Milliwatt Radioisotope Power Supply for Space Applications

John C. Bass and Daniel T. Allen, Hi-Z Technology, Inc., San Diego, California, U.S.A.

Abstract

A small thermoelectric generator is being developed for general use in space, and in particular for any of several proposed Mars atmospheric probes and surface landers that may be launched in the 2003 to 2006 time period. The design is based on using as the generator heat source an existing 1 watt radioisotope heater unit, which has already been used to provide heating alone on numerous spacecraft, including the 1997 Pathfinder/Sojourner Mars lander. The thermoelectric generating module will be bismuth-telluride alloy. The module will combine new manufacturing technology with a basic design that has a two-decade heritage of performance and lifetime data. Power output will be approximately 40 milliwatts. Important technical issues that need to be addressed in the detailed design are the mechanical integrity of the overall power supply in consideration of the impact of landing on Mars and the subsequent performance of the thermal insulation around the heat source, which is critical to delivering the output power. The power supply is intended to meet a 20-year operational lifetime. The paper describes the design status to date, and it presents the analytical approach, the testing program plan and a manufacturing schedule that is needed to meet the launch dates being considered.

Introduction

The generator being developed was described in its preliminary design stage previously [1]. The U.S. Department of Energy is now furthering this technology. The fabrication of the thermoelectric modules utilized in the generator and their test performance will be addressed in another paper at this conference [2].

While the DOE is developing this generator for general use in space and there is no specific mission as yet, NASA has identified a class of applications for this size of radioisotope powered generator [3]. These are the "micro missions", which are physically small-scale spacecrafts and/or probes and which are planned to be executed for relatively low cost. Solar photovoltaic and even primary battery power sources suit some such micro missions, but for those with the objective of long operational lifetime through hostile environments a radioisotope power supply is the only option. There are several proposed Mars atmospheric and surface probes which are comprised of multiple landers that will do such things as report weather or seismic data. These missions need only tens of milliwatts of continuous power to accomplish their objective, since energy can be stored in ultra-capacitors to power burst mode communication to Mars orbiters that will relay data back to Earth science teams.

Design

The starting point for the generator design is to utilize the existing 1 watt Light Weight Radioisotope Heater Unit (RHU) which is used on U.S. spacecraft for localized heating of components [4]. The RHU was designed and developed almost twenty years ago. It consists of a pellet of $^{238}PuO_2$ clad in 1mm (0.039 inch) thick Pt-30%Rh nested in a three layer pyrolitic graphite insulating assembly enclosed in a carbon-carbon composite aeroshell. For example, three RHUs are in place of the Pathfinder/Sojourner unit that explored Mars in 1997, and so the RHU has already met qualification standards for launch, travel and landing on Mars. The only difference in application of the RHU to a generator is that the potential accidental Earth re-entry conditions are complicated by the presence of the generator structure around the RHU capsule and the higher initial RHU temperature that results. The generator structure is essentially all aluminum, however, and it should disintegrate early in the sequence, and this is not expected to significantly change the re-entry scenario. In addition, analyses of the fuel and clad temperature on re-entry have shown that initial temperatures have very little effect on their peak values because of the overpowering re-entry heat pulse [5]. However, a more recent study indicates margin on clad integrity may be inadequate [6]. These differences need to be addressed with further analyses and possibly with experimental verification. In any event, an extensive launch approval process is required for each application of the RHU.

One watt of heat is not a large amount of power to begin with, and so a design challenge is to thermally insulate the RHU to minimize parasitic heat losses. Figure 1 illustrates the generator in crossection and graphically shows the heat flow "budget". Hot and cold side design basis temperatures for the thermoelectric module were selected 250°C and 25°C. At these temperatures 0.82 watts will flow through the module if heat loss down the capsule holder tie wires is 0.01 watt each and heat flow through the remaining capsule insulation is limited to 0.14 watts. The insulation will be multiple alternate layers of 13μm (0.0005 inch) thick aluminized Kapton® and 79μm (0.0031 inch) Cryotherm® glass fiber paper. The volume between the RHU capsule holder and the generator pressure shell will be evacuated at assembly. Gas generated by the isotope fuel decay will mostly be retained in the fuel body. However, the RHU is vented to the capsule container volume which is sealed, and so gas that is released from the RHU accumulates there and does not reach the insulation. This type of multifoil vacuum insulation has been utilized in space radioisotope generators in the past. However, these specific materials need experimental qualification, which is an objective of the ongoing generator development effort.

