milliWatt Generator Design

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Abstract. This paper discusses the design of a High-G capable Radioisotope Power Supply (RPS). It provides details of the procedure that will be used when the device is assembled. A thermal model is then used to determine the heat flow in the generator and ultimately the power produced from the resulting system.

Keywords: Radioisotope generator, thermoelectric generator, milliWatt power, RHU capsule, long lifetime, high shock load.
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INTRODUCTION

For the past several years Hi-Z Technology, Inc. (Hi-Z) has been developing milliWatt Radioisotope Power Supplies (RPS) for the Department of Energy (DoE). The RPS' are being developed by DoE for the National Air and Space Agency (NASA) for various future missions in space. One possible mission is to land a network of 24 weather stations on Mars to take and record weather data over an 18 year period. The data would be relayed to an orbiting space probe, which would then relay the data back to Earth.

A new design of the milliWatt generator is proposed to allow its use in situations requiring High G shocks. Since the proposed design is new, there was desire on the part of the Department of Energy not to proceed without a detail study of how the new design is to be assembled. The objective of this paper is to provide a summary of the assembly procedure for this new design which is given in full by Bass, Hiller, Jovanovic, and Elsner.

The first RPS developed by Hi-Z was the 40 mW RPS shown in Figure 1. This generator used the 1 Watt Radioisotope Heater Unit (RHU) developed and assembled by Los Alamos National Laboratory (LANL) (Tate, 1982) to heat instrument in deep space probes for NASA. The RHU is shown in Figure 2.

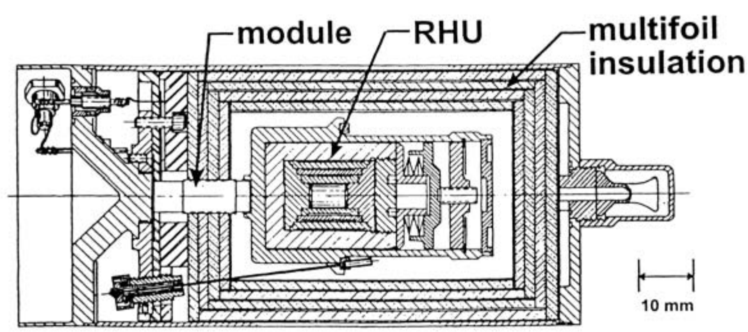

FIGURE 1. 40 mW RPS Design.

Originally most of the specifications for the RPS were somewhat vague, except that Hi-Z was to try to obtain up to 40 mW of output at 5.5 Volts matched load using the 1 Watt RHU. The design effort at Hi-Z continued while NASA developed the specifications that would meet several of their missions. One specific item to come out of study was the need for an RPS which could withstand the High-G impact load of a "beach ball" landing. This is a landing where the payload is installed in a system of balls which are used to absorb the landing shock estimated to be upwards of 3,000 gm as the balls bounce along the surface of the planet. Other requirements anticipate G loads of up to 5,000 gm.

NASA/Ames shock tested Hi-Z's 40 mW RPS to see what it could take in terms of G loading. These tests showed that the original 40 mW RPS design could take between 1,800 and 2,000 gm. The specific G failure point was not clearly determined. In the 40 mW RPS design, the mass of the RHU and the fuel capsule holder are resting on the thermoelectric module. A lateral shock load results in the capsule holder rotating about one edge of the module and then snapping back to its original position. The result is very high stress loads on the module and on the electric contacts.

