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SIMULATED ISOTOPE HEAT SOURCE FOR USE IN BRAYTON POWER SYSTEM

by Robert B. Smith and George M. Prok

Lewis Research Center

Cleveland, Ohio 44135

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16. Abstract

A simulated isotope heat source was designed and tested at Plum Brook Station, Lewis Research Center, for use in the Brayton power system. The simulated isotope heat source enables ground testing of flight-like hardware without the inherent hazards of the isotope heat source. The simulated isotope heat source is electrically powered, and has been operated for 820 hours at various power levels. The design objectives for the simulated isotope heat source were met. Power and temperature levels were well within a usable range and the life was demonstrated to be sufficient for preliminary testing of the isotope Brayton cycle. An array of electrically heated simulated isotope heat sources may be used to supply 25 kilowatts or more of thermal power to the Brayton system heat-source heat exchanger.

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SUMMARY

A simulated isotope heat source was designed and tested at Plum Brook Station, Lewis Research Center, for use in the Brayton power system. The simulated isotope heat source enables ground testing of flight-like hardware without the inherent hazards of the isotope heat source.

The simulated isotope heat source is electrically powered, and has been operated for 820 hours at various power levels. The design objectives for the simulated isotope heat source were met. Power and temperature levels were well within a usable range and the life was demonstrated to be sufficient for preliminary testing of the isotope Brayton cycle. An array of electrically heated simulated isotope heat sources may be used to supply 25 kilowatts or more of thermal power to the Brayton system heat-source heat exchanger.

INTRODUCTION

The NASA Lewis Research Center is engaged in the development of a Brayton power system to provide up to 15 kilowatts of electric power for space applications. Early testing of the power system (ref. 1) has been with an electric (nonflight) heat source. In flight application, the heat supply will be an isotope heat-source assembly which will heat the working gas by radiation from the isotope heat-source assembly to a heat exchanger containing the working gas.

The isotope Brayton cycle power system consists of the isotope heat-source subsystem and the Brayton power-conversion system. Figure 1 shows a schematic diagram of the isotope Brayton cycle power system.

The isotope heat-source subsystem consists of a circular planar array of isotope heat sources enclosed in an insulated container and mounted on a combination support and auxiliary cooling heat exchanger. The isotope heat sources transfer heat solely by radiation to the heat-source heat exchanger which contains the Brayton cycle working fluid.

Each isotope heat source has an external graphite jacket for reentry protection. Inside the protective jacket is a metal container encasing radioisotope fuel. Figure 2 shows the isotope heat-source subsystem and an individual isotope heat source. When isotope heat sources are used, precautions must be taken against their inherent hazards - radiation, possible contamination of surroundings, and high temperatures.

The simulated isotope heat sources were designed to provide an electrically powered, controllable source of heat for preliminary tests on the auxiliary cooling heat exchanger, thermal insulation, safety devices, heat-source heat exchanger, and the complete isotope Brayton cycle power system, without the time-consuming handling required for the isotope heat sources.

Design work was started in January 1970. The first test series on a boron nitride core with a platinum winding was run in March 1970. The purpose of the first test series was to check roughly the filament operating temperature against the filament design temperature. To this end the tests were run with no jacket of any kind over the filament and core.

The second test series was run in April 1970 on an assembly built to simulate the isotope heat source. The assembly consisted of a boron nitride core with platinum windings encased in a stainless-steel capsule, which in turn was encased in a graphite jacket. This configuration was operated at full power for a short time without incident. Up to this time no problems were encountered.

The third test series was run, starting late in April 1970, with the same configuration as the second test series except that the simulated heat source was enclosed in an insulated container such that the graphite surface temperature approximated the design value. Problems were encountered with the platinum filament, the stainless-steel capsule, and the thermocouples.

The fourth test series started in June 1970 with a slightly different test configuration. The stainless-steel capsule was omitted entirely. A platinum filament wound on a boron nitride core encased in a graphite jacket comprised the simulated isotope heat source. This assembly operated at full power for 24 hours then failed after being operated for an additional hour at 12-percent overload (450 watts). The apparent cause of failure was overheating of the platinum winding in spots.

The fifth test series was run in August, September, and October of 1970. The data presented in this report are results of the fifth test series.

