

20,000 Hour Reliability Tests for the CLSS One Watt Linear Cryocooler

Mark Squires and Robert D. Nelson

Carleton Life Support Systems, Inc., Davenport, IA, USA

ABSTRACT

One of the most important characteristics of a cryocooler is its useful operating life. Cryocoolers intended for space environments require cryocoolers with very long lifetimes, as the opportunity for servicing a failed unit is minimal. Tactical cryocooler requirements have increasingly followed the trend of the space cryocooler, with required lifetimes reaching tens of thousands of hours.

Three tactical one watt linear (OWL) cryocoolers at Carleton Life Support Systems, Inc. (CLSS) of Davenport, IA, recently surpassed 20,000 hours of operation. Acceptance tests show that the performance of the cryocoolers has not significantly degraded over this timeframe. This paper reports the performance of the cryocoolers over the span of the test. Steady-state and cooldown performance at various ambient temperatures are reported.

Keywords: stirling, cryocooler, reliability

1. INTRODUCTION

Carleton Life Support Systems, Inc. (CLSS) of Davenport, Iowa designs and manufactures small tactical linear split stirling cryocoolers for the aerospace and defense industries. One cooler that CLSS manufactures is designed to fulfill the requirements of the Standard Advanced Dewar Assembly (SADA) specification PRF-A3165823B, and is named the One Watt Linear (OWL) cooler.

One requirement of the SADA specification is that the cooler have high reliability, defined as operating with a mean time to failure (MTTF) of greater than 4,000 hours. The United States Army added an additional reliability requirement of greater than 12,000 hours MTTF. The OWL cooler demonstrated 12,000 hours operation in October of 2007. The decision was made at that time to continue operating the coolers for as long as possible, to determine the maximum reliability of the OWL cryocooler.

The coolers operated until a MTTF of 15,208 hours. The failure modes were due to vibration and leak rate; the cooling performance was not degraded. The coolers continued operation until an average operating time of 20,051 hours was attained. Although cooling performance was still unchanged, the coolers were removed from test and disassembled for inspection at that point.

2. METHODS

Following is a description of the testing methods and operational requirements of the cryocooler.

Further author information: (Send correspondence to Mark Squires)

Mark Squires: E-mail: mark.squires@cobham.com

Robert D. Nelson: E-mail: bob.nelson@cobham.com

2.1 Test Procedure

The reliability test was conducted on three CLSS OWL cryocoolers, serial numbers R12, R13, and R14. These cryocoolers were pulled from the production line and were built with the same methods that are used in current production. The tests were performed in accordance with the OWL reliability test procedure used at CLSS.

The sequence of the reliability test is as follows:

1. The unit is cycled from -32°C to 23°C to 52°C with a 525 mW applied heat load. The unit is operated for 60 hours out of a 72 hour cycle, in 5–8 hour increments.
2. Step 1 is repeated until 500 hours of operation is accumulated.
3. A cooling performance acceptance test is completed, comprising
 - (a) A cooling run at 23°C, with a 1000 mW heat load applied at 20 minutes operation, and a 525 mW heat load applied at 40 minutes operation.
 - (b) A two hour soak at 60°C.
 - (c) A cooling run at 60°C, with a 650 mW heat load applied at 20 minutes operation, and a 525 mW heat load applied at 40 minutes operation.
 - (d) A two hour soak at -40°C.
 - (e) A cooling run at -40°C, with a 1000 mW heat load applied at 20 minutes operation, and a 525 mW heat load applied at 40 minutes operation.
4. A leak rate check.
5. An operational vibration test.
6. Steps 1 to 5 are repeated.

2.2 Performance Requirements

Failure of the reliability test is defined as any one of the five following criteria:

1. Inability to maintain a cold-tip temperature of 77 K with an applied 525 mW heat load at an ambient of -32°C to 52°C.
2. Failure to cool a 1440 J mass (300 K to 77 K) to 79.5 K in 15.6 minutes or less.
3. Failure to meet the input power requirement of 60 watts when measured at any point during the reliability cycle.
4. Failure to meet the leak rate requirement of $\leq 1 \times 10^{-7}$ standard cubic centimeters per second of helium at 23°C.
5. Output vibration in excess of 0.5 pounds RMS in the compressor axial and radial directions, or in excess of 0.75 pounds RMS in the expander axial direction.

3. RELIABILITY RESULTS

Following are results from each cryocooler. Reported are the ATP data including cooling times, helium leak rate, and output vibration for each axis.