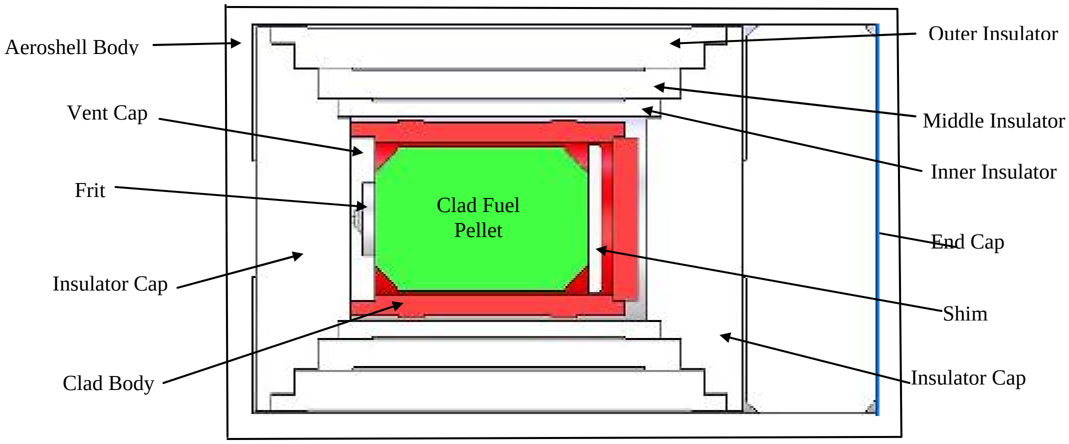

FIGURE 2. 1 Watt RHU Heat Source.

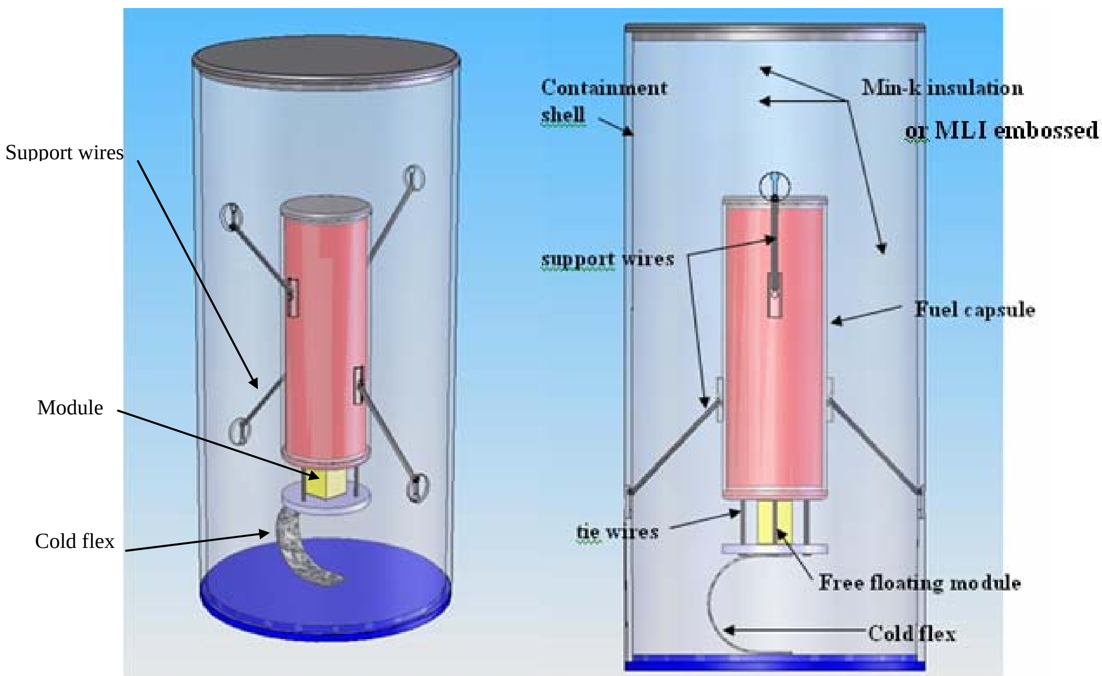

FIGURE 3. An Analytical Three Dimensional Thermal Model of the High-G Load Generator.

RPS Redesign

Hi-Z engineers looked at several options to the redesign of the 40 mW RPS. This included methods of limiting the rotation of the fuel capsule holder. The one ultimately selected was a completely new approach to solving the High-G load problem in which the forces on the module would be minimized.

