Subject: Contract No. NNC08CA11C
A Novel, Ultra-Light, Heat Rejection System for Nuclear Power Generation

Project Summary

Purpose of the Research. To enable long duration, interplanetary- and planetary-based missions, nuclear power is the preferred option based on its high power capability, relatively low mass and volume, and reduced deployment issues. Specifically, for lunar-based Fission Power System (FPS) that will support In-Situ Resource Utilization (ISRU) or Mars robotic and manned missions, power requirements may vary from 10s to 100s of kWe to support initial human missions and longer term lunar bases. Due to the large amounts of waste heat generated by these systems, a key consideration is the development of lightweight, highly efficient, heat rejection systems (HRS) that can operate at elevated temperatures. Currently, an approach that is being strongly considered is the use of titanium-sheathed heat pipe with a carbon-composite over-wrap, combined with a carbon-composite radiator panel to decrease the system mass. Our innovation is the integration of an ultra-light radiator panel based with a lightweight titanium heat pipe.

Research Carried Out. During this Phase II project, Creare continued our long history of developing innovative thermal management solutions to significant technical challenges. Specifically, we designed, fabricated, and tested a novel, lightweight radiator panel that can operate at the elevated temperatures (~405 K) needed for the FPS. In addition, we delivered a 1.0 m by 0.2 m ULHRS demonstrator to NASA Glenn Research Center. To achieve this goal, we completed four main technical tasks. First, we completed a detailed panel design activity during which we tested and evaluated several options for the panel material; developed a panel/heat pipe bonding methodology; developed, evaluated, and tested several Ti 15-3 heat pipes; and identified a space-qualified, high emissivity coating for the panel. Second, we developed the processes and designed the fixtures to fabricate the larger scale panel with functioning heat pipes. Third, we fabricated the larger scale panels using our methodology. Fourth and finally, we tested the prototype panels in our Thermal Vacuum Chamber and scaled their performance to the FPS system to evaluate their performance in comparison with the overall design goals.

Research Results. During this project, we achieved several key results that will enable the realization of a lightweight FPS heat rejection system for lunar-based and other applications. First, we developed unique fabrication techniques that enabled the development of a high strength, thermally conductive bond between our panel and a titanium tube. Second, we designed, fabricated, and implemented unique hardware enabling the manufacture of 1.0 m by 0.2 m panels. Third, we demonstrated the integration of a high emissivity, space-qualified coating on the prototype panels. Fourth, we demonstrated that the panels could be fabricated with functioning, lightweight titanium 15-3 heat pipes. Fifth, we completed extensive thermal and mechanical testing, demonstrating the excellent performance and viability of our innovative approach for the FPS application. Sixth and finally, we designed, fabricated, and demonstrated a ULHRS demonstrator that when scaled to the FPS operating conditions corresponding to an evaporator temperature of approximately 400 K, achieved a mass per unit heat rejection of less than 0.8 kg/kW (including panels, charged heat pipes, structural supports, and coating).