3.1 R12

Unit R12 operated without failure for 17,252 hours, before failing output vibration testing in the compressor radial direction. R12 continued to operate to 21,084 hours, successfully passing all ATP requirements with exception of the failed vibration. At 21,084 hours, the unit was removed from test for tear down and engineering evaluation. Figure 1 shows the cooldown performance of the unit over the reliability test. Figures 2–4 show the cooling performance of the unit with an applied heat load, and Figures 5 and 6 show the output vibration and leak rate of the cooler.

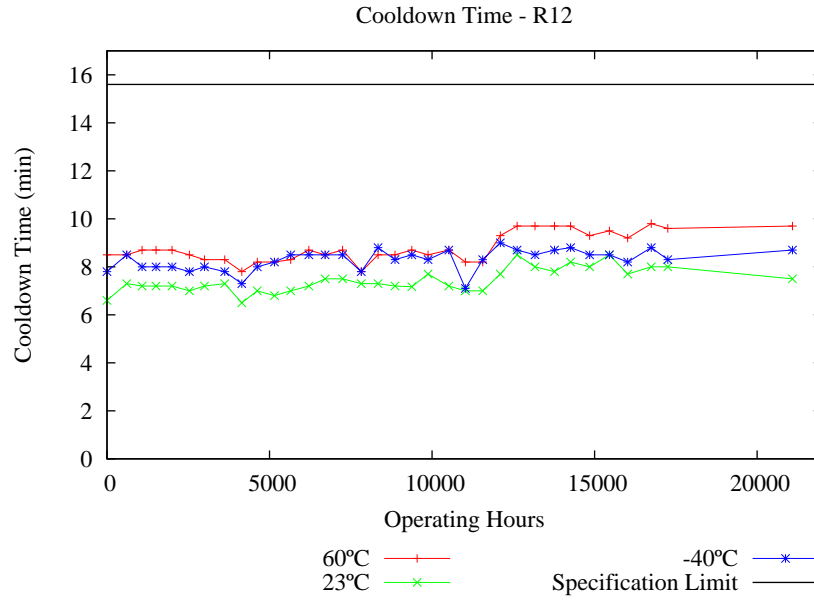


Figure 1. Cooldown time of unit R12 during ATP.

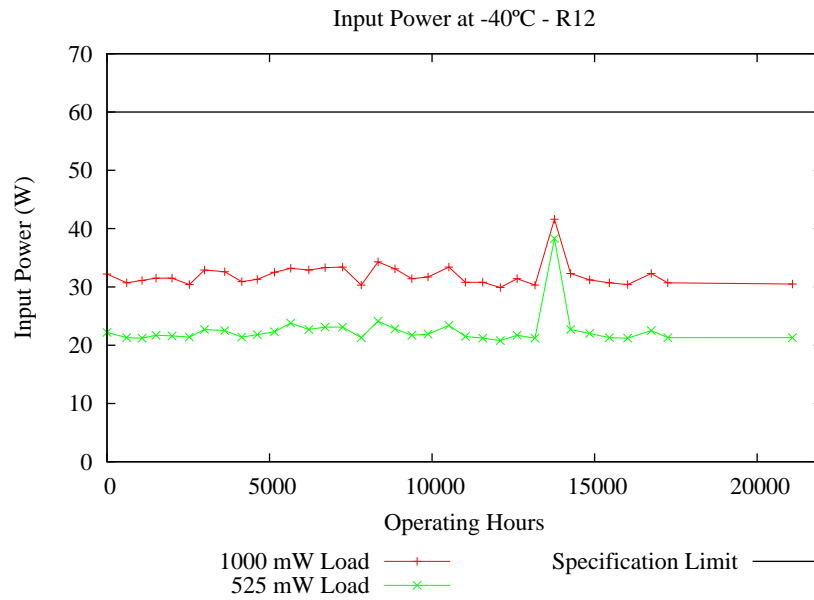


Figure 2. Cooling performance of unit R12 for the -40°C ATP test.