A model of the new approach was constructed using plastic so the internal components could easily be visualized. This model is shown in Figure 3. The DoE funded a study (Bass, et al., 2007) in late 2006 to investigate how this new design could be assembled. In addition, Hi-Z was to investigate methods that could be used to make a higher powered RHU that would minimize the cost of requalifying the RHU. The higher power might be required if the heat leakage of the new RPS is higher then first anticipated from preliminary calculations. Also, a higher power output might allow the RPS to be used for additional missions. In the new RPS design, the fuel capsule holder would be suspended by four wires placed in pairs on opposite ends of the fuel capsules holder. The pairs of wires are located 90° to each other and their extension passes through the center of gravity of the suspended system. In this way, the fuel capsule holder can take shock loads from any direction.

The thermoelectric module is suspended from the capsule holder by four additional titanium wires. These wires are attached to the fuel capsule holder and pass down to the module support base. The module support base end of the wires are spring loaded so that pressure can be applied between the thermoelectric module, the bottom of the fuel capsule, and the module side of the module support base.

The module support base is made in three parts. The inner piece is aluminum; the outer ring, through which the support wires pass, is titanium; the ring between is made of Vespel (a solid form of Kapton). This design inhibits the transfer of heat from the fuel capsule holder, down the titanium support wires, to the outer support ring, through the Vespel, and to the inner aluminum support which acts as the cold sink for the module.

Fuel Capsule Design

One requirement of the current contract was for Hi-Z to suggest ways in which the power of the RHU could be increased in a way that might not require additional re-entry testing. After looking at a number of possibilities (Wiley and Carpenter, 2004) we suggested that the clad fuel capsule be maintained and a new set of longer graphite insulators and aeroshells be made and assembled as shown in Figures 4 and 5. This approach maintains most of the components of the original RHU.

The mass of the proposed 2 W RHU was calculated to be 57.7 grams. Compared to the mass of two 1 Watt RHUs of the original design, which would be slightly less than 80 grams or a 27.9% mass savings. This approach to a 2 W RHU design has neither been reviewed nor approved by DoE.

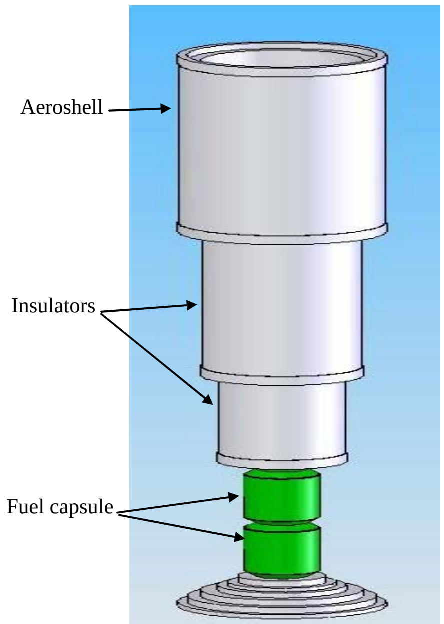

FIGURE 4. Fuel Pellets and Radial Shields

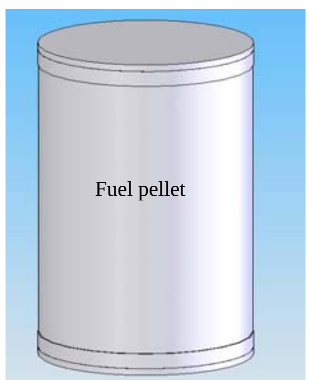

FIGURE 5. Completed 2 Fuel Pellet RHU

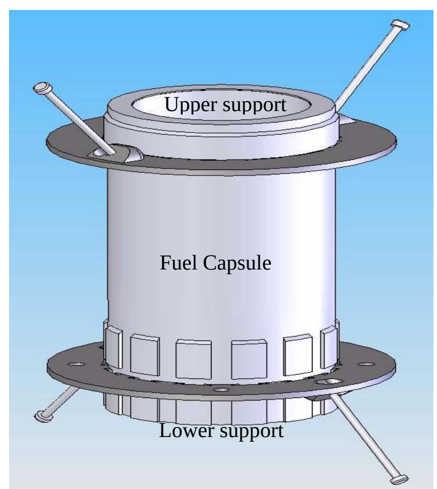

FIGURE 6. Support Rings in Place on Fuel Capsule Holder.

