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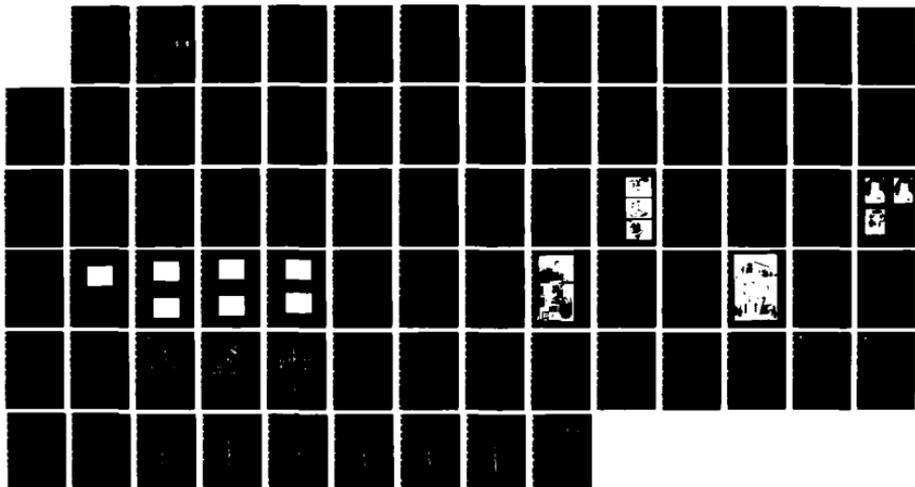
TEST REPORT ON THE QUALIFICATION PROGRAM FOR THE
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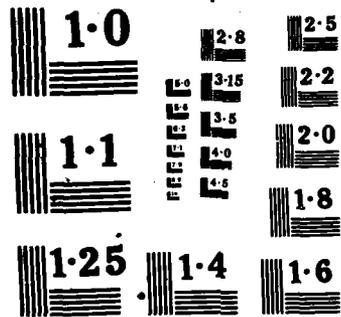
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TEST REPORT
ON THE
QUALIFICATION PROGRAM

for the
One-Quarter (1/4) Watt Split Stirling
Common Module Cryogenic Cooler

CONTRACT NO. DAAK70-82-C-0216

January 1984

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One-Quarter (1/4) Watt Split Stirling Common Module
Cryogenic Cooler

CONTRACT NO. DAAK70-82-C-0216

January 1984

Submitted to:

United States Army
Mobility Equipment Research
and Development Command
Procurement and Production Directorate
Fort Belvoir, Virginia 22606

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PREFACE

This document, which was prepared by Raymond M. Tervo of CTI-CRYOGENICS, A Division of Helix Technology Corporation in Waltham, Massachusetts, describes the testing conducted and the results obtained from performing the qualification tests outlined in CTI-CRYOGENICS approved test plan numbers A3543740 and A3543743. This program was conducted under the direction of Noel J. Holland of CTI-CRYOGENICS. Work on this program began on September 28, 1982 and was completed on October 14, 1983.

This effort was funded by the U.S. Army ERADCOM, Night Vision and Electro-Optics Laboratory (NV & EOL), Fort Belvoir, Virginia, under the direction of Howard Dunmire under Contract Number DAAK70-82-C-0216.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report describes the tests performed and the results obtained by CTI- CRYOGENICS from conducting a qualification program designed for a 1/4 Watt Split Stirling Cryogenic Cooler, under contract no. DAAK70-82-C-0216 for the U.S. Army Night Vision and Electro-Optics Laboratory. Qualification testing included evaluation of the 1/4 Watt Cryogenic Cooler under the following test conditions: (continued)		

- 9 low, room and high ambient temperature tests (-40°C, +23°C, +71°C);
• temperature shock testing (-54°C, +71°C);
9 mechanical vibration testing;
9 mechanical shock testing;
9 audible noise testing; and
P reliability demonstration testing.

The cryogenic cooler design consisted of a motor/compressor assembly, interconnecting stainless steel capillary tubing, and a remote expander assembly. Nominal operating voltage applied to the units was 17.5 VDC with a maximum input power of 35 watts.

The cryogenic cooler assembly did not exceed the maximum weight limit of 2.5 pounds. *Keywords: → field 19*

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TEST CERTIFICATIONS

Bolt, Beranek & Newman, Inc.

AVCO Environmental Testing Services

1.0 INTRODUCTION

This document provides the results obtained from performing the tests established for environmental and reliability qualification testing as directed in Specification B2-28A050122A, Development Specification for Cooler, Cryogenic, Split Stirling, HD-1045(V)/UA Dated 18 June 1982.

Testing was performed in accordance with CTI-CRYOGENICS approved test procedures A3543740, One Quarter (1/4) Watt Common Module Cryogenic Cooler Qualification Test Procedure and A3543743, One Quarter (1/4) Watt Common Module Cryogenic Cooler Reliability Test Procedure. Testing was conducted at CTI-CRYOGENICS in Waltham, MA as well as AVCO Systems Division, Environmental Test Facility in Wilmington, MA and Bolt, Beranek, and Newman's Acoustic Test Facility in Cambridge, MA. The testing was conducted to fulfill the requirements of Contract number DAAK70-82-C-0216 issued to CTI-CRYOGENICS, Kelvin Park, Waltham, MA by the United States Army MERADCOM Procurement and Production Directorate at Fort Belvoir, VA.

1.1 Objective

The objectives of the One Quarter (1/4) Watt Cryogenic Coolers Environmental and Reliability Qualification Tests were:

- a. To demonstrate that the coolers as manufactured by CTI-CRYOGENICS will perform satisfactorily following exposure to extreme environmental conditions anticipated in their service life environments.
- b. To demonstrate a mean time between failure (MTBF) of 1000 hours.
- c. To qualify CTI-CRYOGENICS, A Division of Helix Technology Corporation, as a supplier of One Quarter (1/4) Watt Common Module Coolers.

2.0 APPLICABLE DOCUMENTS

The following documents formed a part of the Test Procedure to the extent specified herein. In the event of any conflict between the Test Procedure and the documents specified herein, the Test Procedure took precedence.

MIL-STD-810C, Environmental Test Methods.

MIL-C-45662, Calibration Standards.

ANSI S1.11 Specification for Octave, Half-Octave, and Third-Octave Band Filter Sets.

MIL-STD-781B, Reliability Tests, Exponential Distribution.

B2-28A050122A, Development Specification for Cooler, Cryogenic, Split-Stirling, HD-1045(V)/UA, dated 18 June 1982.

3.0 QUALITY ASSURANCE PROVISIONS

3.1 Test Facilities

Support test facilities providing environmental testing were certified capable to meet the test requirements of MIL-STD-810. In addition to CTI-CRYOGENICS internal testing, AVCO, Wilmington and Bolt, Beranek & Newman, Cambridge were utilized to provide additional support testing.

3.2 Test Surveillance

Quality Assurance provided test surveillance/auditing as required to certify the accuracy of data collected including verification of test equipment.

3.2.1 Test Inspection

The NV & EOL Project Engineer or his designated representative was invited to visit the test facility to assure compliance with the test requirements.

CTI-CRYOGENICS provided the necessary administrative support to permit such personnel to properly perform their authorized duties.

3.3 Test Equipment Calibration

All test equipment (instrumentation, tooling, and test fixturing) used in conducting the tests specified in the test plan was calibrated in accordance with MIL-C-45662. Suitable certification stickers were affixed to the test equipment as required by the above specification.

4.0 TEST ITEM

Two (2) One-Quarter (1/4) Watt Split-Stirling Cryogenic Coolers, hereafter referred to as the units (CTI-CRYOGENICS P/N D8089001G01 (12" interconnecting transfer line)), were submitted to the tests outlined herein for the Environmental portion of the Qualification Testing (CTI-CRYOGENICS test procedure number A3543740).

The two (2) environmental test units were serialized as unit #1 and unit #2 prior to the start of testing.

Three (3) additional One-Quarter (1/4) Watt Split-Stirling Cryogenic Coolers were submitted to the tests outlined herein for the Reliability portion of the Qualification testing.

The three (3) reliability test units were serialized as unit #3, unit #4, and unit #5 prior to the start of testing. As a result of the testing performed, it was necessary to submit an additional 3 units which were subsequently serialized as unit #6, unit #7, and unit #8.

5.0 TEST SEQUENCE

The following tests were performed in the sequence shown:

Environmental Tests (Units #1 and #2)

- o Baseline Performance Tests
 - o Room Ambient Test (23°C)
 - o Low Ambient Test (-40°C)
 - o High Ambient Test (+71°C)
- o Burn-In Test
- o High Temperature Test
- o Low Temperature Test
- o Temperature Shock Test
- o Vibration Test
- o Mechanical Shock Test
- o Baseline Performance Test (at room ambient, 23°C)
- o Audible Noise Test

Reliability Tests (Units #3-8)

- o Baseline Performance Tests
 - o Room Ambient Test (23°C)
 - o Low Ambient Test (-40°C)
 - o High Ambient Test (+71°C)
- o Burn-In Test
- o Reliability Demonstration Test

6.0 BASELINE PERFORMANCE TEST

6.1 Test Purpose

The baseline performance tests were conducted to verify the basic cooling capacity of the units at high (+71°C), low (-40°C), and room ambient (+20°C) temperature conditions as well as to verify the proper calibration and operation of all the associated test equipment and instrumentation, any out of specification conditions were corrected prior to submittal to the official qualification program.

6.2 Test Requirement

The units were required to operate for one and one half (1.5) hours at each ambient condition. The acceptance criteria for each unit was that listed in Paragraph 8.4.

6.3 Test Instrumentation

The test instrumentation used met the requirements listed in Paragraph 7.4.

6.4 Test Results

Baseline performance tests were conducted on all of the units prior to submittal to the official Burn-In Test outlined in Paragraph 7.0. The data presented below is for reference purposes only.

<u>Unit S/N</u>	<u>Amb. Temp. (°C)</u>	<u>Cooldown Time To 85K or Less (Minutes)</u>	<u>Cold Tip Temp./ Applied Heat Load (K)/(Watts)</u>	<u>Input Power (Watts)</u>
001	+20	*---	74.0/.38	26.3
002	+20	*---	80.0/.38	24.5
003	+20	*---	72.6/.36	30.7**
004	+20	*---	76.8/.36	25.2
005	+20	*---	77.1/.36	25.7
006	+20	5'07"	69.1/.36	29.7
007	+20	4'30"	65.7/.36	26.8
008	+20	5'02"	67.0/.36	30.3**

*Automated printout during this test sequence malfunctioned. This was corrected prior to start of official testing.

**Marginal condition considered to be acceptable due to new seals.

<u>Unit S/N</u>	<u>Amb. Temp. (°C)</u>	<u>Cooldown Time To 85K or Less (Minutes)</u>	<u>Cold Tip Temp./ Applied Heat Load (K)/(Watts)</u>	<u>Input Power (Watts)</u>
001	-40	4'45"	54.4/.22	28.3
002	-40	4'26"	56.8/.18	25.0
003	-40	6'33"	60.3/.22	26.1
004	-40	5'39"	64.8/.22	25.1
005	-40	6'46"	60.5/.22	25.2
006	-40	4'51"	49.8/.21	26.4
007	-40	5'00"	51.4/.21	24.6
008	-40	4'41"	48.2/.21	26.4

<u>Unit S/N</u>	<u>Amb. Temp. (°C)</u>	<u>Cooldown Time To 85K or Less (Minutes)</u>	<u>Cold Tip Temp./ Applied Heat Load (K)/(Watts)</u>	<u>Input Power (Watts)</u>
001	+70	6'58"	70.3/.22	25.4
002	+70	6'24"	64.4/.22	26.0
003	+70	*---	82.3/.22	23.2
004	+70	*---	73.4/.22	29.0
005	+70	*---	74.0/.22	27.9
006	+70	4'48"	59.7/.21	34.0
007	+70	4'17"	57.1/.21	30.0
008	+70	4'40"	61.9/.21	29.3

*Automated printout during this test sequence malfunctioned. This was corrected prior to start of official testing.

Cooldown times to 100K were omitted. The 7.5 minute requirement was exceeded at all of the 85K points.

7.0 BURN IN TEST

7.1 Test Purpose

The Burn-In test was conducted to wear in the displacer and compressor piston seals and to verify the basic cooling capacity of the units at room ambient temperature prior to exposure to any of the environmental or reliability demonstration tests outlined herein.

Running time accumulated during the Burn-In test was not applied to the total elapsed time when calculating the demonstrated MTBF hours.

7.2 Test Requirement

The units were required to operate for eight (8) hours at room ambient temperature as described in Paragraph 7.6.

7.3 Test Mounting

The units were mounted in a suitably designed holding fixture. The cold ends were instrumented for operation as described in Paragraph 7.4 below, and installed in a common dewar capable of achieving a vacuum level of 1.0×10^{-4} Torr or better.

7.4 Test Instrumentation

7.4.1 Those parts of the test fixtures and test equipment that were in contact with the units were visually inspected prior to and during use to insure that they were free of soil, grease, oil, or other contamination. All test instrumentation used were calibrated within the requirements of MIL-C-45662.

- 7.4.2 The mass applied was soldered to the tip of the cold finger. This mass included a silicon diode and a wire wound heater having a thermal mass equivalent to 1.8 grams copper minimum.
- 7.4.3 The electrical voltage for operating the units was 17.5 VDC \pm 0.5 VDC.
- 7.4.4 The instrumentation mounted at the tip of the expander assembly was calibrated at liquid nitrogen temperature.
- 7.4.5 Prior to the start of the operational test, the dewar assembly was evacuated to a vacuum level of 1.0×10^{-4} Torr or better.
- 7.4.6 Heat sinking of the units was sufficient to limit the crankcase temperature to 20°C (36°F) above ambient.
- 7.4.7 Temperatures monitored were measured using calibrated thermocouples.

7.5 Unit Stabilization

The units were considered stable when the compressor housing temperature was within + 3°C of the test chamber ambient conditions for a period of 15 minutes with the units in the non-operating mode.

7.6 Burn-In Test Procedure

The Burn-In test was performed at standard room ambient conditions (23 \pm 5°C). The units were instrumented as required in Paragraph 7.4 to properly measure cooling capacity of the systems. The following performance data was measured and recorded on a copy of the test data sheet shown in Figure 8-1 immediately prior to start-up and at each required time interval during the test:

- o Elapsed time from start-up, Min-Sec.
- o Test chamber ambient temperature, °F
- o Compressor housing temperature, °F
- o Cold finger tip temperature, Kelvin
- o Applied heat load, Watts
- o Applied voltage, VDC
- o Input current, Amps
- o Input power, Watts.

The cold finger tip temperatures were continuously monitored on a strip chart recorder during the following procedure:

- Step 1: After 15 minutes of stabilization, with the units in the non-operating mode, the required data was recorded just prior to start-up on the test data summary sheet (see Figure 8-1).
- Step 2: The units were energized by applying 17.5 ± 0.5 VDC to the input terminals of the system. With no heat load applied to the cold tip, the system was allowed to cool down.
- Step 3: Data was recorded immediately after start-up and when the cold tip temperature reached 100K, 85K, and after 20 minutes of operation.
- Step 4: After 20 minutes of operation was achieved and data was recorded, an electrical heat load of $0.35 \pm 0.03, -0.00$ watts was applied. The system was allowed to operate for an additional 7 hours 40 minutes.
- Step 5: Data was recorded at the time the heat load was applied, at 15 minute intervals, and at the end of the required time period. The units were then shut down.

This concluded the Burn-In test.

7.7 Burn-In Test Acceptance Criteria

7.7.1 Cooldown Time

The cooldown time to reach a cold tip temperature of 100K with a 1.8 gram minimum copper mass load shall be equal to 7.5 minutes or less. Cooldown to 85K shall be equal to 10 minutes or less.

7.7.2 Cooling Capacity

The units shall provide $0.35, \pm 0.03, -0.00$ watts net refrigeration at 85K minimum (reference Figure 8-2).

7.7.3 Input Power

The power consumed by the units shall be equal to or less than 30 watts at room ambient temperature (reference Figure 8-3).

7.8 Burn-In Test Results

The post test visual inspection revealed that there was no evidence of any mechanical damage or deterioration of the units as a result of this test. Performance test results are tabulated below:

<u>Unit S/N</u>	<u>Amb. Temp. (°C)</u>	<u>Cooldown Time To 85K or Less (Minutes)</u>	<u>Cold Tip Temp. Applied Heat Load (K)/(watts)</u>	<u>Input Power (Watts)</u>
001	23	6'22"	68.7/.35	27.2
002	23	5'32"	70.0/.35	26.0
003	23	5'45"	73.1/.36	31.2
004	23	6'11"	77.8/.36	25.8
005	23	5'45"	79.1/.36	26.6
006	23	*	74.0/.37	28.8
007	23	*	69.9/.36	26.1
008	23	*	82.2/.36	28.4

*Malfunction of data logger at 85K printout; subsequent data point below 85K was within the 10 minute requirement.

8.0 OPERATIONAL TEST

8.1 Test Purpose

The operational test was performed to verify cooler performance during and after exposure to the various environmental conditions as required by the test plan.

8.2 Test Requirement

The procedure consisted of instrumenting the units as described in Paragraph 7.4 to measure cooling capacity. The following performance test data was measured and recorded immediately prior to start-up and at each required time interval during the test.

- o Elapsed time from start-up, Min-Sec.
- o Test chamber ambient temperature, °C.
- o Compressor housing temperature, °C.
- o Cold finger tip temperature, Kelvin.
- o Applied heat load, watts.
- o Applied voltage, VDC.
- o Input power, watts.

The cold finger tip temperature was continuously monitored on a strip chart recorder during the operational test.

The operational test was performed once the units had reached stabilization. The units were considered to have reached stabilization when the compressor housing temperature was within $\pm 3^{\circ}\text{C}$ of the test chamber ambient conditions for a period of 15 minutes with the units in the non-operating mode.

8.3 Operational Test Procedure

- Step 1: After 15 minutes of stabilization at the required ambient temperature, with the units in the non-operating mode, record the required data just prior to start-up on the test data summary sheet (see Figure 8-1).
- Step 2: Energize the units by applying 17.5 ± 0.5 VDC to the power input terminals of the system. With no heat load applied to the cold tip, allow the system to cool down.
- Step 3: Record data immediately after start up and when the cold tip temperature reaches 100K, 85K, and after 20 minutes of operation.
- Step 4: After 20 minutes of operation has been achieved and data has been recorded, apply the required heat load which correlates to the ambient temperature of the test being performed per Figure 8-2. Allow the system to operate for an additional 40 minutes.
- Step 5: Record data at the time the heat load is applied, at 10 minute intervals, and at the end of the required time period. Then shut down.

This concluded the operational test.

8.4 Acceptance Criteria

8.4.1 Cooldown Time

The cooldown time to reach a cold tip temperature of 100K and 85K with a 1.8 gram minimum copper mass shall be less than 7.5 minutes and 10 minutes, respectively over the temperature range of -40°C to $+71^{\circ}\text{C}$.

8.4.2 Cooling Capacity

The units shall provide the minimum cooling capacity at 85K as shown in Figure 8-2 below, across the ambient temperature range of -40°C to $+71^{\circ}\text{C}$.

