HISTORIC SOLID CORE NUCLEAR THERMAL PROPULSION FUEL FORMS: FUNCTIONS AND LIMITATIONS.

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Introduction: Because of inherently high thrust levels and commensurate higher vehicle speeds, NTP is considered by many as the preferred form of propulsion for future manned flights to Mars. That is, an NTP engine has the potential for high specific impulse (~900 s) and thrust (~100 klbf); thus, a NTP engine is expected to cut transit time in half compared to a chemical engine on a mars mission. There have been three different historic programs which have extensively developed and tested NTP fuel forms in the United States: NERVA/Rover, 710 Reactor, and the Space Nuclear Thermal Propulsion (SNTP) program as well as comparable efforts by the former Soviet Union. All in all, these programs designed and tested unique fuel forms including: basic coated graphite, CERMET, composite, mixed carbide, and carbonitride fuels in the form of extruded hexagonal, particle, and 'twisted ribbon' geometries. The purpose of this presentation is to characterize NTP fuel forms of the different historic programs in the United States and former Soviet Union in terms of the fuel form's function within the reactor core and the limiting material and mechanical properties of each fuel form.

NERVA/Rover Fuel Forms: The most experience designing and testing NTP fuel forms is a result of the NERVA/Rover programs. Fuel forms were designed as extruded hexagonal elements with 19 channels for coolant flow [1]. Early designs distributed coated UO_2 or UC_2 fuel particles in a graphite matrix. The graphite matrix provided acceptable high temperature strength and neutronic moderation, but was susceptible to corrosion when exposed to the hydrogen propellant. Later fuel design led to the testing of composite (dispersed (U,Zr)C in a graphite matrix) and all carbide ((U,Zr)C) fuel forms.

CERMET Fuel Forms: Developed during the 710 Reactor Program and by efforts at Argonne National Laboratory, CERMET fuel forms retained an extruded hexagonal shape but were composed of UO_2 or UN particles in a tungsten matrix. CERMET fuel forms functioned as structural components within a fast neutron spectrum reactor. The tungsten matrix provided greater high temperature strength and endurance than graphite. Unfortunately, fuel compounds suffered from instabilities in the tungsten matrix at high operating temperatures and could result in possible fission product release [2].

Particle Fuel Forms: The most recent program, SNTP, developed a particle fuel form. Particle (400-450 µm diameter) fuel forms maximized the surface area available for heat transfer, thus maximizing the expected I_{sp} for the mission. The baseline fuel kernel was a UC_2 fuel compound coated with ZrC as well as a dense and porous carbon layer to prevent fuel corrosion and fission product release [3]. Coolability of particle fuels is extremely important in order to retain reactor integrity and control; localized hotspots could lead to fuel particle agglomeration. The baseline fuel particle was limited by the melting point of UC_2 and three alternatives were considered: mixed carbide, infiltrated, and interstitial dispersoid kernels as an attempt to increase the maximum operating temperature of the fuel form [4].

Former Soviet Fuel Forms: The effort of the former Soviet Union closely matched, if not exceeded, the efforts of the United States. Fuel elements were designed to maximize the reactor operating temperature and heat transfer from the fuel to the propellant. A unique design, the 'twisted ribbon' fuel form was capable of maximizing the surface area for heat transfer while maintaining fuel integrity. Advanced fuel forms (di-carbides, tri-carbides, and carbonitride) were developed and tested to maximize reactor operating temperatures [4].

References: [1] Koenig D. R. (1986) *Experience Gained from the Space Nuclear Rocket Program (Rover), LA-10062-H*. [2] Homan F. J. et. al. (1991) *Particle Fuels Technology for Nuclear Thermal Propulsion, AIAA 91-3457*. [3] Jensen R. R. et. al. (1994) *Evolution of Particle Bed Reactor Fuel, AIP Conf. Proc. 301*, 195. [4] Bhattacharyya S. K. (2001) *An Assessment of Fuels for Nuclear Thermal Propulsion, ANL/TD/TM01-22*.