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DEPARTMENT OF THE NAVY
NAVAL AIR DEVELOPMENT CENTER
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Aero-Electronic Technology Department

REPORT NO. NADC-AE-6843 10 February 1969

AN EVALUATION OF SMALL CLOSED-CYCLE CRYOGENIC REFRIGERATORS AS COOLING DEVICES FOR INFRARED DETECTORS

PHASE REPORT
AIRTASK NO. A37533026/2021/F101-05-02
Work Unit No. 3

Miniature closed-cycle cryogenic refrigerators are required to maintain photoconductive and photovoltaic infrared detectors used in airborne passive infrared surveillance devices at their proper operating temperatures in the range of 21° to 90° K. Characteristics, methods of evaluation, results of tests, and photographs of nine such cryostats are presented.

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SUMMARY

INTRODUCTION

Under AIRTASK No. A37533026/2021/F101-05-02, Work Unit No. 3, and other project directives superseded by it, the NAVAIRDEVCEN is conducting a continuing program of developing airborne passive surveillance equipments operating in the 3- to 13-micron portion of the infrared spectrum. Current state-of-the-art equipments employ as their sensing elements photoconductive or photovoltaic infrared quantum detectors made of materials such as mercury doped germanium, mercury cadmium telluride, and indium antimonide. In use, such detectors must be maintained at their proper operating temperatures in the range of 21° to 90° K. Previously, coolants such as liquid helium, liquid neon, and liquid nitrogen were employed but these imposed serious problems of procurement, storage, transportation, and inconvenience of use. One phase of this continuing development program is the testing and evaluation of miniature closed-cycle cryogenic refrigerators designed for operation within this temperature range.

RESULTS

Nineteen closed-cycle cryogenic refrigerators of ten different varieties were procured from Fairchild Stratos Corporation, Hughes Aircraft Company, Malaker Corporation, and North American Philips Company and evaluated from January 1964 to March 1968. Laboratory tests were conducted consisting of measurements of power consumption, cool-down time, minimum temperature achieved, refrigeration capacity, vacuum hold time, working gas hold time, and detector microphonic noise generation. Qualitative observations were made on their reliability, convenience of use, ability to operate at high and low ambient temperatures and inflight performance in infrared surveillance sets. Test results are summarized in appendix A of this report.

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations have been drawn from the component test and the experience gained during operational employment of the cryogenic refrigerators in airborne infrared systems.

1. Small cryogenic refrigerators can be used effectively as infrared detector cooling devices in airborne infrared detecting systems without serious system degradation. The use of such devices eliminates logistics problems associated with liquid coolants and simplifies preflight servicing of the infrared equipments.

2. The refrigeration capacity, size, weight, and power requirements of the Stirling type cryogenic refrigerators are compatible with airborne infrared detecting systems.

3. Better techniques must be devised to provide longer vacuum hold times in the volume surrounding the cold fingers of the refrigerators.

4. The employment of the cryogenic refrigerators in infrared systems has reduced the logistics problems that normally are associated with the use of liquid cryogenic refrigerants, and has simplified the preflight servicing of infrared equipments.

5. Certain Stirling type refrigerators have inherent characteristics associated with their particular design or construction that tend to reduce or override their advantages. Such characteristics observed are: poor vacuum integrity of the volume surrounding the cold finger, excessive vibration, acoustic noise and microphonic generation, and continuous helium contamination of the working gas which necessitates periodic helium purging and recharging.

6. The Joule-Thomson refrigerator operating in the 20°- to 25°-K temperature range is not an efficient device for cooling infrared detectors. Its net refrigeration capacity of 0.5 watt at these low temperatures is considered marginal insofar as this cooler is unable to overcome a "soft" vacuum by cryopumping. However, since the Joule-Thomson type refrigerator has no moving parts in its cold head, it provides a good method for cooling infrared detectors when noise generation must be kept to a minimum.

7. The direction of rotation of the motors used to drive airborne Stirling-cycle cryogenic refrigerators is dependent on the phasing of the three-phase electric power input. If the thermodynamic phase sequence of the Stirling cycle type refrigerator is reversed owing to improper electrical phasing, the "cold finger" will heat rapidly and serious damage may result. Such closed-cycle coolers should be provided with incorrect-phase protection devices.

8. It is recommended that this program be continued and the evaluation be extended to include a "Cryodyne" refrigerator manufactured by Arthur D. Little, Incorporated and a Vuilleumier refrigerator manufactured by Hughes Aircraft Company.

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DISCUSSION

BACKGROUND

The advancement of infrared technology for airborne military applications into the far infrared region of the electromagnetic spectrum can be attributed largely to the successful development of long wavelength infrared quantum detectors and recent developments in cryogenics. Infrared quantum detectors sensitive to long wavelength infrared radiation require cooling to temperatures of 90° K or lower. In the past, the required low temperature cooling was provided by liquid nitrogen, liquid neon, or liquid helium depending on the temperature required by the particular detector.