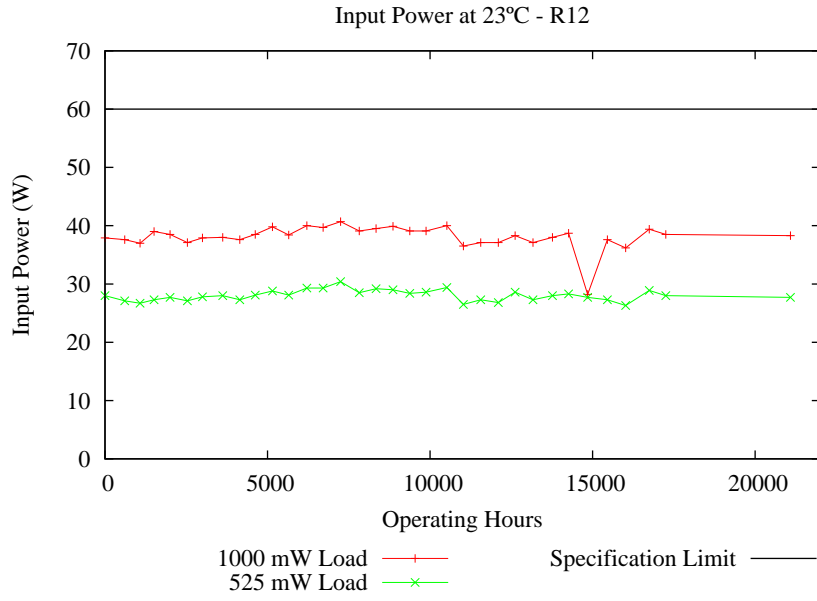


Figure 3. Cooling performance of unit R12 for the 23°C ATP test.

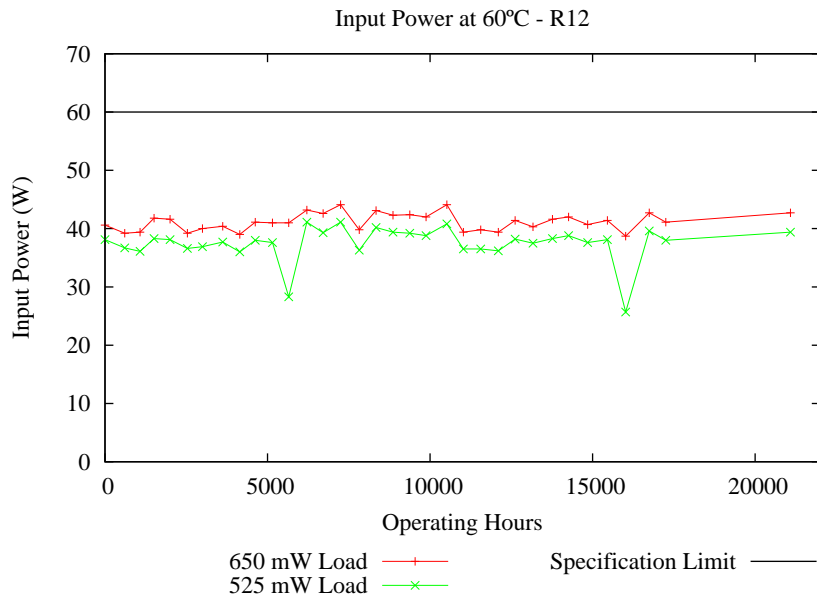


Figure 4. Cooling performance of unit R12 for the 60°C ATP test.

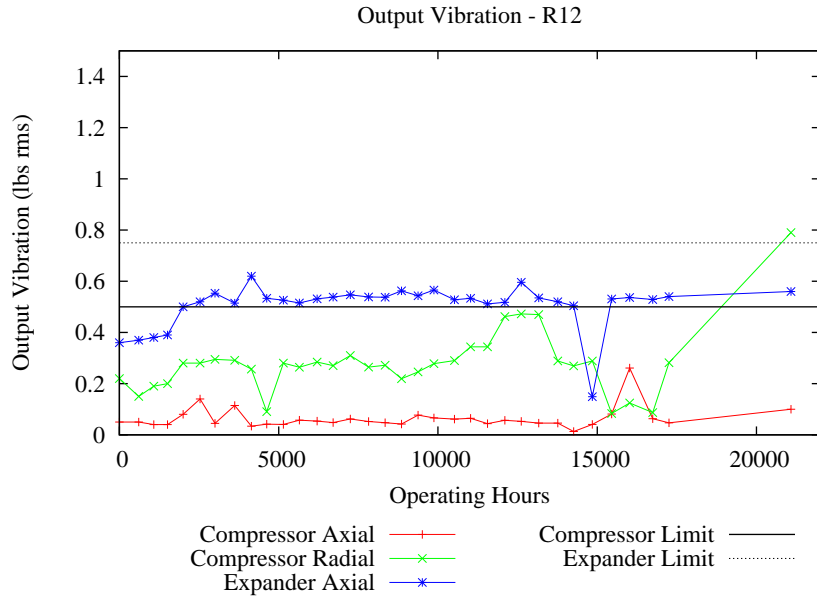


Figure 5. Vibration output of unit R12.