This report describes the simulated isotope heat source, outlines the design method used, and presents the results of tests run at full-power levels in an insulated container in a vacuum.

DESCRIPTION OF TEST SETUP

The simulated heat source (fig. 3) was placed in an insulated container, which in turn was placed in a bell-jar-type test chamber.

The insulated container was designed to reject 400 watts with the heat-source surface at 1090° C (2000° F). Materials available were columbium-zirconium sheet metal, stainless-steel sheet metal, and microquartz felt. Thermal conductivity of the microquartz felt is available in the manufacturer's (Johns-Manville) published information.

The insulated container (fig. 4) was made up of alternate layers of 2.54-centimeter-thick quartz felt insulation and sheet metal. Sheet metal close to the heat source was all columbium-zirconium. Sheet metal on the outer layers and the outer container was all 304 stainless steel. The insulated container was 33 centimeters in outside diameter by 40.6 centimeters high. Figure 4 also shows thermocouple locations on the heat-source faces (TC-2, TC-3, and TC-4).

The power supply schematic, instrumentation, and instrumentation connections are all shown in figure 5. Alternating-current electric power to the heat source was supplied through a variable-output autotransformer. Equipment was protected by fuses and a set of overpressure relay contacts in the power lines to the heat source. The overpressure relay contacts were set to open when the test chamber pressure rose to 1.33 newtons per square meter (1×10^{-2} torr).

DESIGN OF THE SIMULATED ISOTOPE HEAT SOURCE

The design objective was to provide an electrically powered heat source simulator with these characteristics:

(1) Power output of 400 watts with the heat-emitting surfaces at approximately 1090° C (2000° F)

(2) Heat-emitting surfaces of the same material as the isotope heat source (graphite)

(3) Power output capabilities of at least 450 watts to provide a range of test capabilities

(4) Sufficient life to conduct all preliminary testing of the Brayton power system

For the heat surfaces to be at 1090° C (2000° F), it was estimated that the tungsten filament temperature would have to be approximately 1315° C (2400° F).

Data were provided by previous tests run by Mr. G. Prok on the current required in a tungsten filament to make the filament reach 2480° C (4496° F) in a vacuum. Based on these data, an estimate was made of the current required to make a 0.51-millimeter (20-mil) tungsten filament reach 1315° C (2400° F). Knowing the power requirement, 400 watts, and the resistance of tungsten at 2400° F made it possible to approximate the filament length.

Tungsten wire 0.51 millimeter (20 mils) in diameter at a temperature of 1315° C (2400° F) has a resistance of about 4.16 ohms in a length of 213 centimeters (84 in.). The current required to make the filament reach 1315° C (2400° F) was estimated to be 9.81 amperes.

Voltage drop across the filament under these conditions is approximately 41 volts. The same power output can be obtained with smaller diameter and longer filaments or larger diameter and shorter filaments. Filament selection depends on the space, voltage, and current available.

The design result is shown in figure 3. A 0.51-millimeter (20-mil) diameter tungsten filament is wound on a threaded boron nitride core. The 213-centimeter (84-in.) long tungsten filament was designed to operate at a temperature of 1315° C (2400° F) with a power input of 400 watts.

The 4.45-centimeter (1.75-in.) diameter boron nitride rod was made oval on one end to prevent turning in the graphite jacket. The opposite end of the 15.24-centimeter (6-in.) long rod was made round to allow tightening of the graphite retaining ring.

Drilled passageways in the heater core allowed both ends of the tungsten filament to be brought to one end of the core. Power leads could then be connected to the filament ends at that end of the core. The core and filament assembly are encased in a graphite jacket which has the same outer dimensions as the isotope heat source.

The graphite jacket is in the shape of a hollow hexagonal rod. Externally, the jacket is 17.15 centimeters (6.75 in.) long and 8.9 centimeters (3.5 in.) across the flats of the hexagon. The hollow interior of the jacket is 6.35 centimeters (2.5 in.) in diameter.

Instrumentation included a thermocouple embedded in the center of the boron nitride heater core, a thermocouple on the outer surface of the insulated container, and current and voltage meters for the heater. Thermocouple readings were taken on a two-channel recording millivoltmeter.