The use of the liquified gases has serious limitations and presents problems in logistics and employment. These problems have been eliminated by the development of small, relatively lightweight cryogenic refrigerators suitable for airborne applications. Over the past four years NAVAIRDEVCEN has been engaged in a continuing program of performing laboratory and aircraft evaluations of small closed-cycle cryogenic refrigerators as part of AIRTASK No. A37533026/2021/F101-05-02, Work Unit No. 3 and related projects. This report presents a summary of the tests, characteristics, and experiences with cryogenic refrigerators manufactured by Fairchild Stratos Corporation, Hughes Aircraft Company, Malaker Corporation, and North American Philips Company. Figures 1 through 8 are photographs of eight of the cryogenic refrigerators used at the NAVAIRDEVCEN.

PROCEDURE

The information presented in this report was drawn from experiences with these components when employed in laboratory and airborne operations. In laboratory operations the refrigerators were subjected to the following tests to determine their operating characteristics: power consumption, cool-down time, minimum temperature achieved, refrigeration capacity, vacuum hold time, and microphonic noise generation. In airborne operations the refrigerators were installed and operated in passive infrared surveillance systems.

When an infrared detector was used with a refrigerator, the detector capsule was firmly secured in good thermal contact with the refrigerator cold finger with four bolts as shown in figure 9. Good thermal contact between the detector capsule and the cold finger was ensured by placing a thin sheet of indium metal between the two parts.

The following briefs describe the measuring techniques employed in the determination of the refrigerator characteristics.

Power Consumption

The three-wattmeter method was used to measure input electric power to the refrigerators.

Cool-Down Time

A 10-kilohm, 0.1-watt Allen-Bradley carbon resistor, calibrated as a temperature sensor, was mounted in good thermal contact on the cold finger. Its resistance was monitored with a Dymec digital voltmeter, model 2401C, and a Dymec ohms converter, model 2410B, and recorded on a Hewlett Packard digital recorder, model H24562A. Time was measured with a separate timer in addition to that employed in the recorder. Each timer was activated at the start of the refrigerator operation and the time was recorded when the minimum temperature was achieved.

In general, the cool-down time was measured with an infrared detector in a copper or brass capsule (whose mass was approximately 24 grams) mounted on the cold finger in addition to the low-mass temperature sensor. It should be noted, however, that in most cases the infrared detector was cooled to a sufficiently low temperature to permit its operation before the refrigerator achieved its minimum temperature.

Minimum Temperature Achieved

This is the temperature measured with a temperature-calibrated resistor mounted, in good thermal contact, on the cold finger of the refrigerator. This temperature was measured, as was the cool-down time, with the infrared detector capsule mounted on the cold finger along with the temperature sensor. The same temperature measuring techniques were used to measure the minimum temperature achieved as was used to measure cool-down time.

Refrigeration Capacity

The refrigeration capacity was determined with the use of a power dissipation resistor and a temperature sensing resistor mounted on the refrigerator cold finger. A measured current was passed through the power dissipation resistor and the voltage drop across it was measured allowing the power dissipated in it to be calculated while the refrigerator maintained predetermined cold-finger temperatures as indicated by the temperature sensing resistor.

Vacuum Hold Time

This is the period of time measured between successive required evacuations of the volume surrounding the cold finger. In general, the vacuum space was pumped to a pressure of 1×10^{-6} torr at each evacuation. Re-evacuation of the 25° K refrigerators was considered to be required when they could no longer achieve temperatures lower than 30° K.

Microphonic Noise Generation

This test was performed by measuring the microphonic noise* voltage generated in a mercury doped germanium or mercury cadmium telluride infrared detector mounted and cooled on the refrigerator cold finger. The wideband noise generated with the refrigerator operating was compared to that wideband noise observed with the refrigerator stopped for short periods of time.

The routine test procedures described above were supplemented, when necessary, by helium mass spectrometer leak testing to detect and localize leaks in the vacuum jacket and in the helium pressurized volume and also by subjecting the refrigerators to continuous operation for long periods of time to determine long-time temperature stability.

* The term microphonic noise refers to the increase in noise generated in the cooled detector when the refrigerator is operating as compared to that when the refrigerator is momentarily turned off. This noise may be induced mechanically, electrically, thermally, optically, acoustically or by any combination thereof.