Assembly of an RPS with a 2 W RHU

The first step in the assembly of the RPS is to assemble the support wires for the capsule holder. Figure 6 shows how the support rings and wires are assembled on the fuel capsule holder. Notches are provided in the lower section of the fuel capsule holder so the similarly notched support rings are passed through the notched section and then rotated to provide the proper orientation for the support wires.

The next operation is to assemble the three piece lower module support as shown in Figure 7. The module, which is about 7.5 mm square by 11.4 mm long, is then assembled with the lower module support and the module support wires shown in Figure 8. The springs and nuts are then assembled below the lower module support as shown in Figure 9, and the nuts are tightened to provide the module compression desired for good heat transfer.

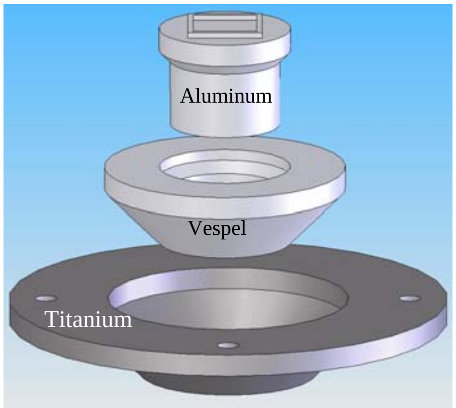

FIGURE 7. Lower Module Support

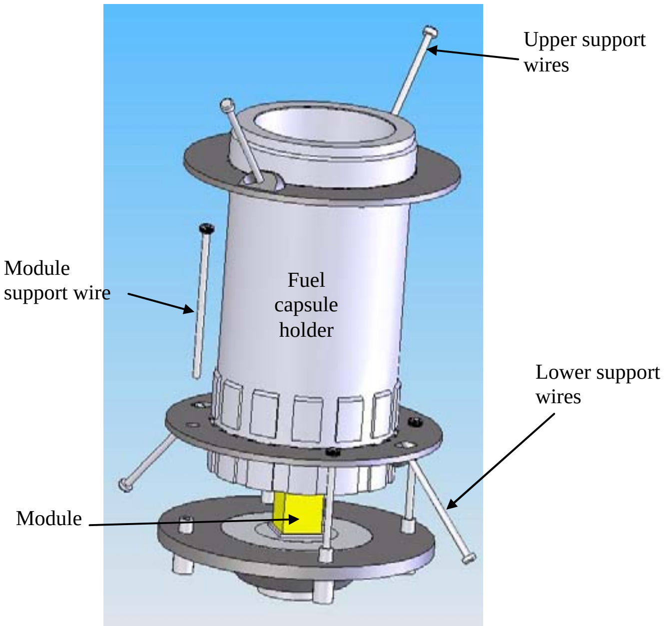

FIGURE 8. Assembly of Module Support Wires

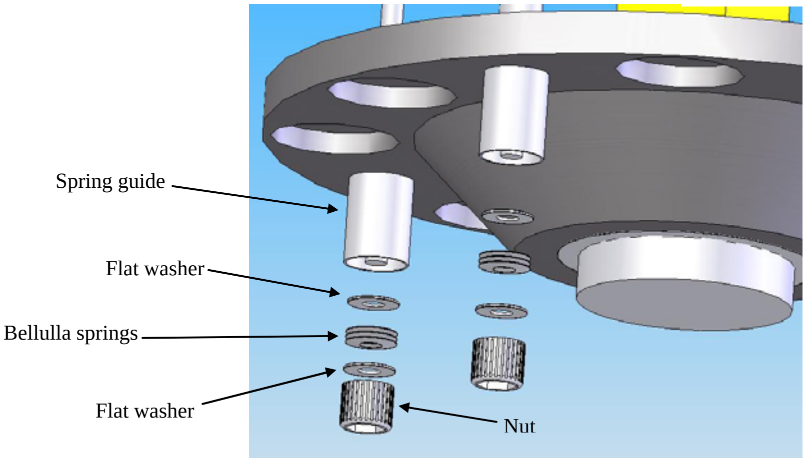

FIGURE 9. Assembly of Belleville Washers and Nuts

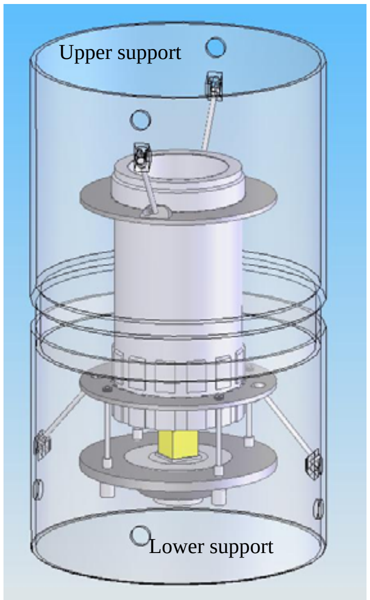

FIGURE 10. Upper Support Tube in Place

The assembly is then placed inside the upper and lower support tubes and the free ends of the wire is passed through the holes provided in the support tubes as shown in Figure 10. The support tubes are placed in tooling which will pull the two halves of the support tubes apart and provide the desired pretension in the support wires as shown in Figure 11. The support tube halves are then TIG welded to maintain the tension in the support wires. The lower thermal shields are put in place, as shown in Figure 12, and the bottom heat sink plug is installed with a small piece of high thermal conductivity graphite felt placed in its center, as shown in Figure 13, and weld. The lower support tube and heat sink are then secured with epoxy. The electric connections are then made through across holes in the lower support tube, as shown in Figure 14. The pressure shell is placed over the bottom heat sink and it is welded in place. The radial shields can now be installed as shown in Figure 15. The 2 W RHU fuel capsule can now be loaded and the remainder of the assembly completed as shown in Figure 16. It should be noted that the fuel capsule support wires are not shown in this view.

