

Extended Operation of Stirling Convertors

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A high-efficiency 110 watt Stirling Radioscope Generator 110 (SRG110) is being developed for potential NASA exploration missions. The SRG system efficiency is greater than 20%, making it an attractive candidate power system for deep space missions and unmanned rovers. The Department of Energy SRG110 Project team consists of the System Integrator, Lockheed Martin (LM), Stirling Technology Company (STC), and NASA Glenn Research Center (GRC). One of the GRC roles is to provide Independent Verification and Validation of the Stirling TDC's. At the request of LM, a part of this effort includes the extended operation of the TDC's in the dynamically balanced dual-opposed configuration. Performance data of Stirling Convertors over time is required to demonstrate that an SRG110 can meet long-duration mission requirements. A test plan and test system were developed to evaluate TDC's #13 and #14 steady-state performance for a minimum of 5000 hours and insure safe, round-the-clock operation of the TDC's. This paper will discuss the design and development, and status of the Extended Operation Test.

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Extended Operation of Stirling Convertors

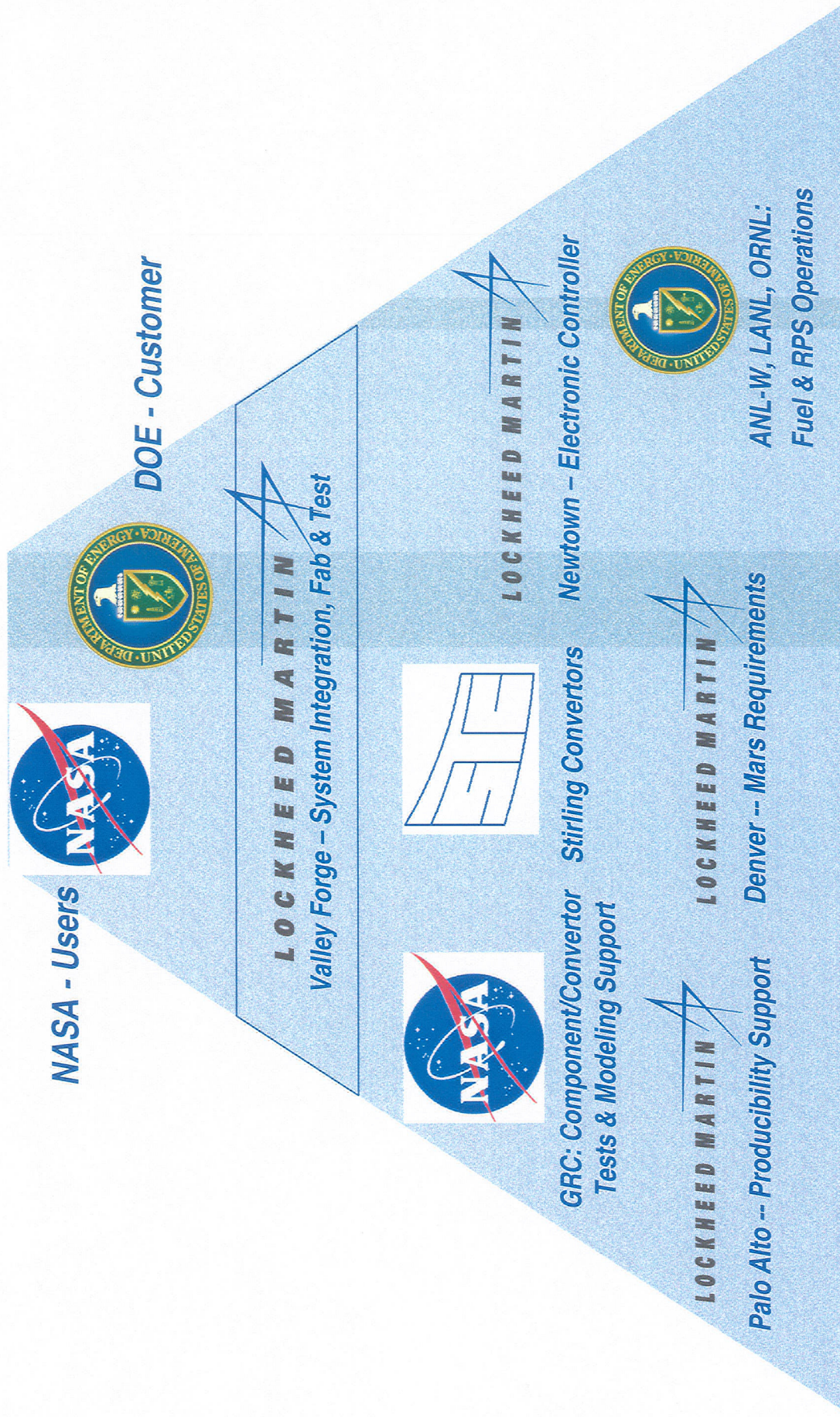
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by