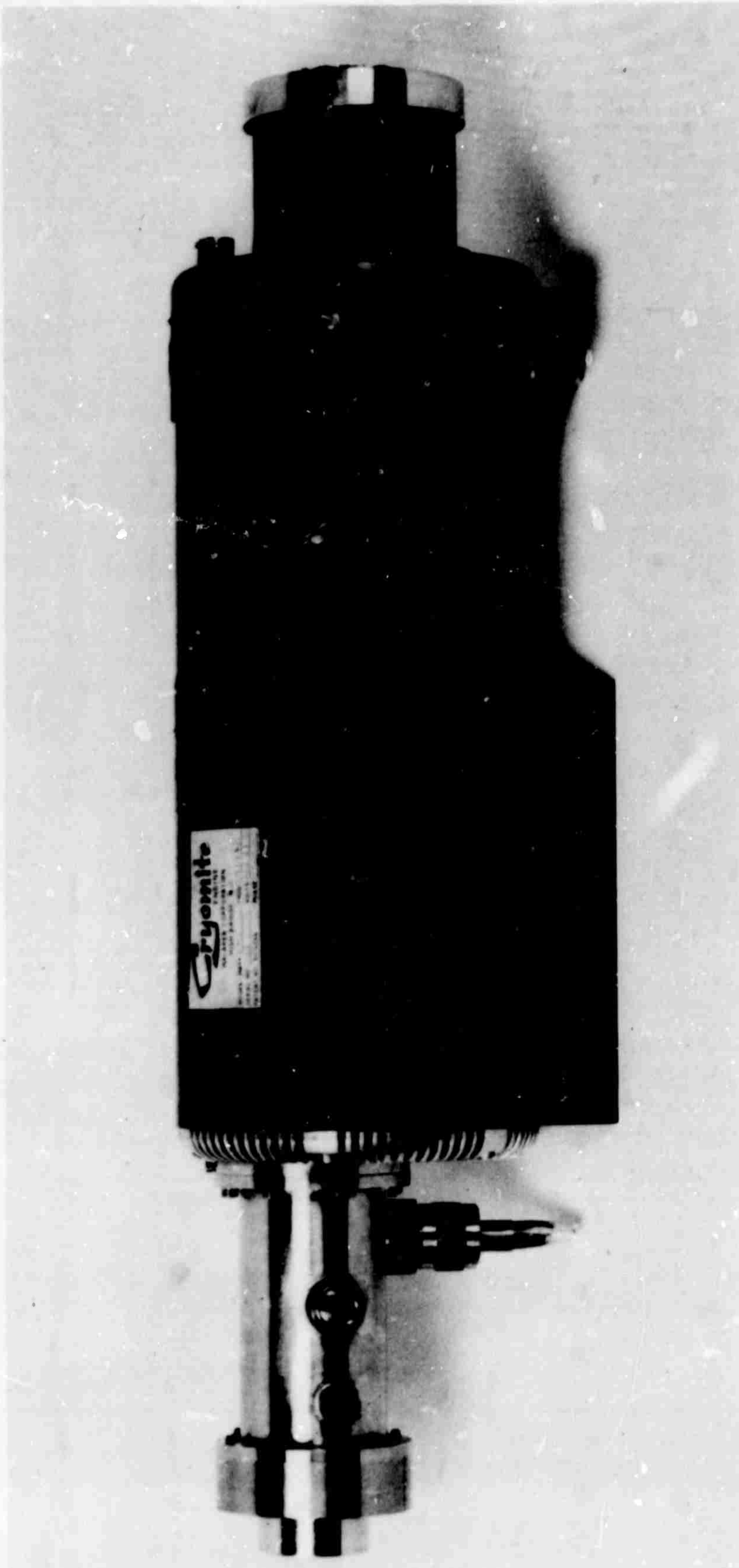


FIGURE 1 - Malaker Cryomite Mark VII C (Inline Configuration)