At the beginning-of-life with 1 watt of heat from the RHU, the generator is expected to provide 40 milliwatts of electric output at 5 volts. The generator is proposed for 15 to 20-year mission lifetimes. This is consistent with the known decay of the isotope heat source of approximately 1% per year. Overall degradation due to that and extrapolated thermoelectric performance decline will be about 25% over 20 years, and so 30 milliwatts is the reference end-of-life

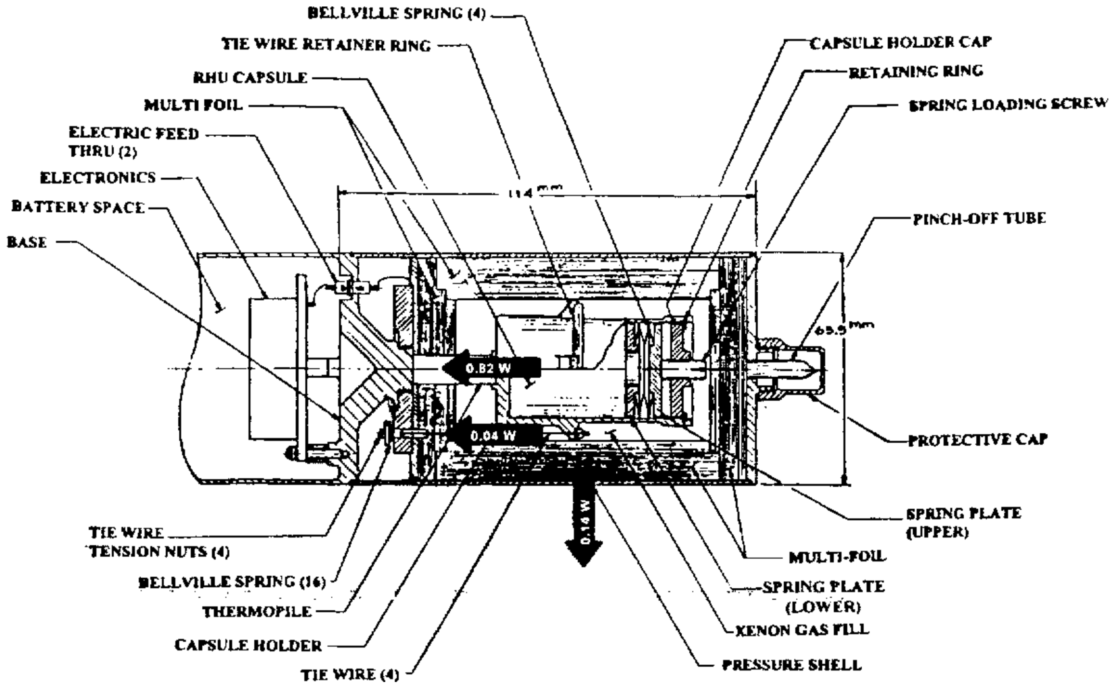

Figure 1- Milliwatt Space Generator

output. Design of the generator is similar to a series of 75 Milliwatt units built by DOE for the US Navy and deployed in the 1970's and 80's. Twenty-seven of these generators, which were designed for 15-year lifetimes, were made. The operating hour history of sixteen of these was documented, and this is summarized in Figure 2. Figure 3 shows representative life test data for these generators. The generators were operating normally past the times represented in Figure 2, but they were removed from service, defueled and scrapped before final performance data points could be obtained. This operating record of over 100 years of generator operation provides verification of the expected lifetime and performance of this generator.