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The SRG110 Team



SRG110

DESIGN METRICS

Design Life: 14 Years + Storage

Power: BOM – 112 We

EOM Mars (3 Yrs) -- 99 We

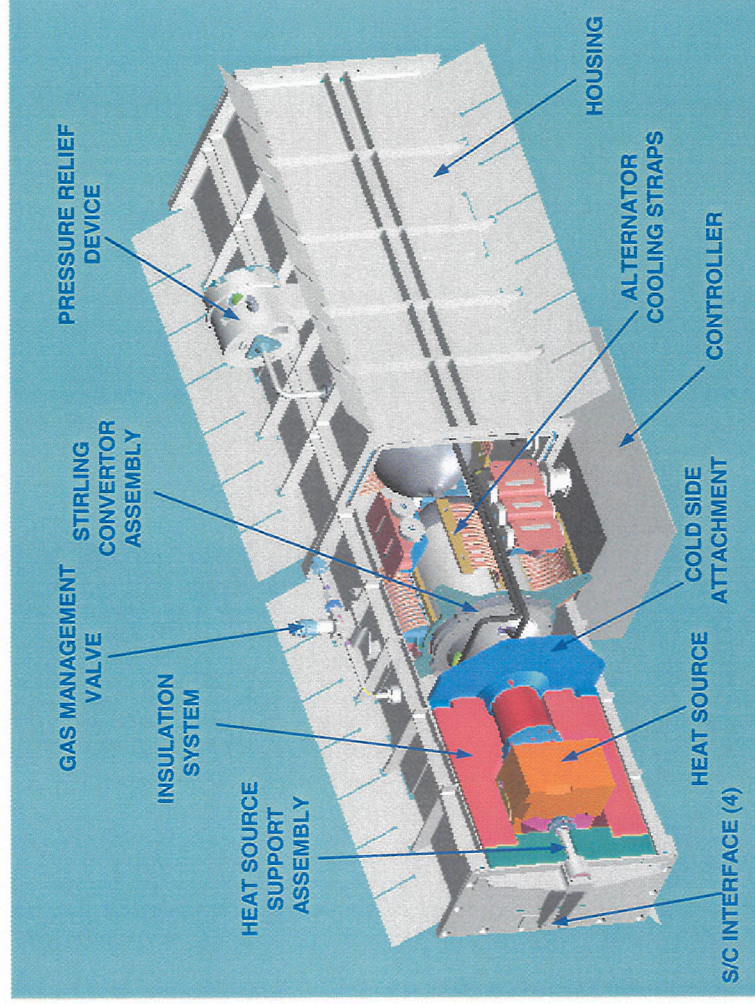
EOM deep space (14 Yrs) -- 97 We

Mass: 34 kg

Size: 11.5"W x 15"H x 37.5"L

ATTRIBUTES

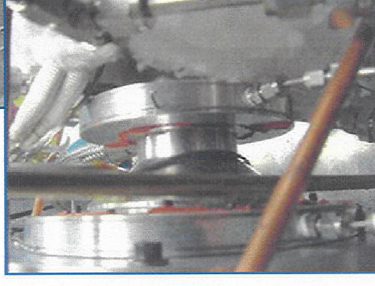
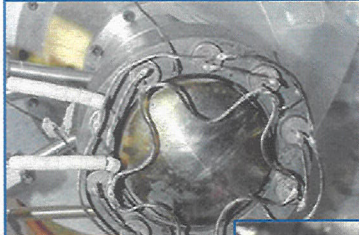
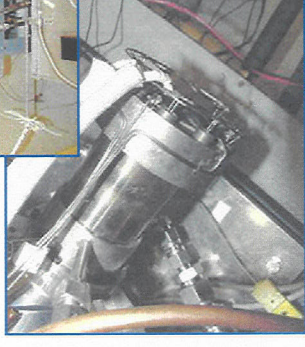
- Two Stirling converters
 - Co-axially aligned for dynamic balance
 - One GPHS (Step 2) per converter
- Integrated, on-board controller
 - Externally mounted
- Beryllium external housing
- Operates open to vacuum or Martian atmosphere
- Detachable cooling system (not shown)



TDC's #13 & #14 Testing

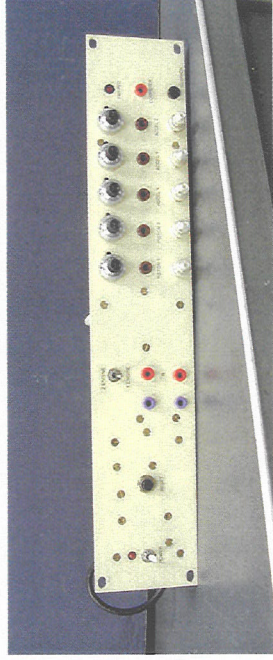
Status

- TDC's #13 & #14 delivered to GRC February 2003
- Installation on test stand
- 500-hour bake out completed, April
- Thermal insulation loss test completed, May
- Full power test completed, May 22
- Single-shift extended operation initiated in June
- Continuous unattended operation began July 18
- TDC's #13 & #14 have accumulated 9,035 hours through August 16, 2004
- Shutdown due to utility grid, faulty TC wire, etc
- Completed gas analysis through 5,000 hours
- Investigate performance degradation
 - Oxidation
 - Argon purge
 - Helium purge

