Compact, Low Specific-Mass Electrical Power Supply for Space Exploration. Steven D. Howe[1], Robert C. O'Brien[1], Troy M. Howe[1], Carl Stoots[2]

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Introduction: Radioisotopic Thermoelectric Generators (RTGs) have been used in the past for all missions past Mars to provide electrical power to the instruments. The currently underway Mars Science Laboratory, however, utilizes Multi-Mission RTGs (MMRTGs) which can operate in the vacuum of space or in a planetary atmosphere. Because of the desire for no moving parts, reliability, and long life, these systems rely on thermocouples to convert heat to electricity and are inherently inefficient. Only about 6% of the thermal energy is converted into electricity. Consequently, the specific masses of the RTG and MMRTG are 200 kg/kWe and 357 kg/kWe respectively [1]. Thus, the power supplies can be a significant fraction of the platform mass.

Recent advances in Stirling engines at the NASA Glenn Research Center indicate that Advanced Stirling Radioisotope Generators (ASRGs) may provide 25% conversion efficiency [2,3]. ASRGs will reduce the amount of Plutonium-238 (Pu-238) required for a given power level. However, ASRGs contain moving parts and may suffer from vibration issues along with shorter life-spans than MMRTGs. In addition, the specific mass of the ASRG is 141 kg/kWe. While this is a significant improvement, the mass of the ASRG still is heavy and takes up valuable room that could be occupied by scientific instruments.

In June of 2010, NASA convened a series of meetings of experts from around the country to discuss potential advances to enhance space exploration. One of these meetings was the Ubiquitous Access To Abundant Power workshop, as part of the Breakthrough Technology Capability study [4]. One of us (Howe) was invited to participate in this workshop. One of the major conclusions of this workshop was the crucial need for future space missions to have an electrical power source that had low specific mass, at least below 100 kg/kWe and perhaps in the 10s of kg/kWe.

The development of a low specific mass power source will be a "game changing" achievement that is crucial to future missions. In addition to providing low mass power supplies to large scale robotic probes to the outer planets, a low specific mass power supply could enable the use of micro and nano satellites on Mars and beyond.

The possible use of micro or nano satellites offers the potential for cheaper exploration of the solar system. To date, though, all smallsats have been solar powered limiting their use to within the orbit of Mars. To travel beyond Mars, a radioisotope source would be required. The smallest nuclear source available, though, will be the ASRG at 140 w with a mass of 22 kg. No power source exists below the 100 w level to support small sat exploration.

In addition, the development of power sources with a low specific mass could enable the realization of Radioisotopic Electric propulsion (REP). REP has been a goal for many years [5-8] because it could provide a cheap method of rapid access to the outer solar system for small payloads such as Cubesats. However, the masses of the regular RTGs are too high to allow REP to be effective. A low mass REP system could also enable the concept of the "mother ship" whereby a large platform, perhaps a nuclear thermal rocket, provides rapid transition between planets and then "drops off" an REP platform at each destination to deorbit for many years of operation.

The concept of thermal photo-voltaic power (TPV) conversion has been investigated for the several years. Researchers at the NASA Glenn Research Center have designed a TPV system [9] that utilizes a simulated General Purpose Heat Source (GPHS) from a MMRTG. The GPHS is a block of graphite roughly 10 cm by 10 cm by 5 cm. A fully loaded GPHS produces 250 w of thermal power and weighs 1.6 kgs. The GRC system relies on the GPHS unit radiating at 1200 K to a tantalum emitter that, in turn, radiates light to a GaInAs photo-voltaic cell. The GRC claims system efficiency of conversion of 15%. The specific mass is around 167 kg/kWe.

The main issue with the NASA GRC approach is that they restricted their design to the use of the GPHS. The specific mass of the GRC system is 15% higher than the ASRG. Thus, even though the RTPV system has no moving parts, NASA may not be sufficiently motivated to proceed with the expensive launch qualification process. However, if the mass of the RTPV system can be significantly reduced, then NASA may determine that the lower mass, robust, long-lived RTPV system may offer sufficient advantages. The CSNR is developing a new, robust encapsulation of PuO_2 that has 5 times the power density of the GPHS and can be sized from 0.5 w to

500 w to allow power levels to match the mission requirements.

Because of the ability to fabricate the tungsten cermet into other shapes, an alternative design may allow less thermal losses through the edges. This will allow the system to reach higher temperatures and increase the conversion efficiency. In addition, if the surface of the shell, i.e the emitter, can be coated or textured to alter the light emitted from the surface toward visible wavelengths, then the efficiency of the PV cells can be increased further [10]. Thus, the system may be able to achieve a conversion efficiency of 25 %. Adding all of these design changes together could enable a power supply with a specific mass of around 50-70 kg/kWe.

The CSNR is developing a new configuration of the Radioisotope Thermal Photo-Voltaic (RTPV) system that weighs less than one half of current sources for a given power level. The eventual power source will utilize metal encapsulated radioisotope source coupled to thermal photo-voltaic conversion. For this project, we will simulate the radioisotope power with electrical heaters. The advantages of this system are low specific mass, high conversion efficiency, no moving parts, and variable power output to match mission requirements.

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