Pressure in the test chamber was measured with an ionization gage.

OPERATING PROCEDURE

After the heat source and insulated container were placed in the test chamber, power leads and instrumentation leads were connected. The test chamber was closed and pumpdown started. Pumpdown to the 1.3×10^{-3}-newton-per-square-meter (10^{-5}-torr) range took approximately 24 hours.

A small amount of power (approximately 100 watts) was applied to the heat source. As the heat source and the insulation system warmed up, the test chamber pressure rose, indicating that outgassing was taking place and that the pumping system could not keep up with it. Throughout the test, added increments of power were limited by the outgassing of the heat source and the insulation system. Additional power to the heat source was applied in small enough increments that the test chamber pressure did not rise above the 1.3×10^{-2}-newton-per-square-meter (10^{-4}-torr) range.

Power was raised in this manner to the 400-watt level in a time period of 11 days. Power was maintained at the 400-watt level for 19 days, then raised to 450 watts for 1 day, then raised to about 480 watts for 3 days.

RESULTS AND DISCUSSION

The simulated isotope heat source was successfully operated for 820 hours with power applied: for 566.3 hours at 400 watts or more, and for 100.22 hours at 440 watts or more. The highest power applied at any time was 506 watts. For 660.94 hours of the 820-hour period the graphite surface temperature was 982° C (1800° F) or more. With 400-watt power input, the graphite surface temperature was approximately 1038° C (1900° F). With 500-watt power input, the graphite surface temperature was approximately 1121° C (2050° F).

Figure 6 shows the power level throughout the test plotted as a function of time. All the time shown at zero power was due to facility-related problems rather than test article problems. The numbers on the curve in figure 6 identify the particular power-off times. The reasons corresponding to the numbers are

(1) Replacement of cold-trap control valve

(2) Power outage

(3) Power shutoff to add additional ammeter

(4) Fuse blown in relay control circuit

Figure 7 shows the temperature level throughout the test plotted as a function of time. The temperatures plotted were taken at thermocouple location TC-2. Temperatures at locations TC-3 and TC-4 differed from the temperature at location TC-2 only above 788° C (1450° F). The biggest temperature difference was at the highest temperature, 1121° C (2050° F), where TC-3 and TC-4 were approximately 11° C (20° F) cooler than TC-2. The numbers on the curve in figure 7 show the same power-off times as in figure 6.

On disassembly of the insulated can and heat-source assembly, other conditions noted were

(1) The tungsten filament had developed whiskers which on analysis turned out to be tungsten boride. The filament had also become very brittle and was broken in several places. Filament breakage did not occur during the test. Cooldown or handling during

disassembly are possible causes of the filament breakage. The tungsten filament and the boron nitride reacted with each other during this test. This interaction may limit the life expectancy of this design.

(2) The microquartz insulation had changed in physical characteristics from being soft and flexible to hard and likely to crack if bent. This change took place only in the innermost layer of insulation. The manufacturer's literature states that shrinkage and weight loss will take place in microquartz at temperatures above 815° C (1500° F).

(3) The columbium container and radiant insulation had not been affected deleteriously by the temperature and pressures involved.

CONCLUDING REMARKS

The simulated isotope heat source has met the design objectives. The fifth test series was run until the planned shutdown time. Power and temperature levels were well within a usable range, and the life was demonstrated to be sufficient for preliminary testing of the isotope Brayton cycle.

The tests described in this report indicate that materials are available to simulate the power and temperature levels of isotope heat sources. The design of the simulated isotope heat source is adaptable to many other shapes besides the hexagonal type tested. A change in the final configuration and power level of the isotope heat source should still allow the use of this technology for a simulated heat source.

On disassembly of the test article, an interaction between the tungsten filament and the boron nitride core was noted. Tests are continuing with the objective of cutting down or eliminating this interaction by separating the filament and core with aluminum oxide spacers.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, June 23, 1971,
120-27.

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2. Klann, John L.; Soffer, Leonard; Barna, Gerald J.; Kaykaty, Gabriel N.; Kerwin, Paul T.; and Bien, Darl D.: Analysis and Selection of Design Conditions for a Radioisotope Brayton-Cycle Space Powerplant. NASA TN D-4600, 1968.