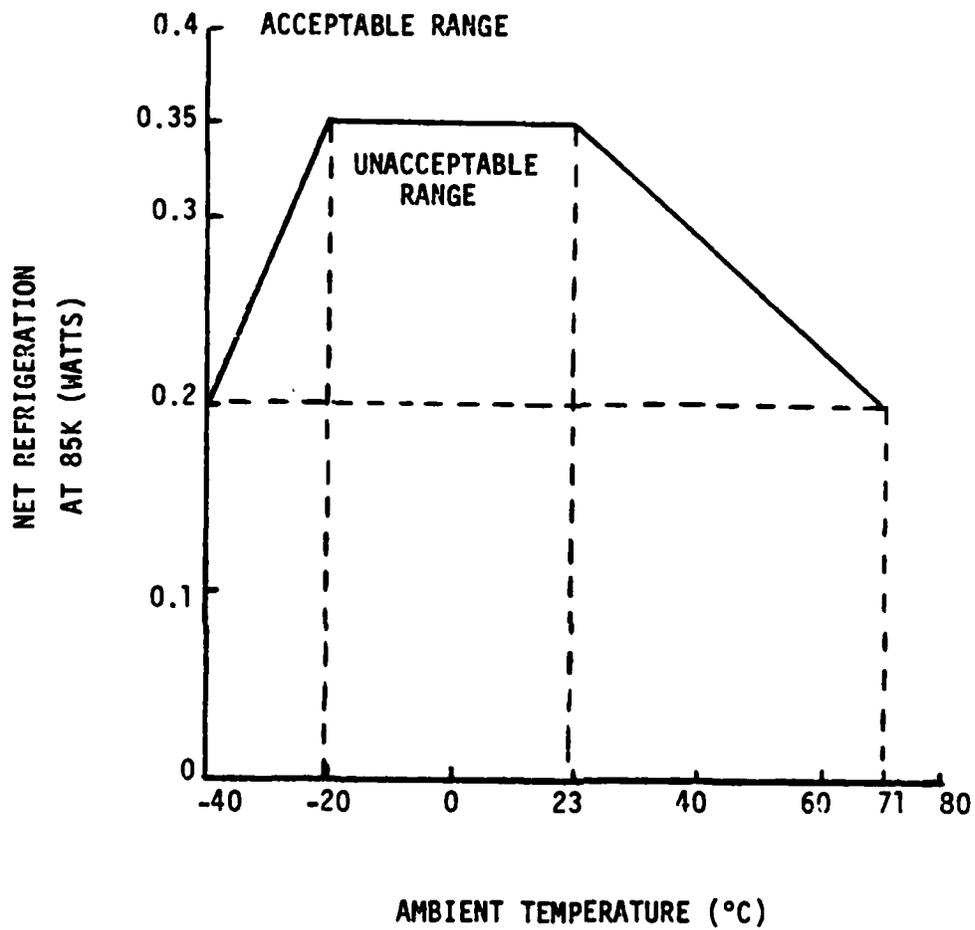


FIGURE 8-2. COOLING CAPACITY

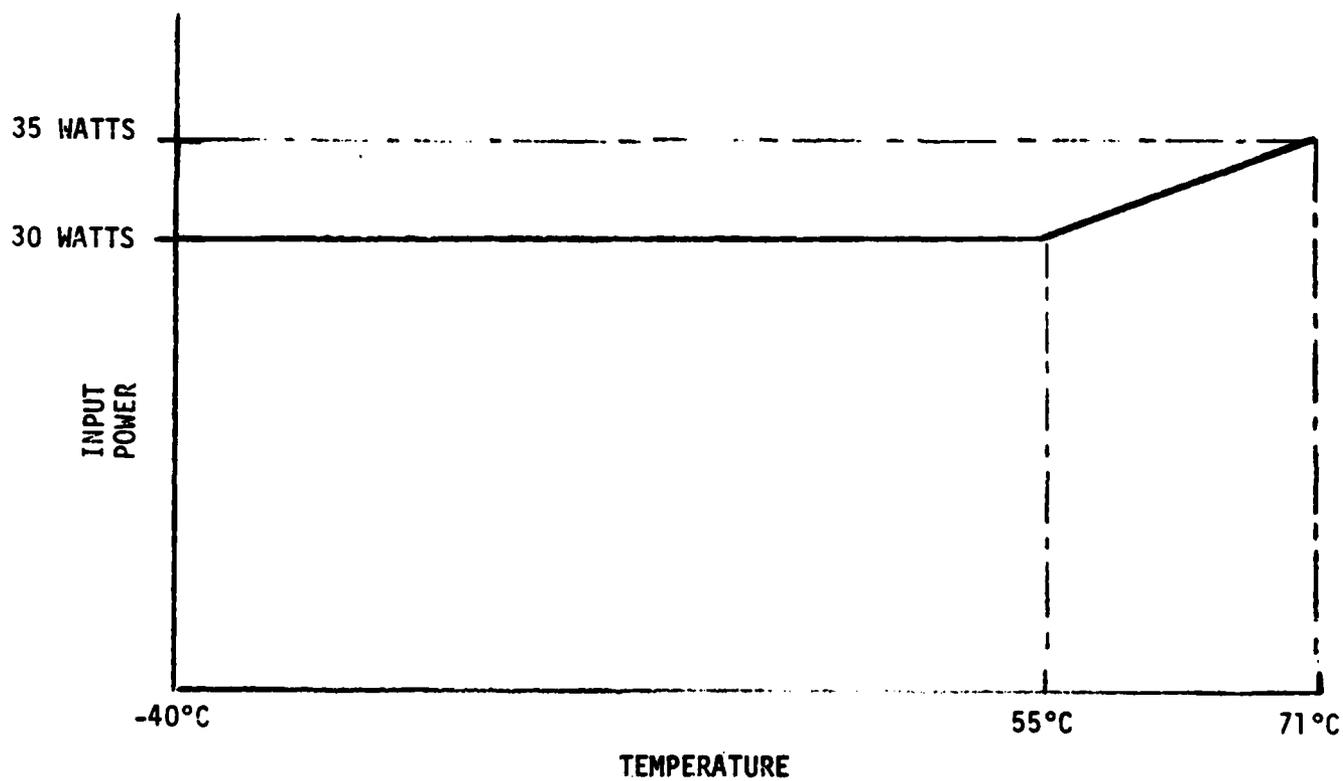


FIGURE 8-3. INPUT POWER

8.4.3 Input Power

The maximum input power shall be as shown in Figure 8-3.

9.0 AUDIBLE NOISE TEST

9.1 Test Purpose

The audible noise test was performed to determine the sound pressure levels emitted from the units over various frequency bandwidths.

9.2 Test Requirement

The audible noise test was performed individually on unit S/N 001 and unit S/N 002. The test was performed in an anechoic chamber where the background noise level was at least 10 dB below the sound pressure levels measured. Maximum allowable sound pressure levels (in dB) can be found in Table 9-1 and Figure 9-1.

9.3 Test Procedure

9.3.1 Test Mounting.

Mounting of the units was accomplished by suspending the system centrally in the anechoic chamber. Soft rubber cords were affixed to the ceiling of the anechoic chamber and attached to each end of the compressor motor assembly and cold end assembly. The cold end was installed in an evacuated dewar to simulate in service conditions. Fabric tape was used to provide additional rigidity to the system and to prevent excessive cold end vibration during the test.

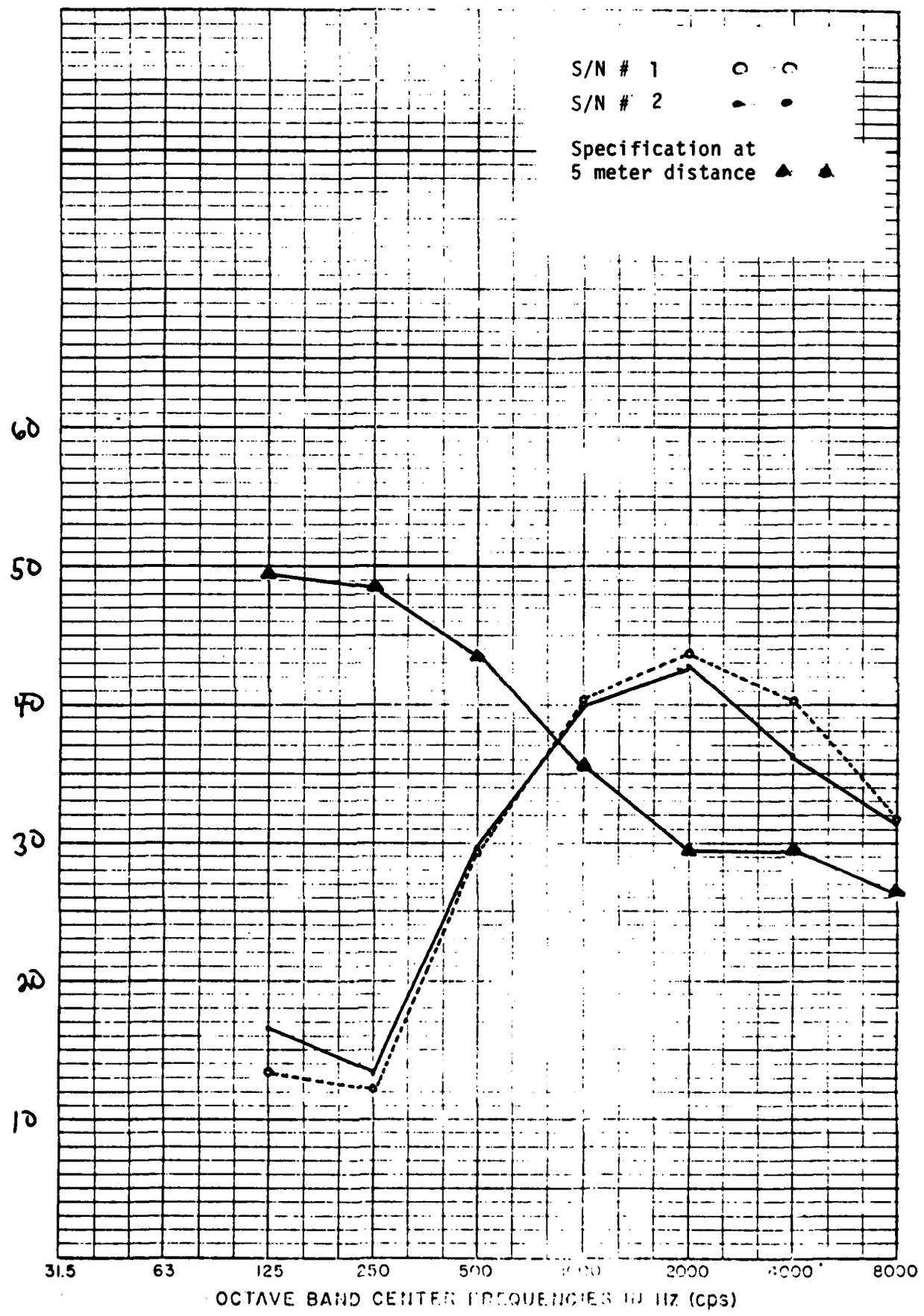
9.3.2 Test Data.

Test data was obtained using an octave band analyzer which complied with ANSI S1.11. The unit was energized to 17.5 ± 0.5 VDC. Using a hand held octave band analyzer, the unit was surveyed to determine the level of maximum noise generation. The microphone was placed at a constant linear distance from the unit in each direction of two principal mutually perpendicular axes. The measured data was recorded in 7 octave band intervals beginning at 125 Hz and ending at 8 KHz. The data points on Figure 9-1 are the results of power averaging the measurements recorded in each axis at each octave interval.

9.4 Acceptance Criteria

Results obtained were tabulated and plotted against the requirements to determine conformance to the criteria established in Table 9-1 and Figure 9-1.

OCTAVE BAND SOUND PRESSURE LEVEL IN dB RE 0.0002 MICROBAR AT 5 METERS



OCTAVE BAND CENTER FREQUENCIES IN HZ (cps)

SOUND PRESSURE LEVEL OF 1/4 WATT COOLERS

4/13/83 FNS

9.5 Audible Noise Test Results

As shown in Figure 9-1 and Table 9-1, both cooler S/N 001 and S/N 002 did not meet the criteria for the sound pressure level (SPL) at 5 meters distance in the one-thousand (1K) to eight-thousand (8K) Hertz frequency band.

<u>Center Freq.</u> <u>(Hz)</u>	<u>Octave Band</u> <u>(Hz)</u>	<u>Max. Allow. Sound</u> <u>Press. Level</u> <u>(dB)</u> <u>(Ref. 0.0002 Microbar)</u>	<u>Calculated SPL</u> <u>(5 Meters)</u>	
			<u>S/N 1</u>	<u>S/N 2</u>
125	87 to 175	49.5	13.5	16.5
250	175 to 350	48.5	12.2	13.3
500	350 to 700	43.5	29.5	29.5
1000	700 to 1400	35.5	40.5	39.7
2000	1400 to 2800	29.5	43.5	42.5
4000	2800 to 5600	29.5	40.2	36.0
8000	5600 to 11200	26.5	31.7	31.5

TABLE 9-1

MAXIMUM SOUND PRESSURE LEVELS

10.0 HIGH TEMPERATURE TEST

10.1 Test Purpose

The high temperature test was performed to determine the resistance of the units to elevated temperatures that may be encountered during service life.

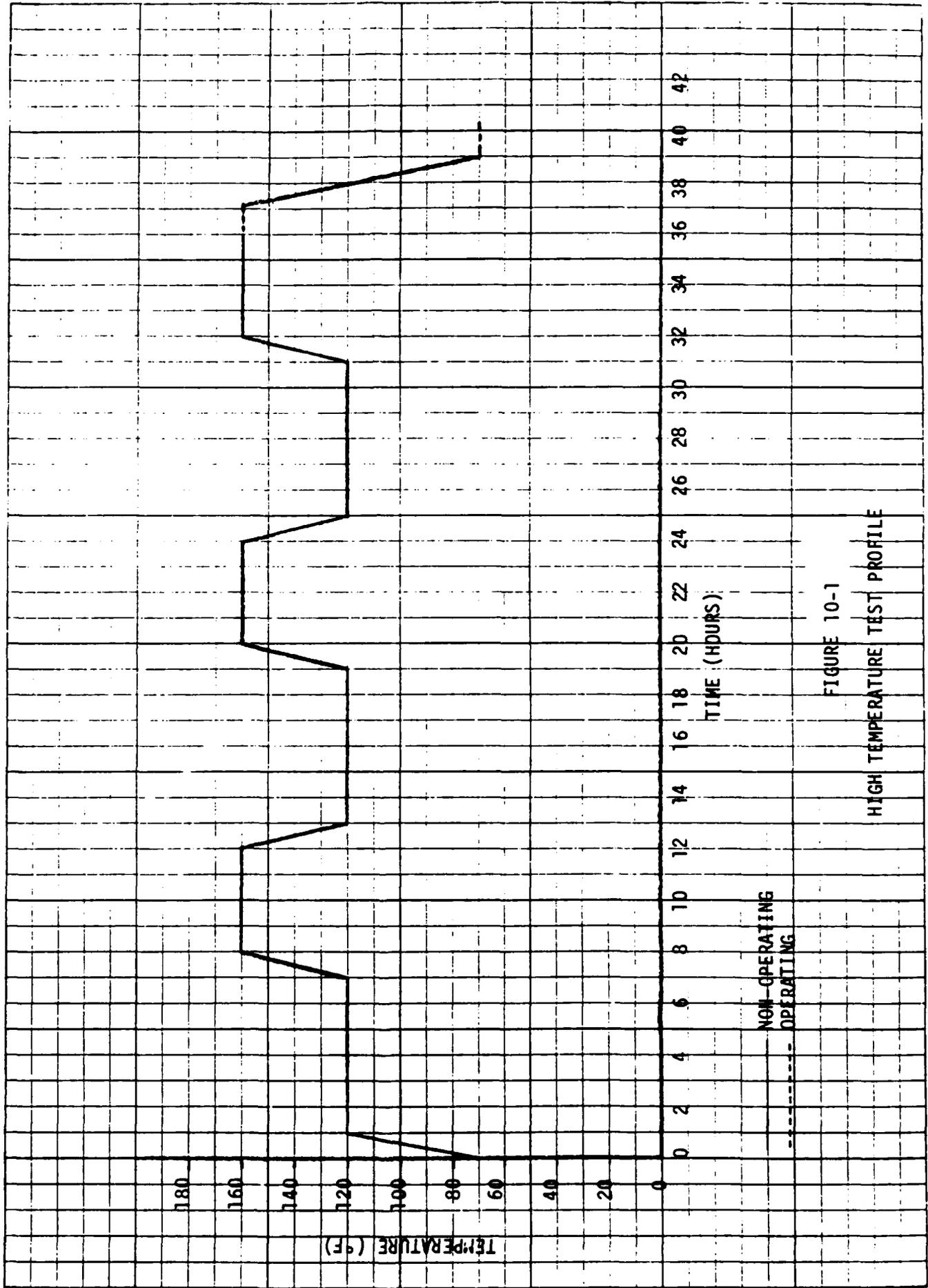
10.2 Test Requirement

The high temperature test was performed in accordance with MIL-STD-810C, Method 501.1, Procedure II as reflected below.

10.3 Test Procedure

Step 1: Install two (2) units, instrumented for operation, into a temperature chamber capable of achieving 160°F (71°C) minimum.

Step 2: Raise the test chamber ambient temperature to 120°F.



NON-OPERATING
OPERATING

FIGURE 10-1
HIGH TEMPERATURE TEST PROFILE

- Step 3: Allow the two (2) units to soak at 120 °F (49°C) for six hours.
- Step 4: Increase the test chamber ambient temperature to 160°F (71°C) within one (1) hour.
- Step 5: Allow the two (2) units to soak at 160°F (71°C) for an additional four (4) hours.
- Step 6: Lower the test chamber ambient temperature to 120°F (49°C) within one (1) hour.
- Step 7: Repeat steps 3, 4, 5, and 6.
- Step 8: Repeat steps 3, 4, and 5 making a total of three (3) 12-hour cycles (see high temperature test profile, Figure 10-1 attached).
- Step 9: Perform the operational test per Paragraph 8.0 as described herein.
- Step 10: Lower the temperature in the test chamber to allow the units (non-operating) to return to standard room ambient conditions.
- Step 11: Perform the operational test per Paragraph 8.0 as described herein. Visually inspect the units for any evidence of mechanical damage or deterioration as a result of this test. Record any abnormal findings on the applicable data summary sheet.

Performance of the above eleven (11) steps concluded the high temperature test.

10.4 Acceptance Criteria

The acceptance criteria was that listed in Paragraph 8.4.

10.5 High Temperature Test Results.

The units were exposed to the test outlined in Paragraph 10.3 . The post-test visual inspection revealed that there was no evidence of any mechanical damage or deterioration of the units as a result of this test. The units met or exceeded the acceptance test criteria outlined in Paragraph 8.4.

<u>Unit S/N</u>	<u>Amb. Temp. (°C)</u>	<u>Cooldown Time To 85K or Less (Minutes)</u>	<u>Cold Tip Temp. Applied Heat Load (K)/(Watts)</u>	<u>Input Power (Watts)</u>
001	70	7'27"	72.5/.22	24.2
001	26	6'10"	70.0/.35	26.9
002	70	6'26"	64.7/.22	26.0
002	26	5'26"	66.9/.35	26.4

11.0 LOW TEMPERATURE TEST

11.1 Test Purpose

The low temperature test was performed to determine the effects of low temperatures that may be encountered during service life of the units.

11.2 Test Requirement

The low temperature test was performed in accordance with MIL-STD-810C, Method 502.1, Procedure I, as reflected in Figure 11-1 herein.

11.3 Test Procedure

- Step 1: Install two (2) units, instrumented for operation, into a temperature chamber capable of achieving -65°F (-54°C) minimum.
- Step 2: Lower the temperature in the test chamber to -65°F (-54°C). (Temperature reduction rate not to exceed 180°F/minute (100°C/min)).
- Step 3: After the units have reached stabilization, allow the systems to soak at -65°F (-54°C) for an additional 24 hours.
- Step 4: Upon completion of the 24 hour soak at -65°F (-54°C), visually inspect the units (as allowed through the test chamber viewing port) for any evidence of mechanical damage or deterioration as a result of this portion of the low temperature test. Record any abnormal findings on the applicable operational test data summary sheet.
- Step 5: Raise the temperature in the test chamber to -40°F (-40°C) and allow the units to stabilize.
- Step 6: Perform the operational test per Paragraph 8.0 of the test plan.