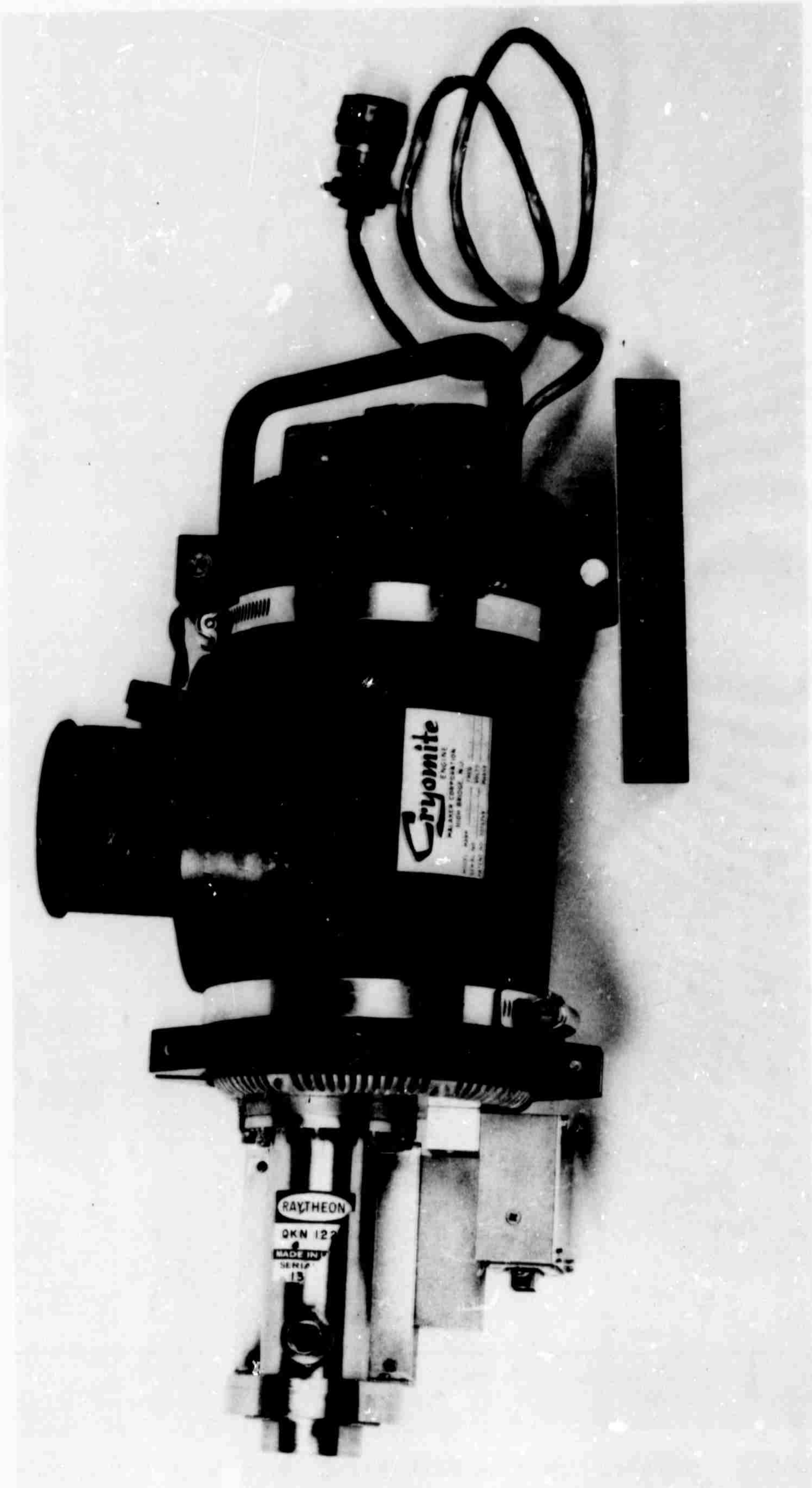


FIGURE 2 - Malaker Cryomite Mark VII C (Single Side Fan Configuration)