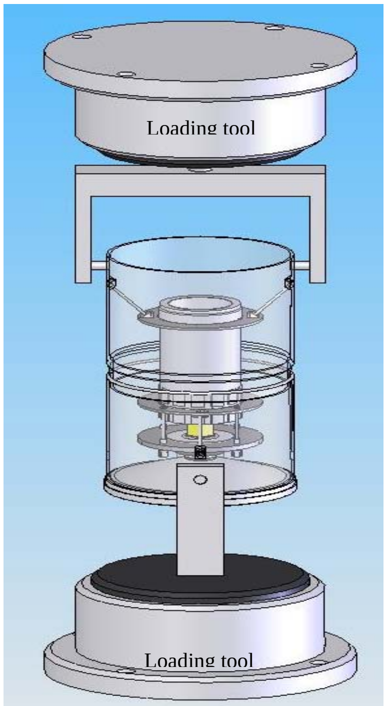

FIGURE 11. Two Halves of Support Tube Being Pulled Apart

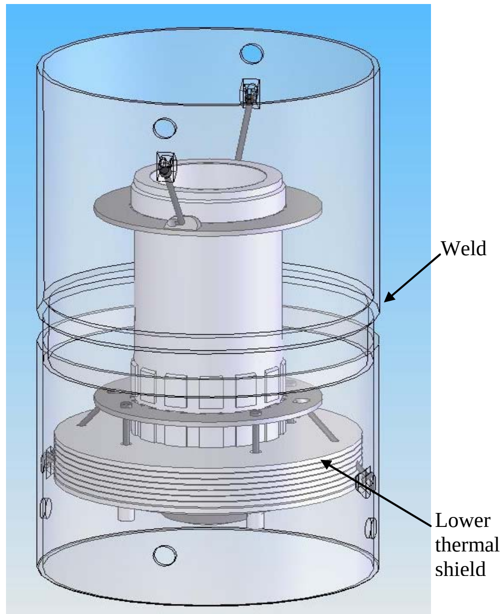

FIGURE 12. Lower Thermal Shields in Place

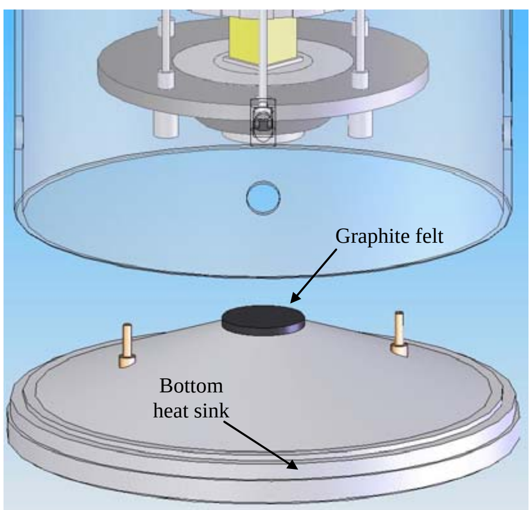

FIGURE 13. Bottom Heat Sink Plug in Place. Seen are the Graphite Pad and Electric Feed Through