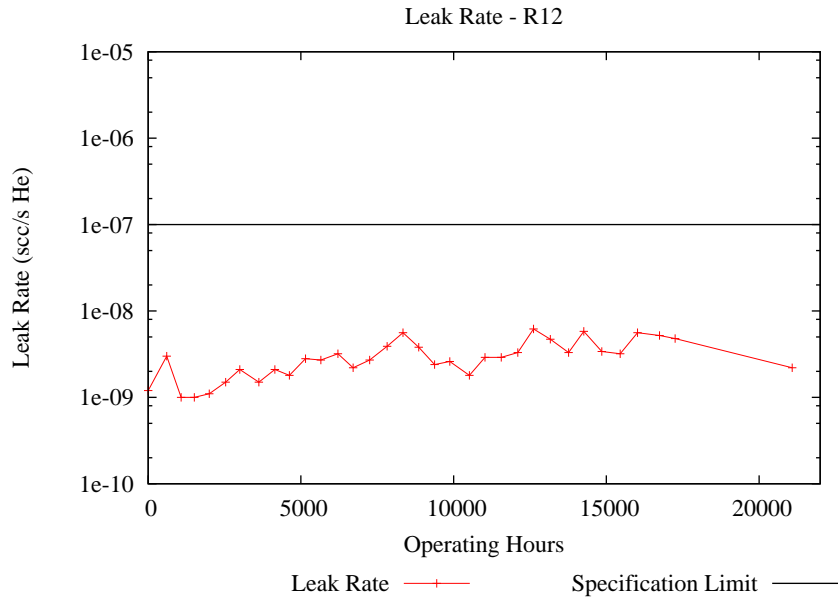


Figure 6. Leak rate of unit R12.

3.2 R13

Unit R13 operated without failure for 15,999 hours, before failing leak rate testing. R13 continued to operate to 21,065 hours, successfully passing all ATP requirements with exception of the failed leak rate. At 21,065 hours, the unit was removed from test for tear down and engineering evaluation. Figure 7 shows the cooldown performance of the unit over the reliability test. Figures 8–10 show the cooling performance of the unit with an applied heat load, and Figures 11 and 12 show the output vibration and leak rate of the cooler.

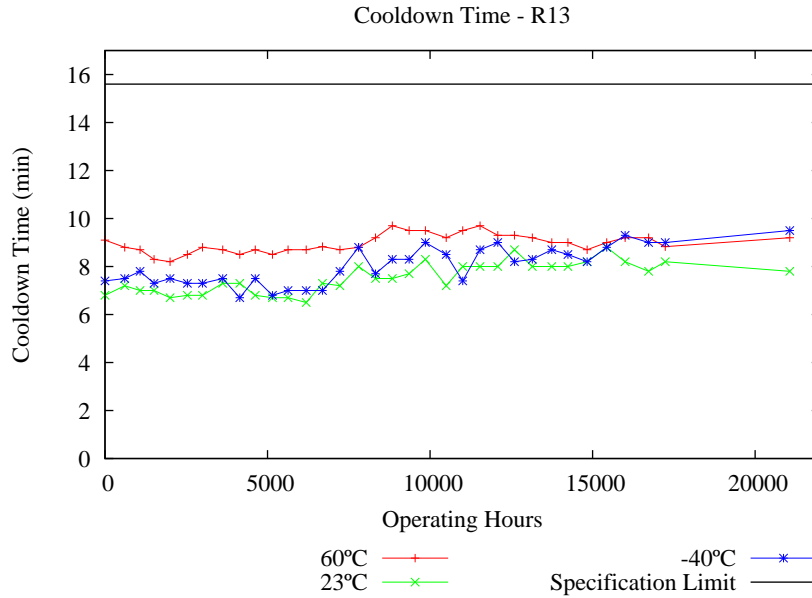


Figure 7. Cooldown time of unit R13 during ATP.

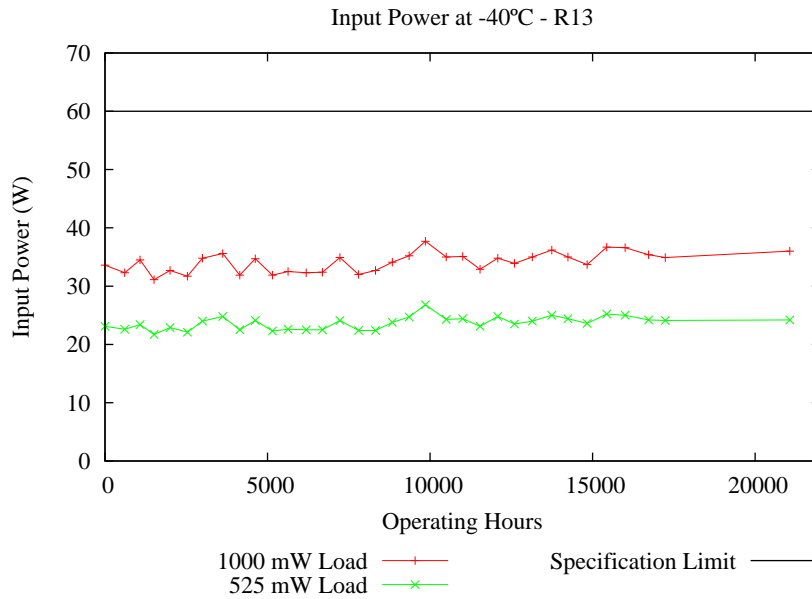


Figure 8. Cooling performance of unit R13 for the -40°C ATP test.