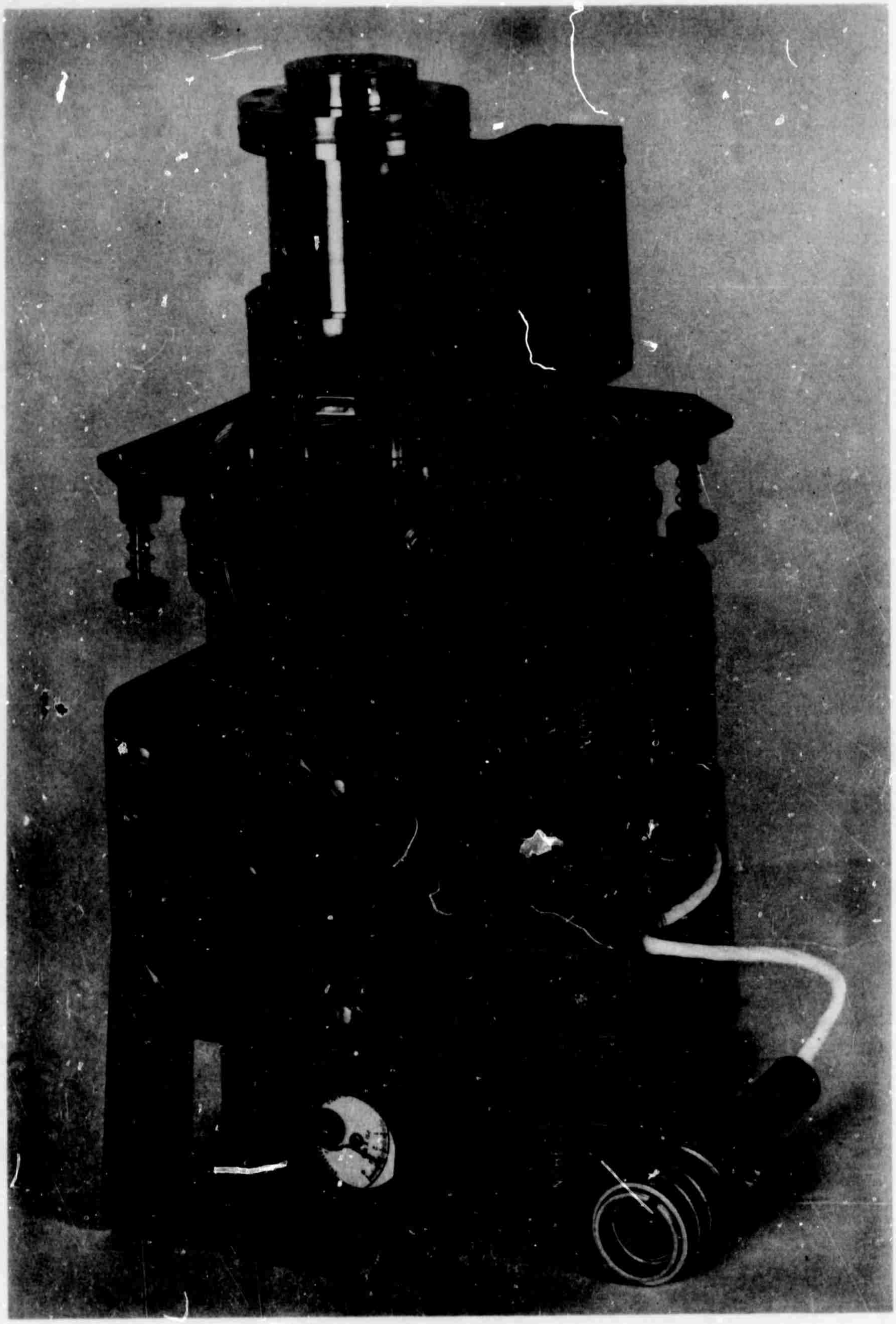


FIGURE 3 - Malaker Cryomite Mark VII C (Double Side Fan Configuration)

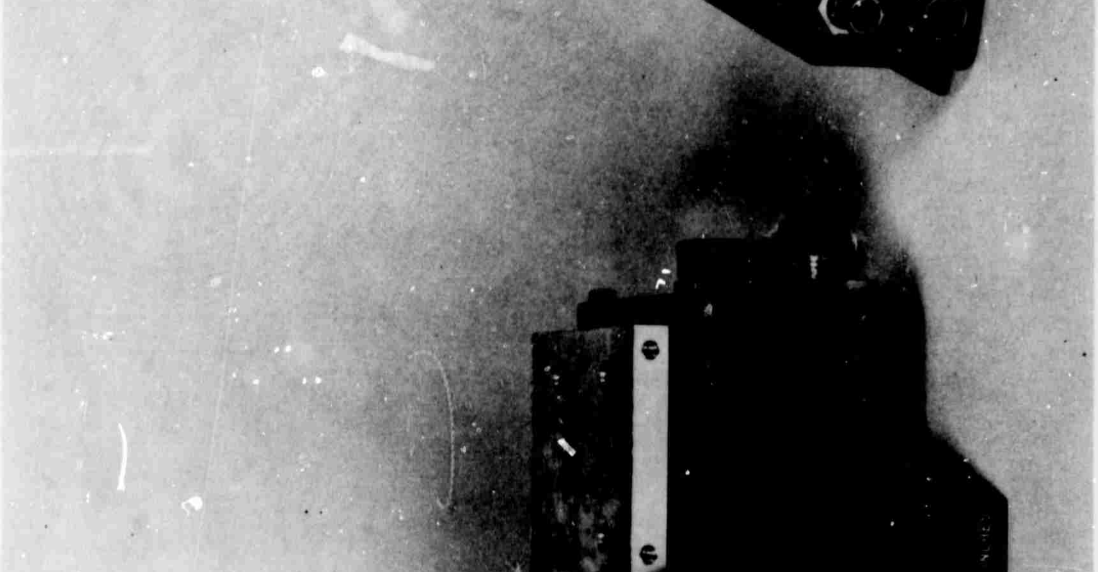


FIGURE 4 - Malaker Cryomite Mark XIII (Right Angle Drive)

