RECENT RESEARCH ACTIVITIES AT THE CENTER FOR SPACE NUCLEAR RESEARCH IN SUPPORT OF THE DEVELOPMENT OF NUCLEAR THERMAL ROCKET PROPULSION.

Robert C. O'Brien[1]*, Nathan D. Jerred[1], Steven. D. Howe[1], Ronald Samborsky[2], Daniel Brasuell[2], Andrew Zillmer[2]
[1]Center for Space Nuclear Research, Idaho Falls, Idaho USA. E-Mail: Robert.Obrien@inl.gov Telephone: +1-208-526-0111
[2]Aerojet Corporation, Sacramento, California, USA

Introduction: Nuclear power and propulsion has been considered for space applications since the 1950s. Between 1955 and 1972 the US built and tested over twenty nuclear reactors / rocket engines in the Rover/NERVA programs [1]. The Aerojet Corporation was the prime contractor for the NERVA program. Modern changes in environmental laws present challenges for the redevelopment of the nuclear rocket. Recent advances in fuel fabrication and testing options indicate that a nuclear rocket with a fuel composition that is significantly different from NERVA can be engineered; this may be needed to ensure public support and compliance with safety requirements. The Center for Space Nuclear Research (CSNR) is pursuing development of tungsten-cermet based fuels for use in Nuclear Thermal Propulsion (NTP) systems.

Challenges and solutions: The recovery of NTP technology in the current socio-political environment is dependent on overcoming several issues. Simply expressed they are:

- System performance should sufficiently justify the "perceived" associated risks.
- Cost of development.
- Radioactivity emitted during operation and the release of fission products into the exhaust stream.
- Risk for "proliferation" on launch abort / re-entry of the Earth's Atmosphere.
- Sub-criticality on launch abort.

Issues three through five may all be addressed by using a tungsten-based fuel form. During the GE-710 program in the 1960s, the retention of fission products by the tungsten matrix was demonstrated using static irradiations. With respect to proliferation resistane, removal of the uranium from the tungsten matrix would be challenging and would require significant infrastructure in chemical processing. Conversely, a graphite based core could be fractured allowing the uranium to be extracted via pyrolisis. The other main advantage of the tungsten fuel form is on the full-power, ground test facility. If the fuel can be shown to not leak radioactivity into the exhaust, then a large, expensive containment facility to scrub out fission products is not required. Use of a smaller test facility could dramatically reduce the program costs.

Tungsten-cermet fuel is a potentially high-endurance fuel form and has excellent compatibility with high-temperature hydrogen gas. Heritage experimental work in programs such as the ANL and GE 710 programs demonstrated the durability of the fuels. Tungsten-cermets exhibit good thermal conductivity, a high melting point, and are resistant to creep deformation at elevated temperatures. Additionally, tungsten-cermet matrices offer radiation self-shielding properties that translate into reductions in external shielding requirements. Tungsten-cermets may be engineered to be resistant to physical changes induced by radiation, such as neutron absorption and swelling due to irradiation and fission product production.

In 2008, the CSNR undertook a small pioneering project to investigate the ability to fabricate tungsten fuel elements via the relatively new Spark Plasma Sintering (SPS) powder sintering process [2]. By using the SPS furnace at the Idaho National Laboratory, several samples of tungsten-cermet elements were produced. The samples were approximately 1.2 inches in length, had a hexagonal cross section with 0.75 inches across the flats (same external profile geometry as the NERVA elements). The samples were fabricated with a 40% by volume blend of CeO_2 that served as a non-nuclear surrogate for UO_2 within the tungsten matrix. The results are shown in Figure 4. The elements illustrated have a density in excess of 90% of their theoretical density.

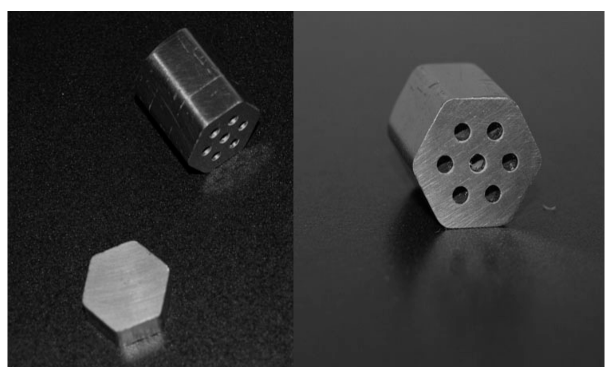

Figure 4: Tungsten-cermet nuclear thermal rocket fuel elements loaded with CeO_2 (40% vol.), which acts as the UO_2 simulant [3]. The samples were fabricated using a Spark Plasma Sintering furnace. This particular example illustrates the capability to produce elements with multiple flow channels. The process can be adjusted to provide single, tens or hundreds of channels if required by a specific element design.

Recent Activities: Most recently, the CSNR has undertaken a number of activities in collaboration with the Aerojet Corporation to further the development of safe, practical and affordable nuclear thermal propulsion systems. Some of these activities include:

- The assessment and development of low cost ground based testing methods (SAFE) for NTP engines.
- The development of a complete cermet fuel manufacturing and qualification process that can be applied and adjusted to a wide range of element geometries, fuel-to-matrix fractions, and flow channel configurations.
- Design, construction and commissioning of a Spark Plasma Sintering Facility for the processing of nuclear materials at the Idaho National Laboratory.
- The testing of cermet thermo-physical and mechanical properties made via the CSNR/Aerojet process in support of accurate computational analyses of NTP system designs.
- Computational modeling of NTP system designs (CFD and neutronics modeling).
- Safety analyses for launch abort and space flight accident conditions.

A summary of these activities is presented with respect to progress made and the challenges that lie ahead.

References:

[1] S.D. Howe, R.C. O'Brien. "Nuclear Thermal Rockets: History, Benefits and Issues Impacting Future Operations". Proceedings of: 57th Joint Army-Navy-NASA-Air Force (JANNAF) Propulsion Meeting, 2010; Colorado Springs, CO.

[2] R.C. O'Brien, R.M. Ambrosi, N.P. Bannister, S.D. Howe, H.V. Atkinson, "Spark Plasma Sintering of simulated radioisotope materials in tungsten cermets". *Journal of Nuclear Materials*. 393 (2009) 108-113.DOI: 10.1016/j.jnucmat.2009.05.012.

[3] R.C. O'Brien, R.M. Ambrosi, S.D. Howe, N.P. Bannister, H.V. Atkinson. "Fabrication of prismatic fuel elements for space power and nuclear thermal propulsion reactors by spark plasma sintering". Proceedings of: Nuclear and Emerging Technologies for Space (NETS-2009), Paper Number 206153; June 14-19, 2009; Atlanta, GA.