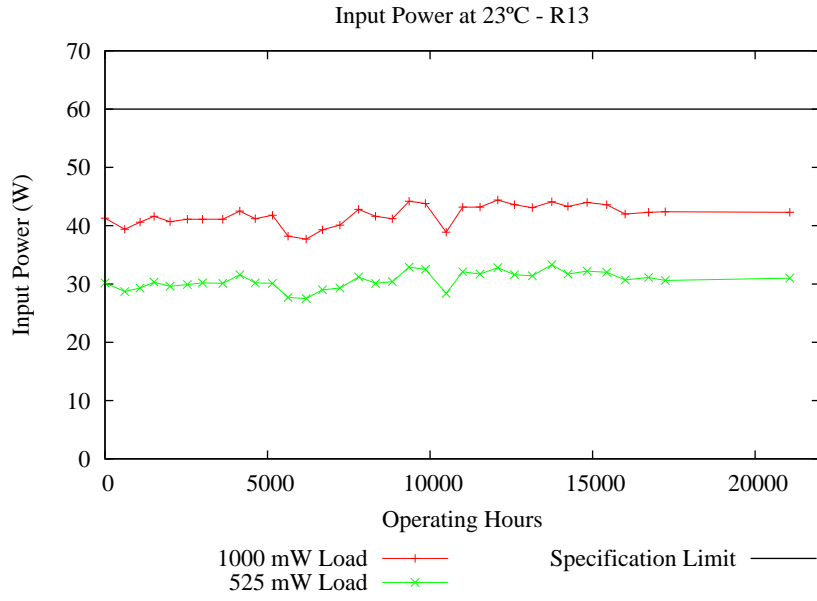


Figure 9. Cooling performance of unit R13 for the 23°C ATP test.

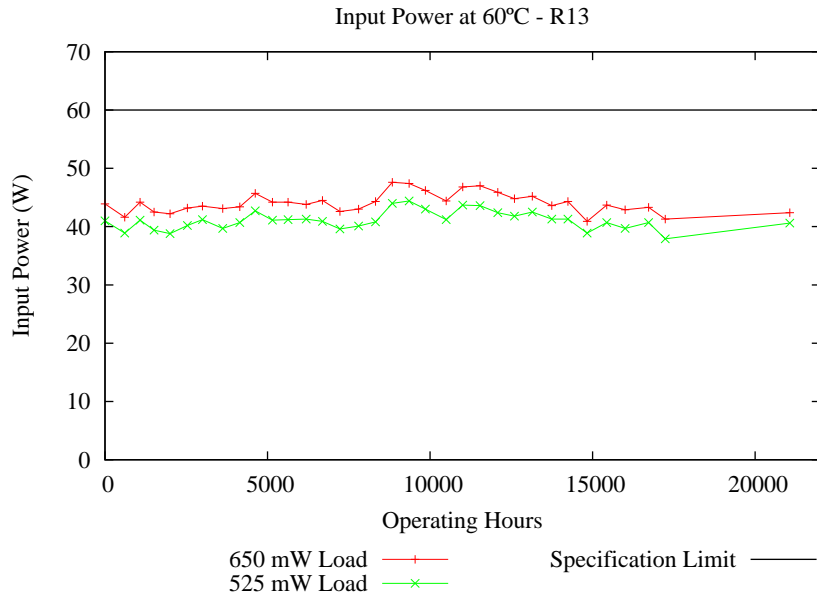


Figure 10. Cooling performance of unit R13 for the 60°C ATP test.

