



Requirements for Repair of a Miniature Liquid Helium-3 Refrigerator

Document: G0107-0303-A-REQ

Version A

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1 Introduction:

1.1 General:

A self-contained closed-cycle miniature liquid helium-3 (^3He) refrigerator is used to cool the active elements of a bolometric radiometer system used at the 10-Meter Sub-Millimeter Telescope of the Arizona Radio Observatory (ARO). The ^3He refrigerator achieves typical temperatures of 0.3K. The refrigerator requirements are described here. Complete technical specifications and descriptions for a prototype unit are contained in applicable document [1].

1.2 Scope:

All performance requirements for the ARO miniature liquid ^3He refrigerator are described. Additional information and descriptions of a prototype unit are provided by applicable document [1]. No references to the bolometer characteristics are needed or included. A refrigerator meeting the described requirements provides the necessary environment for the proper operation of the bolometer system.

1.3 Applicable Documents:

The following document forms part of the requirements to the extent specified herein.

[1] "Miniature liquid- ^3He refrigerator" J. P. Torre and G. Chanin, Review of Scientific Instruments, Vol. 56, No. 2, February 1985, pp 318 – 320.

1.4 Reference Documents:

The following document forms part of the requirements.

[1] ^3He Refrigerator Foot-Print, G0107-0304-A-DWG.

[2] ^3He Refrigerator Cold Plate, G0107-0305-A-DWG.

2 Mechanical Requirements:

2.1 Size:

The overall size of the refrigerator shall be less than 70 mm long x 46 mm wide x 56 mm high.

2.2 Weight

The refrigerator weight shall be less than 300g.

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2.3 Refrigerator Mounting:

The 70 mm x 46 mm mounting foot-print and hole locations are described by drawing G0107-0304-A-DWG.

2.4 Application Mounting:

The user application attaches to the cold plate of the refrigerator. The cold plate mounting details are described by drawing G0107-0305-A-DWG.

2.5 Operating and Storage Environment:

The refrigerator shall withstand temperatures within the range of 0.25K to 323K (50 C) without damage.

The refrigerator shall withstand the shock and vibration associated with normal manual handling and common carrier transportation.

3 Electrical Requirements:

3.1 Heater Requirements:

The sorption pump heater resistance shall be 425 ohms (Ω) with a tolerance of $\pm 5\%$. The sorption pump is weakly coupled thermally to a ^4He stage. When this stage is cooled to about 1.8K, the application of less than 250 Joules of energy shall be sufficient to completely de-sorb the ^3He gas in the pump to start a new cooling cycle. A typical hot cycle consists of the application of 18 volts to the heater for about 5 minutes.

3.2 Temperature Sensors:

Sensors shall be mounted on the ^3He evaporation and sorption pump vessels. Two-wire sensors shall be used. Un-calibrated or “relative” sensors shall be acceptable. If un-calibrated sensors are used, sensor values corresponding to a few operating temperatures shall be provided. The temperatures and sensor location required for calibrations are shown in Table 1.

Location/Temp.	300K	77K	25K	4.2K	1.5K	300mK
^3He evaporator	required	required	N/A	required	required	required
Sorption pump	required	required	required	required	required	N/A

Table 1 – Required temperature calibrations and sensor locations for un-calibrated or “relative” temperature sensors.

4 Operational Requirements:

4.1 Temperature:

4.1.1 Nominal Operating Point:

The evaporator temperature during the cold portion of the refrigeration cycle is primarily determined by the ^3He vapor pressure in the evaporator. The vapor pressure is determined by the pumping capacity of the cryopump and this is determined by the quantity and level of contamination of the absorbing material. This ^3He cold stage temperature shall be measured by a calibrated sensor. The value of the attached two-wire relative cold stage temperature sensor shall be logged. This temperature shall be less than 0.325K when loaded by 10 μw of externally applied heat. The requirement shall be met when the refrigerator is attached to a thermal sink at a temperature no lower than 1.5K, fully instrumented with its two attached temperature sensors and a heating element and surrounded by a heat shield attached to the same thermal sink. Table II and Figure 2 from applicable document [1] describe the operating temperature.