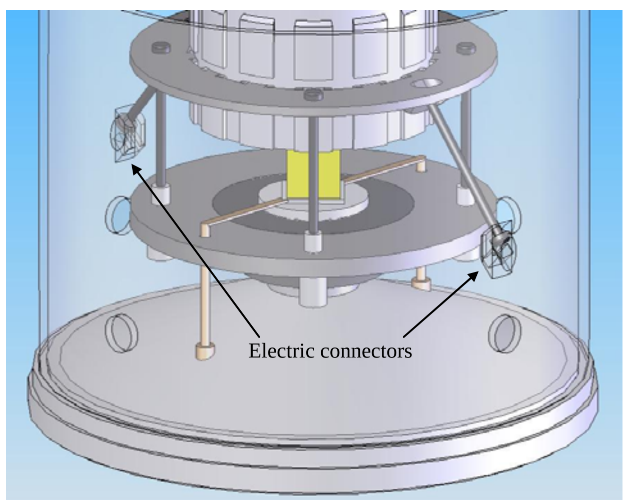

FIGURE 14. Electrical Connection through Side Holes

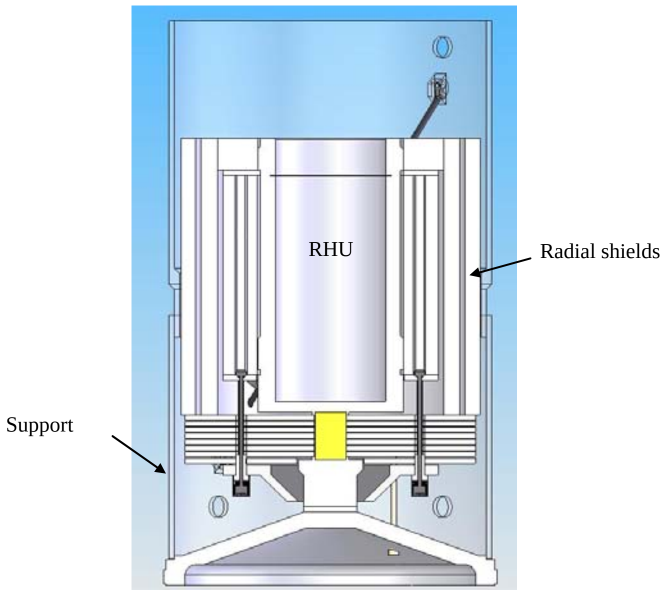

FIGURE 15. Radial Thermal Shield in Place

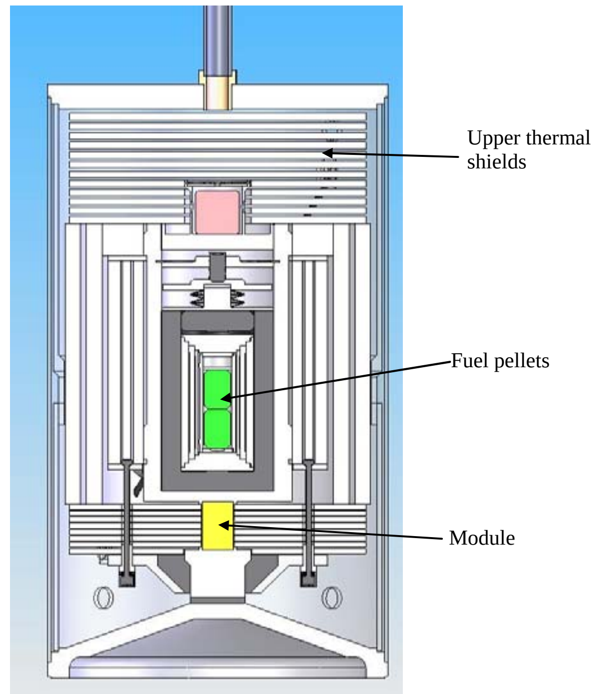

FIGURE 16. All Radiation Shields in place. Cap is Welded to Pressure Shell

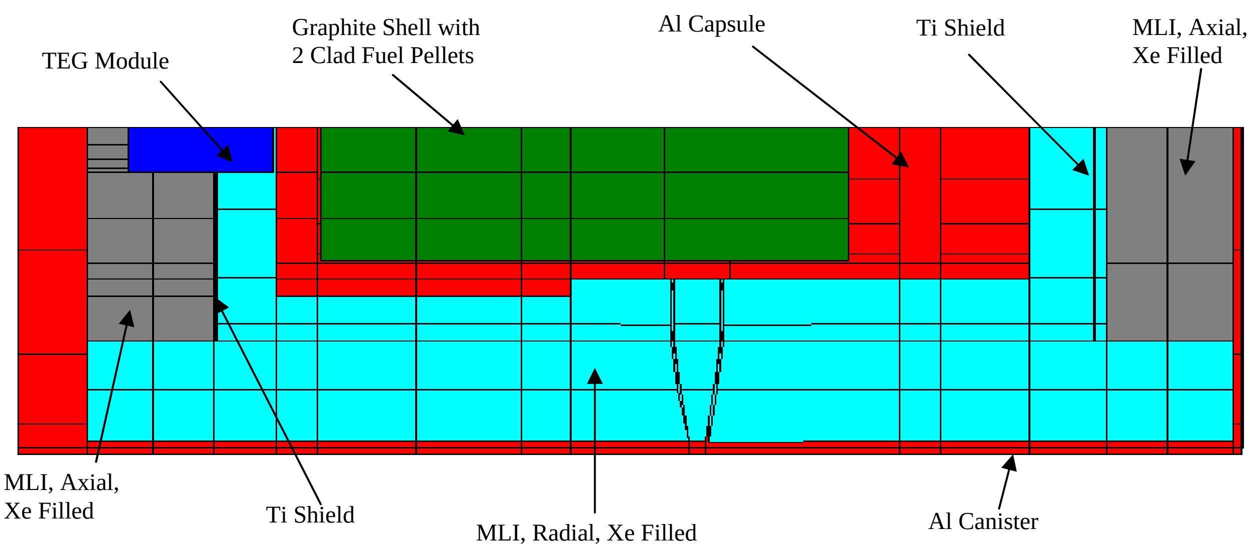

FIGURE 17. Thermal Model of 2 W_t RPS with Two Stacked Clad Fuel Pellets

Thermal analysis

A thermal analysis of the RPS was done for the 2 W RPS using Thermal Analysis System by Harvard Thermal, Inc. (Gubareff, Janssen, and Torborg, 1960). The model is shown in Figure 17. The thermal analysis considered the conduction, convection and radiation modes of heat transfer (Rohsenow, Hartnett, and Cho, 1998) and it was performed with the TAS (Harvard, 2001) computer program. In the thermal analysis, the only two prescribed conditions were used: the outside surfaces of the assembly were assumed to be at the ambient temperature of 25ºC, and the heat from the two stacked