HIGH EFFICIENCY CONVERTERS FOR SMALL RADIOISOTOPE POWER SOURCES

Mark L. Underwood and Richard C. Ewell
Jet Propulsion Laboratory
4800 Oak Grove Dr.
Pasadena, CA 91109-8099
(818) 393-9049

ABSTRACT

Outer planet rendezvous and planetary surface exploration missions are often most logically powered by thermal-to-electric converters with heat supplied from a radioisotope heat source. A new generation of converters is nearing technology readiness and soon should be available to provide spacecraft power. These converters promise up to four fold improvements in power density ($W/kg$) and a 60% or greater reduction in radioisotope requirement as compared to current radioisotope thermoelectric generator (RTG) technology. As part of the 1993 Pluto Advanced Technology Insertion program, high efficiency converters were examined with the goal of reducing the power source mass and heat source inventory. Two technologies, the Alkali Metal Thermal-to-Electric Converter (AMTEC) and Thermophotovoltaic (TPV) converters, were examined through short term, hardware focused programs. A small Stirling Engine design was also completed specifically for the Pluto mission. Projected power system performance, technology development status, and estimated cost and schedule to completion of development will be reviewed. For comparison to the advanced technologies, the Pluto Fast Flyby Pre-project 1993 baseline power source is a small RTG. This RTG is a scaled down GPHS RTG with an inventory of 5 General Purpose Heat Sources (GPHS), a mass of 15.4 kg, and an output of 70 $We$ after 9 years.

AMTEC research was carried out by the Environmental Research Institute of Michigan (ERIM). Four, near-prototypic AMTEC cells were fabricated and tested with each cell including evolutionarily improved components and performance. The second of the four cells operated at 10% conversion efficiency at 700°C. The fourth cell operated at an estimated 10% efficiency at 650°C before an external hardware failure forced the end of the test. The cell was projected to reach 16% efficiency at 750°C. These are the highest efficiencies yet demonstrated with compact AMTEC cells. Further improvements in the design are projected that would lead to an AMTEC system for the Pluto mission with a reduction of 37% in mass and 60% in heat source inventory compared to the RTG baseline.

TPV converter experimental research was conducted by the Boeing Defense and Space Group. A one third scale TPV system was fabricated and tested. This was the first demonstration of an entire TPV system (exclusive of the radiator) designed for the temperature range achievable by the GPHS. The system was composed of a GPHS simulating heater, a thermo-optical cavity, and two arrays of TPV cells and filters. Up to 13% of the thermal input to individual filter/cell assemblies was converted to electricity. The “photon recycling” performance of the optical cavity was not as good as expected resulting in low system performance. Based on the demonstrated performance of the Boeing TPV cells and filters, JPL designed a TPV system that could meet the needs of the Pluto mission with a reduction of 28% in mass and 40% in heat source inventory compared to the RTG baseline. With some performance enhancements now being investigated, these values could be reduced further.

Stirling converter design was done by NASA Lewis Research Center and is based on their extensive experience with design and testing of Stirling engines. The design uses dual, opposed Stirling engines to minimize potential spacecraft vibration and to provide full power in the event that one engine fails. The Stirling system could provide the Pluto mission with a reduction of 17% in mass and 60% in heat source inventory compared to the RTG baseline. This design indicates that Stirling engines are competitive on a mass basis with advanced static conversion technologies at low power levels.
National Aeronautics and Space Administration
Jet Propulsion Laboratory and Sponsored by the
This work was done by the

fax: (818) 393-4272
ph: (818) 354-9049

Pasadena, California 91109
4800 Oak Grove Drive
Jet Propulsion Laboratory
By: Dr. Mark L. Underwood and Richard C. Ewell

Small Radiisotope Power Sources
High Efficiency Converters for
IAA International Conference on Low Cost Planetary Missions

- Reduce Radioisotope Inventory by 60% (5 GPHS modules to 2)
- Reduce Power Source Mass by 50% or more

These New Technologies have the Potential to:
- Stirring Engine Isotope Power System
- TPV - Thermophotovoltaic Converter
- AMTEC - Anode Metal-Electrolyte Converter
- PHT - Proto HT-10 Electric Converter

Pluto AIT Power Conversion Technologies

- Mission Cost Reduction
- Mass Reduction
- Incorporation of New Technology in the Spacecraft Design

Pluto AIT Goals

Pluto Advanced Technology Insertion
IAA International Conference on Low Cost Planetary Missions

- Power system for less than 100 W
- First system design and analysis of a GPSS-heated Stirling
- Demonstrated comprehensiveness of Stirling power systems on a mass basis even down to power levels less than 100 W

Stirling

- Demonstrated Cell/Roller efficiency of 13.3% radiator (in the temperature range for radioisotope systems)
- First demonstration of all TPV system functions except

TPV

- System efficiencies of 18% or higher
- 10% cell efficiency demonstrated with development path to
- First demonstration of near-Prototypic space AMTEC cells

AMTEC

Key ATL Results
technologies for future applications. Pluto AT1 has significantly advanced these.

