GENERAL PURPOSE HEAT SOURCE SIMULATOR

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Abstract – ***The General Purpose Heat Source (GPHS) project seeks to combine the development of an electrically heated, single GPHS module simulator with the evaluation of potential nuclear surface power systems. The simulator is designed to match the form, fit, and function of actual GPHS modules which normally generate heat through the radioactive decay of Pu238. The use of electrically heated modules rather than modules containing Pu238 facilitates the testing of the subsystems and systems without sacrificing the quantity and quality of the test data gathered. Current GPHS activities are centered on developing robust heater designs with sizes and weights which closely match those of actual Pu238 fueled GPHS blocks. Designs are being pursued which will allow operation up to 1100 °C.***

I. INTRODUCTION

Radioisotope Power Systems (RPSs) generate electrical power by converting the heat released from the nuclear decay of radioactive isotopes into electricity The power generated from the RPS can be used in a wide variety of applications such as providing surface electric power at remote locations, providing power for electric propulsion systems, and providing warmth in extremely cold conditions. These RPS units use General Purpose Heat Source (GPHS) modules containing Pu238 to provide the heat necessary for their operation.

The aim of the General Purpose Heat Source (GPHS) project is to combine development of an electrically heated, single GPHS module simulator with the evaluation of potential nuclear surface power systems. The simulator is designed to match the form, fit, and function of actual GPHS modules (Figure 1).

The use of electrically heated modules rather than modules containing Pu238 facilitates the testing of the subsystems and systems without sacrificing the quantity and quality of the test data gathered. The current GPHS project leverages off previous IRAD non-nuclear design and testing activities[1]. Several GPHS simulator modules currently exist from these prior efforts; however, these units have been redesigned to improve their reliability. The GPHS activities during this past year have centered primarily on developing more robust heater designs with more representative sizes and weights. Two designs have been fabricated and tested. The first design tested was a low temperature configuration using commercially available cartridge heaters. The other configuration tested was designed for higher temperature operation and incorporated molybdenum mandrels wound with alumina insulated tantalum wire.

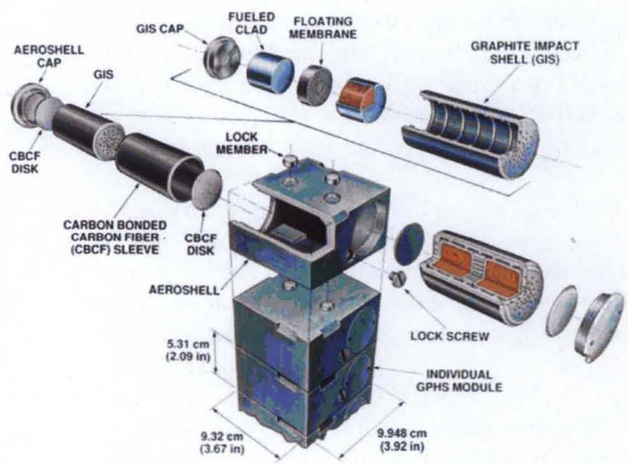

Figure 1 General Purpose Heat Source (GPHS)

II. LOW TEMPERATURE HEATER DESIGN

The low temperature heater design incorporated a commercially available cartridge heater encased in a tungsten shell. This design was capable of achieving GPHS block surface temperatures of 850 °C continuous or

900 °C for short time periods. Figure 2 illustrates the details of an individual heater assembly.

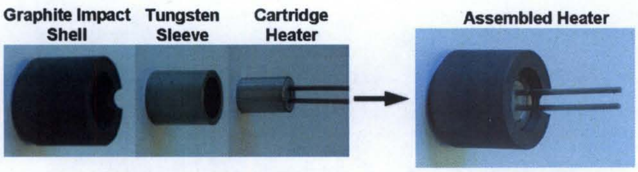

Figure 2 Low temperature Heater Assembly

Two heater assemblies were normally tied together in series and inserted into the Graphite Impact Shell (GIS). Two GIS assemblies are then inserted into a GPHS block and wired in parallel to the main bus rods running axially through the blocks (Figures 3 and 4). The nominal power level of the GPHS blocks is 250 W.

