Emissivity Tuned Emitter for RTPV Power Sources

Nuclear and Emerging Technologies for Space

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Introduction: Every mission launched by NASA to the outer planets has produced unexpected results. The Voyager I and II, Galileo, and Cassini missions produced images and collected scientific data that totally revolutionized our understanding of the solar system and the formation of the planetary systems. These missions were enabled by the use of nuclear power. Because of the distances from the Sun, electrical power was produced using the radioactive decay of a plutonium isotope. Radioisotopic Thermoelectric Generators (RTGs) used in the past and currently used Multi-Mission RTGs (MMRTGs) provide power for space missions. Unfortunately, RTGs rely on thermocouples to convert heat to electricity and are inherently inefficient (~3-7% thermal to electric efficiency).

A Radioisotope Thermal Photovoltaic (RTPV) power source has the potential to reduce the specific mass of the onboard power supply by increasing the efficiency of thermal to electric conversion. In an RTPV, a radioisotope heats an emitter, which emits light to a photovoltaic (PV) cell, which converts the light into electricity. Developing an emitter tuned to the desired wavelength of the photovoltaic is a key part in increasing overall performance.

Researchers at the NASA Glenn Research Center (GRC) have built a Thermal Photovoltaic (TPV) system [1] (Fig. 1), that utilizes a simulated General Purpose Heat Source (GPHS) from a MMRTG to heat a tantalum emitter. 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.

Figure 1. Exploded view of the TPV assembly at the GRC.

A RTPV power source that utilized a ceramic or ceramic-metal (cermet) matrix would allow for the combination of the heat source, canister, and emitter into one compact unit, and allow variation in size and shape to optimize temperature and emission spectra.

Method: Recent developments in powder metallurgy fabrication using the Spark Plasma Sintering (SPS) furnace at the Center for Space Nuclear Research (CSNR) indicate that a solid, robust, high-temperature ceramic or ceramic-metallic (cermet) matrix can be formed to encapsulate radioisotopic heat source materials [2, 3]. Thus, upon impact or explosion under launch accident conditions, radioisotopic materials are contained within the matrix and not dispersed. The cermet matrix has the capability to reduce significantly the surface radiation dose rate. Such a matrix will have significant savings in volume that translate into an overall system mass saving. In addition, the surface of the emitter can be coated or textured to alter the light spectra emitted from the surface to optimize conversion efficiency of the PV cells [4]. Combined together, a power supply with a specific mass of around 30-50 kg/kWe may be possible.

Because the current radioisotope power sources generate roughly 50We minimum, a power source is not available for small electronic instruments that may require a power source within their housing. The encapsulation of the radioisotope inside the cermet matrix instead of a GPHS allows for the heat source to be scaled up or down, and rearranged into a variety of geometric shapes for optimal conversion. With the introduction of a low power RTPV for individual components, a number of new options can be made available for exploration missions.

The CSNR is currently developing a method of creating, testing, and tuning the emissive surfaces to the optimal photovoltaic conversion wavelengths and building a proof-of-concept prototype capable of emulating the conditions of a functioning RTPV. Cermet matrices containing CeO2 as a surrogate for radioisotopic materials will be fabricated by CSNR (Fig. 2). Specific emissive coatings and tuning processes will be applied to the sample surfaces. These samples will be tested to measure the radiance spectrum as a function of temperature. The optimal temperatures can then be found for each emitter and PV cell combination to ensure maximum conversion efficiency. They will then be inserted in to a vacuum chamber and heated to temperature to simulate the conditions of a functioning RTPV. Their input thermal and output electrical powers then will be measured to determine efficiency.
Cermet heat sources are of particular interest because of their compactness and anticipated enhanced safety, security and stability of encapsulated nuclear materials for space flight. The strength of the matrix material gives rise to its ability to retain the decay products of the radioisotopic materials, as well as forming an encapsulation from which it is extremely difficult to remove from the matrix. The fabrication and testing of surrogate loaded matrices of different isotropic loadings is an integral part of developing an optimized RTPV system.

Discussion: Due to the nature of the cermet matrix, the size of the power source can be scaled much more easily than current power sources which rely on a series of layered materials. Therefore, power sources can be designed for specific instruments or missions. After an RTPV system is designed based on the conceptual prototype, a small scale system can be fabricated due to versatility of the design. The smaller designs have the added benefits of being easier to produce and being able to use the thermal contact with the instruments as a heat sink instead of radiators. It is anticipated that an RTPV system producing 50mWe can be built with a few grams of a radioisotope that would be roughly the size of a small electrochemical battery (Fig. 3).

Unlike the GPHS, radioisotope fuels other than \(^{238}\text{Pu}\) can be used to produce a working prototype that demonstrates functionality. As the size of the RTPV increases to produce more power, other efficiency improving methods can be utilized such as filters, reflectors, and a wide variety of selective emitters.

Conclusion: Within the next three years, it is anticipated that a complete RTPV system will be designed to provide around 50mWe for instruments on space exploration missions. If possible, we would like to be able to fabricate a functioning RTPV prototype capable of producing power for years that is suitable for space based as well as terrestrial applications.

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References