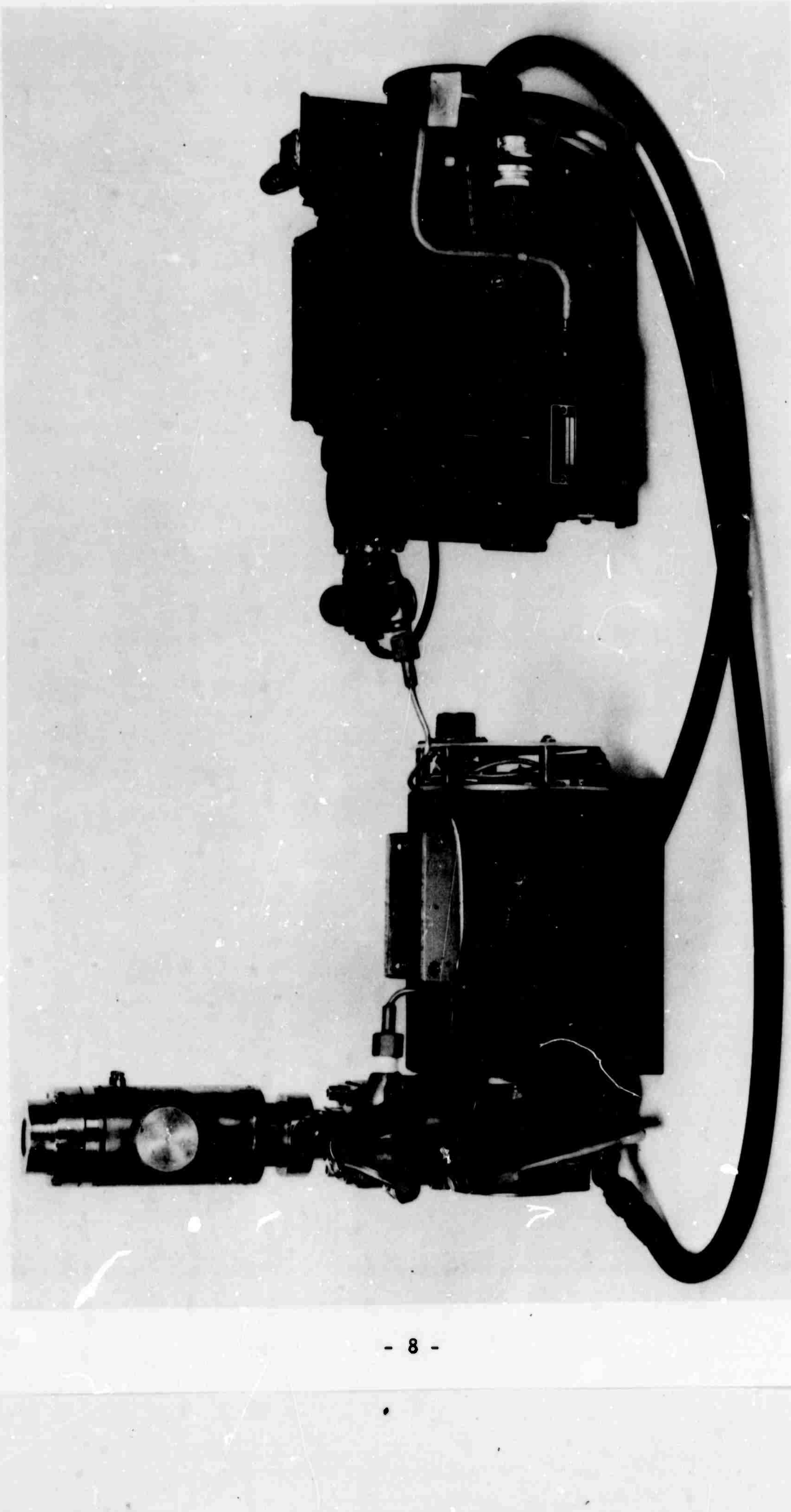


FIGURE 5 - Philips Cryogem Model 42325 With Heat Exchanger

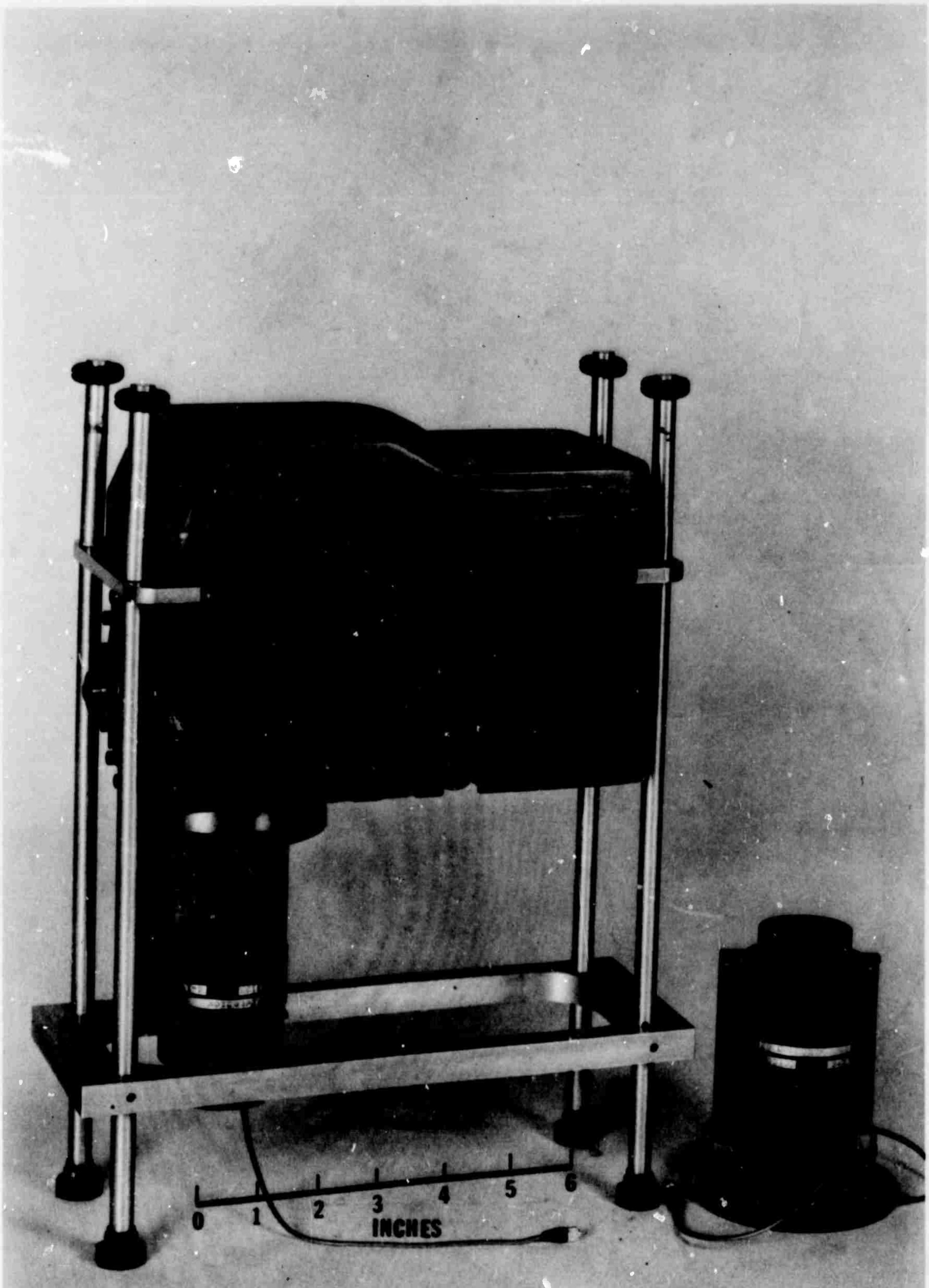


FIGURE 6 - Hughes Model X461307 Mark IV/25 Refrigerator With Santa Barbara Research Center Slip-On Detector-Dewar