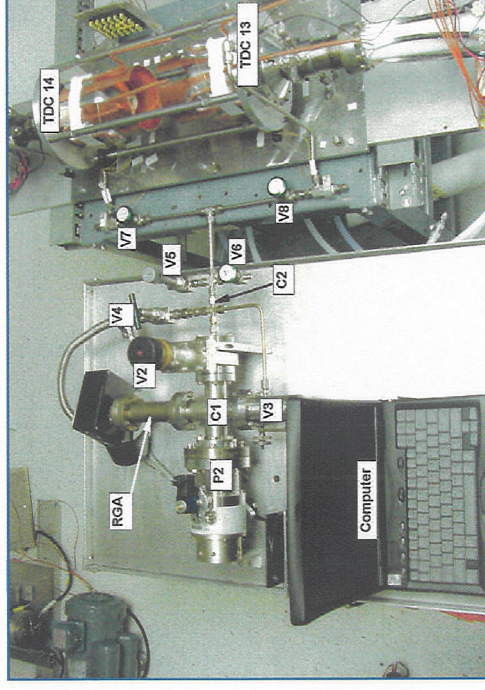


TDC #13 & #14 Test Stand Design

- **Standard test stand**
 - Table for mounting converters
 - Rack with data and control system
 - Chillers to circulate liquid coolant
- **Enhancements for Unattended Operation**
 - Modifications to data system software
 - Addition of uninterruptible power supply
 - Failsafe Protection Circuit
 - Gas charging system



Failsafe protection circuit



Gas charging system

TDC #13 & #14 Bakeout

Thermal Loss Test

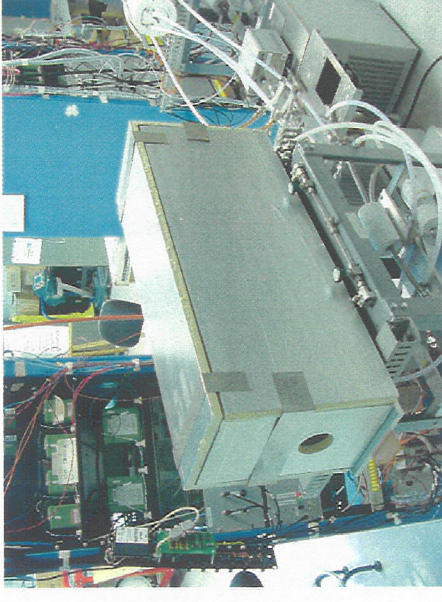
- Reduced thermal loss at 650°C to about 69 watts on TDC #13 and 65 watts on TDC #14

Bakeout

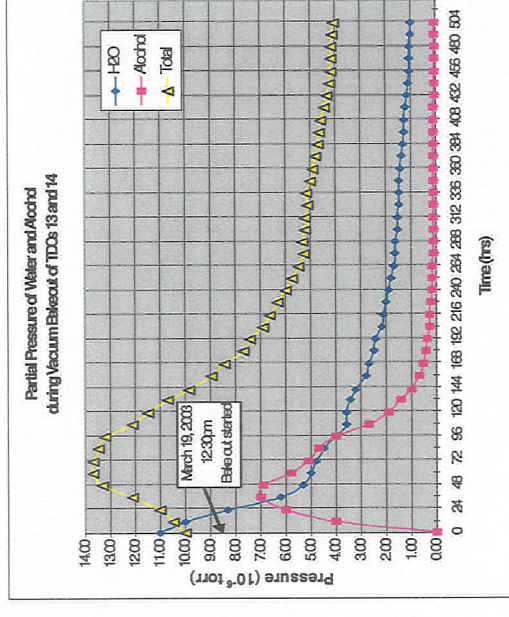
- Bakeout completed on April 9, 2003
- Water vapor partial pressure about 1×10^{-6} torr
- After 25.8 hours of operation since bakeout reduced
- water vapor, however CO is now present
- Still some argon remains from insulation test
- Water vapor and oxygen in supply was absent from TDC
- Water vapor partial pressure $\sim 1 \times 10^{-10}$ torr

