Oral Presentation/Viewgraph Summary:

The Advanced Stirling Radioisotope Generator (ASRG) is being considered to power deep space missions. An engineering unit, the ASRG-EU, was designed and fabricated by Lockheed Martin under contract to the Department of Energy. This unit is currently on an extended operation test at NASA Glenn Research Center to generate performance data and validate the life and reliability predictions for the generator and the Stirling convertors. A special test facility was designed and built for testing the ASRG-EU. Details of the test facility design are discussed. The facility can operate the convertors under AC bus control or with the ASRG-EU controller. It can regulate input thermal power in either a fixed temperature or fixed power mode. An enclosure circulates cooled air around the ASRG-EU to remove heat rejected from the ASRG-EU by convection. A custom monitoring and data acquisition system supports the test. Various safety features, which allow 24/7 unattended operation, are discussed.

Design of a Facility To Test the Advanced Stirling Radioisotope Generator Engineering Unit

Presented at the 7th International Energy Conversion Engineering Conference
Denver, CO
August 2-5, 2009

Edward J. Lewandowski, NASA Glenn Research Center
Jeffrey G. Schreiber, NASA Glenn Research Center
Salvatore M. Oriti, NASA Glenn Research Center
David W. Meer, Sest, Inc.
Michael H. Brace, NASA Glenn Research Center
Gina Dugala, NASA Glenn Research Center

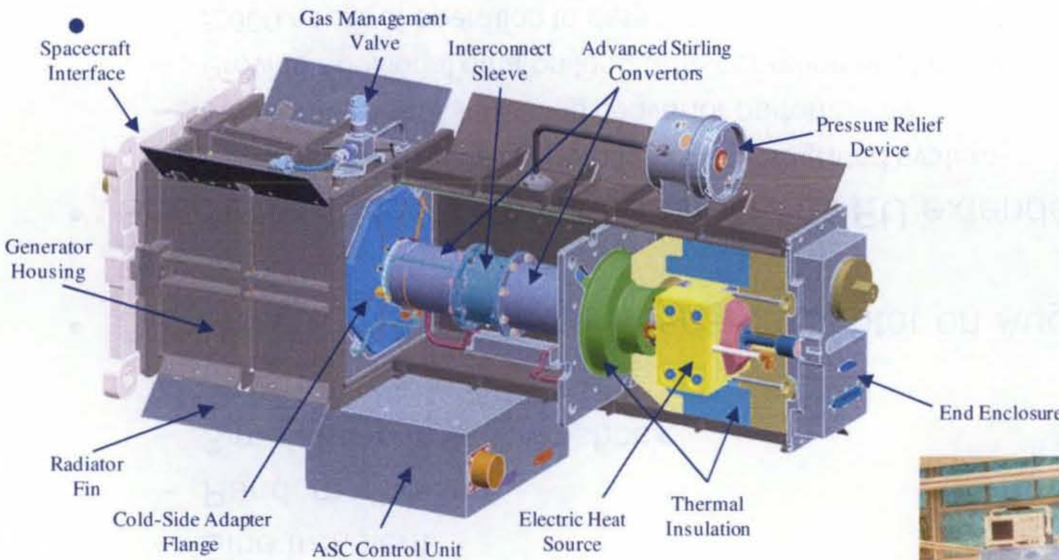
Outline

- Advanced Stirling Radioisotope Generator Engineering Unit
- Test facility requirements
- Mechanical mounting
- Heat rejection system
- Argon system
- Convertor control
- Heat source
- Test facility maintenance
- Improvements
- Conclusion

Introduction

- System integrator Lockheed Martin Space Systems Company (LM) is under contract to the Department of Energy to develop the Advanced Stirling Radioisotope Generator (ASRG)
- ASRG Engineering Unit (EU) designed and fabricated by LM, then underwent system-level tests
  - Thermal balance
  - Thermal performance
  - Mechanical disturbance
  - Sine transient
  - Random vibration
  - Simulated pyrotechnic shock
  - EMI
- Delivered to NASA Glenn Research Center on August 28, 2008, for extended operation
- Special test facility designed for ASRG EU extended operation
  - Demonstrate extended operation of an integrated system
  - Monitor for trends in Stirling convertor performance
  - Provide additional data on long-term operation of Stirling convertors
  - 5,000 hours of operation to date