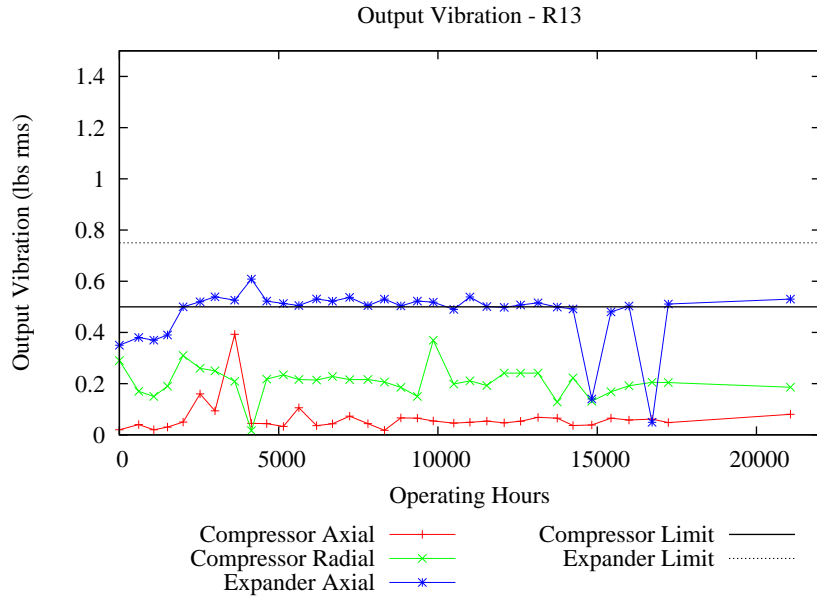


Figure 11. Vibration output of unit R13.

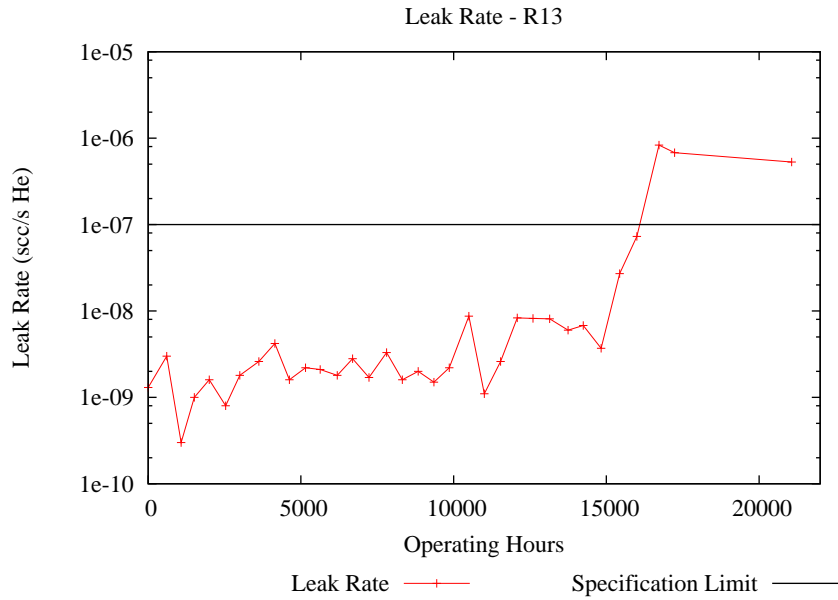


Figure 12. Leak rate of unit R13.

3.3 R14

Unit R14 operated without failure for 12,374 hours, before failing output vibration testing in the compressor radial direction. R14 continued to operate to 18,006 hours, successfully passing all ATP requirements with exception of the failed vibration. At 18,006 hours, the unit was removed from test for tear down and engineering evaluation. Figure 13 shows the cooldown performance of the unit over the reliability test. Figures 14–16 show the cooling performance of the unit with an applied heat load, and Figures 17 and 18 show the output vibration and leak rate of the cooler.

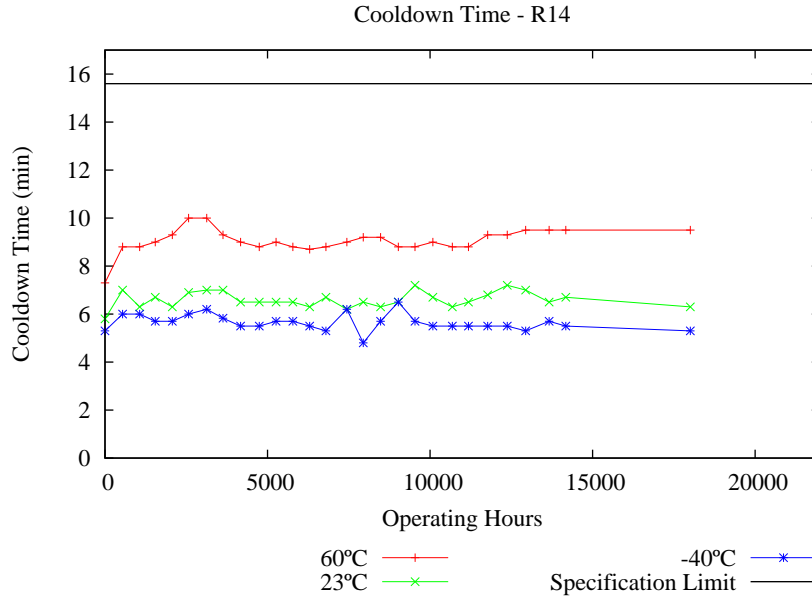


Figure 13. Cooldown time of unit R14 during ATP.

