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Next-Gen RTG Peltier Cooling Testing

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Changing the World's Energy Future

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Background

The General Purpose Heat Source Radioisotope Thermoelectric Generator (GPHS-RTG) Flight Unit #5 (F5) is being refurbished and recertified for flight. The GPHS-RTG produces 300-watts of power to support NASA missions by converting heat from decaying Pu-238 into electricity using 572 thermocouples. The thermocouples are arranged inside the generator cavity circumferentially with their hot shoes exposed. This arrangement is shown in Figure 2.

The electrical circuit of GPHS-RTG thermocouples is called the thermopile. The thermopile is comprised of two parallel circuits: the inboard and outboard circuits. Both circuits contain a series of parallel wired thermocouples. This thermopile configuration is shown in Figure 3. The parallel connection of the two circuits and the thermocouple pairs creates electrical redundancy to maintain power production in the event of a thermocouple electrical failure.

Ten of the thermocouple hot shoes are fractured as shown in Figure 4. These hot shoes present concern for damaged electrical connections that cannot be visually verified. The Peltier Cooling Test was integrated into the F5 recertification plan to verify the electrical connections of all 572 thermocouples.

The Peltier cooling effect is a thermoelectric phenomenon that occurs when an electrical current flows through two dissimilar conductive or semiconductive materials. One junction of the metals emits heat while the other side absorbs it. This phenomenon will be utilized to verify the thermocouple electrical connections as demonstrated in Figure 5.

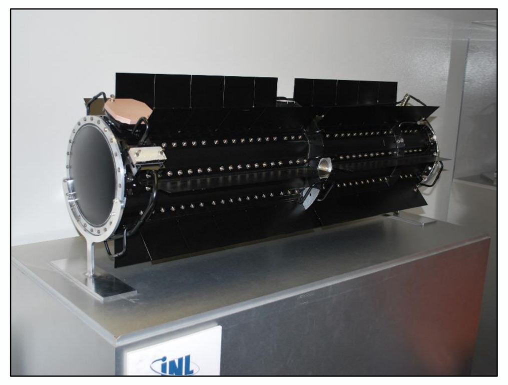

Figure 1: F5 GPHS-RTG Exterior

Figure 2: F5 GPHS-RTG Interior

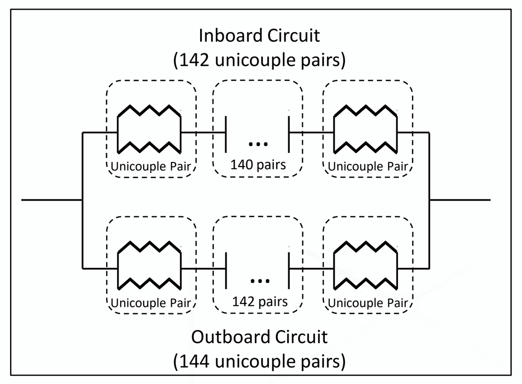

Figure 3: Thermopile Electrical Wiring

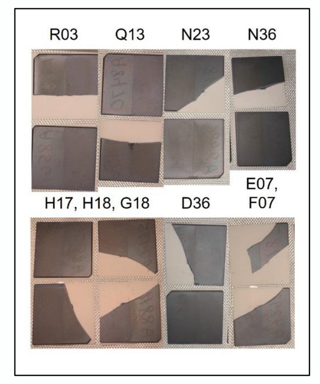

Figure 4: F5 Ten Broken Thermocouple Hot Shoes

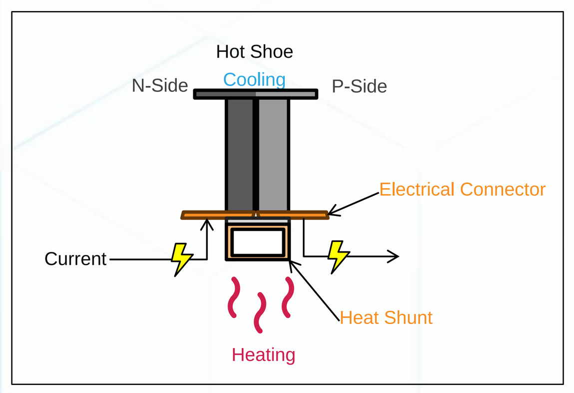

Figure 5: Peltier Cooling on a Thermocouple

Method

The Peltier Cooling Test consists of steady-state and transient tests. The steady-state test begins by applying power to the F5 generator in a constant-current mode. All electrically connected thermocouples experience a Peltier cooling effect on their hot shoes. Once the temperature reaches a steady-state, a protected silver mirror is passed through the generator cavity. The mirror reflects the hot shoes to a thermal imaging camera outside of the generator. This process captures the temperature of each hot shoe in a row. The electrical connections of thermocouples with cooled hot shoes are verified, and any thermocouples that require further investigation through transient testing are identified.

