of up to 25 atom percent ($^{atom}/_{O}$) rhenium to the metal matrix of the cermet was also demonstrated for mechanical performance and submersion criticality safety enhancement. The geometry of the initial prototypic cermets was designed to resemble the NERVA heritage fuels with a flat-to-flat distance of approximately ¾ of an inch and an internal 19 flow channel configuration [1]. By the end of FY 2011 a prototypic element section was fabricated to a length of 1.2 inches from 8 individual segments via diffusion bonding using the same SPS equipment. Through FY 2012 and FY 2013, the CSNR continued to advance cermet fuel production via SPS by refining net-shape tooling, facility construction and work control development. This developmental research led to the successful production of the first depleted uranium loaded tungsten cermet samples [2], segments and prototypic element sections by SPS which in turn marked the first successful prototypic production revival of NTP fuels since the ANL/GE-710 programs [3]. Several technical highlights of this research are presented.

Radiological Spark Plasma Sintering Facility: In order to advance the manufacture of tungsten cermet fuels beyond surrogate demonstrations, the CSNR developed a first of its kind Radiological Spark Plasma Sintering (RSPS) Facility specifically designed to handle and process nuclear materials through collaboration with Thermal Technology LLC , Innovative Technology LLC and Flanders Filters Inc. The RSPS Facility was designed and constructed between fiscal years 2011 to 2012, and completed it's first production of a cermet fuel element sub-section in 2013. The RSPS facility houses powder preparation, die loading and sample press-out equipment within an inert atmosphere glovebox that is integrated with the SPS furnace vacuum chamber. The RSPS glovebox line can operate with either an Argon or Nitrogen atmosphere containing less than 0.1ppm O_2 and less than 0.1 ppm H_2O. In-line active DOP tested HEPA filtration protects the facility and facility exhaust from radiological contamination. A photograph of the RSPS facility during initial construction is provided in Figure 1.

Figure 1: Phase-A construction of the prototype RSPS facility onsite at the Idaho National Laboratory's Center for Advanced Energy Studies.

3-inch depleted uranium cermet element subsection: In 2013, the RSPS facility was used to produce an initial batch of four prototypic cermet segments that were ¾ inch long, ¾ inch across the flats. Sintering from mixed constituent powders was performed at around 1500 °C and at a pressure of approximately 20 MPa. Each segment was composed of approximately 55 $^{Vol}/_{O}$ depleted UO_2 within a 45 $^{Vol}/_{O}$ metal matrix composed of 75 $^{atom}/_{O}$ W and 25 $^{atom}/_{O}$ Re. No alteration to the net shape of each segment was required since it is derived from the graphite dies used in the initial SPS process. Once sintered, the end faces of each segment were polished using a precision diamond cup wheel grinder that was developed at the CSNR. These polished faces allow for the onset of diffusion bonding processes to take place between the level surfaces of multiple segments. A photograph of the first segment is provided in Figure 2. Once polished, the 4 segments were installed within a graphite bonding die and subjected to similar temperatures and current flow regimes as were used during segment sintering from powder using the RSPS Facility furnace. Following successful diffusion bonding, the 3-inch long element section was pressed from the graphite bonding die via a hand operated hydraulic press. During press out, some surfaces were lightly contaminated with graphite powder which was removed by a minor cleaning process.

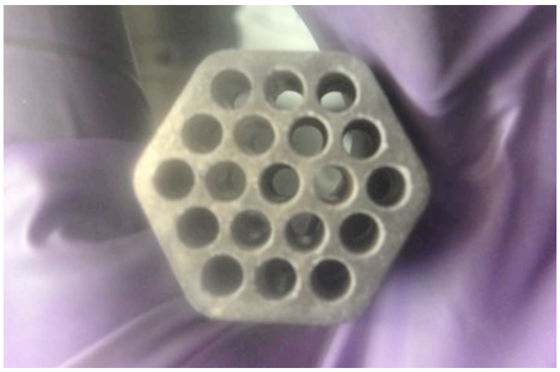

Figure 2: The first depleted uranium-cermet fuel element segment produced by SPS. The prototypic segment is approximately ¾ of an inch across the flats and ¾ of an inch in length. A 19 flow channel configuration similar to that of the NERVA fuels is visible.