Step 7: Raise the temperature in the test chamber to allow the units (non-operating) to return to standard room ambient conditions.

Step 8: Perform the operational test per Paragraph 8.0 of the test plan. Visually inspect the units for any evidence of mechanical damage or deterioration as a result of this test. Record any abnormal findings on the test data summary sheet.

Performance of the above eight (8) steps concluded the low temperature test.

11.4 Acceptance Criteria

The acceptance criteria was that listed in Paragraph 8.4.

11.5 Low Temperature Results

The units were exposed to the test outlined in Paragraph 11.3. The post-test visual inspection revealed that there was no evidence of any mechanical damage or deterioration of the units as a result of this test. The units met or exceeded the acceptance test criteria outlined in Paragraph 8.4 above.

<u>Unit S/N</u>	<u>Amb. Temp. (°C)</u>	<u>Cooldown Time To 85K or Less (Minutes)</u>	<u>Cold Tip Temp. Applied Heat Load (K)/(Watts)</u>	<u>Input Power (Watts)</u>
001	-38.2	4'34"	57.5/.20	25.8
001	24.9	5'45"	69.1/.35	26.7
002	-38.2	4'34"	59.3/.20	27.1
002	24.9	5'07"	68.8/.35	26.7

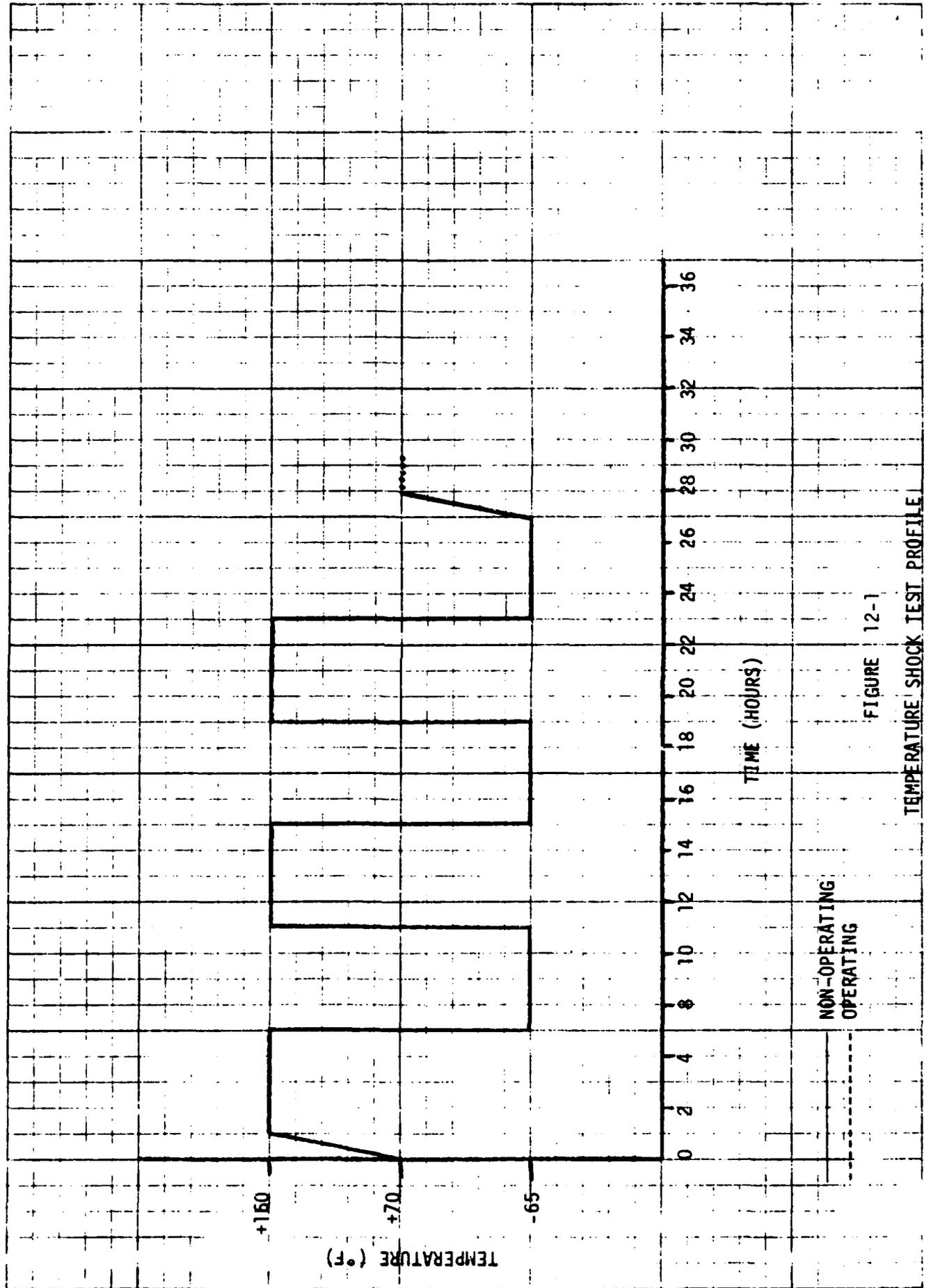
12.0 TEMPERATURE SHOCK TEST

12.1 Test Purpose

The temperature shock test was conducted to determine the effect on the units of sudden changes in temperature of the surrounding atmosphere.

12.2 Test Requirement

The temperature shock test was performed in accordance with MIL-STD-810C, Method 503.1, Procedure I, with the exception that the temperature extremes were limited to +160°F (71°C) and -65°F (-54°C). See Figure 12-1 for temperature shock test profile.



12.3 Test Procedure

- Step 1: Install two (2) units (non-operating) into a temperature chamber capable of achieving 160°F (71°C) minimum.
- Step 2: Raise the test chamber temperature to 160°F (71°C) and allow the units to soak at this temperature for four (4) hours minimum or until the units stabilize.
- Step 3: After four (4) hours minimum exposure to the high ambient soak, move (within 5 minutes) the systems into a test chamber with an ambient temperature of -65°F (-54°C). Allow the units to soak at this temperature for four (4) hours minimum or until the units stabilize.
- Step 4: After four (4) hours minimum exposure to the low ambient soak, return (within 5 minutes) the units to the test chamber set at 160°F (71°C). Allow the units to soak at this temperature for four (4) hours minimum or until the units stabilize.
- Step 5: Repeat Step 3.
- Step 6: Repeat Step 4.
- Step 7: Repeat Step 3.
- Step 8: Remove the units from the low temperature test chamber and allow them to stabilize at standard room ambient conditions.
- Step 9: Visually inspect the units for any evidence of mechanical damage or deterioration as a result of this test. Record any abnormal findings on the applicable test data summary sheet. Instrument the two (2) units for operation. Perform the operational test described in Paragraph 8.0 of the test plan.

12.4 Acceptance Criteria

The acceptance criteria was that listed in Paragraph 8.4 above.

12.5 Temperature Shock Test Results

The units were exposed to the test outlined in Paragraph 12.3 above. The post-test visual inspection revealed that there was no evidence of any mechanical damage or deterioration of the units as a result of this test. The units met or exceeded the acceptance test criteria outlined in Paragraph 8.4.

<u>Unit S/N</u>	<u>Amb. Temp. (°C)</u>	<u>Cooldown Time To 85K or Less (Minutes)</u>	<u>Cold Tip Temp. Applied Heat Load (K)/(Watts)</u>	<u>Input Power (Watts)</u>
001	22	5'52"	69.9/.36	26.9
002	22	5'14"	68.3/.35	26.6

13.0 VIBRATION TEST

13.1 Test Purpose

The vibration test was performed to determine if the unit's design would withstand the expected dynamic vibrational stresses and to insure that performance degradation or malfunction will not be produced by the service vibration environment.

13.2 Test Requirement

The vibration test was performed in accordance with MIL-STD-810C, Method 514.2, Procedure VIII, Equipment Category F (see Figure 13-1) with the exception that the input vibration levels were those listed in the U.S. Army Development Specification B2-28A050122A entitled "Development Specification for Cooler, Cryogenic, Split-Stirling HD-1045(V)/UA", dated 18 June 1982. (See Figure 13-1 attached.)

The vibration test was performed with the units in their operating, steady-state mode (as described in Step 3 below). The vibration was applied in each of three (3) mutually perpendicular axes of the cryocooler assemblies (see Figure 13-2 for axis identification).

Test set-up is shown on Figure 13-3.

13.3 Vibration Test Levels

13.3.1 Sinusoidal Cycling

The applicable test times and test levels were as follows:

Sinusoidal Sweep Time:	15 minutes
Swept Frequencies:	5-500-5 Hz
Cycle Time:	120 minutes/axis

<u>Frequency</u>	<u>Test Level</u>
5 Hz - 14 Hz @	0.4" DA*
14 Hz - 47 Hz @	4.0 g's
47 Hz - 52 Hz @	.036" DA
52 Hz - 500 Hz @	5.0 g's

*Reduced due to limited shaker table capabilities at the low end of the vibration test curve.

LOUIS BRUTE COMPANY, INC. NORWOOD, MASSACHUSETTS
MADE IN U.S.A.

NO. 31 888. LOGARITHMIC THREE BY THREE 2 1/2 INCH CYCLES (BASE SHORT WAY).
MADE IN U.S.A.

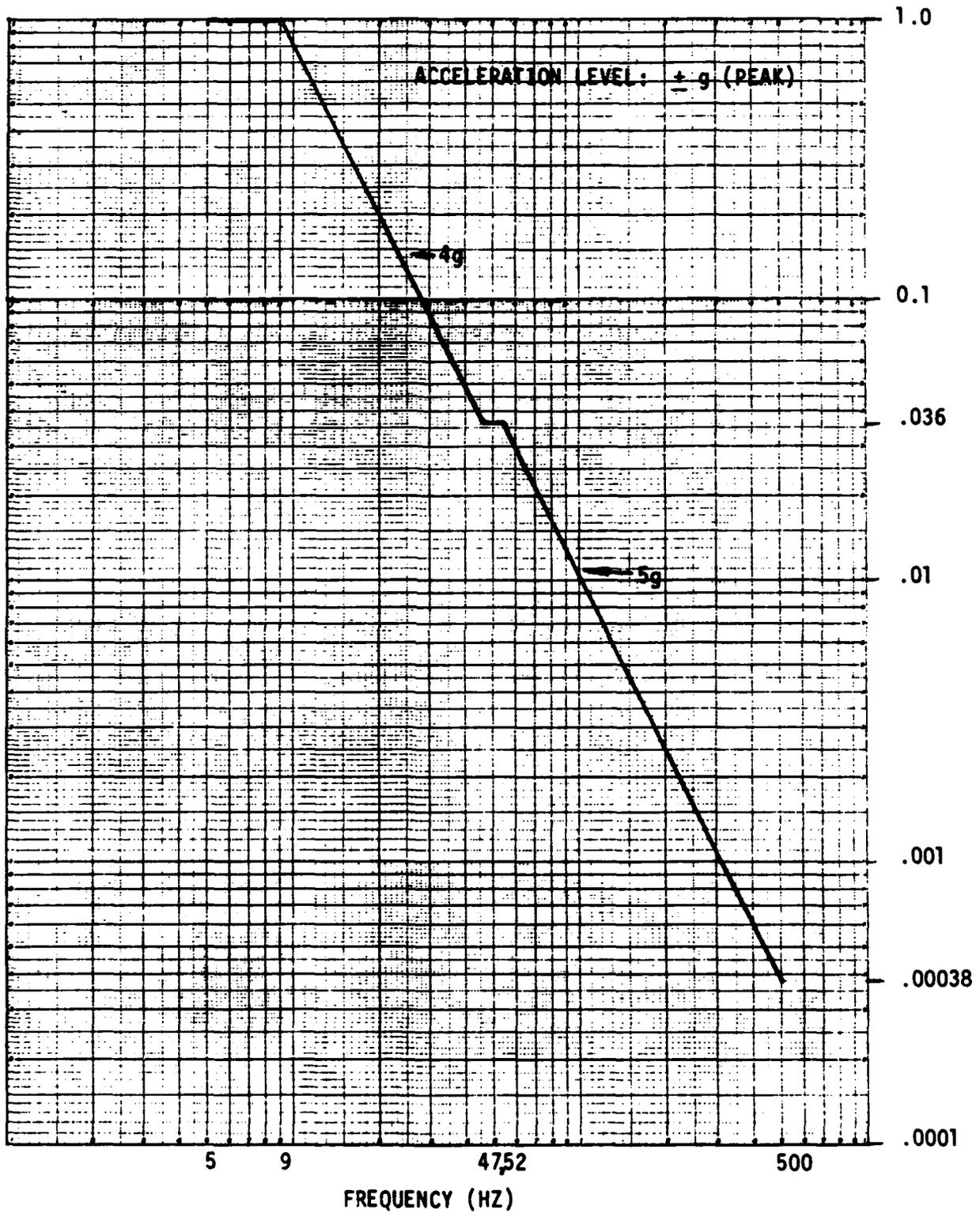


FIGURE 13-1 VIBRATION TEST PROFILE

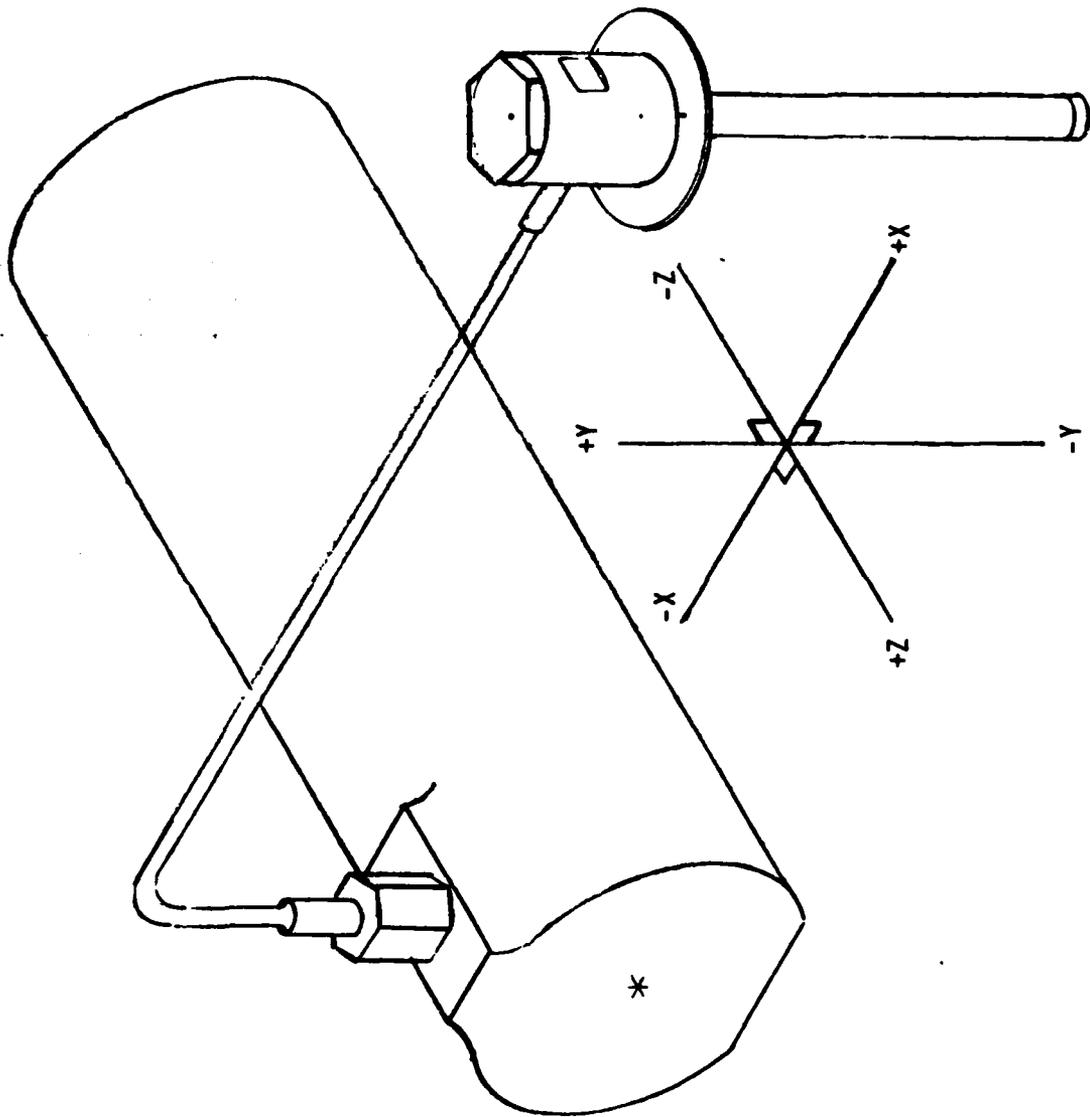
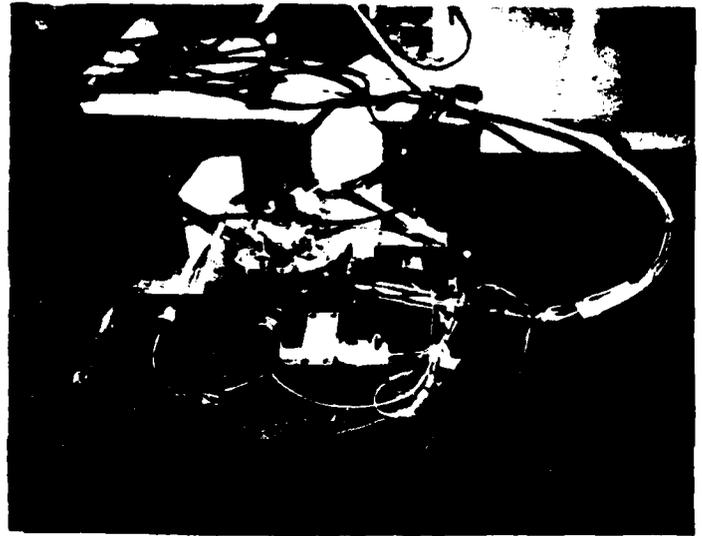


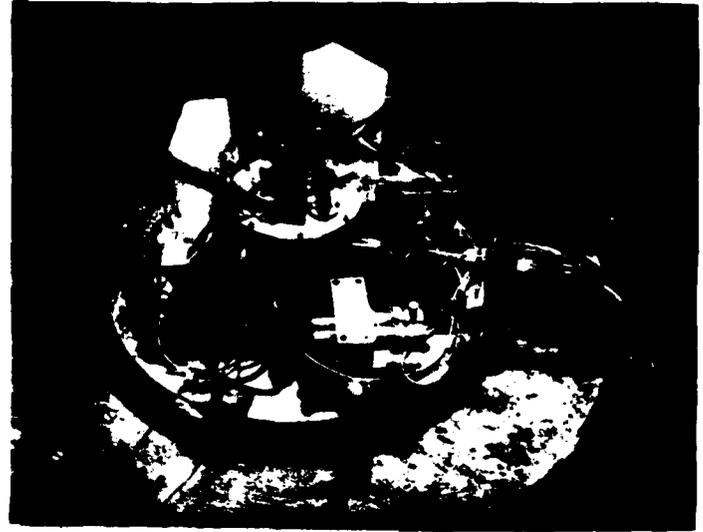
FIGURE 13-2
CRYOCOOLER ASSEMBLY AXIS DEFINITION

VIBRATION TEST SET-UP

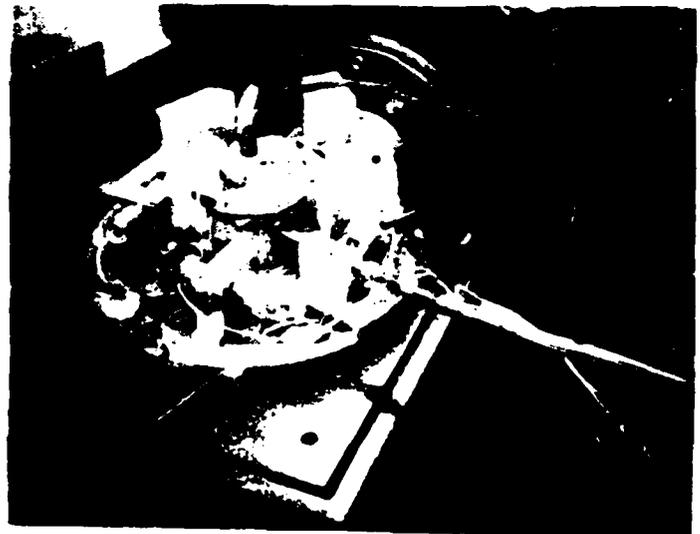
AXIS: X-AXIS



AXIS: Y-AXIS



AXIS: Z-AXIS



13.3.2 Resonance Dwell

A resonance search was performed during the first sinusoidal sweep. If more than four (4) significant resonant frequencies were found, the four (4) most severe resonant frequencies would have been chosen for the dwell test. A resonance is defined as any vibratory output which is two (2) times that of the input vibration level.