The transient test captures the thermal response of two unicouple pairs at a time. The hot shoe temperatures are measured while the applied power is increased in constant-current mode. Once the temperature has leveled-out at the desired current level, the power is removed. The hot shoe thermal reaction to the current removal is observed. The thermal behavior of the thermocouple pairs in this process provides insight on the condition of the thermocouples.

Peltier cooling is proportional to current as shown in the equation:

$$\dot{Q} = I * S * T$$

where $\dot{Q}$ represents the amount of heat transferred per unit time, I represents the current flow, S represents the material Seebeck coefficient, and T represents the temperature of the material junction.

Joule heating is another thermoelectric phenomenon that occurs during this testing. It is the heat generated when current flows through a resistance. It is proportional to current squared by the following equation where R is the resistance of the medium:

$$J = I^2 R/2$$

Both thermoelectric effects are considered in the analysis of the test results.

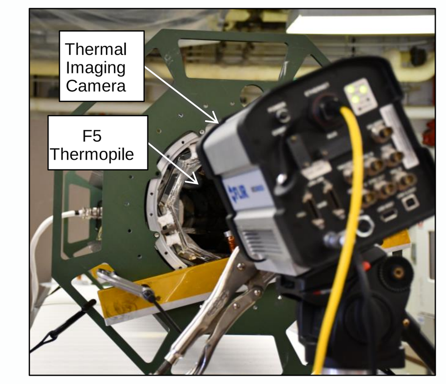

Figure 6: F5 Peltier Test Setup

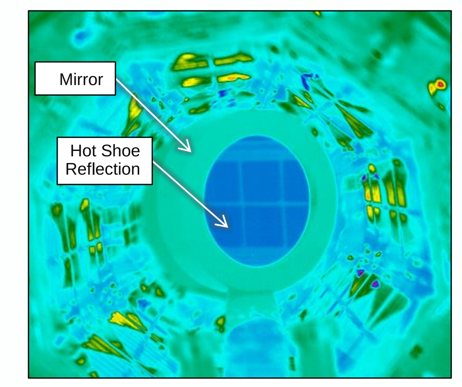

Figure 7: F5 Peltier Thermal Capture

Results

The nominal thermopile resistance of a new GPHS-RTG is in the range of 0.75-ohms to 0.90-ohms. However, the measured thermopile resistance of F5 was 1.46-ohms. The two circuits were proven to be resistively balanced based on their response to the Peltier cooling.

The electrical connection to thermocouple Q13 is no longer intact. Therefore, all current flowing through the inboard circuit flows through thermocouple R13, the parallel counterpart to Q13. This discovery presents a risk to the power producing capability of F5 due to the potential for loss of circuit redundancy.

Thermocouple pair AB04 had an imbalanced temperature during Peltier cooling. This indicates a difference in resistance between the thermocouples in the pair. This information and its impact on the F5 functionality will be considered as the refurbishment project continues.