The ASRG EU and Test Facility

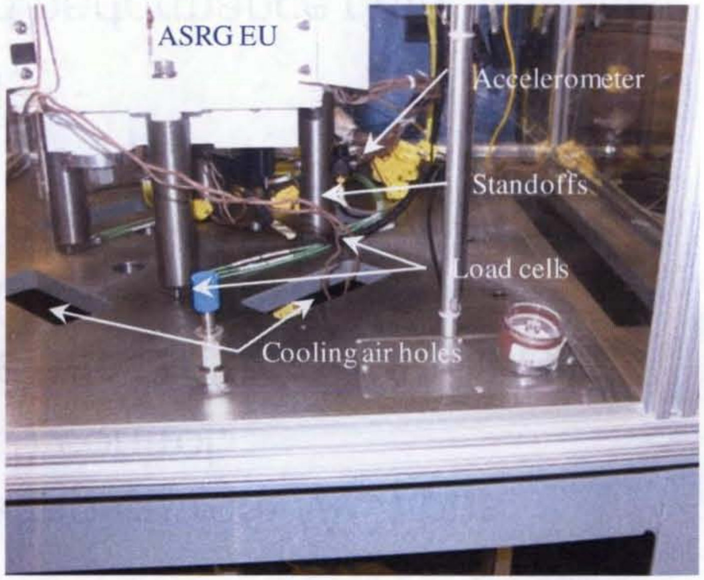


Test Facility Requirements

- Mount in a vertical orientation.
- Provide two control options: (1) alternating-current (AC) bus control, and (2) ASC Control Unit (ACU) control.
- Provide two input power options for the heat source control: (1) fixed hot-end temperature mode, and (2) fixed heat input mode.
- Remove heat from the EU to maintain a fairly constant rejection temperature at the convertor cold end, ~50 °C.
- Maintain argon pressure inside the EU.
- Monitor various parameters and record performance data regularly.
- Monitoring and safety systems allow 24/7 unattended operation.
- Achieve high uptime (85 to 90%).
- Appealing display for visitors, but protect the unit from unauthorized activity.

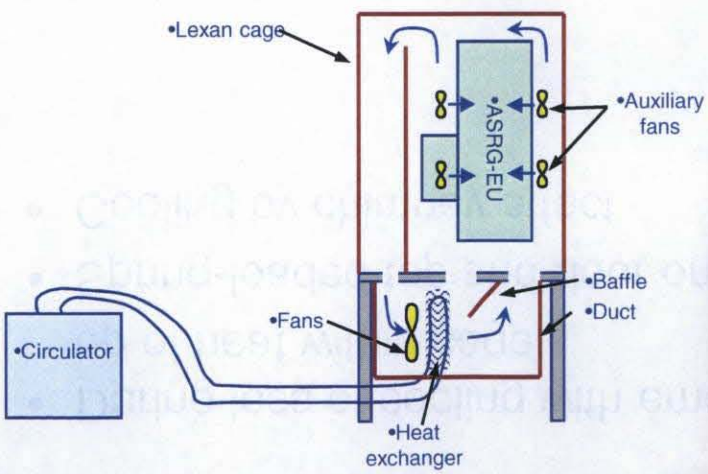
Mechanical Mounting

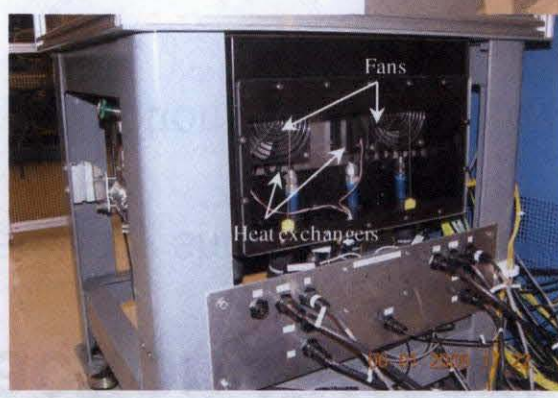
- ASRG EU housing bolted to four standoffs
- Load cells under standoffs monitor interface force
- Table doubles as transporter