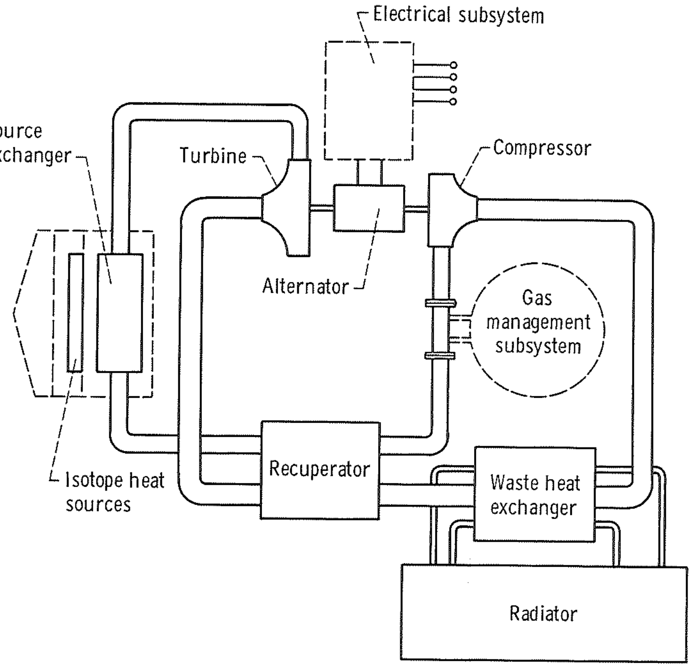

Figure 1. - Schematic diagram of Brayton power system.

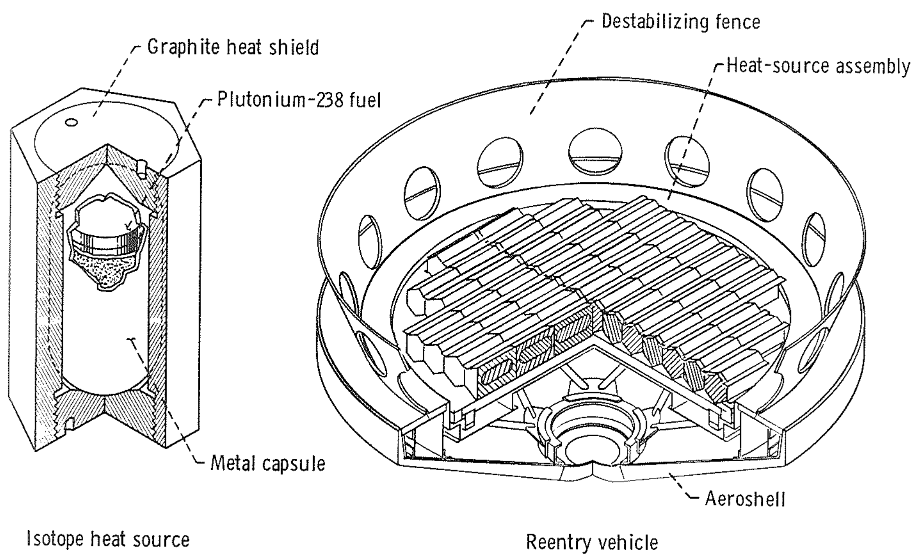

Figure 2. - Brayton isotope heat-source unit.