Full Power Test

- Full Power Test Completed May 22, 2003



Bakeout housing



500 hour Bakeout

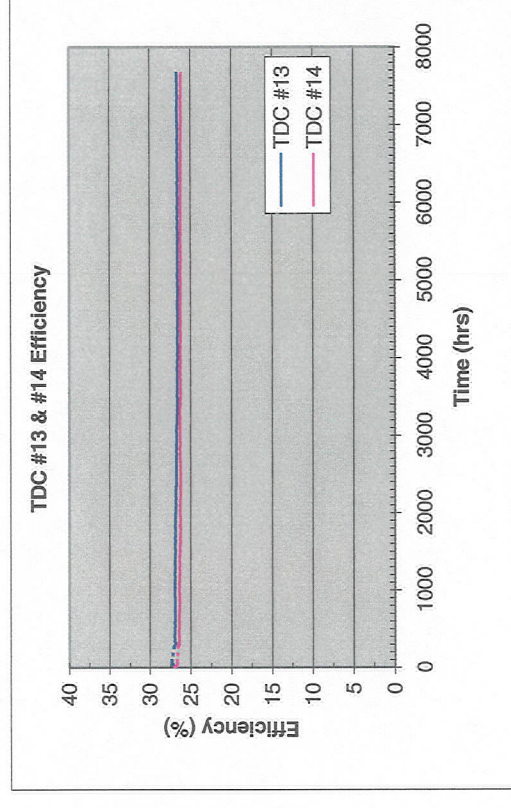
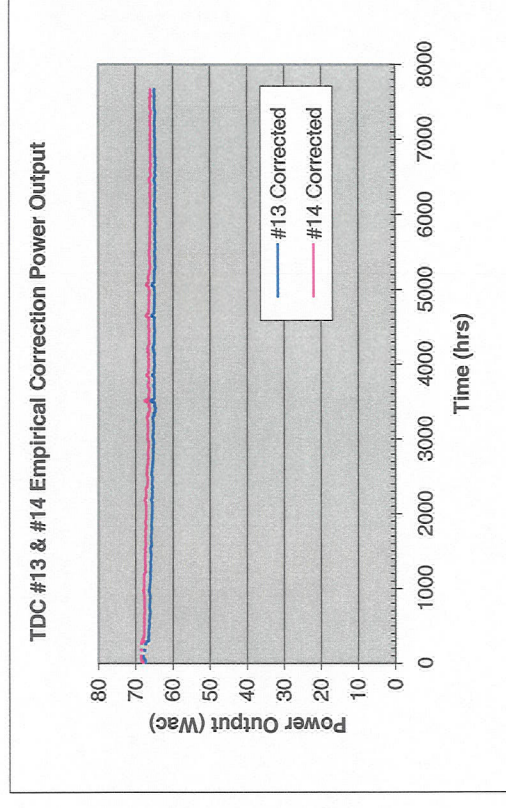


TDC #13 & #14 Performance

- Performance for TDC #13 & #14 has generally been steady

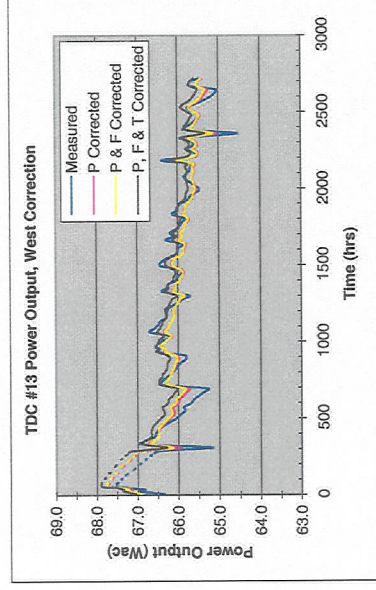


- However, a more detailed look at the performance has shown some change in power and efficiency
- The story is not simple

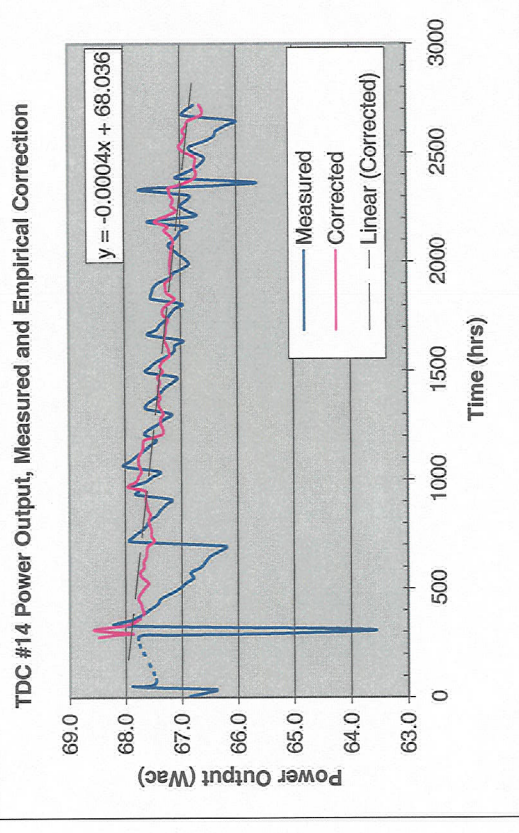
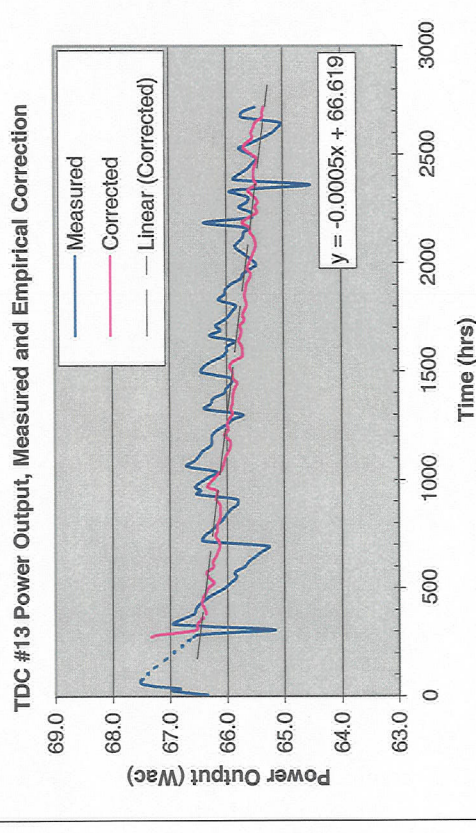