The entire cycle time (120 minutes) was reduced by 1/6 (20 minutes) for each resonance dwell test performed.

13.4 Test Procedure

- Step 1: Install two (2) units, instrumented for operation, into the vibration test fixture.
- Step 2: Mount the vibration test fixture to the moving element of the vibration table so that the input from the vibration table coincides with "X" axis of the units.
- Step 3: Perform the operational test as described in Paragraph 8.0 of the test plan . Allow the units to continue operating during the entire vibration test cycle with .35 +.03, -.00 watt heat load applied.
- Step 4: Once the units have achieved a steady-state cold tip temperature, perform the sinusoidal vibration test per Paragraph 13.3.1 and resonance dwell as required per Paragraph 13.3.2 of the test procedure.
- Step 5: Repeat Steps 2, 3, and 4 except the vibratory input shall be along the "Y" axis of the units.
- Step 6: Repeat Steps 2, 3, and 4 except the vibratory input shall be along the "Z" axis.
- Step 7: With the vibration testing completed, perform the operational test as outlined in Paragraph 8.0 of the test plan at room ambient conditions.

13.5 Acceptance Criteria

The acceptance criteria was that listed in Paragraph 8.4 above.

13.6 Vibration Test Results

The units were exposed to the test outlined in Paragraph 13.3 above. The post test visual inspection revealed that there was no evidence of mechanical damage or deterioration of the units as a result of this test. The units met or exceeded the acceptance tests criteria outlined in Paragraph 8.4.

No resonant frequencies were noted in either the "Y" or the "Z" axes. A resonance was found in the "X" axis at 450 Hertz. The resonance dwell test was performed as described in Paragraph 13.3.2 above with no detrimental effects.

<u>Unit S/N</u>	<u>Amb. Temp. (°C)</u>	<u>Cooldown Time To 85K or Less (Minutes)</u>	<u>Cold Tip Temp. Applied Heat Load (K)/(Watts)</u>	<u>Input Power (Watts)</u>
001				
X-AXIS	23.3	5'44"	65.8/.35	27.4
Y-AXIS	20.1	5'52"	67.8/.35	26.5
Z-AXIS	20.7	5'57"	69.3/.35	26.3
002				
X-AXIS	23.3	4'56"	69.5/.35	26.9
Y-AXIS	20.1	5'27"	71.7/.35	27.1
Z-AXIS	20.7	5'19"	67.5/.35	27.1
POST VIB.				
001	24.5	5'52"	67.7/.35	26.2
002	24.5	5'13"	71.4/.35	26.8

Test certificates as well as control and monitoring accelerometer input/outputs can be found in the enclosed appendix.

14.0 MECHANICAL SHOCK TEST

14.1 Test Purpose

The mechanical shock test was performed to determine if the units are constructed to withstand the expected dynamic shock stresses without performance degradation or malfunction from exposure to the expected service shock environment.

14.2 Test Requirement

The mechanical shock test was performed in accordance with MIL-STD-810C, Method 516.2, Procedure IV, High Intensity Test, except units were not operated during exposure to the shock pulses described below. The test set-up is shown in Figure 14-2.

14.3 Test Procedure

- Step 1: Install two (2) dummy loads onto the shock test fixture to simulate the expected mass that will be encountered when the actual units are installed onto the test fixture.
- Step 2: Attach the test fixture/dummy load to the moving element of the shock test machine.

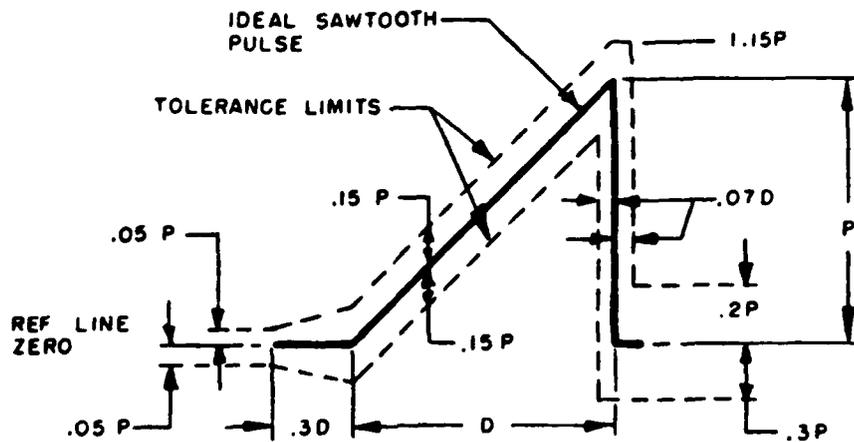


Figure 14-1

TERMINAL-PEAK SAWTOOTH SHOCK PULSE CONFIGURATION
AND ITS TOLERANCE LIMITS

TEST	PEAK VALUE (P) g's	NOMINAL DURATION (D) MS
HIGH INTENSITY SHOCK	100	11

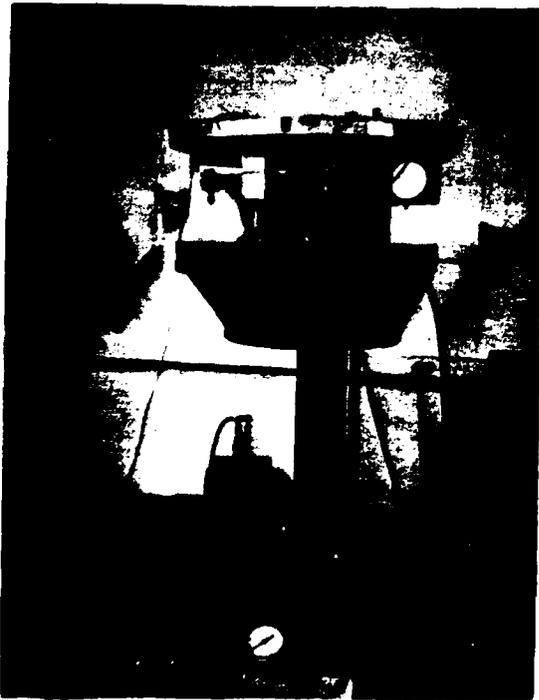
MECHANICAL SHOCK TEST SET-UP



AXIS: +X



AXIS: -Z



AXIS: -Y

FIGURE 14-2

- Step 3: Calibrate the shock test machine to assure conformance to the specified waveform (see Figure 14-1). Two consecutive shock applications to the dummy loads shall fall within the specified tolerance envelope shown in Figure 14-1 prior to installation of the actual units.
- Step 4: After the shock test machine has been successfully calibrated for conformance to the applicable waveform, the units shall then be installed into the test fixture for the dummy loads.
- Step 5: Apply two (2) shocks in each direction of three mutually perpendicular axes for a total of twelve (12) shock pulses. Axis identification is shown in Figure 13-2.
- Step 6: Upon completion of the shock test as described above, the operational test described in Paragraph 8.0 of the test plan was performed at room ambient conditions. The units were also visually inspected for any evidence of mechanical damage or deterioration as a result of this test. Any abnormal findings were recorded on the applicable test data summary sheet.

14.4 Acceptance Criteria

The acceptance criteria was that listed in Paragraph 8.4 above.

14.5 Mechanical Shock Test Results

The units were exposed to the test outlined in Paragraph 14.3 above. The calibration shock pulse (Figure 14-3) and a representative sample of the applied shock pulses may be found in Figures 14-4 through 14-6. The post-test visual inspection revealed that there was no evidence of any mechanical damage or deterioration of the units as a result of this test. The units met or exceeded the acceptance test criteria outlined in Paragraph 8.4.

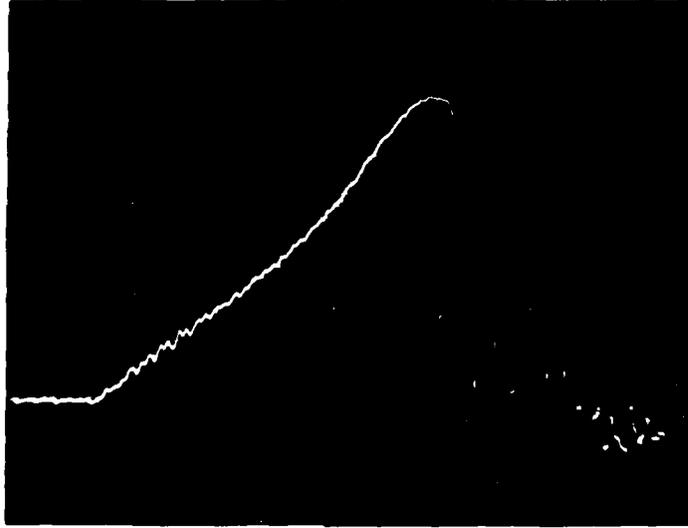
<u>Unit S/N</u>	<u>Amb. Temp. (°C)</u>	<u>Cooldown Time To 85K or Less (Minutes)</u>	<u>Cold Tip Temp. Applied Heat Load (K)/(Watts)</u>	<u>Input Power (Watts)</u>
001	27	6'07"	66.1/.35	26.7
002	27	5'39"	71.5/.35	26.4

15.0 RELIABILITY DEMONSTRATION TEST

The reliability demonstration test was conducted in accordance with the parameters listed below:

- o Temperature: -40°C to +71°C
- o Temperature cycling: as depicted in Figure 15.1
- o Equipment on/off cycling: as depicted in Figure 15.1

MECHANICAL SHOCK TEST



CALIBRATION SHOCK PULSE
100 G's/11 ms

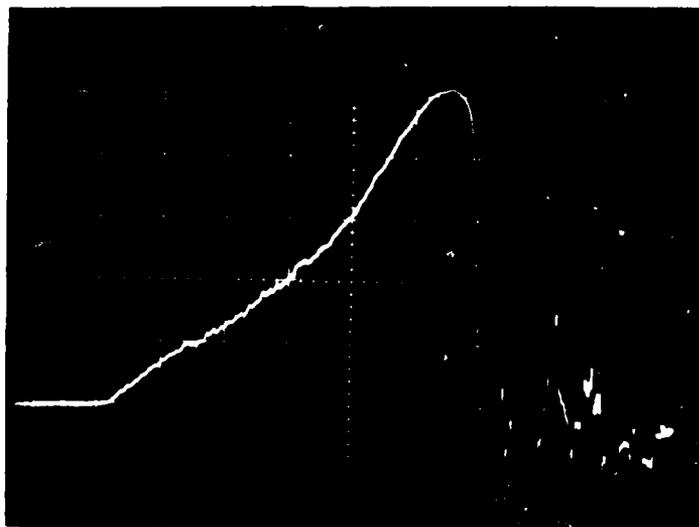
FIGURE 14-3

APPLIED SHOCK PULSE



AXIS: +X

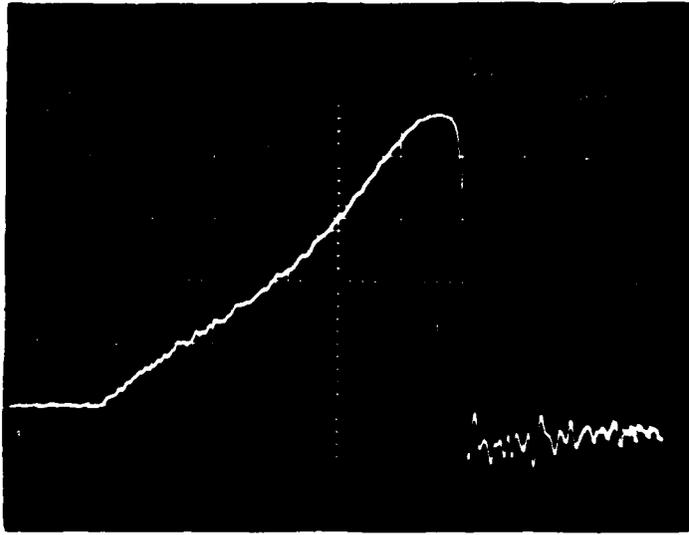
APPLIED SHOCK PULSE



AXIS: -X

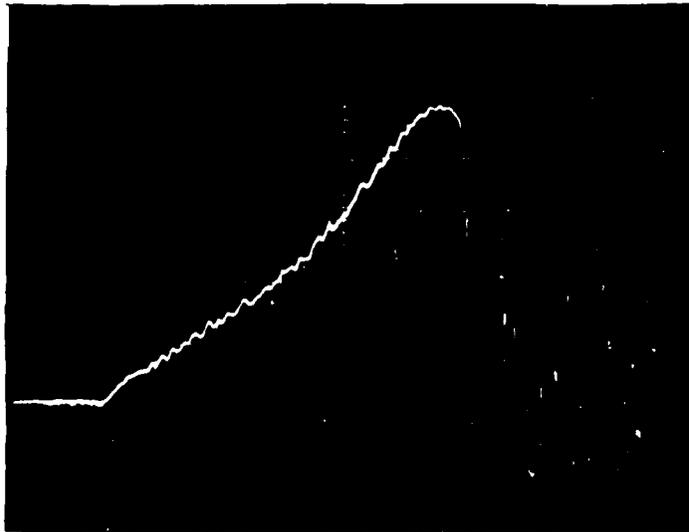
FIGURE 14-4

APPLIED SHOCK PULSE



AXIS: +Y

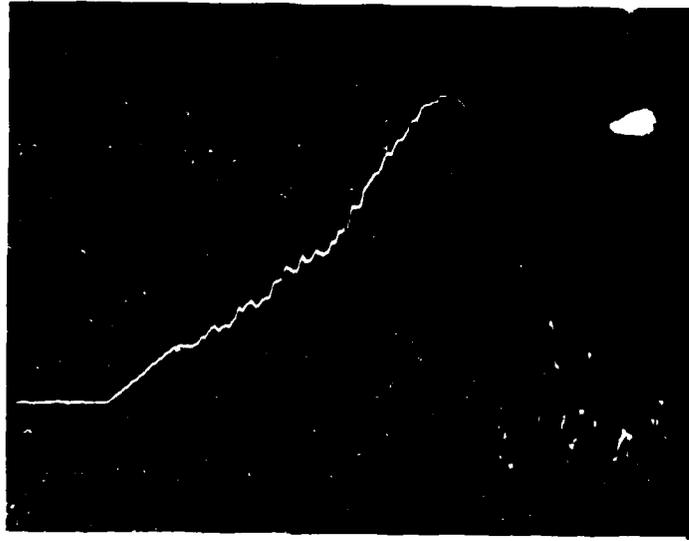
APPLIED SHOCK PULSE



AXIS: -Y

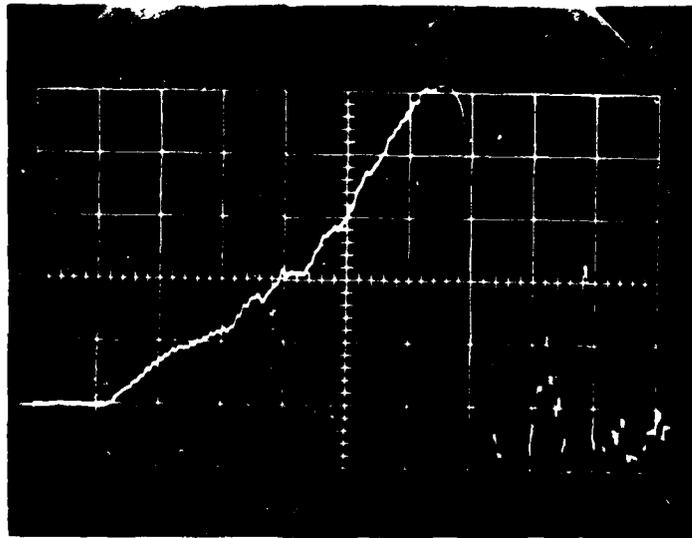
FIGURE 14-5

APPLIED SHOCK PULSE



AXIS: +Z

APPLIED SHOCK PULSE



AXIS: -Z

FIGURE 14-6

15.1 Reliability Test Concept

CTI-CRYOGENICS conducted the reliability tests using AGREE-TYPE environmental test equipment. The equipment was comprised of three (3) major elements:

- o An automatically controlled high/low temperature chamber.
- o A microprocessor which was programmed to automatically cycle the temperature chamber through the required temperature profile while operating the systems at the required ambient temperatures.
- o An automated data logger which sensed, processed, and recorded the data required.

15.1.1 Test Equipment The test equipment required for the reliability demonstration test is listed in Table 15-1. The function of each item is also included. Equipment substitution was made (as required) only upon the approval of the Project Engineer. Figure 15-3 shows the test equipment used.

TABLE 15-1

TEST EQUIPMENT LIST

<u>ITEM</u>	<u>DESCRIPTION</u>	<u>MANUFACTURE/MODEL NO.</u>	<u>FUNCTION</u>
1	Environmental Chamber	Assoc. Envir. Systems #SK-3108	Temperature cycle the equipment.
2	Vacuum Supply	CTI-CRYOGENICS CRYO-TORR ^R 8	Provides clean vacuum for test dewar.
3	Ionization Gauge	Veeco #RG-75K	Senses vacuum in test dewar.
4	Vacuum Gauge Sensor	Varian #841	Conditions signal from ionization gauge and converts signal to digital readout of vacuum level.
5	Microprocessor	Micro-Pro #1000	Controls temperature cycling in chamber and unit operating status during test cycle.

