

## Thermal Design Optimization of a Compact 120 W<sub>th</sub> PbTe-Based Radioisotope Thermoelectric Generator

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### 1. Introduction

Radioisotope thermoelectric generators (RTGs) provide reliable electrical power for long-duration missions and remote environments where solar energy is limited or unavailable [1]. Compact RTG systems are particularly attractive for small-scale space exploration devices and space systems requiring long-term operation without maintenance. Among thermoelectric materials, PbTe exhibits excellent performance in the intermediate temperature range of 700–900 K and has been widely used for medium-temperature thermoelectric conversion [2].

In compact RTGs, system performance is highly sensitive to the geometric configuration of thermoelectric generator (TEG). In particular, the thermal resistance of the TEG module significantly affects the temperature gradient across the device, internal electrical resistance, thermal losses and overall power output. Therefore, optimization of the thermal resistance is essential for maximizing electrical performance.

In this study, thermal analysis and power optimization were performed for a 120 W<sub>th</sub> PbTe-based RTG, focusing on the impact of thermoelectric (TE) leg length and radiative heat loss on overall electrical performance.

### 2. RTG Design and Analysis Method

The RTG model consists of a cylindrical heat source, thermoelectric module, structural fixture, and outer case. The heat source was modeled using PuO<sub>2</sub> with a heat generation rate of 0.502 W/g and a density of 11.5 g/cm<sup>3</sup>. The fuel pellet dimensions were designed as 20 mm in diameter and 66.3 mm in height to generate 120 W of thermal power. The overall geometry of the radioisotope heat source module was 94.5 mm in diameter and 120 mm in height. To minimize radiative heat loss and enhance heat transfer to the thermoelectric legs, gold-coated surfaces with low emissivity ( $\epsilon = 0.03$ ) were applied to the fixture and outer case. Steady-state thermal simulations were conducted to obtain temperature distributions and electrical output characteristics.

### 3. Results and Discussion

Figure 1 illustrates the temperature distribution of the compact RTG under the optimized geometric configuration. A clear temperature gradient ( $\Delta T = 500.8^\circ\text{C}$ ) is established between the heat source and the outer structure, indicating effective thermoelectric operation. As the leg length increases, the temperature difference across the TEG module increases due to higher thermal resistance. However, the electrical resistance of the TEG module also increases proportionally with leg length. These competing effects result in the existence of an optimal geometric configuration that maximizes power output.

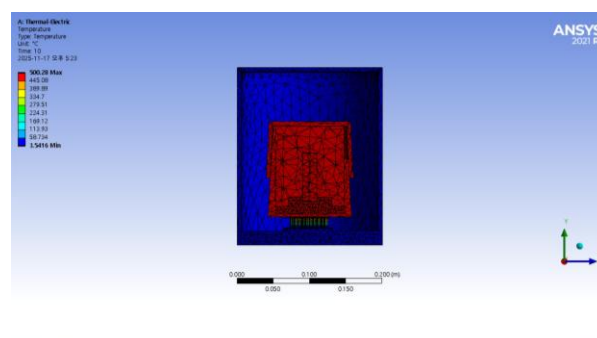


Fig. 1. Temperature distribution of the compact RTG under the optimized geometric configuration

Figure 2 presents the electrical output power as a function of leg length. The output power initially increases with leg length up to approximately 13 mm, driven by steep temperature gradient across the TEG module; However, as leg length exceeds this point, radiative heat loss from the RHU module—ranging from approximately 23 to 52 W—increases significantly. This behavior arises from the elevated hot-side temperature, which intensifies radiative heat transfer due to its strong T<sup>4</sup> dependence as described by the Stefan–Boltzmann law. In addition, the increased leg length results in higher internal electrical resistance, thereby amplifying Joule losses. The combined effect of enhanced radiative heat dissipation and rising internal resistance ultimately reduces the net electrical output. Accordingly, the peak electrical output of 8.99 W (system efficiency of ~7.49%) was achieved with a leg dimension of 3 mm × 3 mm × 13 mm.

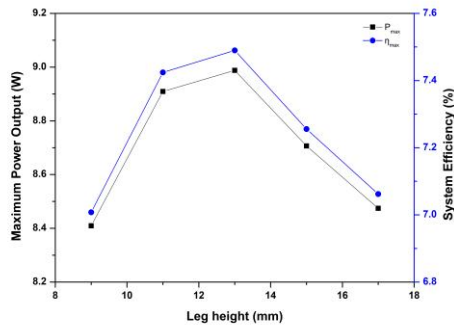


Fig. 2. Maximum electrical output power and system efficiency as functions of thermoelectric leg length.

#### 4. Conclusion

A thermal analysis of a compact 120 W PbTe-based RTG demonstrates that the thermoelectric leg length is a decisive design parameter governing both the thermal gradient and electrical performance. By optimizing the leg length through a careful balance between thermal and electrical resistance, an optimal value of 13 mm was identified, yielding a peak electrical output of 8.99 W with a corresponding system efficiency of 7.5%. These findings highlight the importance of geometrical optimization in maximizing conversion efficiency and provide practical design guidelines for compact RTG systems intended for space applications.

#### ACKNOWLEDGEMENTS

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