Because the potential applications of the generators include the Mars surface landers, another design issue of significance is the mechanical shock load on the unit in the landing. The typical trajectory to Mars involves an entry velocity there at about 5 km/s. Although Mars does have an atmosphere to dissipate this kinetic energy and the landing scenario includes further parachute deceleration, the lander still could have a surface impact velocity at 30 to 40 m/s (65 to 90 miles per hour). The ultimate shock load depends on design of the probe, especially the design of a "crushable impact attenuation feature". It is estimated that the deceleration along the axis parallel to the possible landing trajectories will be less than 2000 g's and probably less than 1000 g's. A representative mock-up of the generator was in early 1998 subjected to a sequence of high-g shock tests at NASA/Ames Research Center, and the assembly survived 3600 to 3800 g's along the longitudinal axis of the generator but failed at this load when inclined at 45°. Further mechanical testing is an early objective of the current development program.

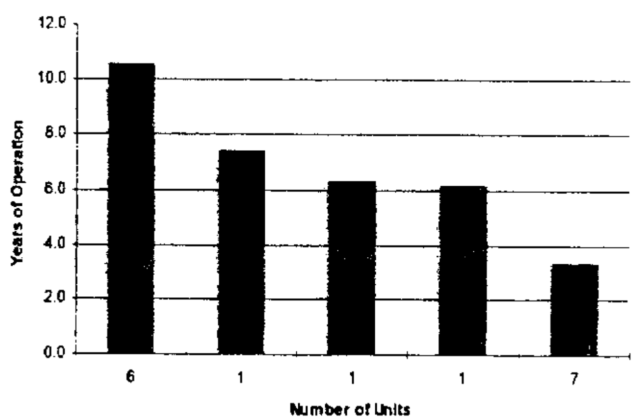

Figure 2 - Heritage of Operating History, 75 mW Generator

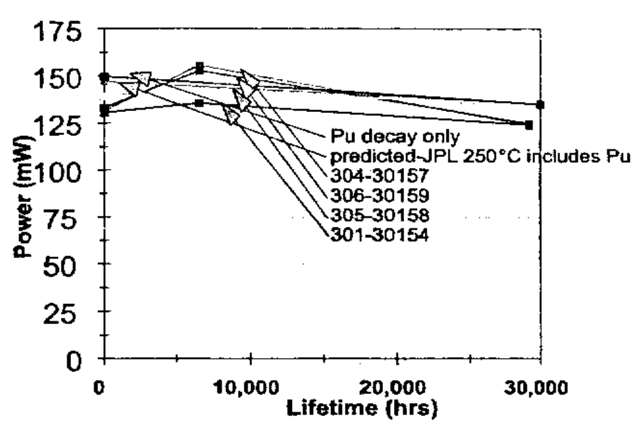

Figure 3 - Representative Life Test Data, 75 mW Generator

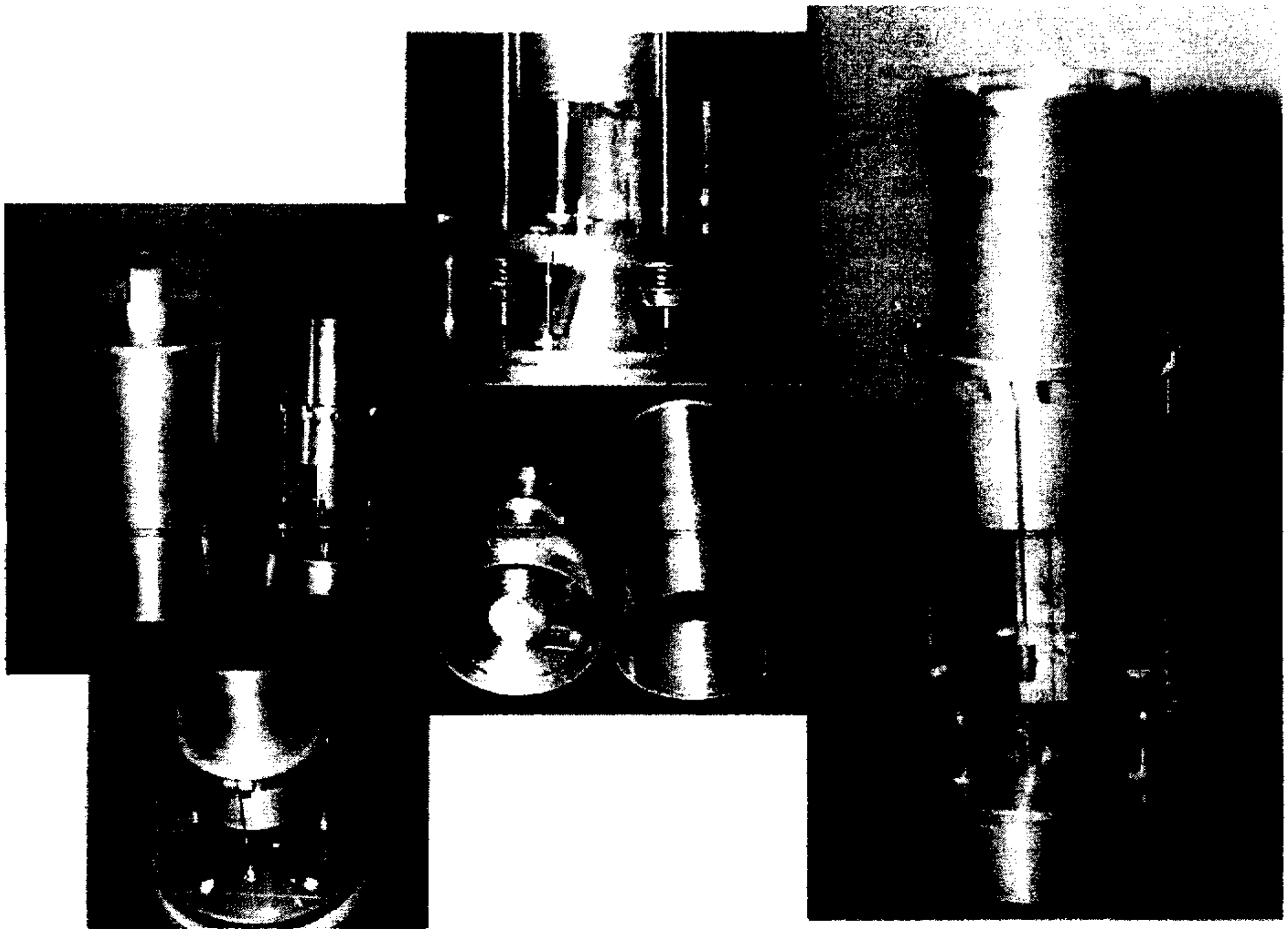

Figure 4 - Model of Generator

The development timetable up to this point next year (September 2000) calls for fabrication and testing the generator components critical to the design, with attention to the performance, stability and longevity of the thermoelectric module, efficiency of the thermal