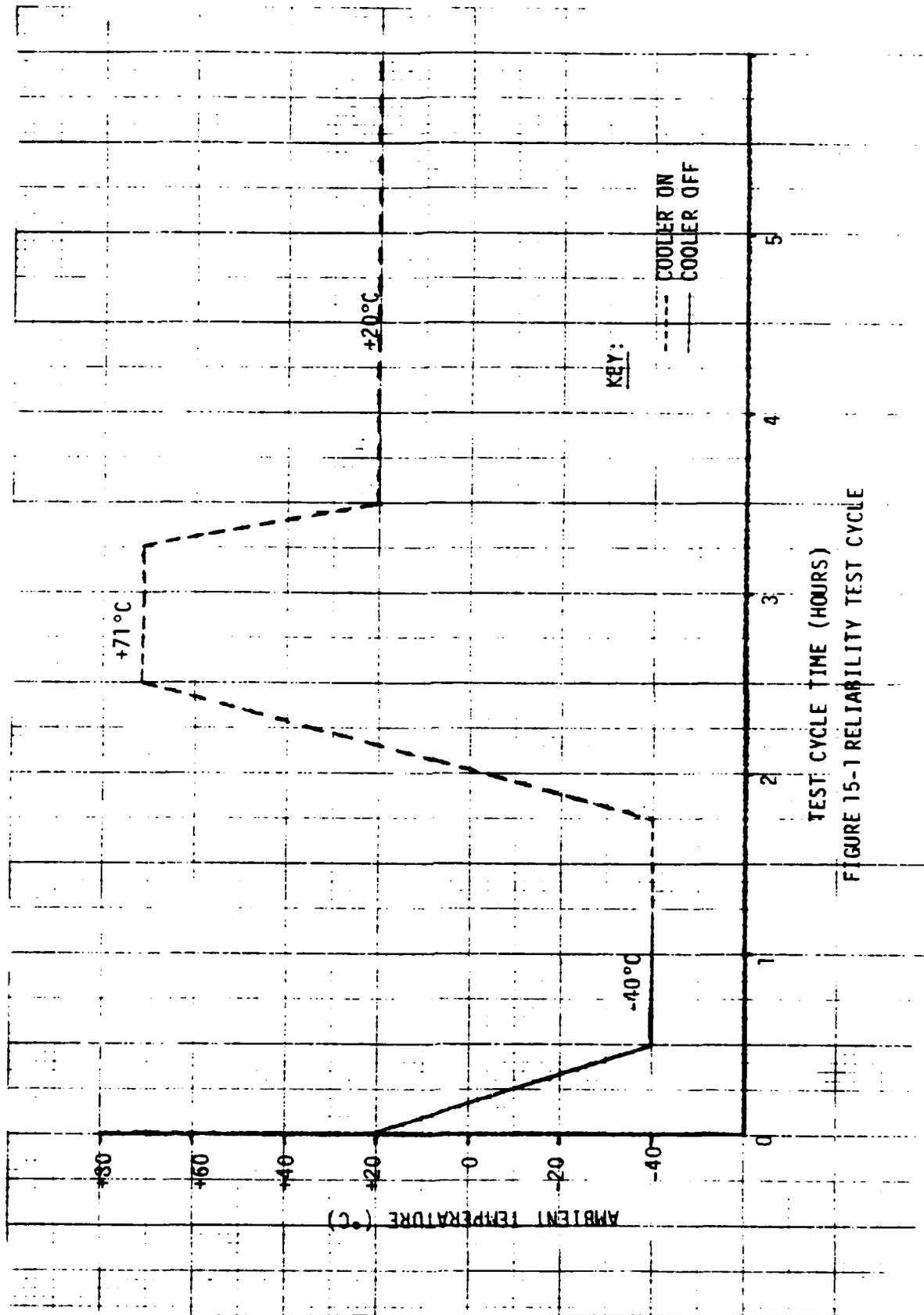


FIGURE 15-1 RELIABILITY TEST CYCLE

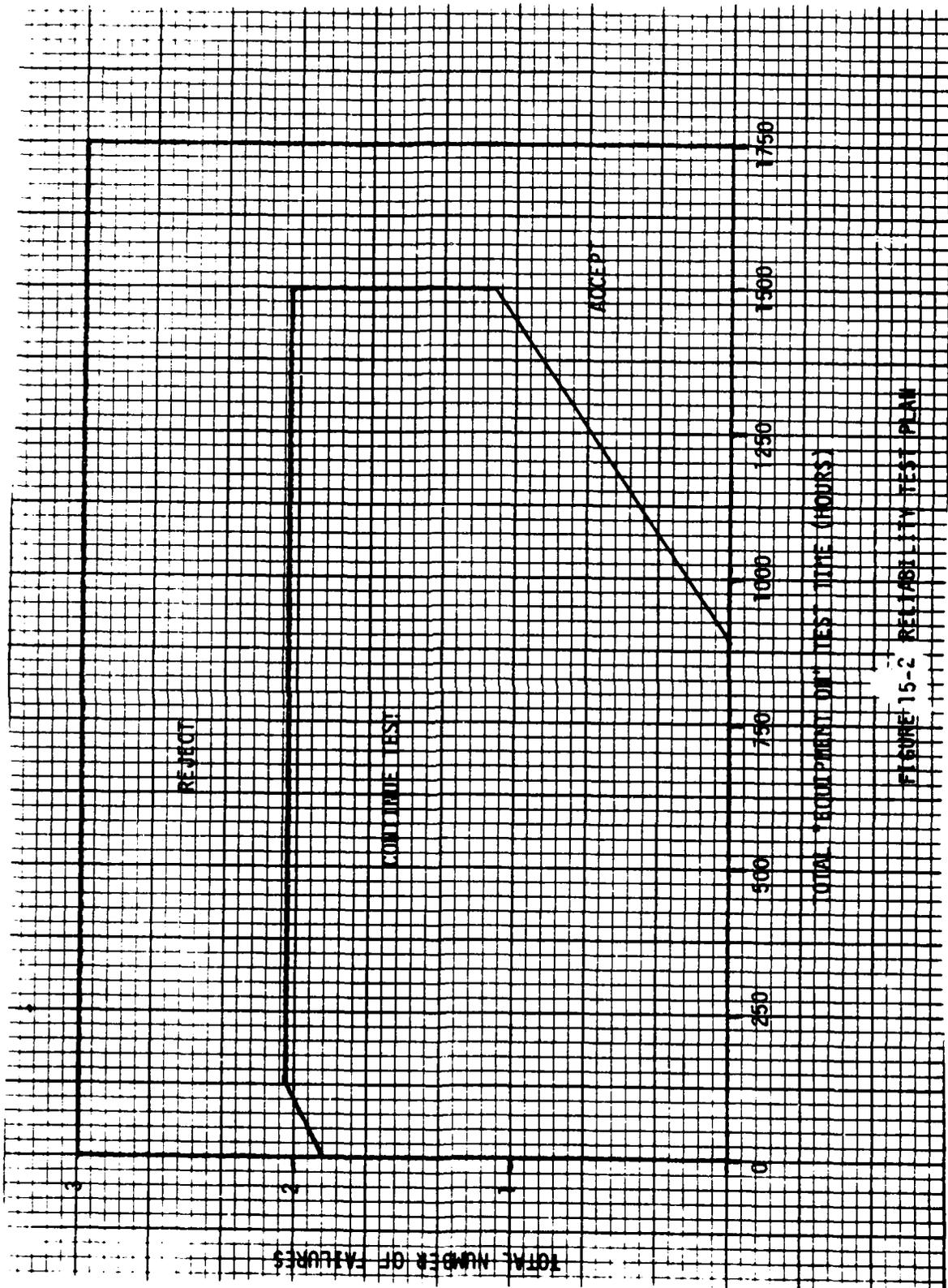
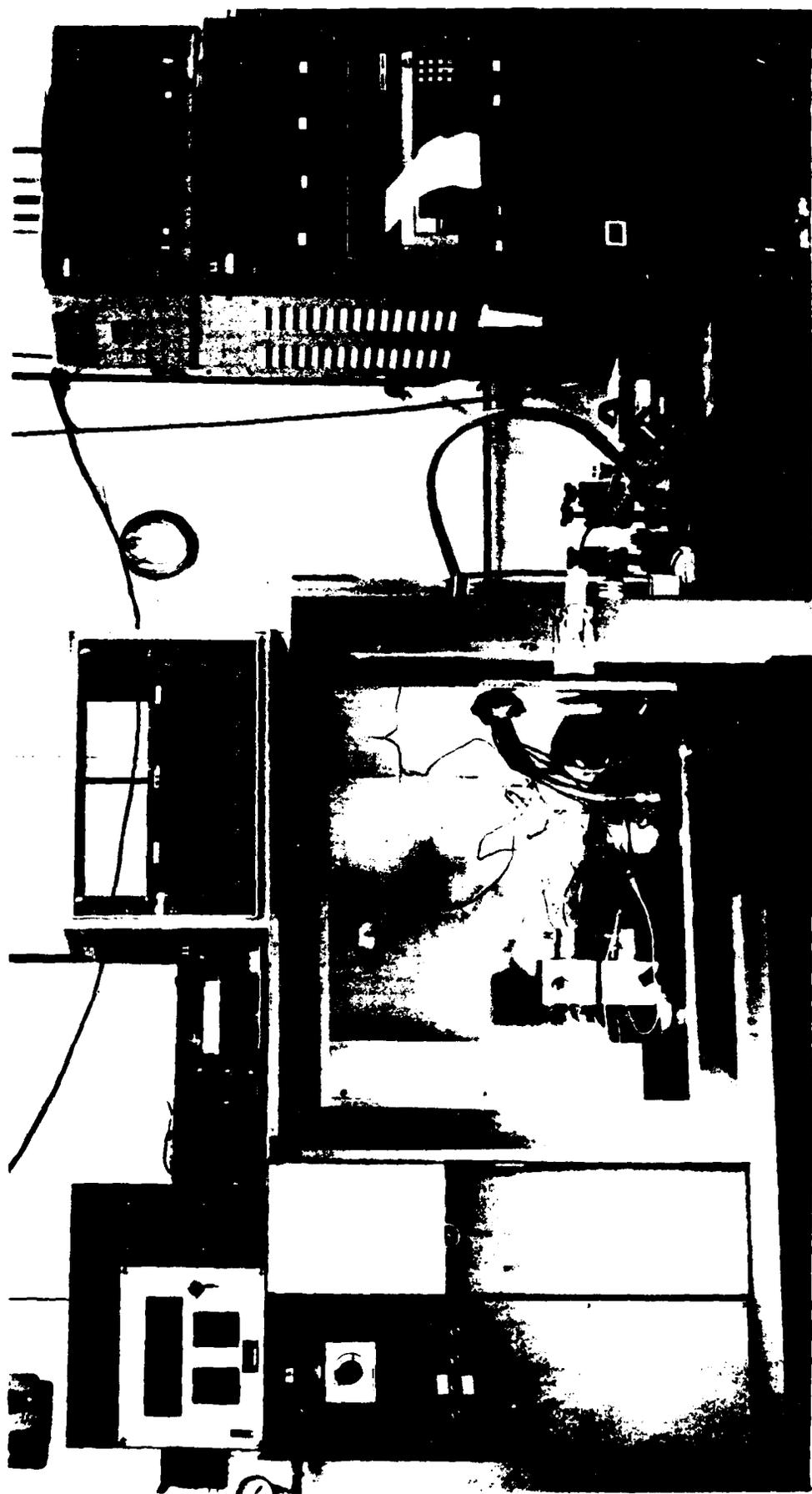


FIGURE 15-2 RELIABILITY TEST PLAN

SIZE A	FSCM NO. 31949	DWG NO.	REV.
SCALE		SHEET	



RELIABILITY DEMONSTRATION TEST
TEST EQUIPMENT

FIGURE 15-3

6	Data Logger	Esterline-Angus #8D-2064	32 Channel Data Acquisition System: <ol style="list-style-type: none"> 1. Conditions and records data from thermocouples. 2. Records cold end heater powers. 3. Records cold end and compressor housing temperatures. 4. Establishes alarm channels and initiates appropriate action in the event of an alarm condition. 5. Records time and date of all data taken. 6. Records time, date and a complete data scan whenever an alarm condition exists.
7	Silicon Diode Temperature Sensor	Laser Analytics #ST14	Measures cold finger temperature of each system.
8	Heater/Diode Power Supply	CTI-CRYOGENICS	Provides adjustable power outputs to each cold end heater.
9	DC Power Supply	CTI-CRYOGENICS	Provides DC power for each system under test. Provides for voltage, current and power monitoring.
10	Chart Recorder	Esterline-Angus #MS-411B	Provides continuous monitoring of cold end temperature of units on test.

15.2 Test Plan Summary

The reliability test was conducted in accordance with Test Plan IVA of MIL-STD-781B. Table 15-2 quantifies the test plan and Figure 15-2 depicts the actual test plan.

TABLE 15-2

SUMMARY OF TEST PLAN

Decision Risks:

Producers decision risk: Alpha = 20%
Consumers decision risk: Beta = 20%
Discrimination Ratio (D.R.) = 3:1
 θ_1 = minimum acceptable MTBF = 333.3 hours
 θ_0 = specified MTBF = (D.R. x θ_1) = 1000 hours
Minimum 0.89 (θ_0) = 890 hours
Expected 1.14 (θ_0) = 1,140 hours
Maximum 1.50 (θ_0) = 1,500 hours

15.3 Reliability Test Compliance

Determination of compliance was in accordance with Paragraphs 5.4.8.1 through 5.4.8.4 of MIL-STD-781B. Failure actions complied with Paragraph 5.5 of the same specification.

15.3.1 Acceptance Criteria During Reliability Testing

15.3.1.1 Cooldown Time

The cooldown time to reach a cold tip temperature of 100K and 85K with a 1.8 gram minimum copper mass shall be less than 7.5 minutes and 10 minutes, respectively over the temperature range of -40°C to +71°C.

15.3.1.2 Cooling Capacity

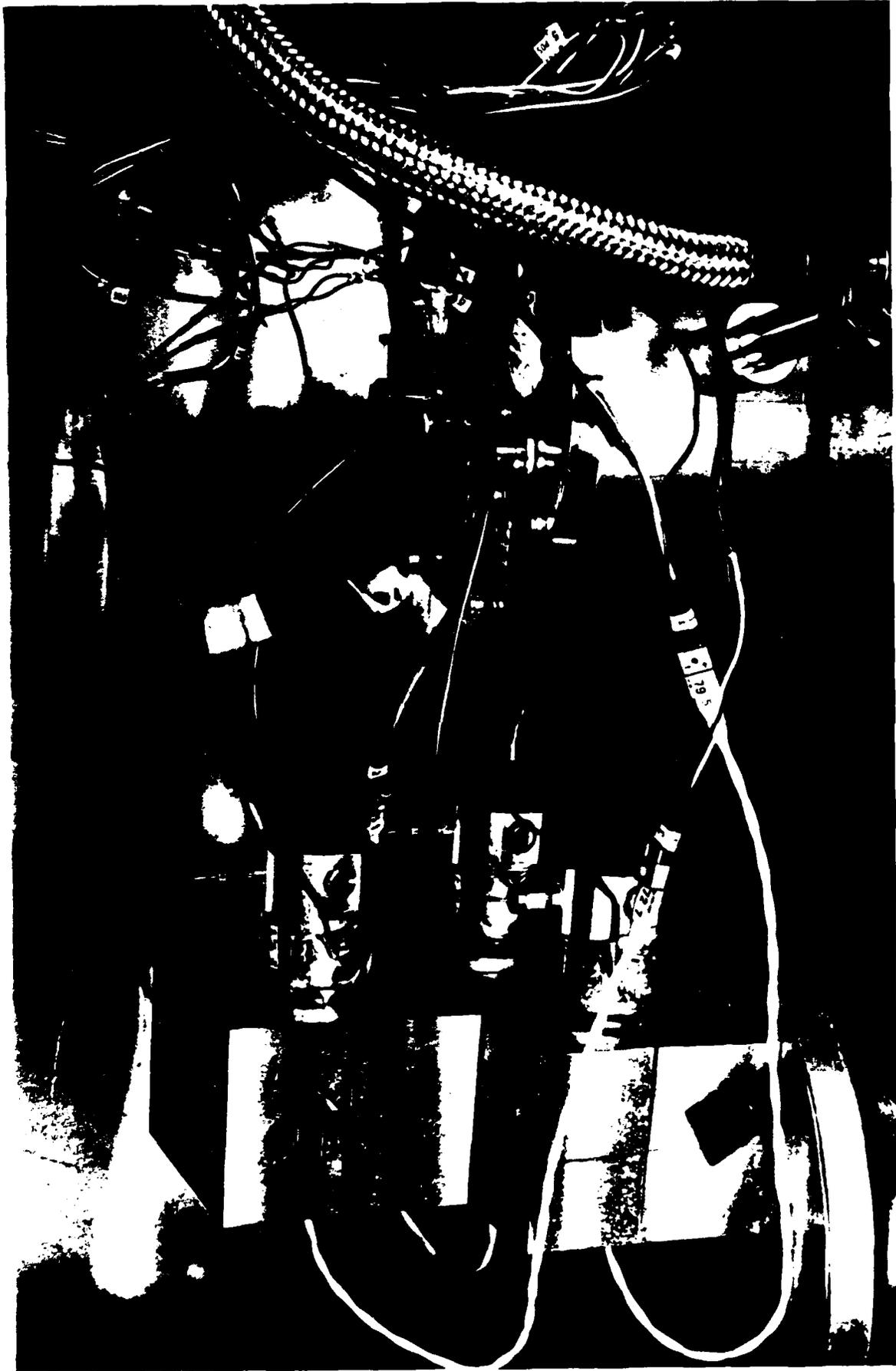
The units shall provide the minimum cooling capacity at 85K as shown in Figure 8-2, across the ambient temperature range of -40°C to +71°C.

15.3.1.3 Input Power

The maximum input power shall be as shown in Figure 8-3.

15.4 Reliability Demonstration Test

The reliability test consisted of instrumenting the units as required in Paragraph 7.4 to properly measure cooling capacity of the system. The following performance data was measured and recorded using a data logger preprogrammed to sense, process, and record the required data. The data recorded by the data logger was manually reduced and entered onto copies of the test data summary sheet (Figure 8-1). Data was recorded immediately prior to start-up and at one (1) hour time intervals minimum.



RELIABILITY DEMONSTRATION TEST
TEST SET-UP

FIGURE 15-4

- o Elapsed time from start-up, Min-Sec.
- o Test chamber ambient temperature, °F.
- o Compressor housing temperature, °F.
- o Cold finger tip temperature, Kelvin.
- o Applied heat load, Watts.
- o Applied voltage, VDC.
- o Input current, Amps.
- o Input power, Watts.
- o Test Dewar vacuum, Torr.

The cold finger tip temperature was continuously monitored on a strip chart recorder during the test.

A microprocessor was preprogrammed to control the operation of the units and test instrumentation through the test cycle as shown in Figure 15-1. Test set-up is shown in Figure 15-4.

15.5 Accept/Reject Decision

Success or failure of the reliability test was based on the total cooler "ON" time accumulated versus the number of relevant cooler failures as shown in Table 15-3.

TABLE 15-3
ACCEPT/REJECT LIMITS

Number of Failures	Accept if Total "ON" Time Accumulated is Equal to or Greater than		Reject if Total "ON" Time Accumulated is Equal to or Less Than
	Total (3) Units	Min (1) Unit	
0	890 hours	148 hours	N/A
1	1440 hours	240 hours	N/A
2	1500 hours	250 hours	120
3	N/A	N/A	1500

16.0 FAILURE CRITERIA

All failures related to the reliability testing were recorded. Each failure was categorized as either relevant or non-relevant, as defined below:

16.1 Relevant Failure Criteria

The inability of the units to meet the conditions described in Paragraph 15.3.1 above constituted a relevant failure.

16.2 Non-Relevant Failure Criteria

A failure of the test specimen caused by a condition external to the cooler under test which is not a test requirement and is not encountered in actual service was classified as non-relevant. These external conditions included human error, test equipment failures, test instrumentation failures and power failures.

The above failures were deemed non-relevant failures provided no permanent damage was sustained by the cooler. Should permanent damage occur, the relevancy of the failure was determined by the NV & EOL Program Manager.

17.0 RELIABILITY TEST RESULTS

Baseline testing for the reliability test began on May 3, 1983. Upon determination that the units provided acceptable refrigeration per the requirements outlined in the test plan, the units were submitted to the Burn-In test outlined in Paragraph 7.0. This test was performed on May 9, 1983. The results of this test were acceptable. (See baseline performance test results Paragraph 6.4 and Burn-In test results Paragraph 7.8.)

Upon completion of the Burn-In test, the three (3) reliability test units were submitted to the reliability demonstration test as outlined in Paragraph 15.0 on May 12, 1983. The performance levels of the three units at each ambient condition are shown in Figures 17-1, 17-2, and 17-3.

The first relevant failure occurred on May 16 during the third test cycle (approximately 15 hours). At this time during the reliability demonstration test, Unit S/N 004 failed to meet the criteria outlined in Paragraph 15.3.1.2. The out of specification condition was noted when the coolers were operating at a -40°C ambient temperature. The cryocooler system failed to maintain a temperature less than 85K when a heat load of 0.20 watts was applied to the cold tip. The subsequent failure analysis indicated that the failure was related to the displacer lip seal. The repair action then consisted of replacement of the displacer lip seal assembly, and a re-purge/charge of the system. The cooler was then installed into the test set-up. After this rework had been performed, a notable increase in performance was observed at the -40°C ambient condition, however performance levels had suffered at room (20°C) ambient and high (+71°C) ambient conditions.