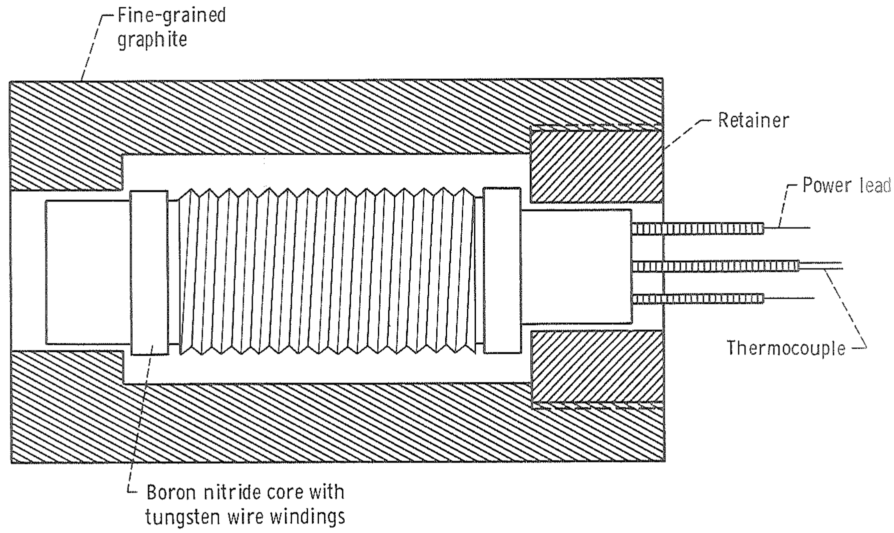

Figure 3. - Simulated isotope heat source.

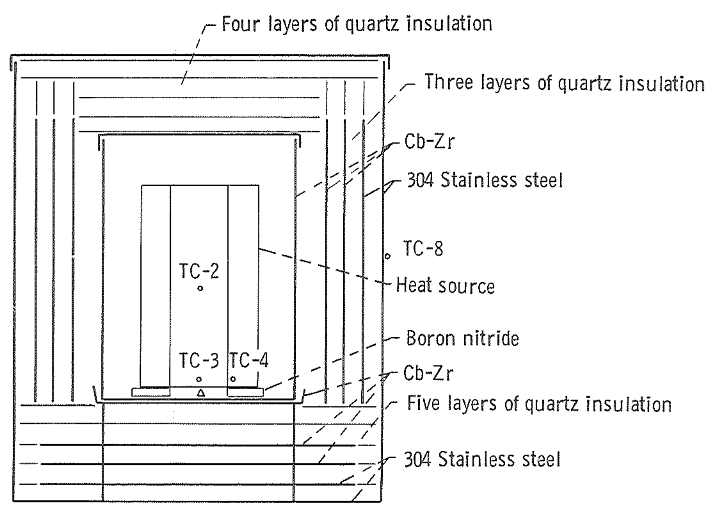

Figure 4. - Insulated container.

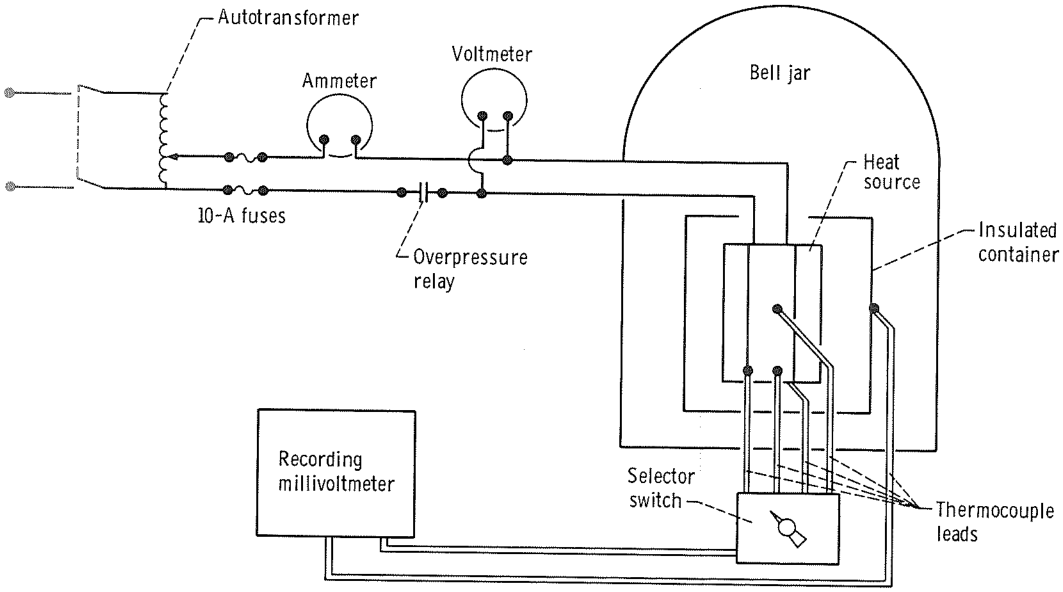

Figure 5. - Schematic diagram of test setup.