Heat Rejection System

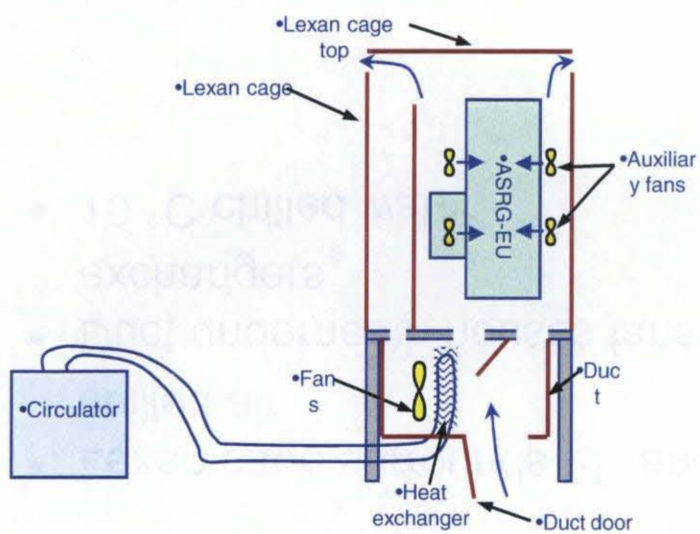
- Lexan cage surrounds EU and circulates chilled air
- Duct underneath houses fans and heat exchangers
- 10 °C chilled water





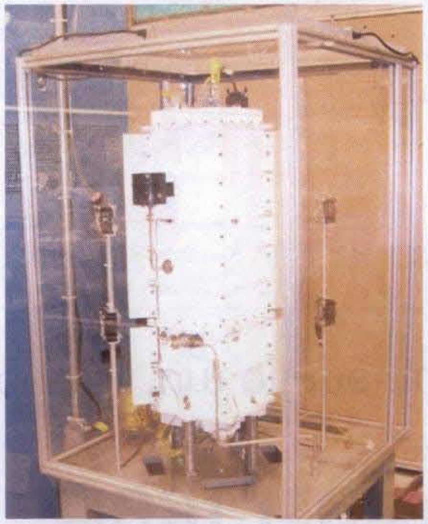
Heat Rejection System

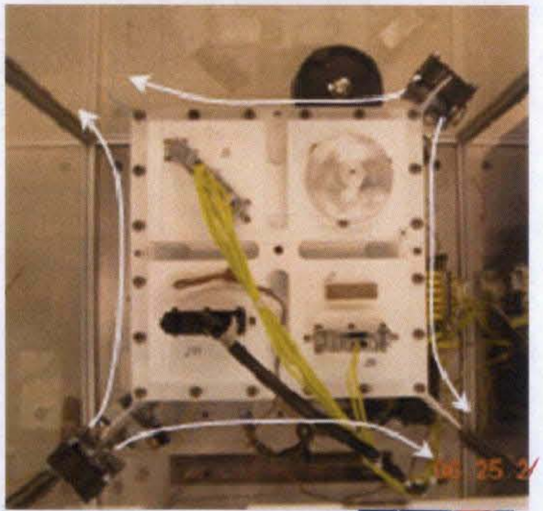
- During loss of cooling with emergency shutdown, need to prevent build-up of heat within cage
- Spring-loaded top and door on the bottom held closed by solenoids
- Cooling by chimney effect