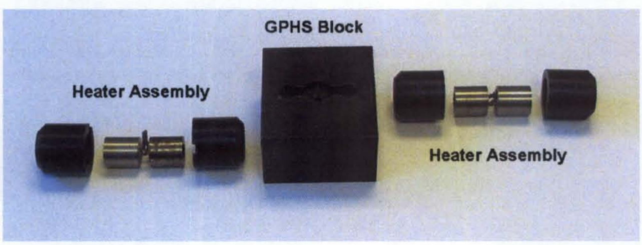

Figure 3 GPHS Heater Block Assembly

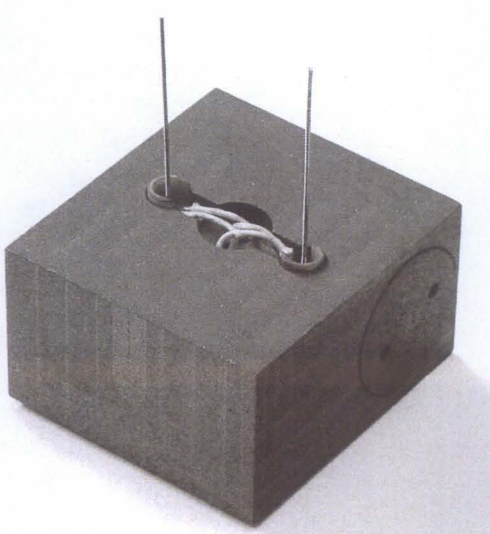

Figure 4 Completed GPHS Heater Block

When needed, several GPHS blocks can be screwed together using the bus rods which are threaded.

Testing has been performed on several of the units and has consisted of short term transient testing and long term endurance testing. The transient testing has taken the form of powering up the units, raising the power level to 1.5 times nominal power (375 W), achieving steady state temperature conditions, and shutting the units down. This transient sequence has been performed on one GPHS block assembly and has consisted of six complete startup/shutdown cycles. No degradation was observed on the unit at the conclusion of the transient tests. Long duration testing was performed on several GPHS blocks with the longest test running for approximately 650 hours. This test was also run at 15 times nominal power in a partially insulated condition. The steady state temperature achieved during the tests was 665 °C. Again after these tests no degradation of the GPHS blocks was observed.

The next series of tests consisted of testing multiple units configured in a stack of three. Testing proceeded as in prior runs by progressively raising the power in a series of steps until full power is reached. Unfortunately, due to a GPHS block design limitation the maximum temperature achieved was 400 °C. An examination of the units after testing revealed that the failure was due to localized melting of the main stainless steel bus rod and not the heater units themselves. It was determined that what was happening was that as modules were added to the stack, the resistance of the heaters went down because they were wired in parallel while at the same time the resistance of the bus rod went up because the length increase required to accommodate the taller stack. The net result was that the heating of the bus rods went up by almost an order of magnitude over the one module test. This additional heating was sufficient to melt the stainless steel bus rod and cause an open circuit. The solution for future tests will be to switch to molybdenum bus rods which have both lower resistance and higher melting points.

After the transient and endurance testing was completed the decision was made to test a single GPHS unit at progressively higher powers until heater failure occurred. During these tests the GPHS blocks were placed in a highly insulated test cavity to reduce heat loss and thereby achieve the maximum possible temperature (Figures 5 and 6). The temperatures increased in steps as the power increased until surface temperatures in the block reached 850 °C. Nothing unusual occurred at this temperature and the unit was held at this temperature for approximately one day. Achieving this temperature under steady state conditions had been the original goal of this round of testing. Further power increases were then initiated and as the temperature approached 880 °C, it was observed that small voltages fluctuations began to occur. No further power increases were initiated. The voltage fluctuations continued for about two hours until suddenly there was a catastrophic failure of one of the heater units in the GPHS block. The test unit was then shutdown to terminate the test. The temperature at failure was 900 °C.