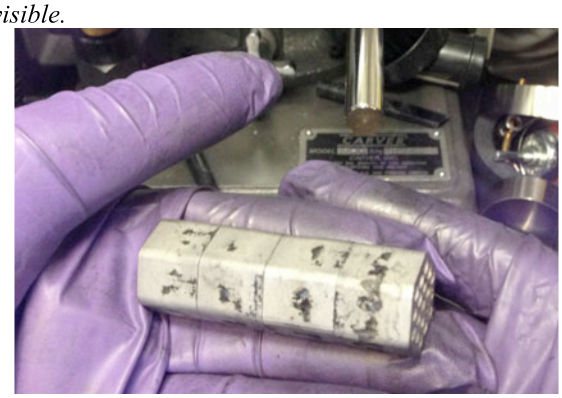

Figure 3: The first 3-inch long prototypic depleted uranium-tungsten cermet segment produced via SPS as pressed from its graphite bonding die inside the RSPS facility glovebox. Loose graphite surface contamination is visible on some surfaces prior to minor cleaning.

Full Length Fuel elements: Full length cermet fuel elements for NTP reactor applications may be approximately 30 inches in length. Such fuel elements would be assembled from several element sections each of 8-10 inches in length. As a demonstration of the scalability of the SPS process, the fabrication of two 8-inch long element sections is currently being completed at the time of writing. These element sections feature the lock and key nodes that could be used to assemble sections into the full length element in a similar process to that used by the NERVA graphite fuels [1]. These element sections are likely to be tested at NASA Marshall Space Flight Center in collaboration with Aerojet Rocketdyne and the CSNR.

Summary: Successful adaptation and demonstrations of the Spark Plasma Sintering process for the fabrication of uranium-cermet fuels has been performed at the CSNR. Based on these research and development activities, the CSNR is completing its feasibility and economics of production study. The CSNR will continue to develop and support testing of materials properties and fuel components under NTP operational atmospheric conditions through future collaboration with NASA Marshall Space Flight Center and Aerojet Rocketdyne.

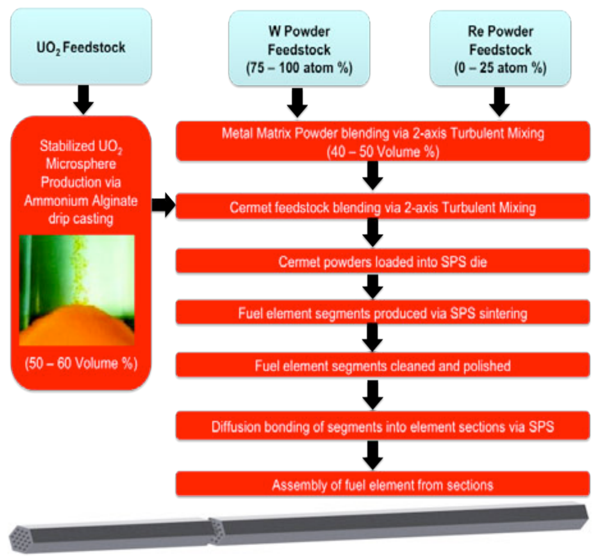

Figure 4: Summary of the CSNR cermet fuel fabrication process.

References:

[1] Finseth, J.L. "Overview of ROVER Engine Tests: Final Report" (1992) NASA Marshall Space Flight Center Report CR-184270.

[2] O'Brien, R.C., Jerred, N.D. "Spark Plasma Sintering of W-UO_2 cermets", Journal of Nuclear Materials 433 (2013) 50-54.

[3] General Electric. "710 high-temperature gas reactor program summary report. Volume I". GEMP-600 (Vol.1). (1968).