Heat Rejection System

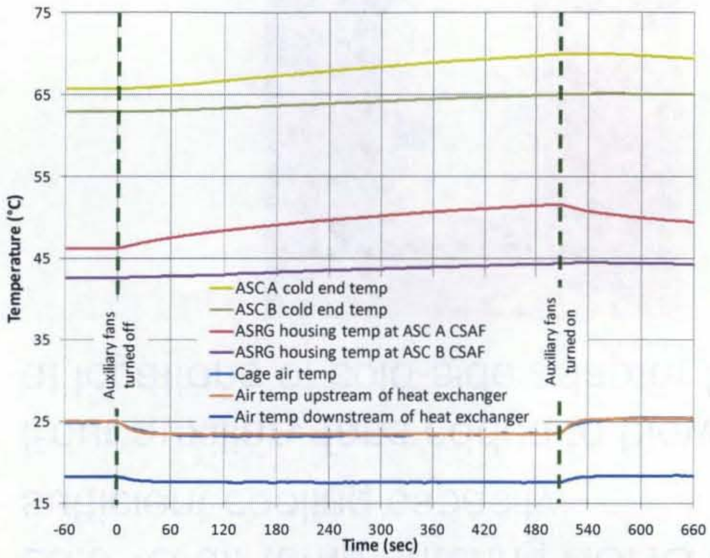
- Prior to ASRG EU installation, heat rejection system tested with power resistors
- 360 W input, 20 °C fluid temperature
- 6.9 °C air temp ΔT and 0.6 °C fluid temp ΔT across heat exchangers
- 23.9 °C air temp entering ASRG cavity -> sufficient cooling capacity
- Four auxiliary fans added to blow air across EU at locations of cold-side adapter flanges

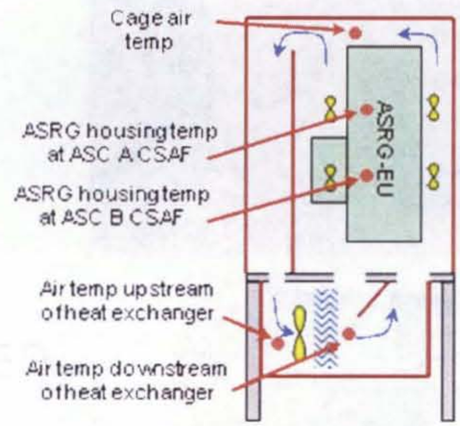




Heat Rejection System

- What happens if I turn off the auxiliary fans?