TDC #13 & #14 Early Operation

- Weekly pressure variations were observed
 - Each TDC lost about 2 psi per week
- Through 2800 hours, performance fell slowly
 - Rate of about 0.4 – 0.5 watts per 1,000 hours
- All data were being studied to identify changing performance
 - Steady state data
 - Accelerometers
 - Gas analysis data



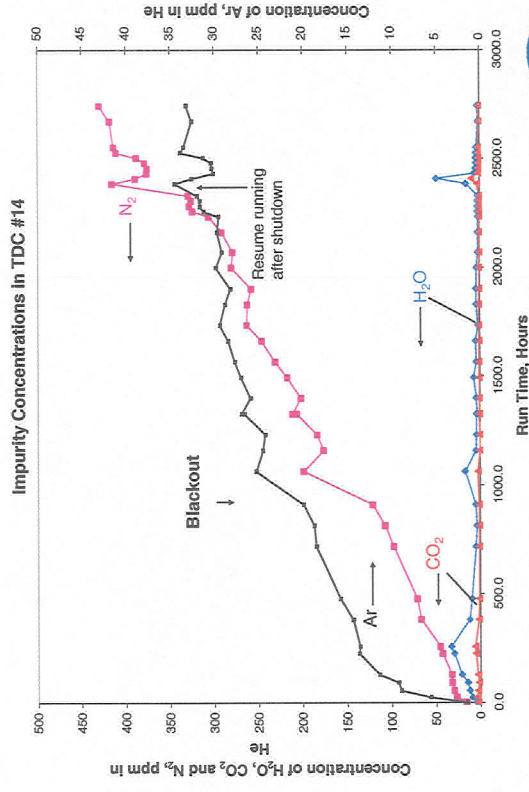
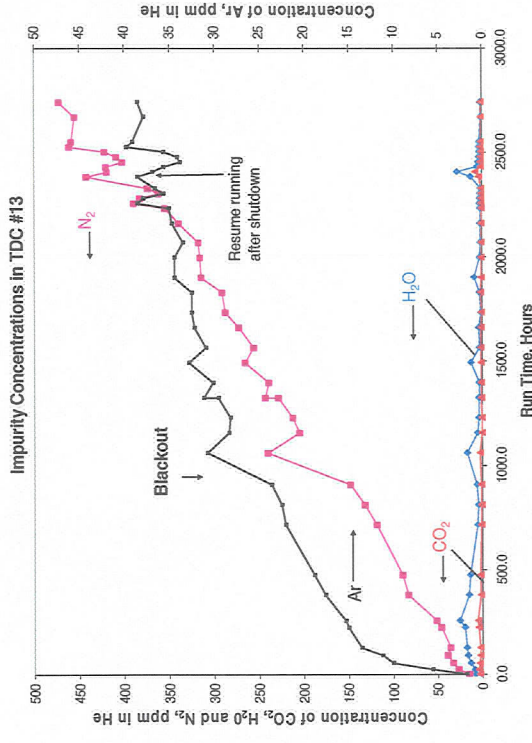
Data with West number correction



