—ABSTRACT—

Carbon-Carbon-Composite, Salt-Cooled Electric Space Reactors

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The primary requirements for a deep space or planetary reactor are reliability, long life, and a high power-to-mass ratio. Advanced reactors (core, structure, radiator, etc.) are proposed that are built entirely from carbon-based materials that use salts (liquid or gas) as the heat transfer medium between the reactor and power-generation equipment and/or heat rejection systems to create reactor systems with very high power-to-mass ratios.

1. Carbon-carbon composites are among the strongest and lightest (less than one half the density of metals), high-temperature engineered materials. Moreover, carbon-carbon composites today can be fabricated into complex forms. Unlike metals, the strength of carbon-based materials increases up to temperatures of ~2300ºK. *This technology has been developed primarily over the last 20 years, after the last major effort to develop nuclear space systems in the United States, and carbon-carbon composites are the only new class of materials with the potential to dramatically improve performance.*

2. Coated-particle nuclear fuels with zirconium carbide and other coatings have operating temperatures that approach 2300ºK. This coated-particle fuel can be incorporated into carbon-based matrixes.

3. Carbon foams are a new material with extraordinary low densities and high thermal conductivities—a class of materials that may enhance heat transfer in radiators.

At high temperatures, only two classes of fluids are chemically compatible with carbon-based materials: inert gases such as helium-xenon mixtures and fluoride-based salts. Liquid metals are incompatible with carbon-based materials. Fluoride-based liquid salts (molten salts) were used in the Nuclear Aircraft Propulsion program and have demonstrated compatibility with carbonaceous materials. The choice of constituent salts in a salt mixture can be adjusted to modify the physical properties (freeze point, volume change upon melting, vapor pressure, viscosity, boiling point, etc.) to meet mission requirements.

These innovative materials are logical candidates for the construction of advanced space reactors operating at very high temperatures—between 1800 and 2300ºK. Higher-temperature operation fundamentally leads to higher cycle efficiency and thereby higher power-to-mass ratios. Major technical challenges exist for application of these materials (including radiation damage susceptibility and permeability of some types of carbon-based materials to fluids); however, the potential exists for major advances in performance. The first applications would be for space missions. Planetary missions provide the additional challenge of protectively coating the exterior, high-temperature carbon-based materials against oxidizing environments (such as that of Mars). The characteristics of carbon composites, coated-particle fuels, and carbon foams, as well as their compatibility with salts and the constraints and characteristics of these salts, are described. Furthermore, the challenges, some potential reactor configurations, and the implications for a family of advanced space reactors are described.