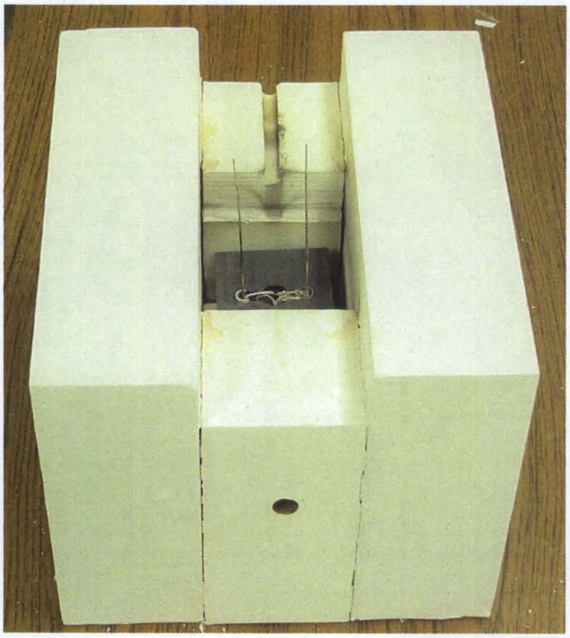

Figure 5 Insulating Cavity Housing GPHS Block

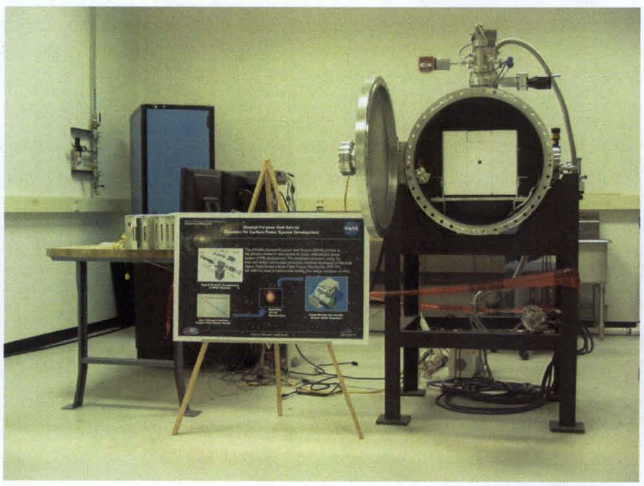

Figure 6 GPHS Test Rig with Insulating Cavity

III. HIGH TEMPERATURE HEATER DESIGN

After the "low" temperature testing of the GPHS block was completed, it was determined that a new heater design would be needed to accommodate higher temperatures. The goal of the testing would be to achieve a design temperature of 1100 °C or greater. Since there were no commercially available cartridge heaters that could survive temperatures of this magnitude, an in house effort was initiated to come up with a new design. After a bit of trial and error a design was found that at present appears to be able to achieve the stated design goal. This design consists of a spiral cut molybdenum mandrel wound with tantalum wire which has been insulated with alumina braid. The wound assembly is then encased in a molybdenum sleeve and locked into place with a threaded molybdenum rod. Figure 7 illustrates the assembly of the high temperature heater unit (minus the tantalum wire wrap).

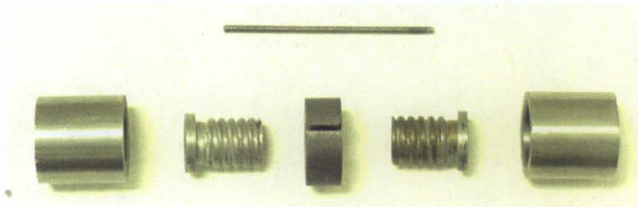

Figure 7 GPHS High Temperature Heater Assembly

The heater unit has thus far been tested by itself in a vacuum and has achieved temperatures of 1033 °C (see Figure 8). The heater unit was held at this temperature for about 3 hours after which time the test was terminated. An examination of the heater unit after the test indicated no degradation whatsoever. The next step will be to fabricate a second heater unit and integrate both units into a GPHS block. Based upon the results of this recent test, it seems likely that the new heater design will allow operation of the GPHS block at temperatures in excess of 1100 °C.

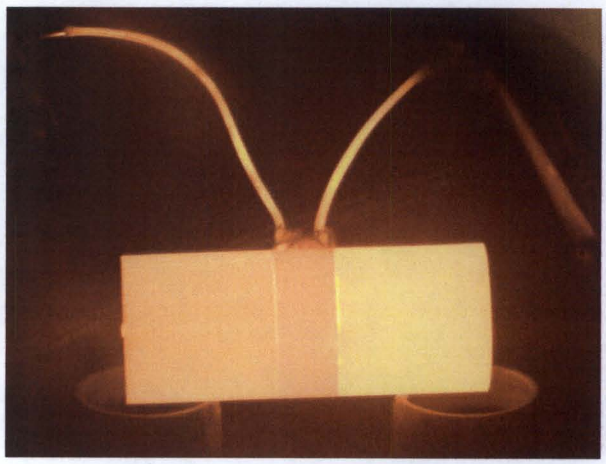

Figure 8 GPHS High Temperature Heater Unit at 1033 °C

IV. CONCLUSIONS

GPHS testing to date has been quite successful and should lead to a robust block assembly which can withstand high temperatures under transient conditions. This block will be available in the near future for further testing in conjunction with its integration into larger RPS test assemblies. These blocks also match the mass of actual plutonium fueled assemblies within a few percent and should give dynamically similar results when vibration testing is approved.

ACKNOWLEDGMENTS

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REFERENCES

1. D. Wagner, J. Turpin, J. Farmer, "Development of an Electrically Powered General Purpose Heat Source (GPHS) Simulator for Use in Nuclear Surface Power System Development", NASA, Marshall Space Flight Center, Nuclear Systems and Analysis Team, ER24-06-GPHS-003, August 8, 2006.