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Author(s): Michael G. Houts, David I. Poston
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Heatpipe Power System Development

Michael G. Houts* and David I. Poston

Abstract

This is the final report of a one-year, Laboratory Directed Research and Development (LDRD) project at the Los Alamos National Laboratory (LANL). The objective of the project was to develop a design approach that could enable the development of near-term, low-cost, space fission-power systems. Sixteen desired attributes were identified for such systems and detailed analyses were performed to verify that they are feasible. Preliminary design work was performed on one concept, the Heatpipe Power System (HPS). As a direct result of this project, funding was obtained from the National Aeronautics and Space Administration to build and test an HPS module. The module tests went well, and we now have funding to build a bimodal module.

Background and Research Objectives

Space fission-power and propulsion systems can enhance or enable numerous missions of interest. Potential missions of interest include manned missions to the moon or Mars, *in situ* propellant production on the moon or Mars, probes to Europa, and others. Research into space fission-power and propulsion systems has been ongoing at various levels since the 1950s, but to date the United States has flown only one space fission system, SNAP-10A in 1965. High cost and long development time have been a significant reason that space fission systems have not been used by the United States.

High cost and long development time are not inherent to the use of space fission-power and propulsion. However, high cost and long development time are inherent to any program that tries to do too much at one time. Nearly all US space fission-power or propulsion programs have attempted to field systems capable of high power and/or high thrust, even though more modest systems had not yet been flown. All of these programs have failed to fly a space fission system.

*Principal Investigator, e-mail: houts@lanl.gov

The purpose of this project was to explore and develop an approach that might enable near-term (less than 5 years), low-cost (less than \$100M) development of a space fission-power system that could be modified to provide both electric power and thermal propulsion. The power level of the first system would be relatively low (<100 kWe), although the system would be suitable for several missions. Experience gained in the development of the low-power / low-thrust fission system could then be used to enable cost-effective development of high-power / high-thrust fission systems.

Importance to LANL's Science and Technology Base and National R&D Needs

The research performed was directly related to the core technical competencies of *Analysis and Assessment* and *Nuclear and Advanced Materials*. The research led directly to work related to *Complex Experiments and Measurements*. The US DOE is responsible for providing nuclear power supplies to NASA missions that require them (most recently the Cassini mission). This research supports that DOE responsibility. In addition, NASA is beginning to examine missions that will require space fission-power systems. This research directly supports that NASA activity.

Scientific Approach and Accomplishments

The approach used by this project was to use current technology to resolve issues that had caused previous space fission-power and propulsion programs to fail. The first step was to identify 16 attributes that a space fission-power and/or propulsion system should have. Two systems, the Heatpipe Power System (HPS) and the Heatpipe Bimodal System (HBS), were then devised that have these attributes, which are listed below.

1. **Safety.** The HPS and HBS are designed to remain subcritical during all credible launch accidents without using in-core shutdown rods. This passive subcriticality results from the high radial-reflector worth and the use of resonance absorbers in the core. The systems also passively remove decay heat and are virtually nonradioactive at launch (there is no plutonium in the system).
2. **Reliability.** The HPS has no single-point failures and is capable of delivering rated power, even if several modules and/or heatpipes fail. The HBS has very few single-point failures, which are limited to ex-core components (e.g., the propellant tank).

3. Long life. The low power density in the HPS and HBS cores and the modular design give the potential for long life. At 100 kWt, fuel burnup limits will not be reached for several decades.
4. Modularity. The HPS and HBS consist of independent modules, and most potential engineering issues can be resolved by testing modules with resistance heaters (used to simulate heat from fission).
5. Testability. Full HPS/HBS tests can be performed using resistance heaters, with very few operations required to replace the heaters with fuel and ready the system for launch. The HBS can be tested in the bimodal mode using resistance heaters. Flight qualification is accomplished with resistance-heated system tests and zero-power criticality tests. No ground nuclear power test is required. The HPS or HBS flight unit can be tested at full power prior to launch. This is not possible in systems where the fuel cannot be readily replaced by resistance heaters.
6. Versatility. The HPS and HBS can use a variety of fuel forms, structural materials, and power converters.
7. Scalability. The HPS design approach scales well to >1000 kWt. Very high power (>10 MWt) systems based on the HPS approach are possible, but are much more complex than lower power versions (large number of heatpipes) and would most likely suffer a system mass penalty compared with other options.
8. Simplicity. There are few system integration issues. There is assured shutdown without in-core shutdown rods, no hermetically sealed refractory metal vessel or flowing loops, no electromagnetic pumps, no coolant thaw systems, no gas separators, and no auxiliary coolant loop.
9. Fabricability. The HPS has no pumped coolant loops and does not require a pressure vessel with hermetic seals. There are no significant bonds between dissimilar metals, and thermal stresses are low. There are very few system integration issues, thus making the system easier to fabricate. The HBS may require a pressure vessel for the propulsion mode.
10. Storability. The HPS and HBS are designed so that the fuel can be stored and transported separately from the system until shortly before launch. This capability will reduce storage and transportation costs significantly.
11. Early Milestones. Several milestones early in the development of the HPS and HBS will prove the viability of the concepts. The most significant early milestones were the development and testing of an HPS module.
12. Near term. An HPS and/or HBS capable of enhancing or enabling missions of interest can be built with existing technology.

13. Bimodal. The basic approach can be used to provide either a power-only or bimodal system.
14. Dual use. Technology utilized by the HPS and HBS has military, commercial, and civilian uses in both aerospace and terrestrial applications.
15. Acceptable mass. The HPS and HBS have a high fuel fraction in the core, which reduces core, reflector, and shield mass for criticality-limited systems. The HPS has no pumped coolant loops and relatively simple system integration, further reducing mass.
16. Reduced program expense. The attributes of the HPS should allow for inexpensive (<\$100 M) development. After development, the unit cost should be <\$20 M. The attributes of the HBS (especially the ability to test bimodal operation with resistance heaters used to simulate heat from fission) will significantly reduce cost as compared with other bimodal concepts.

Detailed analyses related to core design were also performed. Methods for ensuring launch safety were further developed. Detailed neutronic models showed that enriched boron, rhenium, or a combination of the two materials could increase the shutdown margin during launch accidents without an unacceptable mass penalty. Peak axial and radial heat fluxes were calculated and shown to be well within the existing database for heatpipe operation. Shield designs were evaluated and certain innovative shield designs appear feasible. Significant axial and radial power flattening is possible through proper location of the boron or rhenium used to ensure launch accident subcriticality. A beryllium oxide reflector would have a smaller volume than a beryllium reflector with an equivalent reactivity worth, but reflector mass would be comparable because of beryllium oxide's higher density. The feasibility of electrically heated tests of the full system was confirmed. Control can be accomplished using control drums or sliding reflectors—sliding reflectors should be less massive. In general it was shown that the design approach could lead to a near-term, low-cost, space fission-power supply with good safety and performance features.

A schematic of the HPS is shown in Figure 1. Additional information is contained in the publications and on our web site (www.lanl.gov/home/spacenuke). As noted previously, the project led to programmatic funding.

Publications

1. Houts, M. and D. Poston, "Terrestrial Applications of the Heatpipe Power System," American Institute of Physics Conference Proceedings 387, Volume 1, pp 299-304 (1997).
2. Houts, M. and D. Poston, "Heatpipe Power System and Heatpipe Bimodal System Design and Development," American Institute of Physics Conference Proceedings 387, Volume 1, pp 1317-1322 (1997).

Figure 1. Cross section of a 12-module HPS core.