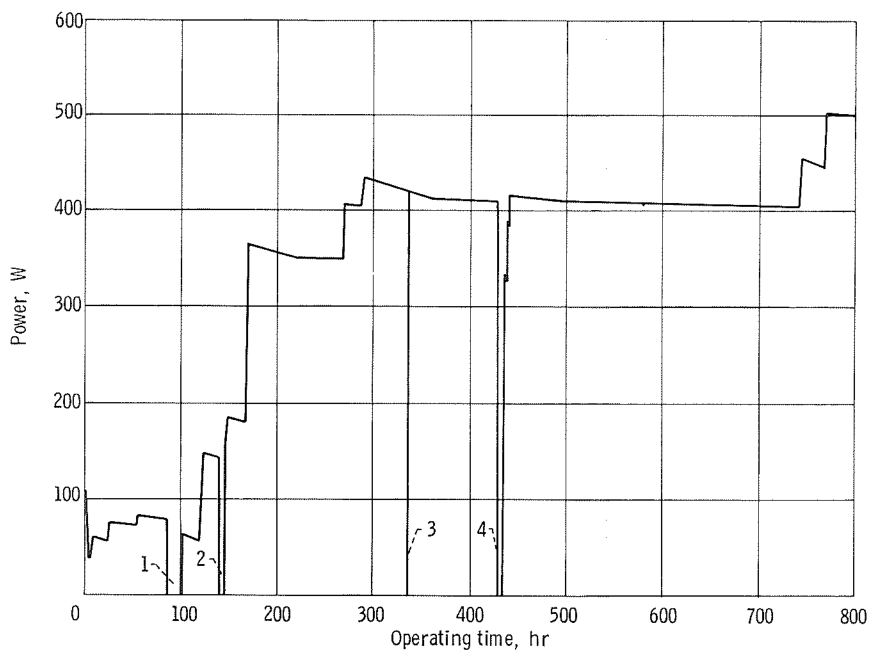

Figure 6. - Time history of power input to the simulated isotope heat source.

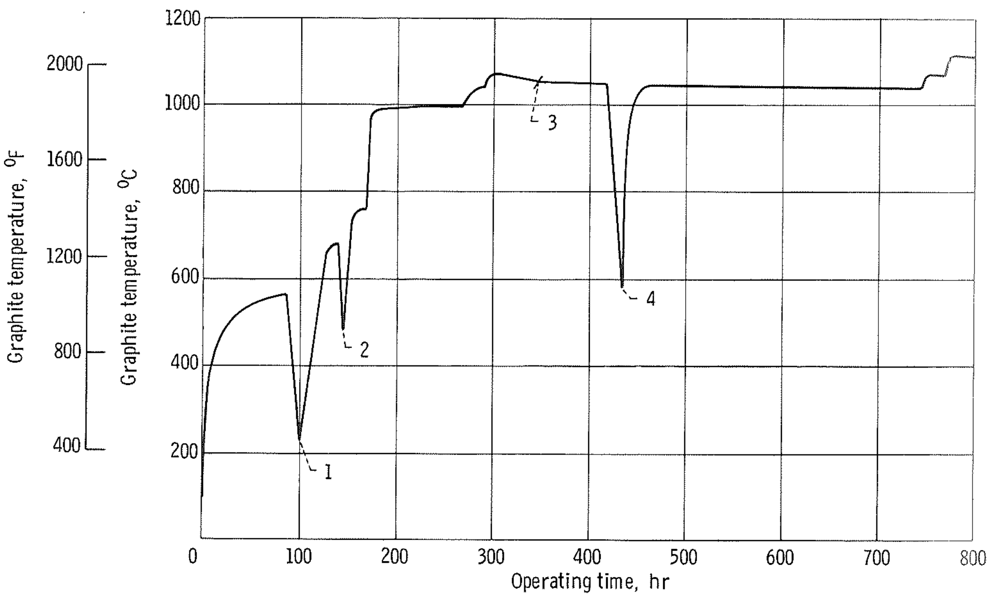

Figure 7. - Time history of simulated-heat-source surface temperature.

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