- RTG Power Source retained as the baseline
- Development Risk
- Funding Limitations

Ready for launch on a near-term Pluto mission.

No advanced technology can be expected to be available.

All three technologies could significantly reduce the power mass and radioisotope inventory.

High efficiency thermal power conversion technologies are

The Pluto AT1 demonstrated that:

Pluto Power Source Outlook
Supports

- Innovations
  - Low Mass
  - Power Output: 85 W (BOM)
  - Each 250 W (BOM)
- # CPHEs: 5
- Mass: 1.54 Kg

Performance Parameters:

Pu-238 Base Inc. RTC
AMTEC Description
AMTEC Systems Design

- Power Output: 76 W (BOM)
- # of Cells: 2
- Mass: 9.8 kg
- Performance Parameters:

AMTEC AT1 Research was performed by the Institute of Michigan (ERIM) under contract to TPL. For more details see Chemical Society, Vol I, p 655.
POWIR

IAA International Conference on Low Cost Planetary Missions

For more details see:

Durability to shock and vibration loads
Mechanical Durability Demonstration
Power output up to 1.6 kW/cell
Power Demonstration
Efficiency Demonstration

AMTEC Experimental Results
IAA International Conference on Low Cost Planetary Missions

Remaining Issues

- Performance in Zero-Gravity
- Flight expected before 2005
- Phase A begins in 1994
- Experiment (Joint JPL & ERIM)
- Selected for In-STEP Flight

Flight Test Planned

- Fundamental understanding is being completed at JPL
- ERIM is also planning terrestrial use for AMTEC
- Space solar designs are being investigated
- Conversion efficiency and further improvements are projected
- At ERIM Pluto-like cells have recently demonstrated 15%

Development Continues

AMTEC Prospects
14th International Conference on Low Cost Planetary Missions


For more details see:

Advantages

- Photovoltaics developed under a separate program
- High efficiency x Power Density with "Photon Recycling"
- Static System
- Capture of Infrared Radiation by a Low Bandgap Photovoltaic Thermophotovoltaic Converter

TPV Description
IAA International conference on Low Cost Planetary Missions

Key technologies:
- Reflective cavity
- Bypass filler
- Gas bubble photovoltaics

Parameters:
- Output (W): 89.95
- BOM power
- # GPHS: 3
- Mass (kg): 11.1
- Diameter (m): 1.0-1.3
- 0.8-0.9

JPL TPV System Concept

TPV Systems Design

JPL
TPV AIT experimental work performed by JPL - contract to JPL.

Very close match of experimental and model measured efficiency - up to 13.3% filter/cell efficiency was demonstrated.

Up to 65% transmission at peak wavelength.

Filter fabrication.
IAA International Conference on Low Cost Planetary Missions

- System efficiency demonstration
- Reflective surfaces
- Lifetime, including life limiting mechanisms and contamination of (some data exists for Gaps)
- Radiation degradation of photovoltaics
- Modification
- Filter optimization and performance and/or emitted spectrum

Remaining Issues

- TPV also has terrestrial uses that are being developed
- DOE has issues an SIRR solicitation for TPV development

Germany

Download MD, PSC-ESD-03-519A

Reference: A. Sjodin et al., "Radiation and Thermophotoelectrical (RTP) Generator and Technology" to 134 W" (BOM), predicted improved technology

Predicting a 2 GPHS, 72 kg design producing 76 W" (BOM), near term

Fairchild Space and Defense completed a TPV system concept

Development Continues

TPV Prospects

- Single frequency vibration easily attenuated
- Scalable to a wide range of power levels
- Similar to Stirling cryocoolers that have operated in space

Advantages

- Pistons suspended on linear gas bearings or flexures
- Hermetically sealed
- Mechanically simple, 2 moving parts per engine
- Free piston Stirling engine combined with a Linear Alternator

Stirling Engine Description
I2 Year design lifetime
- Power in case one fails capable of delivering the design
- Dual opposing engines, each
- Power Output: 81 W (BOM)
  - # GPHS: 2
  - Mass: 12.75 kg
- Performance Parameters:

> Striking Engine Systems Design
IAA International Conference on Low Cost Planetary Missions

- Lifetime
- Failure modes demonstration
- Vibrational damping demonstration
- Two engine synchronization

• Remaining Issues for Space Power System
  - Small power sources for remote sites
  - Automobiles
  - Terrestrial uses still under development
  - Year

  In-STEP Experiment (Hughes) to fly on Shuttle within the
  - Long-life space cryo-coolers are under development
  - Space power development has failed off

• Development Continues

Stirling Engine Prospects