Data with empirical correction

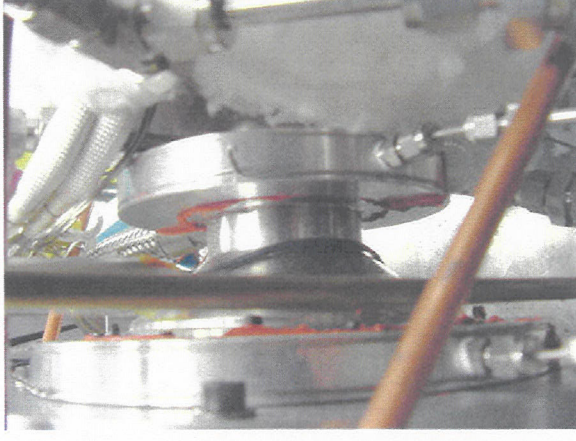
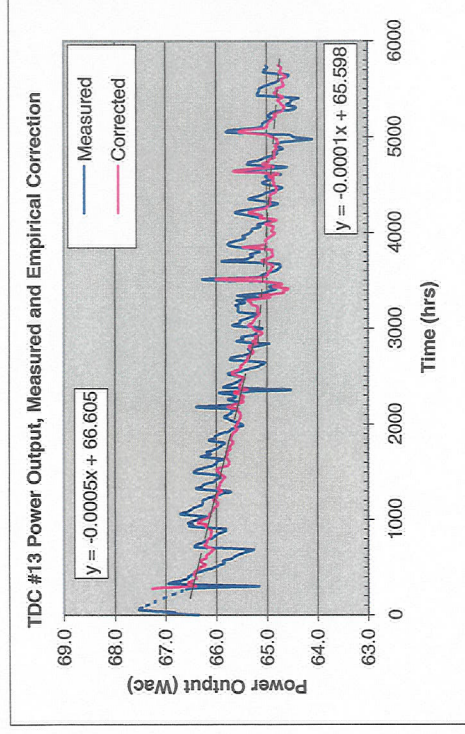
Gas analysis through 2800 hours

- Nitrogen appeared to be increasing linearly with time
- Argon appeared to be increasing, but reaching an asymptote
- Gas analysis from both convertors appeared very similar
- Helium was found in the vicinity of both o-ring flanges on both TDC's
- Argon was believed to be residual gas from thermal loss test
- Source of nitrogen was theorized to be ambient air permeating inward
- Oxygen was not being observed, thought to be consumed by hot components
- Purge rings were installed and argon purge initiated



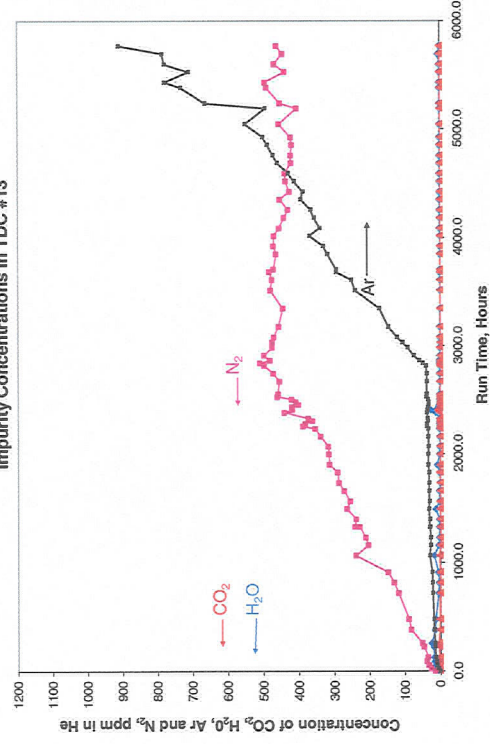
Results through 5860 hours

- Nitrogen content leveled immediately
- Argon content rose
- Performance remained nearly level