The decision was made to allow the cooler to run in while performance levels were observed. As shown in Figure 15-2, the cooler eventually met specification at all ambient conditions.

The second relevant failure occurred on May 26, 1983, test cycle #14 (approximately 70 hours). Unit S/N 003 failed to meet the criteria outlined in Paragraph 15.3.1.2. The out of specification condition was noted when the coolers were operating at the high ambient (+71°C) temperature condition. The cryocooler system failed to maintain a temperature of 85K when a heat load of 0.20 watts was applied to the cold tip.

No failure analysis was performed at this time. The cooler was allowed to operate for several test cycles to monitor its performance. During the next eight (8) cycles the cooler performed out of specification at the high ambient condition. On June 1, 1983 the cryocooler system performed within specification at all ambient conditions. This trend continued for the next four (4) test cycles. At this point in time, Unit S/N 003 exceeded specification at the high ambient condition. This erratic trend continued throughout the remainder of the test.

The third relevant failure occurred on May 26, 1983 during the 16th cycle (approximately 80 hours) of the reliability demonstration test. Unit S/N 005 failed to meet the criteria outlined in Paragraph 15.3.1.2. The out of specification condition was noted when the coolers were operating at the low ambient (-40°C) temperature condition.

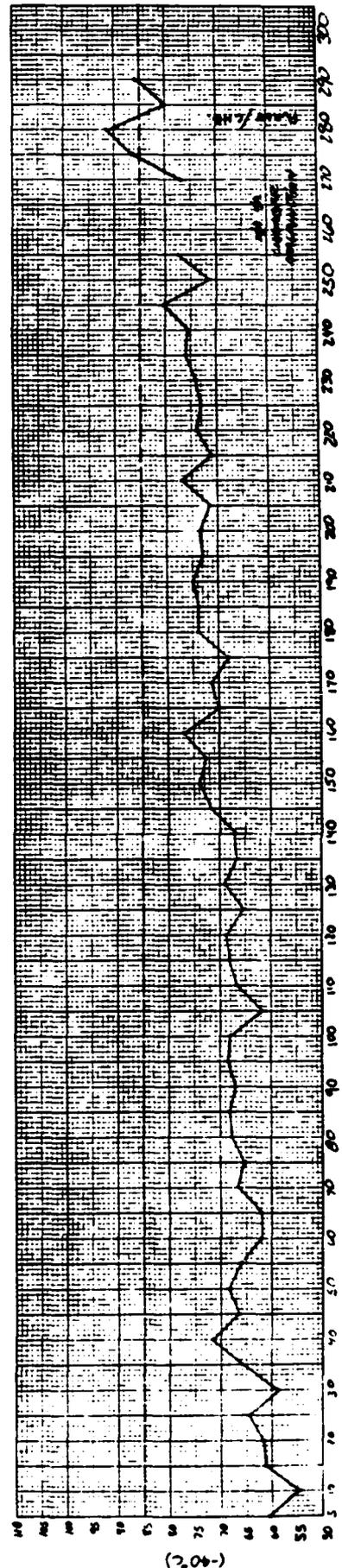
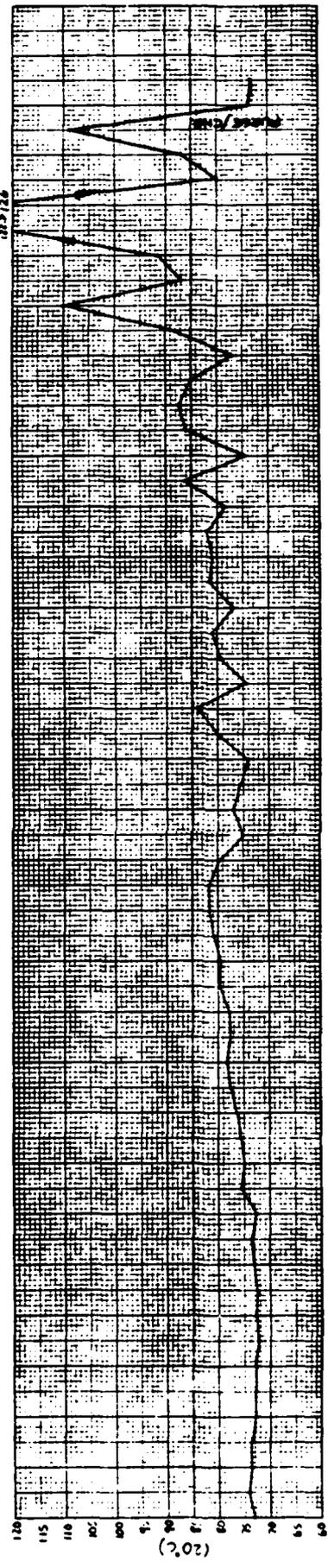
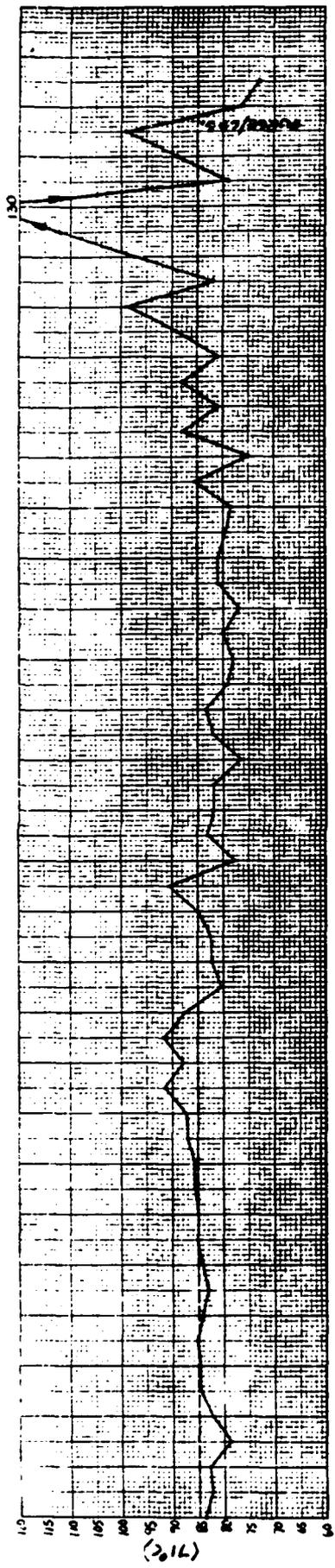
The cryocooler system failed to maintain a temperature of 85K when a heat load of 0.20 watts was applied to the cold tip. Failure analysis consisted of checking the gas pressure, performing a gas analysis with a subsequent purge/charge and retest of the cryocooler system.

There was no apparent loss of gas from the system when checked. The level of performance when retested was improved at high and room ambient conditions. The level of performance at the low ambient condition was still out of specification. This lack of performance was attributed to a problem with the displacer lip seal.

An investigation into the problem with displacer lip seals indicated that the vendor had changed their manufacturing procedure. This in turn yielded inconsistent piece parts which resulted in poor seal performance.

At this point in time, a new set of hardware was assembled with displacer lip seals manufactured to a more tightly controlled procedure. Baseline testing began on August 12, 1983 with the Burn-In test being conducted on August 16, 1983.

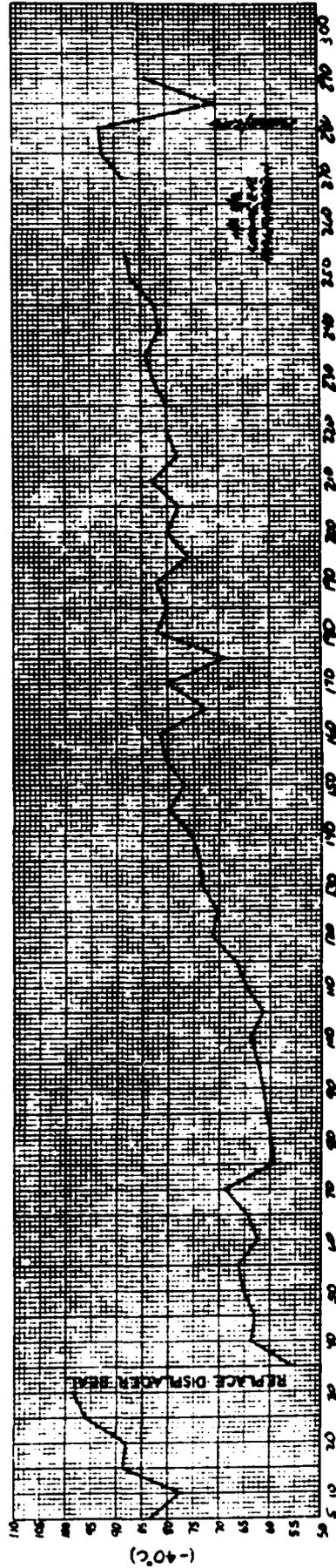
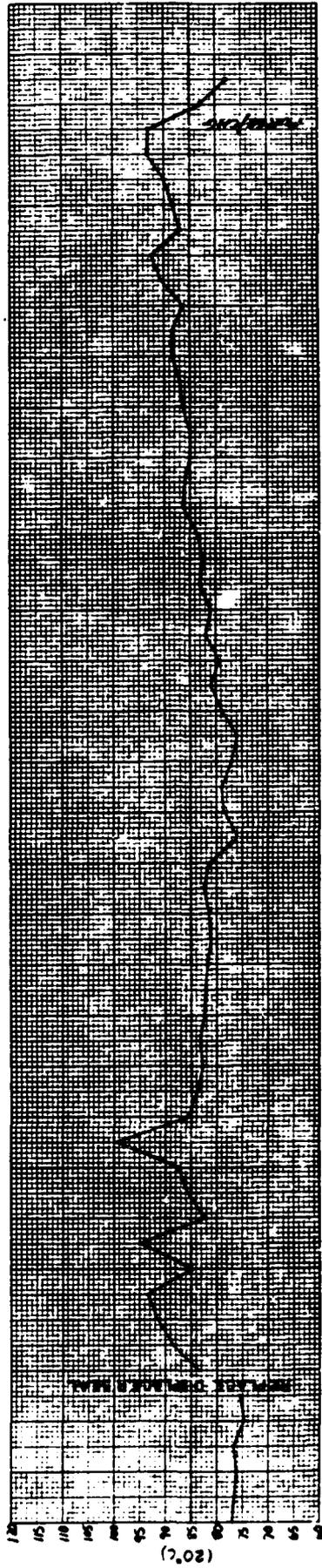
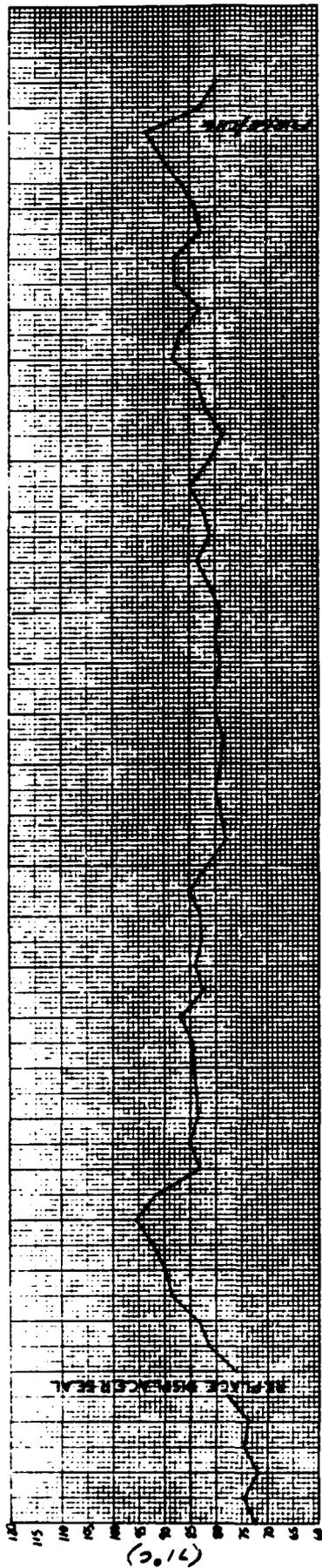
Performance of the three (3) units (S/N 6, S/N 7, and S/N 8) went without incident through twelve (12) test cycles. During cycle #13 (approximately 65 hours), the first relevant failure occurred when unit S/N 6 did not meet the criteria specified in Paragraph 15.3.1.2. The out of specification condition occurred when the units were operating at room ambient (20°C) temperature. The cryocooler system did not maintain a temperature of 85K or less when a heat load of 0.35 Watts was applied to the cold tip.



COOLER OPERATING TIME (HOURS)

CTI-CRYOGENICS

FIGURE 17-1
RELIABILITY TEST PERFORMANCE GRAPH UNIT 3

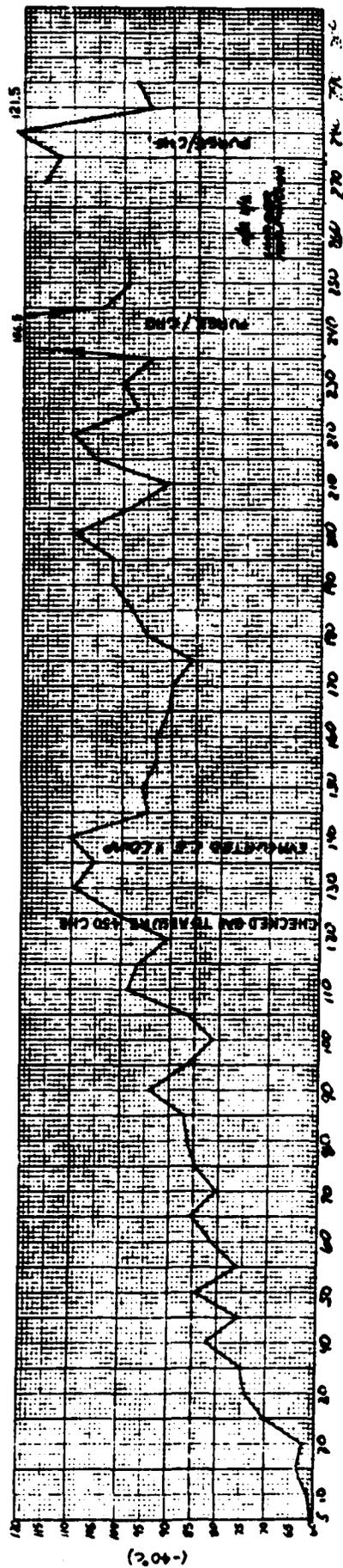
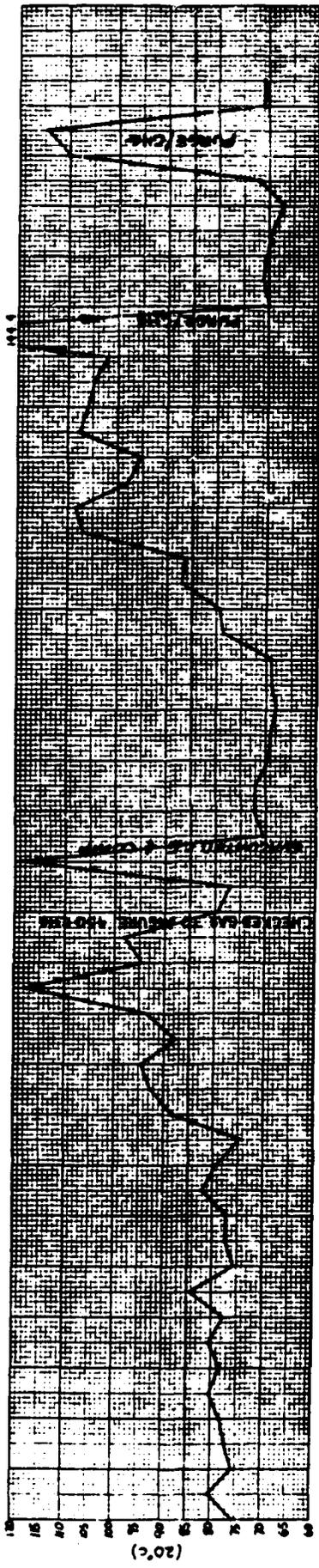
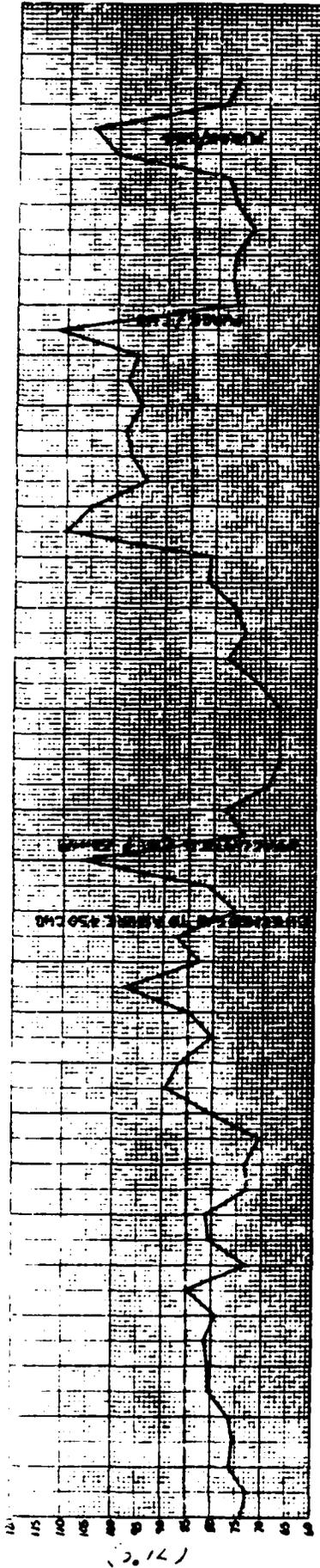


COLD TIP TEMPERATURE (K)

COOLER OPERATING TIME (HOURS)