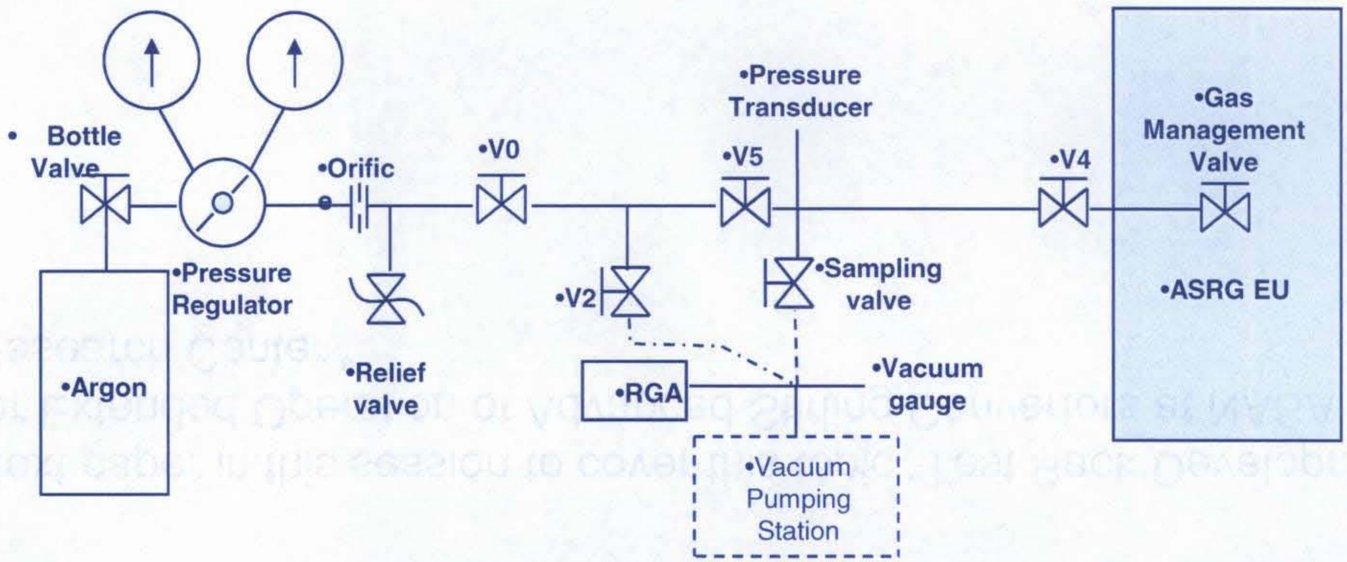


- Housing temperatures rose 5 °C in 8 minutes, and hadn't leveled off
- Air temps around EU dropped -> decreased heat transfer -> larger ΔT between EU housing and air required to transfer heat

→ **Auxiliary fans critical to maintaining operation at desired operating conditions**

Argon system

- Maintains argon pressure inside the EU between 5 and 9 psig
- (Stirling convertors are hermetically sealed and contain helium)

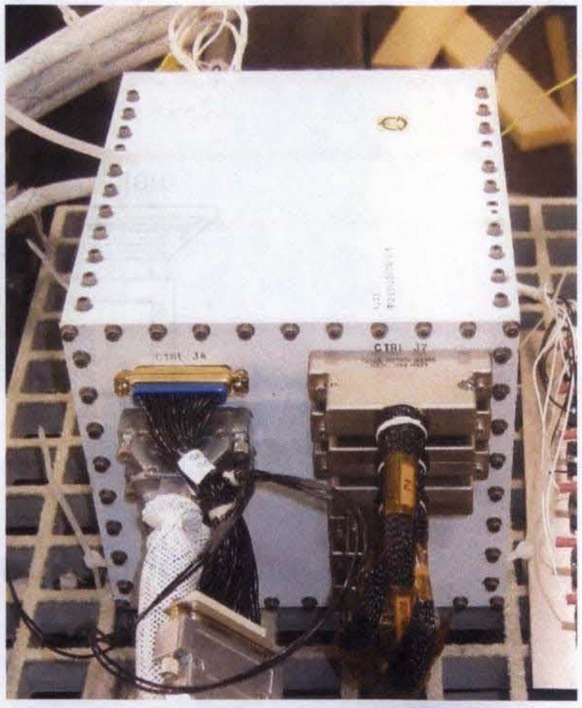


Instrumentation, Monitoring, and Safety Systems

- Next paper in this session to cover this topic “Test Rack Development for Extended Operation of Advanced Stirling Convertors at NASA Glenn Research Center ”