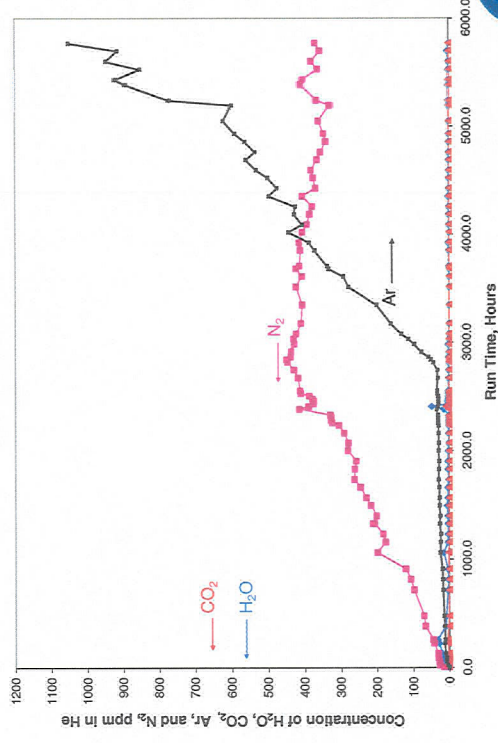


Purge rings on TDC #14

Impurity Concentrations in TDC #13

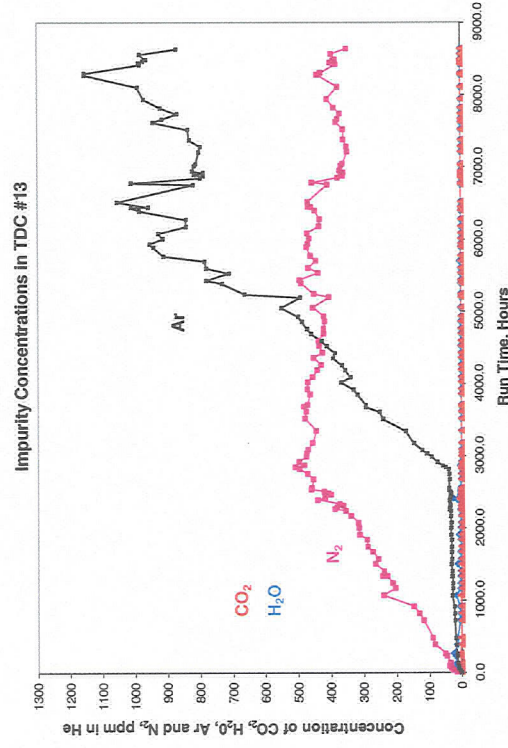
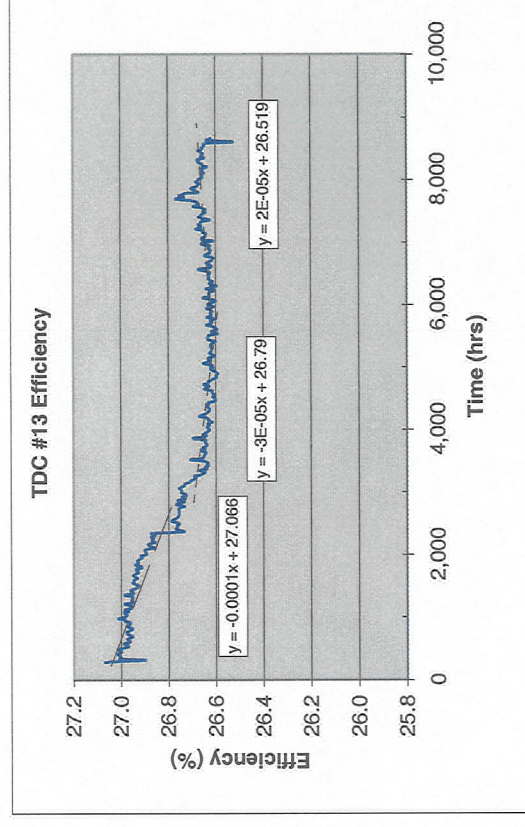
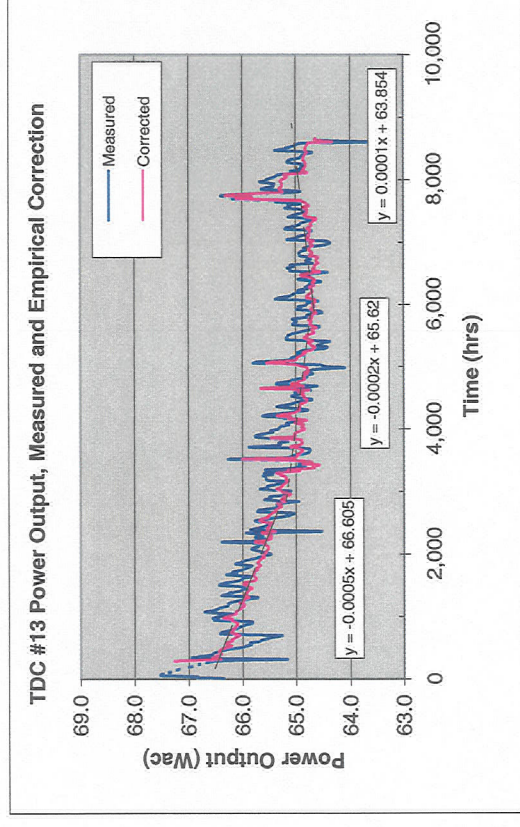