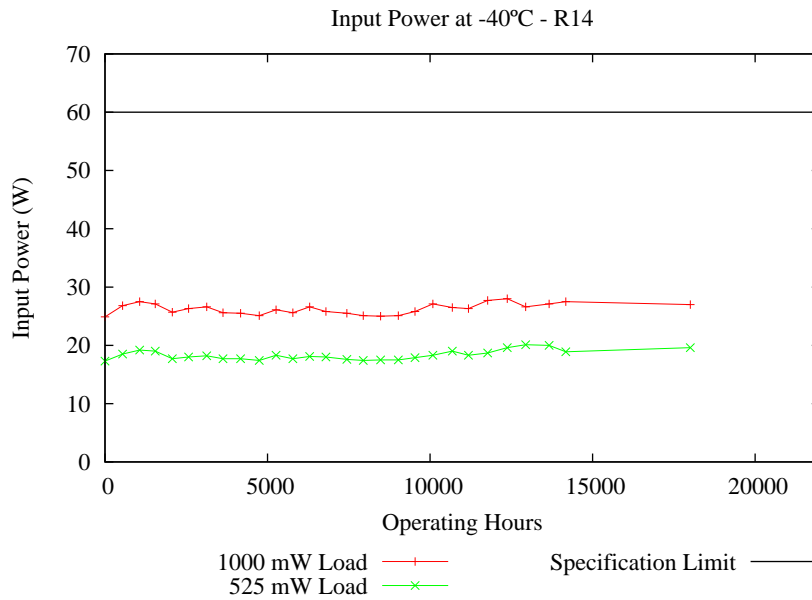


Figure 14. Cooling performance of unit R14 for the -40°C ATP test.

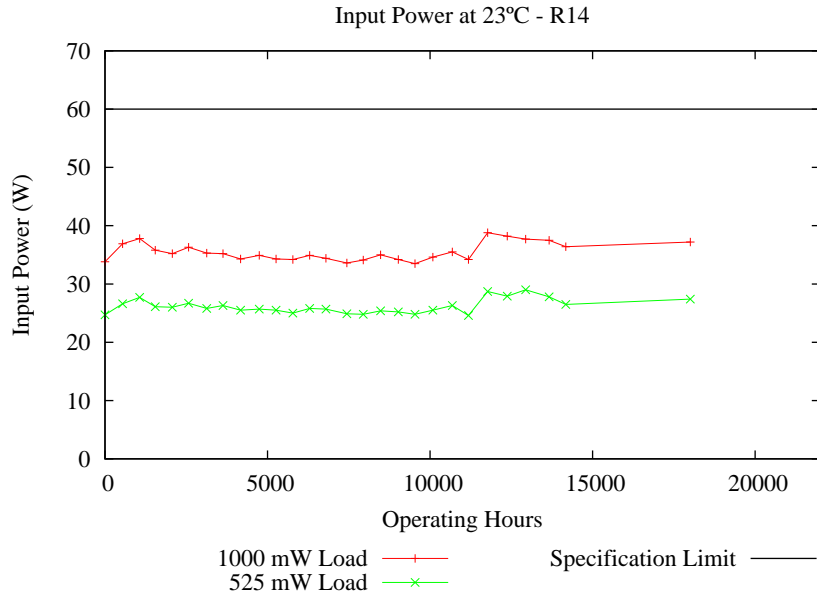


Figure 15. Cooling performance of unit R14 for the 23°C ATP test.

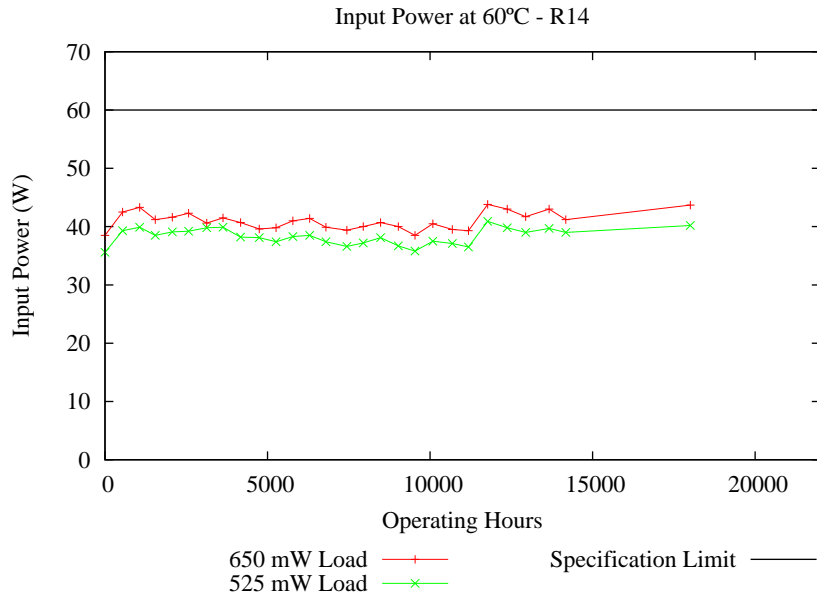


Figure 16. Cooling performance of unit R14 for the 60°C ATP test.