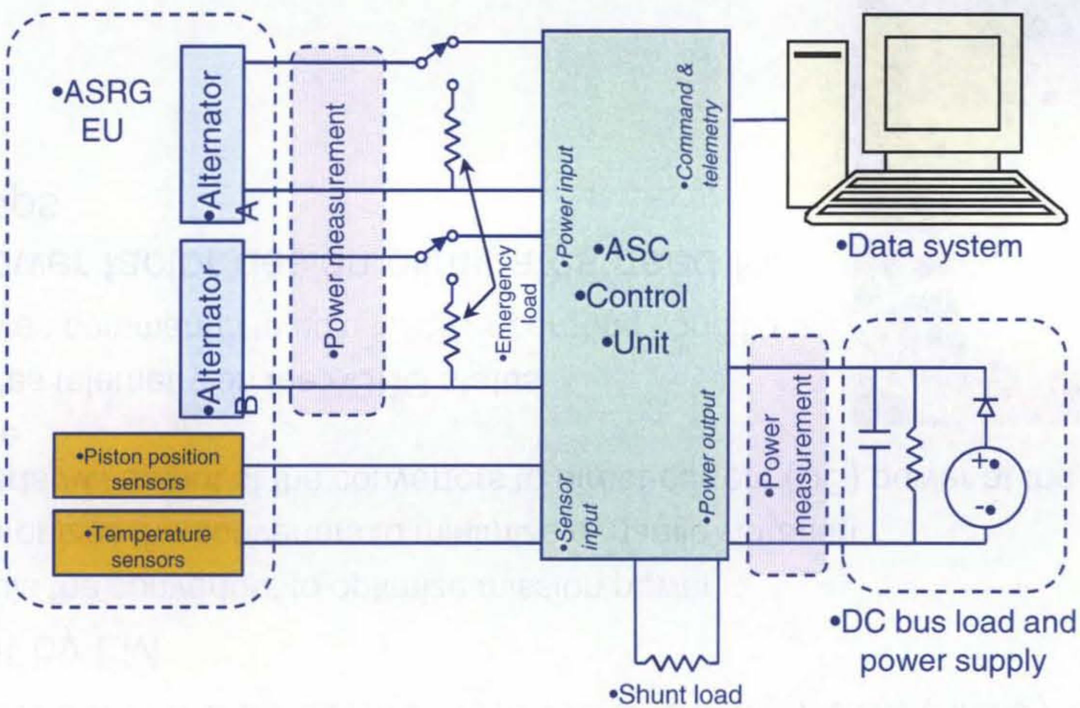
Convertor Control

- Two methods: AC bus control and ASC Control Unit (ACU) control
- ACU built by LM
  - Controls the convertors to optimize mission power
  - Synchronizes the convertors to minimize dynamic vibration
  - Converts AC output of the convertors to direct-current (DC) power at the spacecraft bus voltage
  - Provides telemetry on the ASRG status
  - Receives commands to adjust ASC operating conditions
- Active power factor design eliminates need for tuning caps



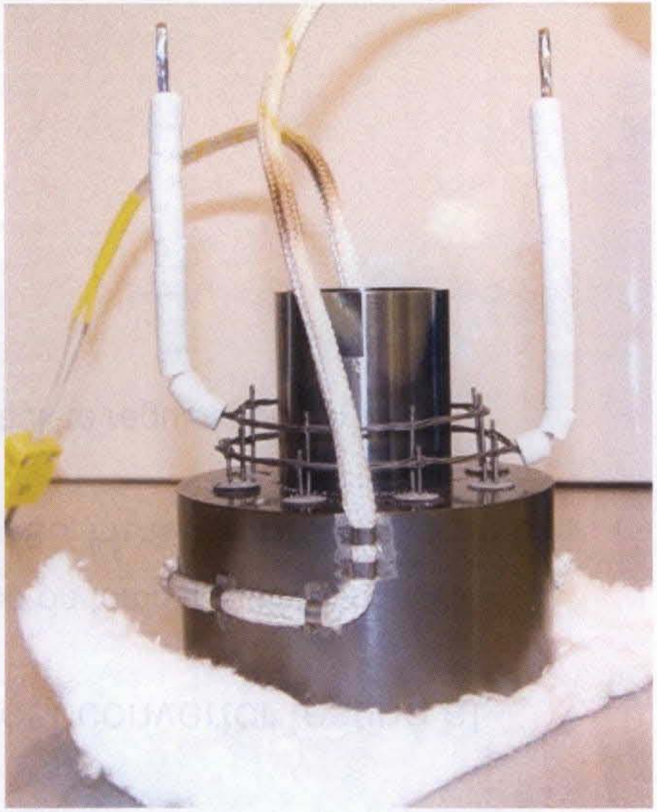
System with ASC Control Unit

- Measure power from alternators to ACU, but minimize line impedance



Heat Source

- ASRG EU tested with electric heat source dynamically and dimensionally equivalent to General Purpose Heat Source
- Long-term performance of this heat source unknown
- Drop-in replacement heat source designed at GRC based on existing heat sources proven at GRC's Stirling Research Laboratory
- Up to 400 W with temp rise of 1 °C/sec