Impurity Concentrations in TDC #14



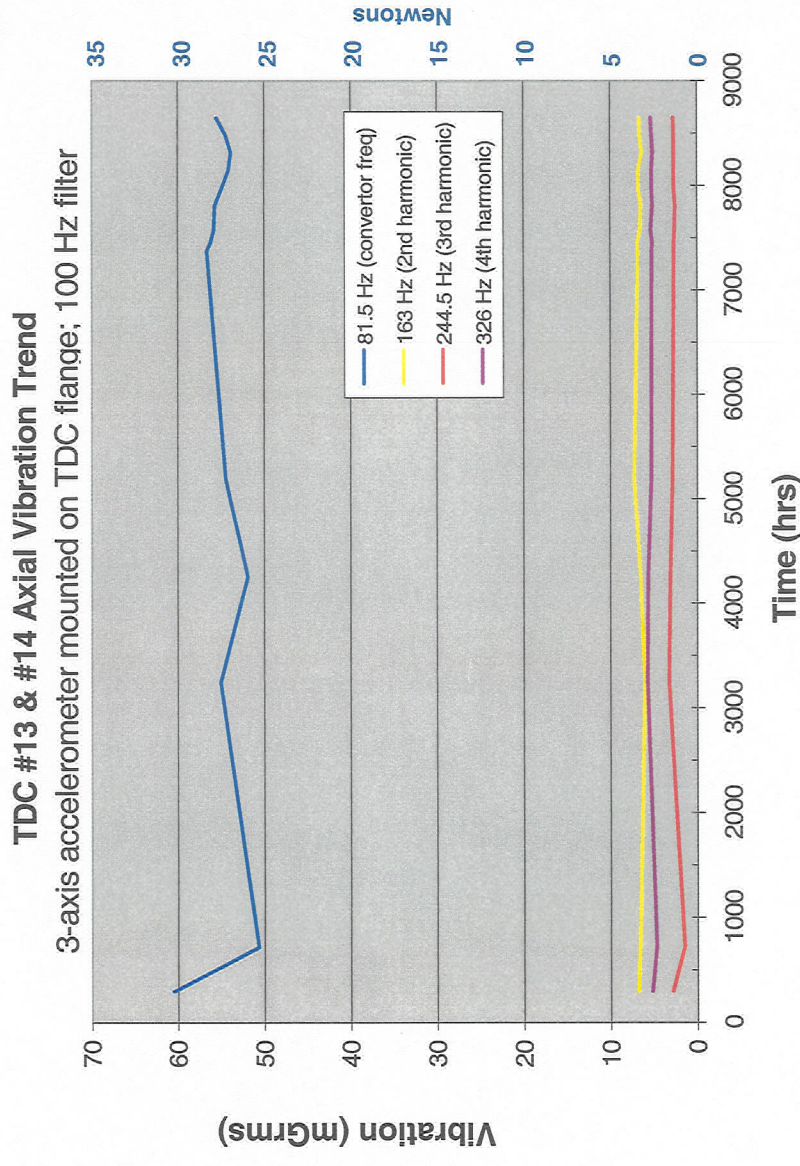
Results through 8700 hours

- Changed to helium purge after 5860 hours to reduce impact of argon on performance
- Converter performance tracks the trends in the gas analysis
- Degradation observed early in the test are believed to be due to permeation through the o-rings, which is not an issue in flight system



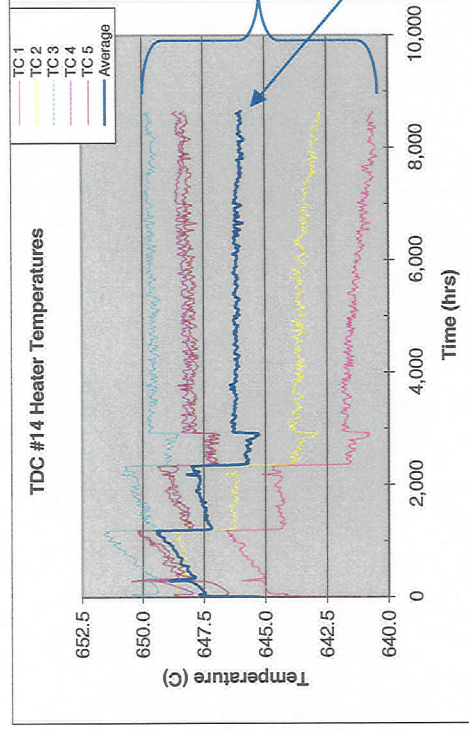
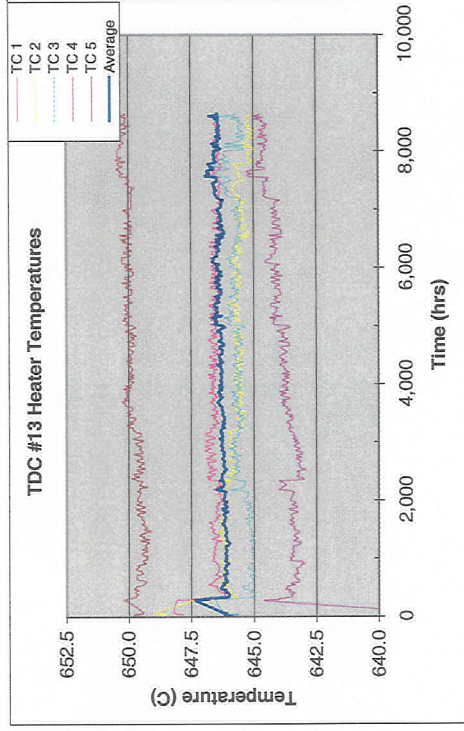
Dynamic signature through 8700 hours

- TDC's #13 & #14 are operating in the dual-opposed, dynamically balanced configuration
- Dynamic forces are the result of mismatch permitted within the fabrication process
- No effort was made to achieve minimal dynamic signature
- There has been no change observed in the dynamic signature



TDC #14 Performance

- TDC #14 performance is nearly level, but not quite
- It is becoming more level over time
- This may be attributed to heater temperature distribution,
- This is, once again, a ground test issue, not a Stirling issue



Conclusion

- TDC's #13 & #14 have reached over 9,000 hours of operation at GRC
- Facility modifications for unattended operation have been successful
- All shutdown have been facility or instrumentation related
- Permeation through the o-rings has been the major concern, but will not exist in the flight units
- Real-time gas analysis capability has proven to be beneficial
- Since permeation has been eliminated, performance has been generally constant
- There has been no changes in performance measured that are attributed to the TDC's
- The current plan is to continue with the Extended Operation Test