fuel pellets was used. All other values were calculated. Using the input heat of 0.5 W (1/4 of the total heat of 2 W from the two stacked fuel pellets), steady-state thermal analysis was performed. The predicted temperature contours for the milliWatt RPS assembly are shown in Figure 18. The maximum temperature of 379.4ºC was predicted for the graphite shell with clad fuel pellets. It should be noted that the clad fuel pellets were not modeled in detail because their configuration is not known at this time. Once this information becomes known, the thermal model can be easily made more detailed in this region, yielding detailed temperature distributions in the clad fuel pellets to make sure that their maximum temperature is less than their temperature limit.

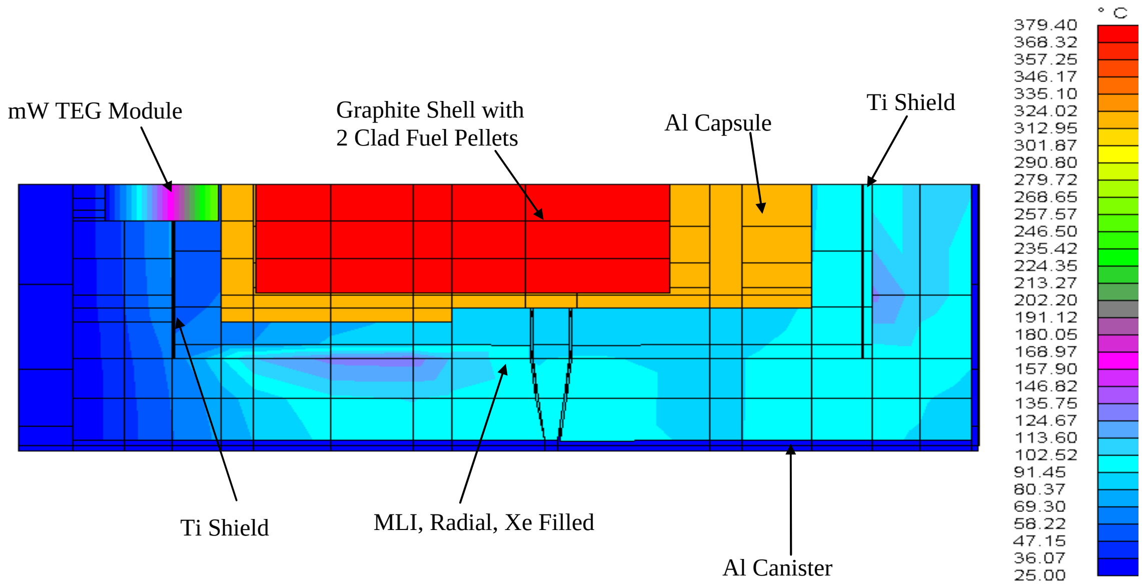

FIGURE 18. Temperature Contour Plot of $2W_t$ RPS with Two Stacked Clad Fuel Pellets

Table 1. Specifications for the High-G Capable milliWatt RPS

Power output at BOL (mW)	80
Voltage at matched load (V)	5.5
Fuel	PuO_2
Capsule power at BOL (mW)	2 W(t)
Heat to cold sink (W)	1.52
Generator diameter (cm)	7.62
Generator length (cm)	14.5
Thermoelectric parameters T_H T_C Material Circuits Cross connections	 225°C 25°C BiTe 2 13
Insulation	MLI + Xenon gas
Generator mass Fuel capsule (g) Generator (g) Total Mass (g)	 57.7 512.7 570.4
G Loading capability (g)	5000
Design life (yrs)	18

Conclusions

The concept of a RPS capable of accepting High-G impacts is presented. This concept uses a suggested 2 Watt variation of the RHU. The entire assembly sequence for the RPS is shown and appears feasible. The program is now ready to proceed with the detail design of the system. A summary of the design specifications for the High-G capable milliwatt RPS is shown in Table 1. A thermal model of the RPS is presented. The analysis of the model indicated that the power output of the RPS should be about 80 mW at the beginning of life (BOL).

Acknowledgement

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