insulation and endurance of all of the generator components under modereate g loads. First articles of all of the generator components have already been fabricated. Figure 4 is a collage of generator component photos. In Figure 5 the insulation assembly is shown. These have been assembled into test articles for mechanical shock load testing. Two complete units are to be assembled but without the RHU. One will be mechanically shock tested as a unit proof test. The other unit will be tested for thermal and electrical performance and then placed on life test.

Non-nuclear testing presents the problem of how to assuredly apply 1 watt to a surrogate RHU. In previous radioisotope generator development on electric heater has been used, but for this generator the power desired is on the

Figure 5 - Generator Insulation Mock-up

same order as the uncertainty in losses along heater electrical leads. For this reason, a solid-state adjustable continuous wave IR laser will be used to beam the 1 watt into the ecaluated generator through a window and small holes is the insulation, is shown schematically Figure 6.

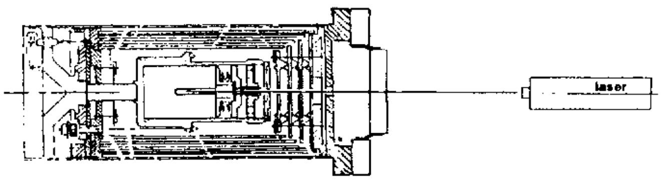

Figure 6 - Use of Laser for Non-RHU Heating

Conclusion

At the end of the present work effort a year from now, at least one of the two complete units will be made available for RHU loading and actual radioisotope fueled proof testing.

Acknowledgment

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for more information contact:

Hi-Z TECHNOLOGY, INC.

Hi-Z Technology, Inc.
7606 Miramar Road
San Diego CA 92126-4210, USA
tel.: +1 858 695 6660
FAX: +1 858 695 8870
e-mail: info@hi-z.com
http://www.hi-z.com