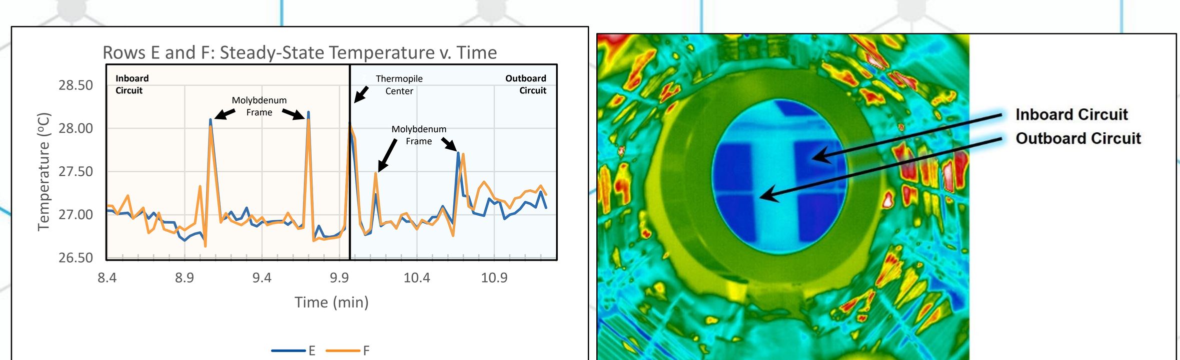

Figure 8: F5 Peltier Steady-State Results on the Inboard and Outboard Circuits

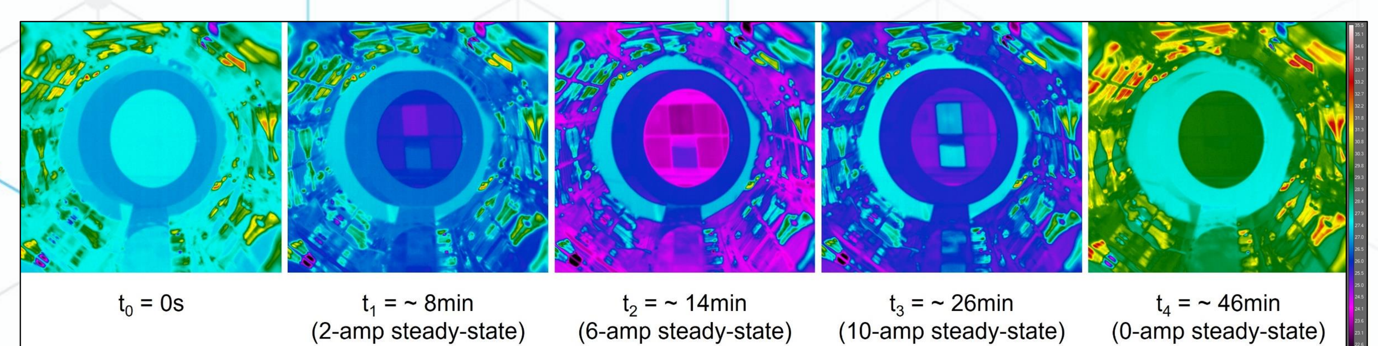

Figure 9: F5 Electrical Disconnect of Thermocouple Q13 Transient Results

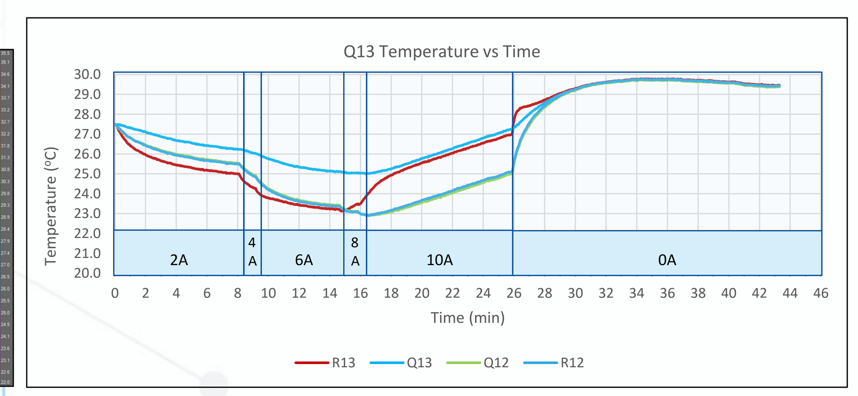

Figure 10: Electrical Disconnect of Thermocouple Q13 Plot

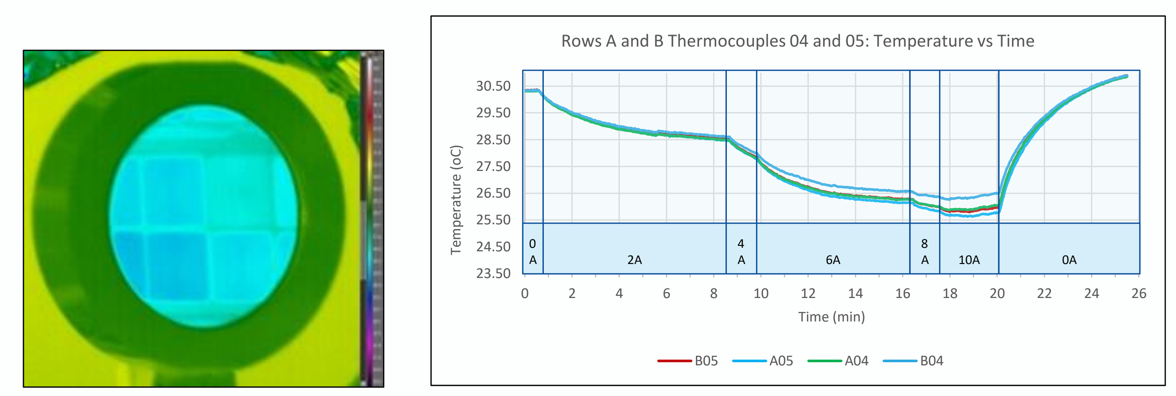

Figure 11: F5 Thermocouple Pair AB04 Thermal Imbalance Transient Results