Heat Source Control

- Two input power options:
    1. Fixed hot-end temperature mode
    2. Fixed heat input mode
- Fixed hot-end temperature mode used for most convertor testing at GRC to date
    - PID controller regulates power to heat source based on temperature feedback
- Fixed heat input mode mimics General Purpose Heat Source (GPHS) characteristics
    - Microcontroller uses DC voltage and current feedback to regulate power to heat source

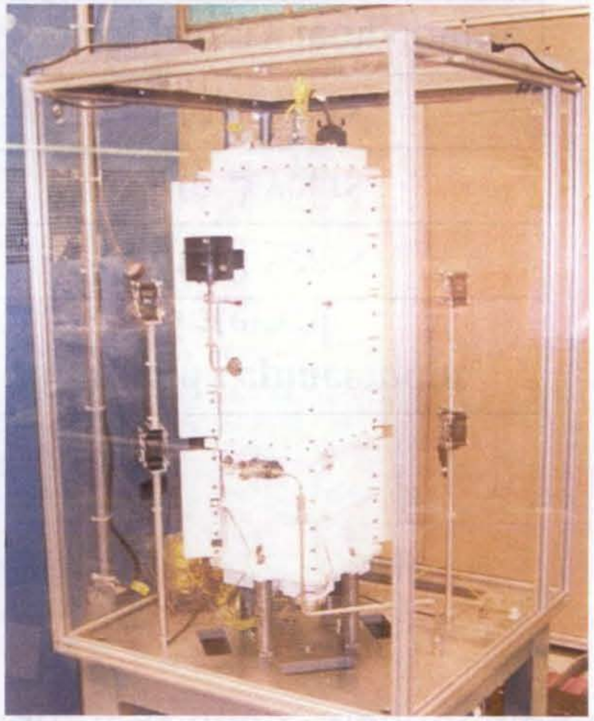
Test Facility Maintenance

- Certain components replaced prior to failure to reduce unscheduled downtime

Component	Planned replacement interval
Cooling air fans	1 to 2 years
Auxiliary fans	1 to 2 years
Circulator	3 to 4 years
UPS batteries	Monitor battery temperature

Improvements: Heat Rejection System

- Actual cold end temperatures are running 5 to 10 °C hotter than the desired operating point of 60 °C
- Increase size of auxiliary cooling fans



Improvements: Alternator Load Circuit

- Under AC bus control, alternator power and piston amplitude variations due to test rack impedance variation
- 3-mΩ increase in impedance results in a 0.01-mm increase in piston amplitude and corresponding increase in power
- First set of improvements: removed some quick disconnects, seated some quick disconnects better, soldered some connections
- Anomalous behavior reduced but not eliminated
- Second set of improvements:
  - Replaced quick disconnects and jumpers in tuning cap bank with soldered bus bars
  - Bypassed relays with soldered connections
- Data to date suggests anomalies have been eliminated
- Plan to use hermetically-sealed relay

Conclusion

- Test facility was designed and built for testing the Advanced Stirling Radioisotope Generator Engineering Unit
- Facility allows heat input under fixed-temperature or fixed-power modes
- EU can be operated with either AC bus control or ACU control
- Safety features allow 24/7 unattended operation
- Test facility has met its design requirements, although a few areas for improvement have been identified

Acknowledgment

This work was funded through the NASA Science Mission Directorate. Any opinions, findings, and conclusions or recommendations expressed in this article are those of the authors and do not necessarily reflect the views of the National Aeronautics and Space Administration.

The authors wish to acknowledge the many people who supported the design and build-up of the ASRG EU test facility in the Stirling Research Laboratory at the NASA Glenn Research Center, including those at Lockheed Martin in Valley Forge and Denver who guided us in ASRG EU control and operation.