4.1.2 Load Map:

The evaporator temperature during the cold portion of the refrigeration cycle varies with applied heat and provides another indicator of the pumping performance of the cryopump. This performance shall be demonstrated by measuring the temperature of the ^3He cold stage for various amounts of applied heat. External heat loads ranging from 1 μw to 100 μw in 7 logarithmic steps, a 1, 2, 5 sequence, shall be applied. A calibrated sensor shall measure the cold plate temperature 5 minutes after any change to the applied heat. Both values of the attached two-wire relative sensor shall be logged. The operating conditions are as described in Section 4.1.1, the refrigerator is attached to a thermal sink at a temperature no lower than 1.5K stage, it is fully instrumented with its two attached temperature sensors and a heating element and it is surrounded by a heat shield attached to the same thermal sink. The measured temperature versus applied heat shall be within 10% of the values described by Figure 2 from applicable document [1].

4.2 Run Time:

The run time of the “cold” portion of the refrigeration is determined primarily by the energy capacity of the refrigerator. This is determined by the quantity of liquid- ^3He that condenses into the evaporator, and this is determined by the amount of gaseous ^3He in the system. Tests shall demonstrate the capacity.

4.2.1 Typical Operation:

The first test verifies typical operation. During the “cold” portion of the cycle, the temperature shall not exceed 0.325K for 24 hours. A calibrated sensor shall measure the cold stage temperature at least once every hour. The values from the two attached two-wire

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relative sensor shall be logged. The refrigerator shall be loaded by 10 μ w of externally applied heat, attached to a thermal sink at a temperature no lower than 1.5K, fully instrumented with its two attached temperature sensors and heating element, and surrounded by a heat shield attached to the same thermal sink.

4.2.2 Capacity

The second test attempts to quantify the refrigeration capacity. The ^3He refrigerator is loaded by applied heat and a calibrated sensor measures the cold stage temperature every 15 minutes until it exceeds 125% of the initial value. The cold cycle time is determined from when the refrigerator temperature stabilizes until it exceeds 110% of its stabilization value. The requirement is met if the applied heat exceeds 1.8 Joules. During this test, values obtained from both attached two-wire relative sensors shall be logged. The refrigerator shall be loaded by 100 μ w of externally applied heat, attached to a thermal sink at a temperature no lower than 1.5K, fully instrumented with its two attached temperature sensors and heating element, and is surrounded by a heat shield attached to the same thermal sink.

4.3 “Hot” Recycle:

The “hot” portion of the refrigeration cycle determines the amount of available ^3He gas and affects the cycle efficiency. The performance of the sorption pump during a “hot” portion of the cycle shall be measured. A calibrated sensor shall measure the pump temperature every 30 seconds. Simultaneously, the values of the attached two-wire relative sensor shall be logged. The test shall continue until all ^3He gas has been de-sorbed as indicated by a rapid increase in the pump temperature. This temperature shall be recorded and the value of the two-wire relative sensor logged.

5 Performance Validation:

Two different approaches to performance validation are permitted. One approach involves taking operational measurements on the subject refrigerator when mounted in an instrumented test Dewar. The other approach involves taking operational measurements when the refrigerator is mounted within the ARO 19-Channel Bolometer Dewar. If the ARO Dewar is used, the 19-Channel bolometer system must be attached to the ^3He refrigerator for the safety of the bolometer components. In this situation, there is an unknown heat load supplied by the 21 wires connecting to the bolometer. The tests could assume that this added load is zero or a method to measure this contribution could be designed and then all applied loads compensated for by this value. If the wire loading is measured, the measurement techniques, processes, and assumptions shall be agreed upon in writing. The use of the ARO 19-Channel Bolometer system may be problematic since no permanent modifications are permitted to the hardware.

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6 Instrumentation Calibration:

6.1 Temperature Sensors:

Any sensor used as the basis for temperature measurements shall support a calibration within the preceding 12 months and be traceable to recognized standards. The calibration data and procedures shall be available upon request. Spot temperature calibration is acceptable. Procedures for their use shall be available upon request.

6.2 General and Specialized Instrumentation:

All commercially provided instrumentation shall support valid calibration. The manufacturer, type, and model number of any test instrument used during the evaluation shall be included with the test results. Custom specialized instrumentation shall support a valid calibration or a statement describing the validity of its measurements. A list of custom specialized instrumentation used during the evaluation shall be included with the test results. Calibration data and procedures for all instrumentation shall be available upon request.

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