FIGURE 17-2
RELIABILITY TEST PERFORMANCE GRAPH UNIT 4

CTI-CRYOGENICS

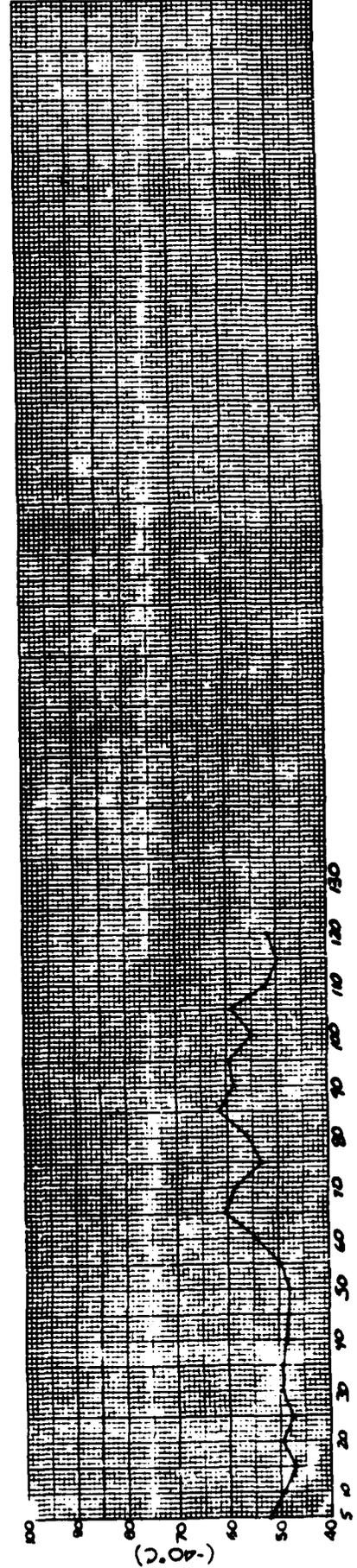
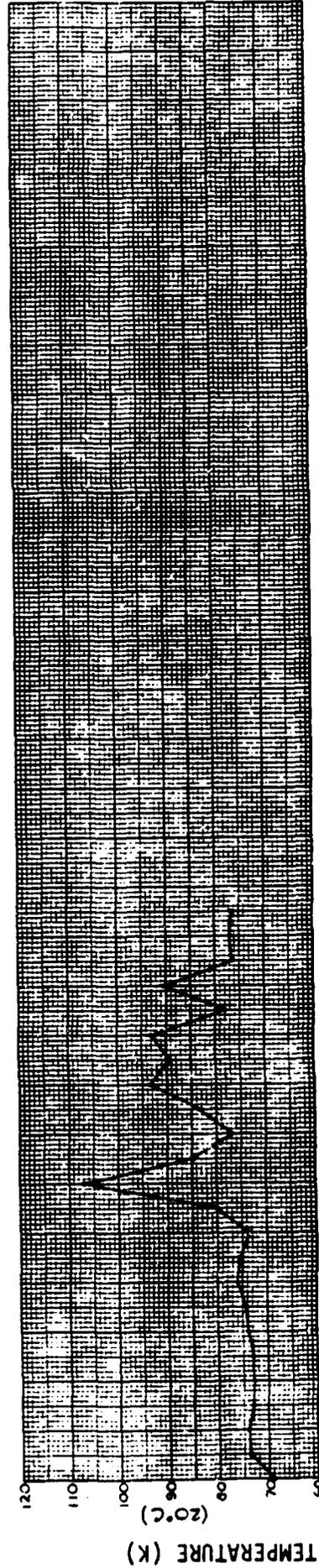
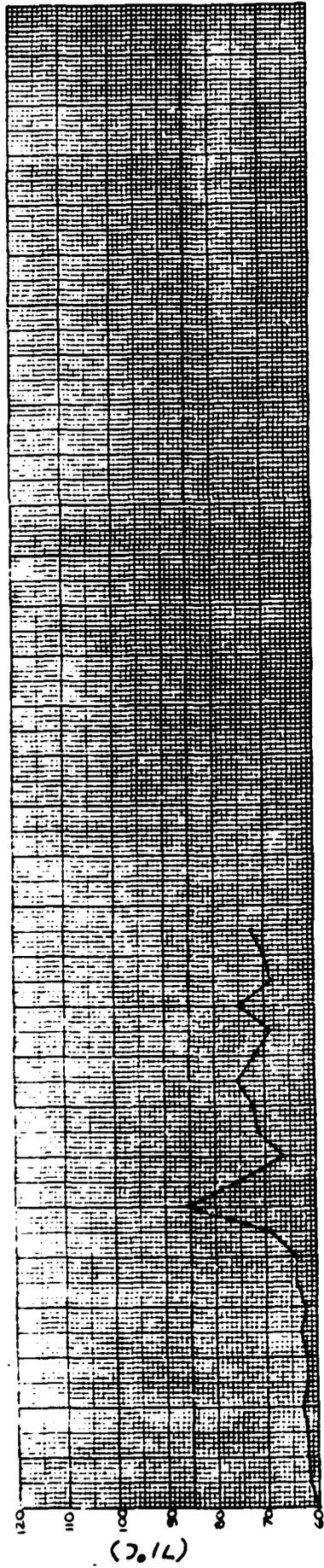


COOLER OPERATING TIME (HOURS)

FIGURE 17-3
RELIABILITY TEST PERFORMANCE GRAPH UNIT 5

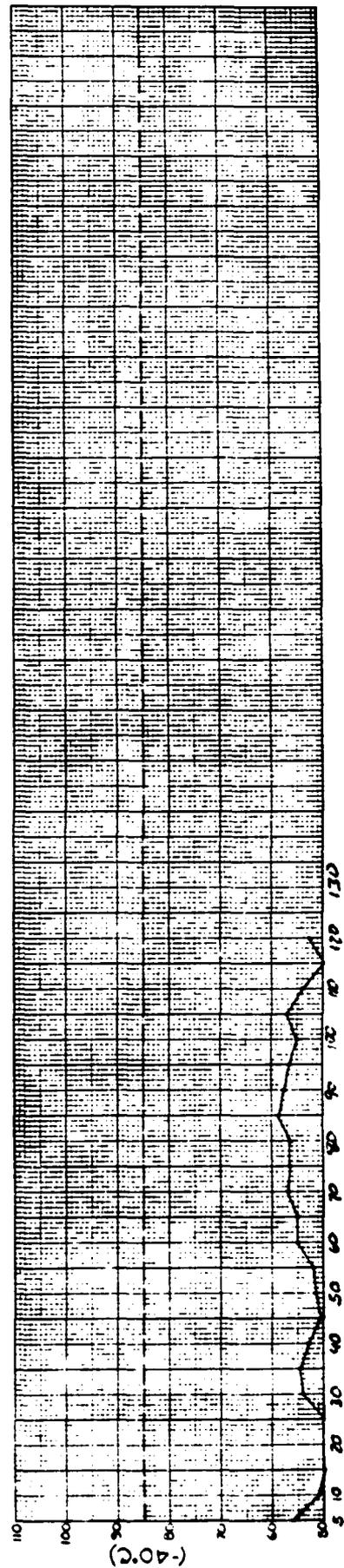
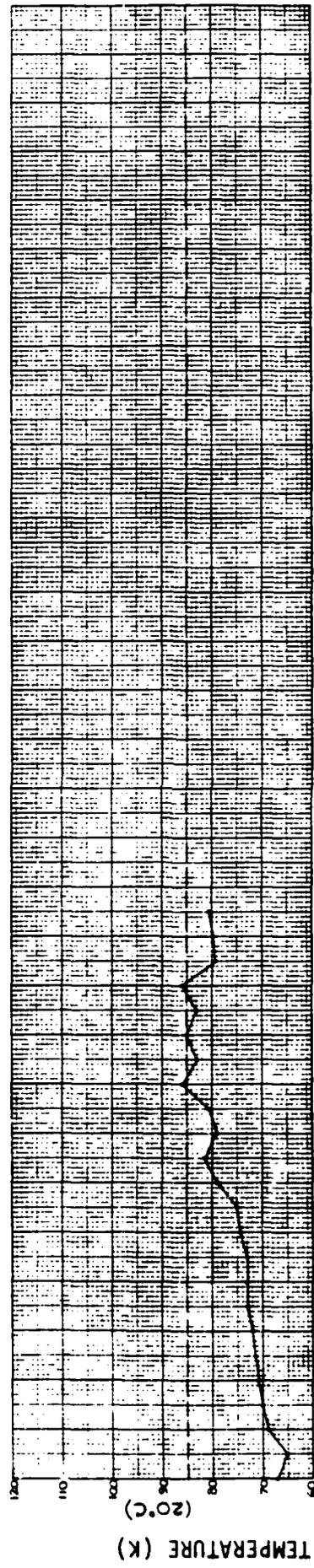
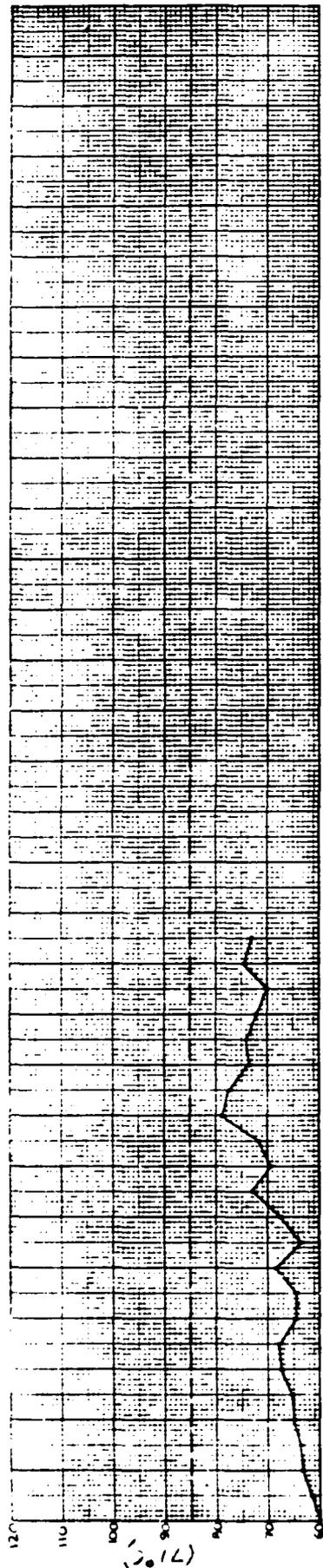
CTI-CRYOGENICS

COLD TIP TEMPERATURE (K)



CTI-CRYOGENICS
 COOLER OPERATING TIME (HOURS)
 FIGURE 17-4
 RELIABILITY TEST PERFORMANCE GRAPH UNIT 6

COLD TIP TEMPERATURE (K)



COOLER OPERATING TIME (HOURS)

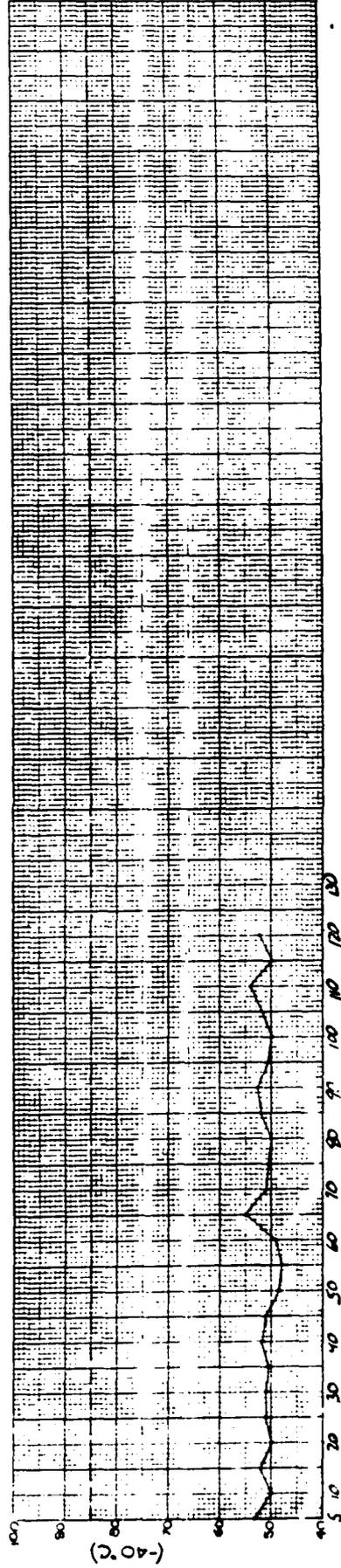
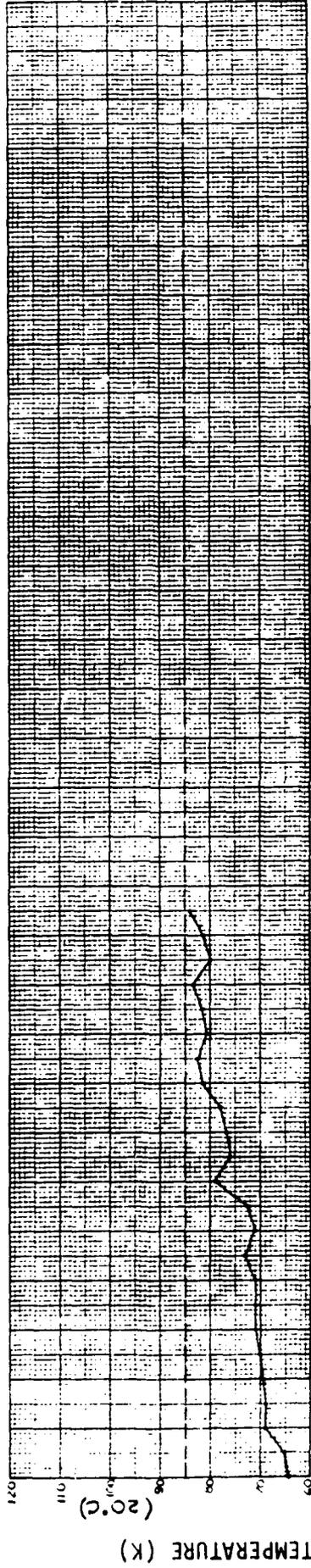
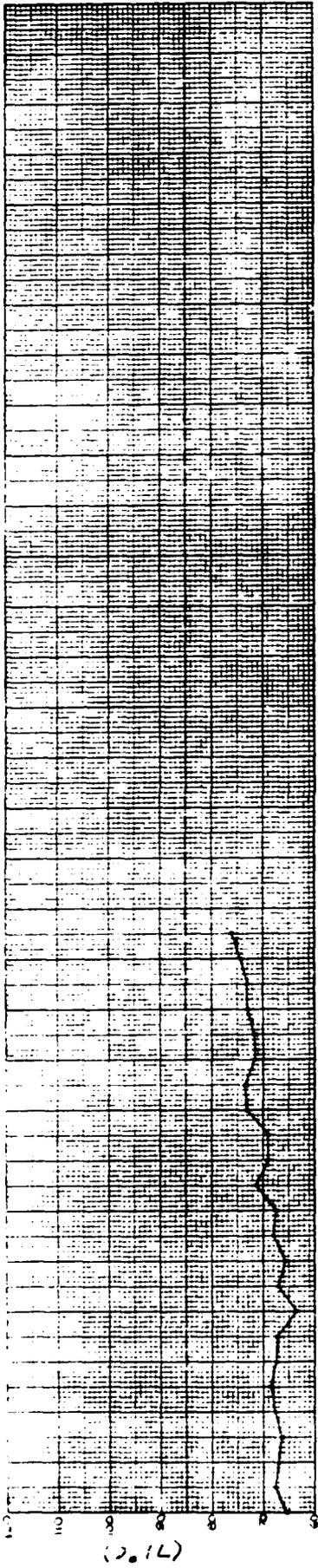
FIGURE 17-5
RELIABILITY TEST PERFORMANCE GRAPH UNIT 7

CTI-CRYOGENICS

CTI-CRYOGENICS

COOLER OPERATING TIME (HOURS)

FIGURE 17-6
RELIABILITY TEST PERFORMANCE GRAPH UNIT 8



The second relevant failure occurred on September 27, 1983 during cycle #17 (approximately 85 hours). Unit S/N 007 did not meet the criteria specified in Paragraph 15.3.1.2. The out of specification condition occurred when the units were operating at room ambient (20°C) temperature. The cryocooler system did not maintain a temperature of 85K or less when a heat load of 0.35 Watts was applied to the cold tip.

At this point in time, failure analysis activities were not initiated. The units were allowed to run through several subsequent test cycles. Performance of the units through the remainder of the test can be found in Figures 17-4, 17-5, and 17-6.

18.0 CONCLUSIONS

The 1/4 Watt cryogenic cooling system, CTI-CRYOGENICS' P/N D8062001, modified with a 12" long gas transfer line, when tested in accordance with CTI-CRYOGENICS' Qualification Test Procedure A3543740 as approved by NV & EOL, passed all the environmental test requirements with the exception of the Audible Noise Test. The cooler exceeded the noise requirements in the range of approximately 1000-8000 Hertz.

The failure of the first three reliability test coolers S/N's 003, 004 and 005 to demonstrate a 1,000 hour MTBF in accordance with the requirements of U.S. Army Specification B2-28A050122A, dated 18 June 1982 was attributed to the malfunctioning of the plastic lip seal in the expander assembly. The next three coolers designated as S/N's 006, 007 and 008 were submitted to the reliability test cycle utilized the same design plastic lip seal, only this time they were manufactured by CTI-CRYOGENICS using much tighter tolerances to better control the seal form factor; these coolers demonstrated an improved level of performance. Upon reviewing the performance versus time plots of the coolers shown in Figures 17-4, 17-5 and 17-6, the only major perturbation in cooler performance was experienced by cooler S/N 006 at +20°C ambient temperature. Also, coolers S/N 007 and S/N 008 were exhibiting marginal performance at +20°C.

APPENDIX

10 Moulton Street
Cambridge, MA 02238
Telephone (617) 491-1850
Telex No. 92-1470

Bolt Beranek and Newman Inc.



15 April 1983

Mr. Raymond Turbo
CTI-Cryogenics
266 Second Avenue
Waltham, MA 02154

Subject: Acoustic Measurements of Two 1/4 Watt Coolers
Serial Numbers 747,728 For Government Contract
DAAK70-82-C-0216

Dear Ray,

Enclosed are two graphs showing the results of the acoustic measurements of the two 1/4 watt coolers (Serial #747, #728) at the anechoic chamber at BBN on April 13, 1983.

The measurement data shows that from 1 KHz - 8 KHz the cooler SPL is above the specification.

The data points were the result of energy averaging the measurement information from each of the four measurement positions. The positions were motor positive, motor negative, charge valve positive, and charge negative.

If you have any questions, please call.

Sincerely,

BOLT BERANEK AND NEWMAN INC.

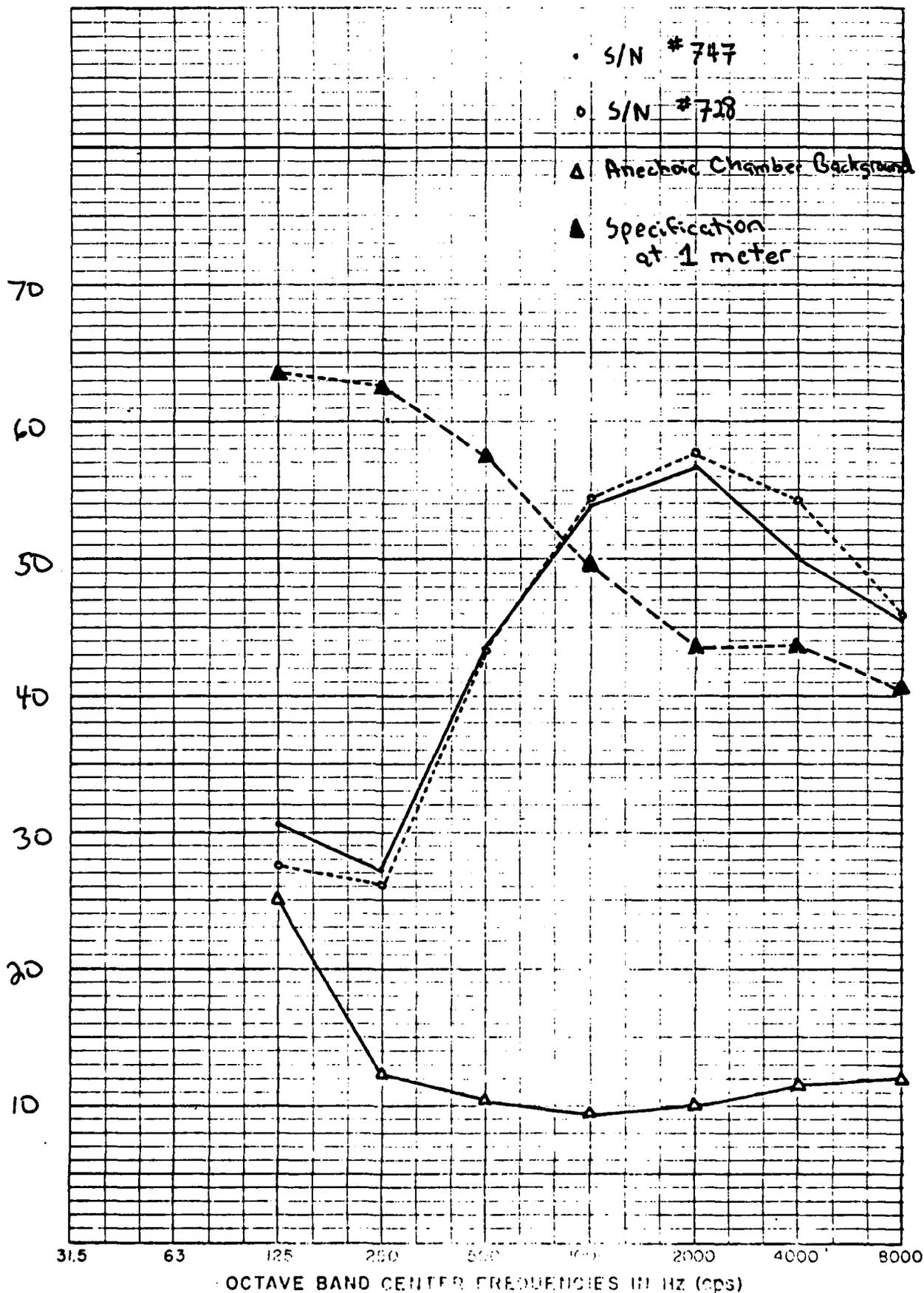
A handwritten signature in cursive script, reading 'Frank N. Iacovino', is written over the typed name.

