Innovative Nuclear Space Power and Propulsion Institute

"Space Exploration is the ultimate investment in America's Future"

G. Bush

INSPI

An International Leader in Space Applications

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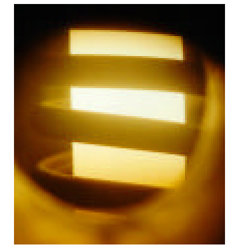


Advanced ultrahigh temperature nuclear fuels are recognized as an enabling technology for *lower cost, high performance nuclear thermal propulsion (NTP) systems* for use in

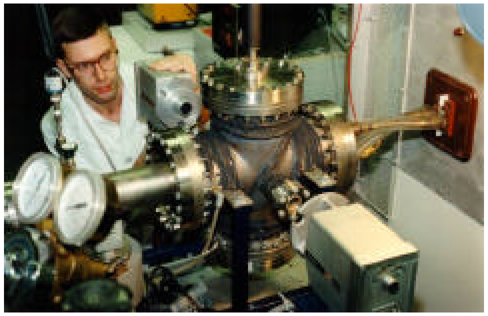
- future manned missions to the moon or mars
- cargo transport to the moon or mars
- unmanned explorations of the outer planets
- earth orbit transfers of satellites

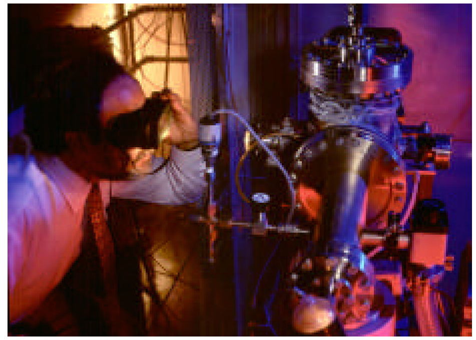
Uranium bearing, solid-solution tri-carbide fuels such as (U, Zr, X)C with X = Nb, Ta, Hf, or W offer many advantages for high performance, advanced space power and propulsion applications. Binary carbide fuels of (U, Zr)C were first studied for nuclear thermal propulsion (NTP) during the Rover/NERVA program of the 1960s and early 1970s. These advanced fuels evolved from earlier designs and represented the most promising space nuclear fuel at the time the program was cancelled in 1973.

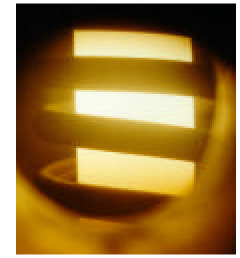
The Innovative Nuclear Space Power and Propulsion Institute (INSPI) at the University of Florida has focused on improvements in the processing and fabrication of these fuels with the goal of producing net-shape fuel elements.

Uranium TRI-CARBIDE

Nuclear Fuels







The chief physical characteristics of mixed uranium/refractory metal carbide fuels, referred to as tri-carbide nuclear fuels include:

• **Significantly higher melting points** nearer to those of the constituent refractory carbides (~3800K vs. 2800 K for UC) depending on the metal mole fraction of uranium.

• **Significantly higher thermal conductivity** than conventional oxide nuclear fuels (~30 to 70 W/m K versus about 3 W/m K for uranium dioxide).

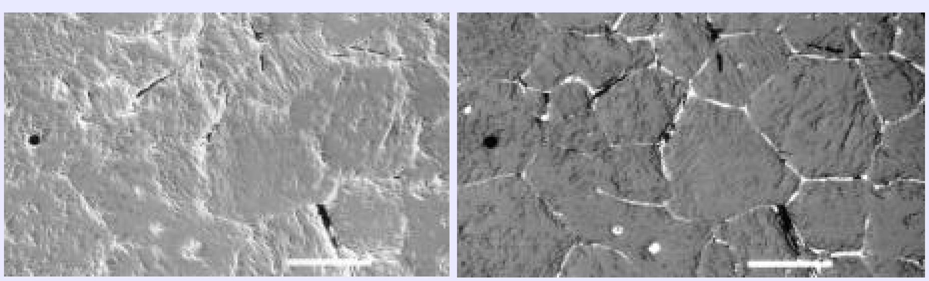
• **Greater stability** especially at high temperatures in comparison with the monocarbide UC or other prime candidate nuclear fuels such as UO_2 and UN. Their thermochemical stability in a flowing hot hydrogen propellant is important to the reliability and long lifetime of a NTP system.

These physical properties lead to improvements in design and operation for greater efficiency and reduced cost through:

• **Higher operating temperatures** (as high as 3000 K) provide for greater specific impulse (more efficient use of propellant) for NTP.

• **Reduced nuclear fuel** requirement leading to reduced launch cost owing to smaller more compact cores as a result of the greater power density and reduced mass losses owing to greater thermochemical stability of the fuel and propellant.

• **Reduced propellant** requirement leading to reduced launch cost and reduced refrigeration and thus power necessary to provide for propellant storage cooling.



SEM 100 μm SEM with compositional contrast 100 μm

Hypostoichiometric tri-carbide, $(U_{0.1}, Zr_{0.77}, Nb_{0.13})C_{0.95}$
sintered for 4 Min. at ≥ 2800 K and 128 Min. at ≥ 2500 K

High solid-phase solubility of uranium carbide in zirconium and niobium carbides provides for high flexibility in using very low to very high uranium fractions in the fuel. For requirements of compactness, high performance, and long life, space power reactors require low uranium fractions in the mixed carbide fuel and higher enrichments of uranium.

The presence of non-uranium carbides in the fuel allows for gradient coating of fuel pellets and particles with refractory metal carbides, which act as a robust barrier for containing fission products. No additional coating is necessary as with earlier graphite matrix and composite fuels, which lead to cracking of the coating and mass losses due to corrosion by the hot hydrogen propellant.

Some problems identified for these fuels during the Rover/NERVA program include a susceptibility to fracture and difficulty fabricating more complex fuel element geometries used in earlier NTP studies. The mixture of carbide powders is difficult to extrude and are very hard leading to excessive wear on the dies. INSPI has focused on improvements in the processing and fabrication of these fuels with the goal of producing net-shape fuel elements.

Processing and fabrication efforts at INSPI have developed methods of cold pressing and UC liquid phase sintering of near-stoichiometric and hypo-stoichiometric tri-carbides to produce high-quality, single-phase, solid-solution samples with less than 5% porosity. In light of the difficulties in extruding solid solution binary carbide fuel elements in the Rover/NERVA experiments, an innovative space reactor fuel geometry, square-lattice honeycomb (SLHC), was developed that would better lend itself to net-shape fabrication methods available to tri-carbide fuels.

Efforts at testing and characterizing their performance under extreme NTP conditions are currently underway. The development and characterization of these fuels could lead to advanced NTP systems with specific impulse of greater than 1000 seconds making future long term, *power rich* space missions to Mars or other destinations possible.