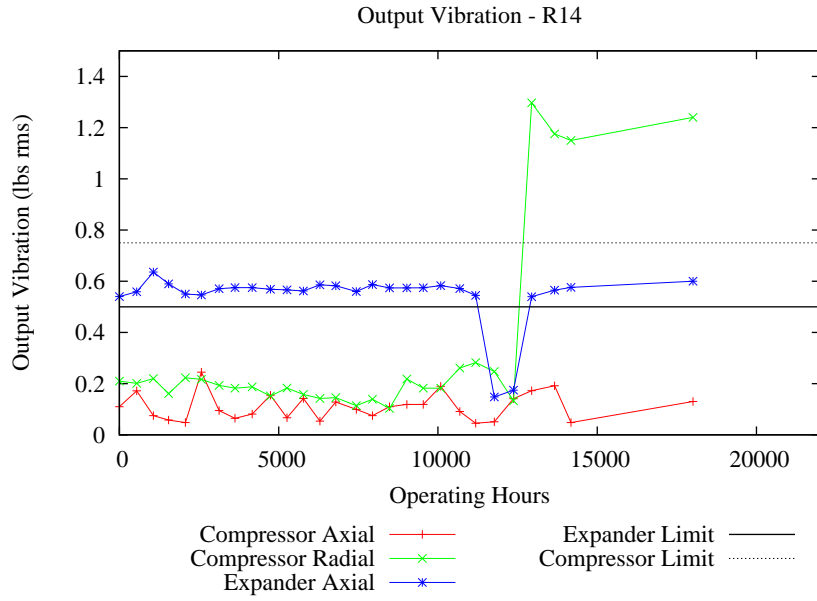


Figure 17. Vibration output of unit R14.

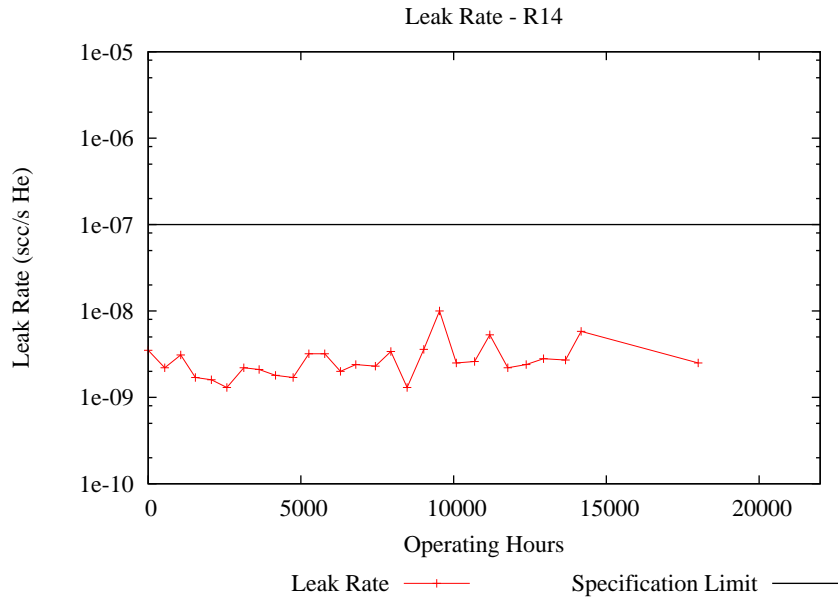


Figure 18. Leak rate of unit R14.

3.4 Reliability Test Summary

Table 1 contains a summary of the reliability units, with their operating hours and failure modes.

Table 1. Summary of the reliability units.

Unit Number	Run Time Without Failure	Total Run Time	Failure Mode
R12	17,252 hours	21,084 hours	Output Vibration
R13	15,999 hours	21,065 hours	Leak Rate
R14	12,374 hours	18,006 hours	Output Vibration
Mean	15,208 hours	20,051 hours	

4. CONCLUSION

CLSS has completed a reliability test on three OWL cryocoolers. MTTF of the cryocoolers exceeded 15,000 hours, and the units continued to operate until a mean operating time in excess of 20,000 hours while maintaining cooling performance.