Frank N. Iacovino

Encls.

FNI:gms

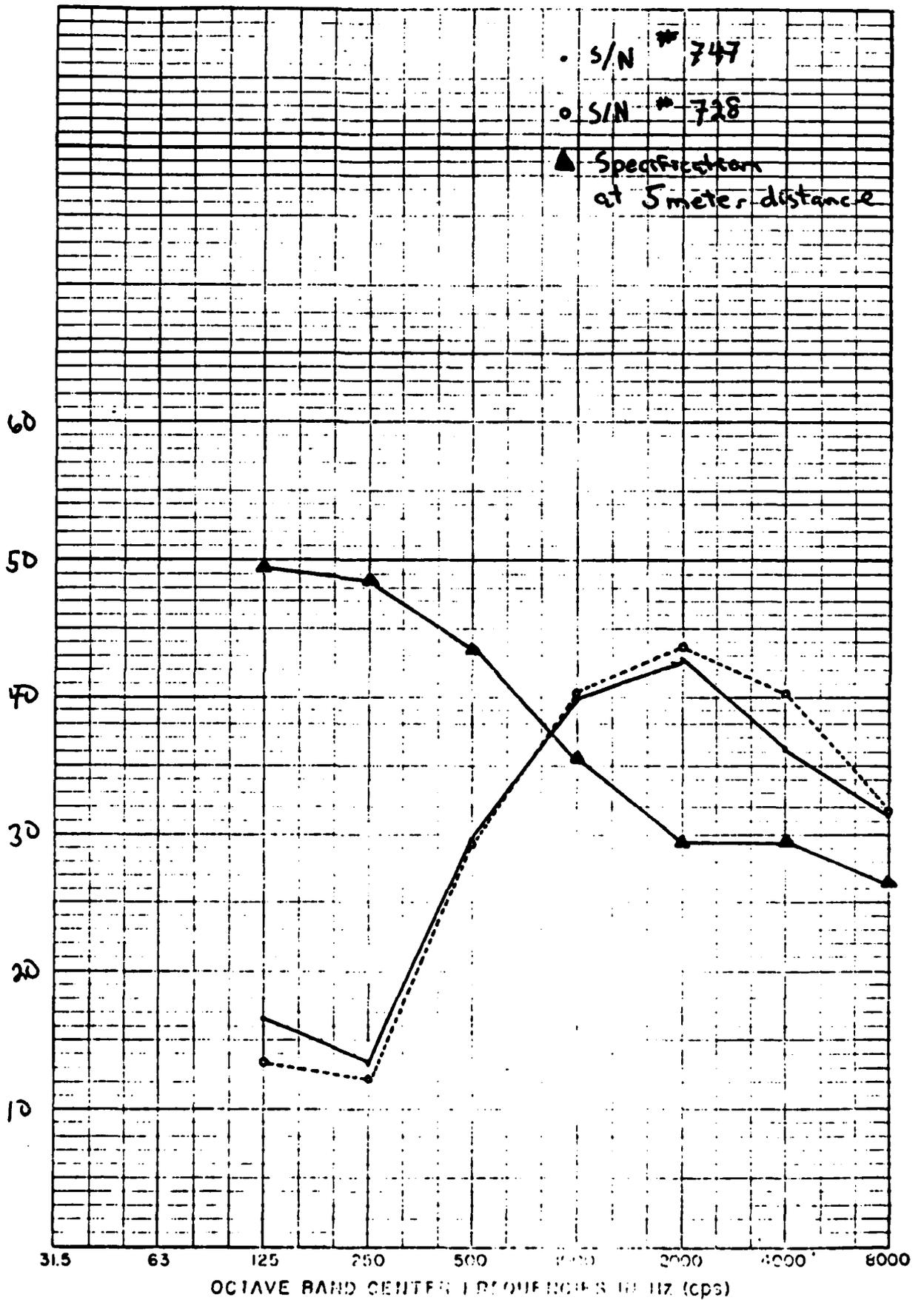
Octave Band Sound Pressure Level in dB re 0.0002 microwas at 1 meter



Sound Pressure Level of 1/4 Watt Coolers

4/12/83 FNI

Octave Band Sound Pressure Level in dB re 0.0002 Microbar at 5 meters



Sound Pressure Level of 1/4 Watt Coolers

4/13/63 FNI



AVCO ENVIRONMENTAL TESTING SERVICES
201 LOWELL STREET, WILMINGTON, MASS 01887

TEST CERTIFICATE

CUSTOMER CTI-Cryogenics	P.O. NO. 10875	WORK ORDER NO. 2418		
ADDRESS 266 Second Avenue, Waltham MA 02154		DATE 24 March 1983		
TEST ITEM Cryogenic Cooler	MODEL/SERIAL NO.			
TEST TITLE Temperature	APP. SPEC. MIL-STD-810C	TEST DATE(S) 14-23 March 1983		
TEST PROCEDURE The test unit was subjected to the following tests. 1. High temperature, MIL-STD-810C, Method 501.1, Proc. II 2. Low temperature, MIL-STD-810C, Method 502.1, Proc. I 3. Temperature shock, MIL-STD-810C, Method 503.1, Proc. I except that the temperature was limited to +71°C and -54°C.				
INSTRUMENTATION	MFGR.	MODEL NO.	SERIAL NO.	CAL. DATE
Thermotron -4	Thermotron	FM-35	R-23938	Due 3/84
ARC-2	ARC	511	R-11374	Due 3/83
TEST ENGINEER	DATE	CHIEF ENVIRONMENTAL SERVICES <i>Alfred A. Koch</i>	DATE 3/24/83	
TEST WITNESS	DATE	GOVERNMENT INSPECTOR	DATE	



AVCO ENVIRONMENTAL TESTING SERVICES
 201 LOWELL STREET, WILMINGTON, MASS 01887

TEST CERTIFICATE

CUSTOMER CTI-Cryogenics	P.O. NO. 10875	WORK ORDER NO. 2418		
ADDRESS 266 Second Avenue, Waltham MA 02154	DATE 5 April 1983			
TEST ITEM Cryogenic Cooler	MODEL/SERIAL NO. 1/4-Watt - S/Ns 1 and 2			
TEST TITLE Vibration/Shock	APP. SPEC. MIL-STD-810C	TEST DATE(S) 24-28 March 1983		
TEST PROCEDURE <u>GOVERNMENT CONTRACT:</u> DAAK 70-82-C-0216				
<p>This certificate defines the test levels and procedures used to determine if the two CTI Cryogenic Coolers will withstand the dynamic stresses expected during service life. Each Cryo-cooler, instrumented with a single accelerometer, was connected to the test setup and exposed to the service environments in accordance with the test conditions established in the Military Standard, except where levels were determined by the Army Development Specification B2-28A050122A dated 26 March 1982.</p> <p><u>SINUSOIDAL VIBRATION</u></p> <p><u>Resonant Search</u> - The Cryo-coolers, at ambient room conditions and operating, were subjected simultaneously to simple harmonic motion at frequencies from 5 to 500 cps at the vibration amplitudes shown in Table I. The change in frequency was varied logarithmically, traversing 5 to 500 cps in 7.5 minutes, recorded as the first sweep during the swept sine vibration tests in each of the three principal axes. (Refer to Figures 1-6 for the results.)</p>				
INSTRUMENTATION	MFGR.	MODEL NO.	SERIAL NO.	CAL. DATE
Vibration System #1				
Shaker	MB	C25HB	AF3518	12/83
Control	BK	1019	AF3518	12/83
Accelerometer(1)	Endevco	2213C	GR42	11/83
Accelerometer(2)	Columbia	504	516 and 521	10/83
Shock Machine	Avco	SM110	1017	Prior to use
Cathode Follower	Columbia	4000	R7493	06/83
Scope	Tektronix	535A	34673	08/83
Calibrator	Ballantine	420	1302	08/83
TEST ENGINEER <i>[Signature]</i>	DATE 4/5/83	CHIEF ENVIRONMENTAL SERVICES <i>[Signature]</i>	DATE 4/5/83	
TEST WITNESS	DATE	GOVERNMENT INSPECTOR	DATE	

Swept Sine - The Cryo-coolers, at ambient room conditions and operating at a steady-state cold tip temperature, were subjected simultaneously to swept sine vibration at frequencies from 5 to 500 cps at the vibration amplitudes shown in Table I and defined in Method 514.2 of MIL-STD-810C. The change in frequency was varied logarithmically from 5 to 500 to 5 cps, traversing a complete cycle (2 sweeps) in 15 minutes. The cycle was repeated for a total of 120 minutes (2 hours) in each of the Z and Y axes and 100 minutes in the X axis.

TABLE I

Frequency (cps)	Amplitude	Time
5 to 14	0.40" D.A.	7.5 min./sweep
14 to 47	4.0g	
47 to 52	0.036" D.A.	
52 to 500	5.0g	

Resonant Dwell - The Cryo-coolers were subjected to the discrete frequency dwells identified during the resonant search tests. The frequency, amplitude, and time are shown in Table II.

TABLE II

Axis	Frequency (cps)	Amplitude		Input	Time
		Cooler #1	Cooler #2		
X	450	15.5g	14.5g	5.0	20 min.
Y	No resonances noted				
Z	No resonances noted				

SHOCK

The Cryo-coolers were firmly torqued to the test fixture and shock tested in accordance with the test conditions established by Method 516.1 of MIL-STD-810C, applied in each of the three principal axes.

CTI-CRYOGENICS
CRYOGENIC COOLER
VIBRATION/SHOCK

TEST CERTIFICATE
WORK ORDER 2418
PAGE 3

Impact Shock - The Cryo-coolers, at ambient room conditions and non-operating, were mounted to the SM110 shock machine and subjected to impact shock tests consisting of a sawtooth pulse profile of 100g and 11 milliseconds, applied two times in each direction of the three principal shocks (12 shocks).

EXAMINATION OF PRODUCT

The physical and operational characteristics of the Cryo-coolers were monitored by CTI personnel throughout the tests. All data was submitted to CTI at the conclusion of the tests.

TWO 2418	CUSTOMER C.T.I. Cryogenics	
ITEM 1/4 Watt Coolers SN 1		
SINE <input checked="" type="checkbox"/>	AXIS X	REF.
RANDOM <input type="checkbox"/>		
ANALYSIS <input type="checkbox"/>	SYST. NO. 1	SHAKER C.57H8A
OPERATOR S. Brills		DATE 9/24/83

Monitor response #1

C.V. meter reading
compressor operating
5.5g with no vibration

- 20g
- 10g

SCALE - 1.0 DB/DIV.



5
100
500

FREQUENCY IN CPS.

SCALE - 1.0 DB/DIV.

Control response (Red)
Monitor response (Black) # 2

C.V. Meter reading
Compressor operating
6.8 g - No Vibration

TWO	R418	CUSTOMER	C. T. I. Cryoplasma
ITEM	1/4 Watt Cooler	REF.	5412
SINE	<input checked="" type="checkbox"/> AXIS X	SHAKER	CASHB2
RANDOM	<input checked="" type="checkbox"/>	SYST. NO.	
ANALYSIS	<input type="checkbox"/>	DATE	3/24/79
OPERATOR	S. Brillo		

20g

10g

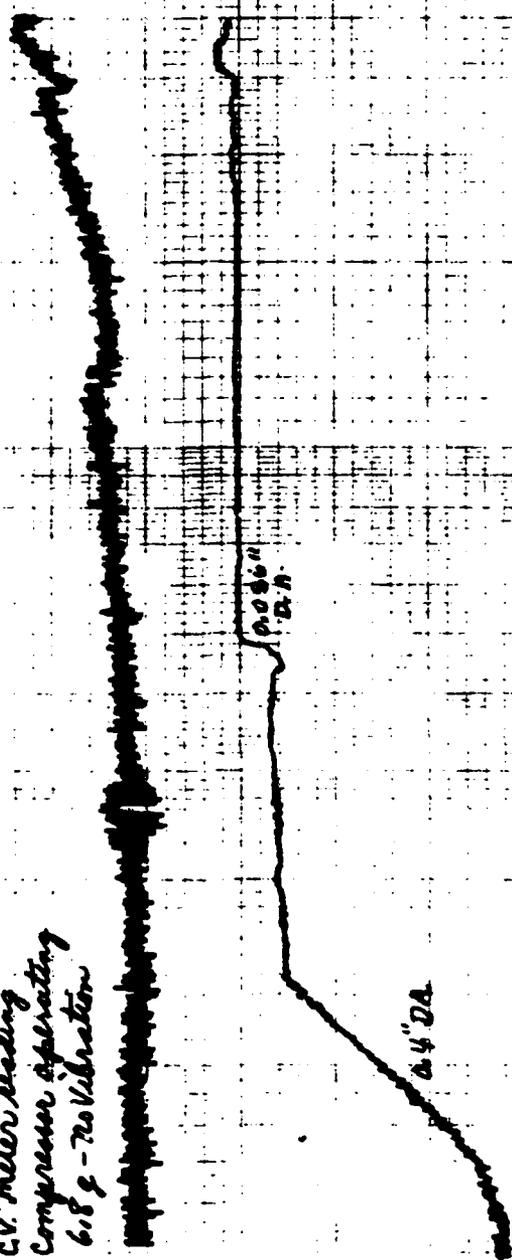
5g

1.25g

500

100

FREQUENCY IN CPS



NO. 2418 DIETZEN GRAPH PAPER
 M. LOGARITHMIC
 5 DIVISIONS PER INCH

ENGINE DIETZEN CO.
 MADE IN U.S.A.

6-2470
 7-60

TWO 2418	CUSTOMER C.T.I. Chemical
ITEM 1/4 Watt Coaler S/N 1	
SINE <input checked="" type="checkbox"/>	AKIS Y
RANDOM <input type="checkbox"/>	REP.
ANALYSIS <input type="checkbox"/>	SHAKER C25H82
OPERATOR S. Brullo	DATE 3/25/52

Monitor response S/N 1

C.V. Meter reading
 Compressor operating
 2.5g - 70 Vibration

- 10g
 - 5g
 - 2.5g

SCALE - 1.0 DB/DIV.

1
 5

1
 100

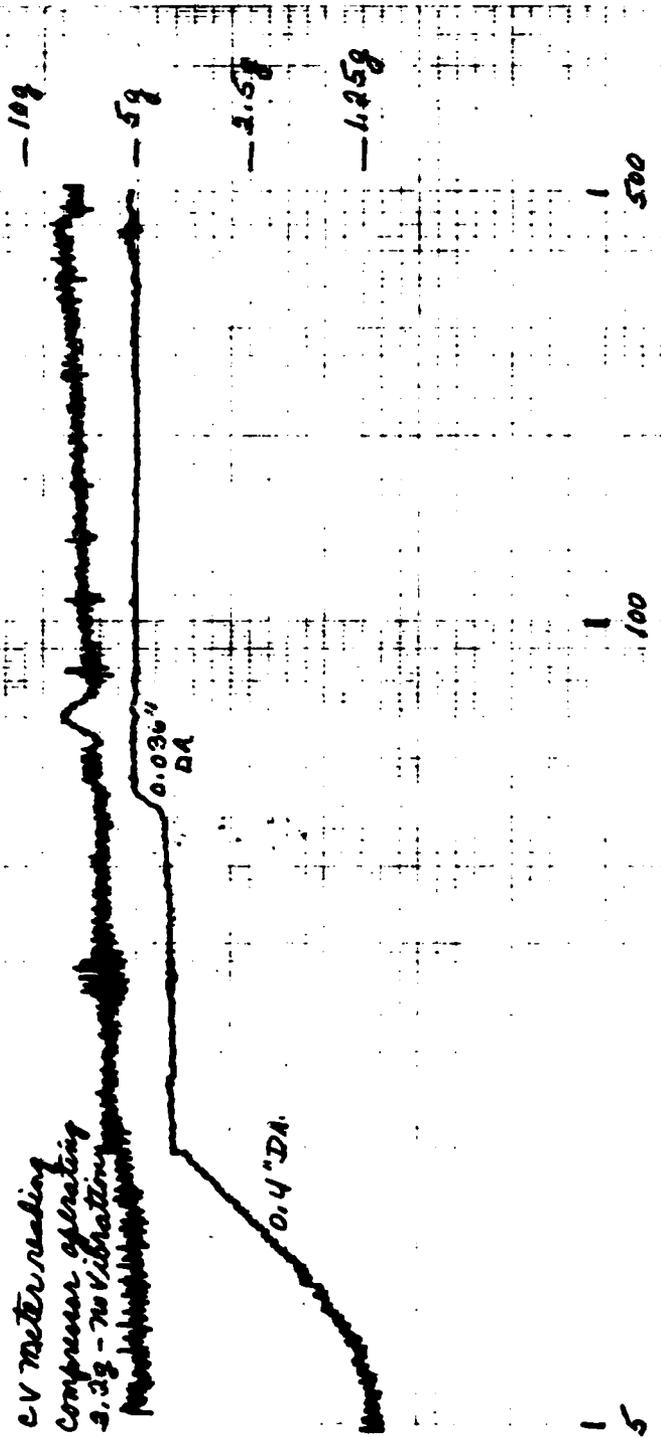
1
 500

FREQUENCY IN CPS.

TWO	REVIT	CUSTOMER	E. T. I. Corporation	
ITEM	1/4 Watt Control	DATE	5/11/52	
SINE	<input checked="" type="checkbox"/>	AMIS	<input checked="" type="checkbox"/>	REF.
RANDOM	<input type="checkbox"/>	SYST. NO.		
ANALYSIS	<input type="checkbox"/>	OPERATOR	L. Brella	
		SHAKER	CASHMERE	
		DATE	5/11/52	

Control response (Red)
Monitor response (Black) 5/11/52

CV Meter reading
Compressor operating
2.3g - No Vibration
Noch...



SCALE - 1.0 DB/DIV.

Monitor response #1

CV meter reading
Compressor operating
4g - No Vibration

TWO 3418	CUSTOMER C. T. I. Cryogenics	
ITEM 1/4 Watt Coolers	S/N 1	
SINE <input checked="" type="checkbox"/>	AXIS Z	REF.
RANDOM <input type="checkbox"/>	SYST. NO. 1	SHAKER CASHB2
ANALYSIS <input type="checkbox"/>	OPERATOR S. Brillo	
		DATE 3/24/83



FREQUENCY IN CPS

SCALE - 1.0 DB/DIV.

Control response (Red)
Monitor response (Black) #2

TWO 2418	CUSTOMER C.T.I. Pyropines	
ITEM 1/4 Watt Cooler	S.P.A.	
SINE <input checked="" type="checkbox"/>	AXIS Z	REF.
RANDOM <input type="checkbox"/>	SYST. NO. 1	SHAKER
ANALYSIS <input type="checkbox"/>	DATE 3/24/83	
OPERATOR	S. Grillo	

C.T. Meter reading
Compressor vibrating
4g - 70 Hz
Control response



FREQUENCY IN CPS

END

Dtjic

7-86