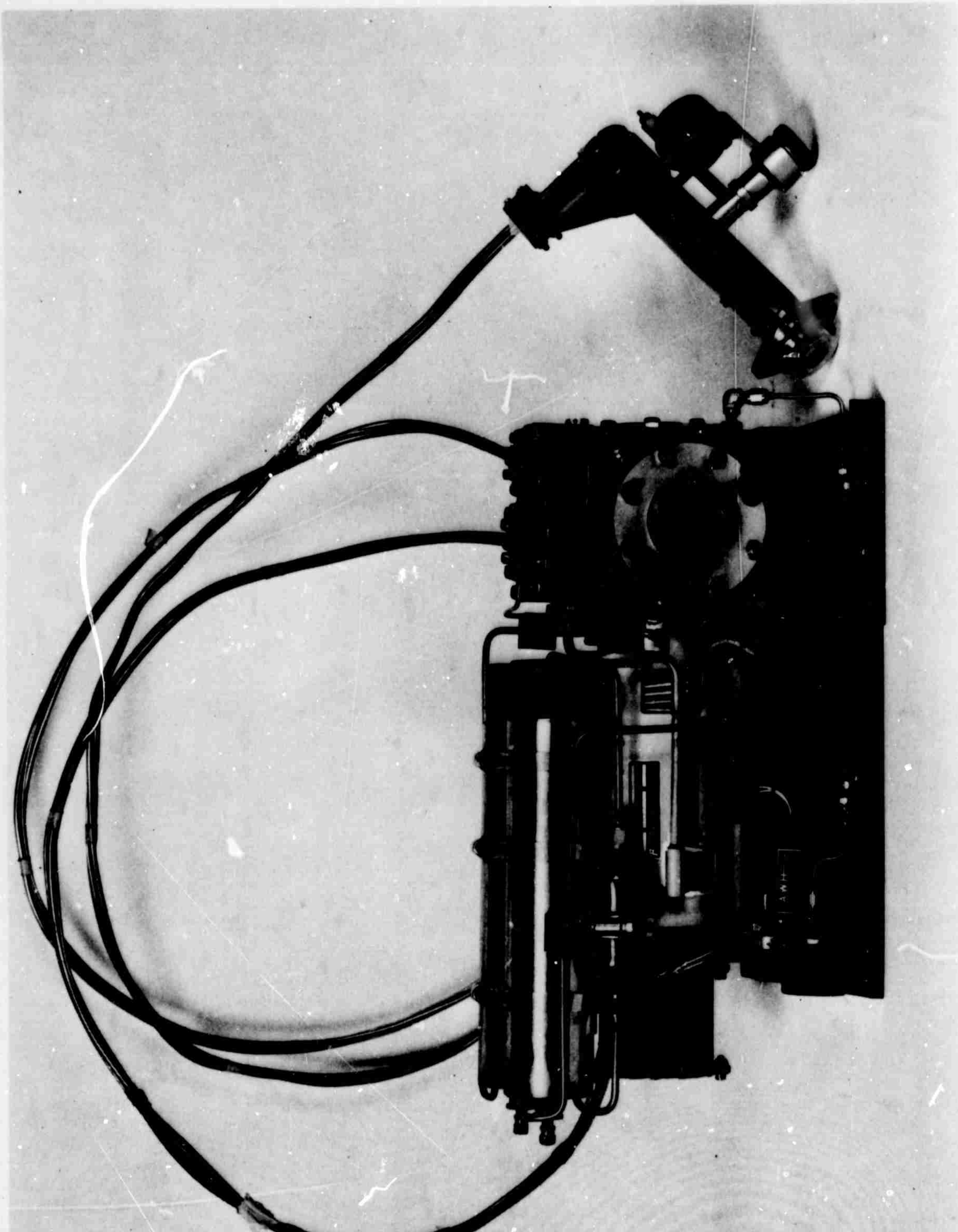


FIGURE 7 - Fairchild Stratos Dual Loop Cryostat and Compressor System

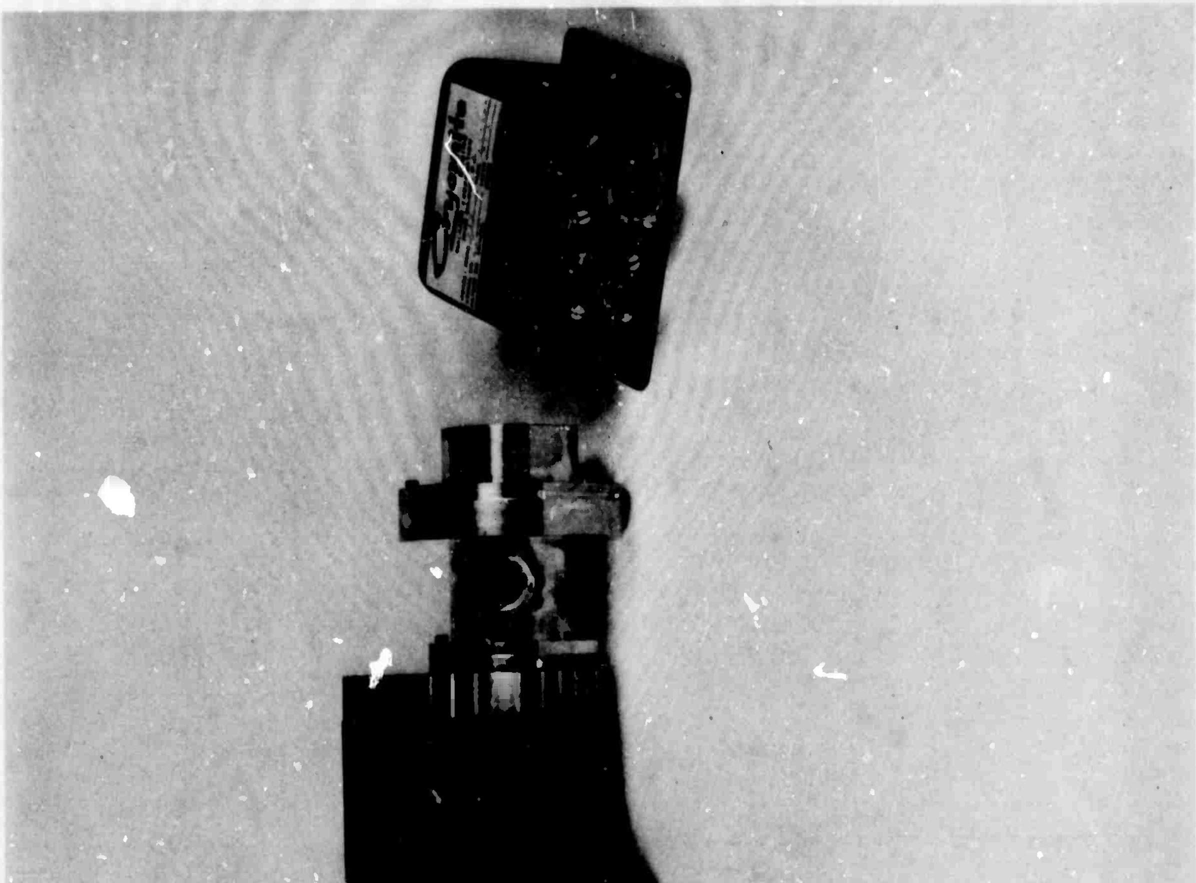
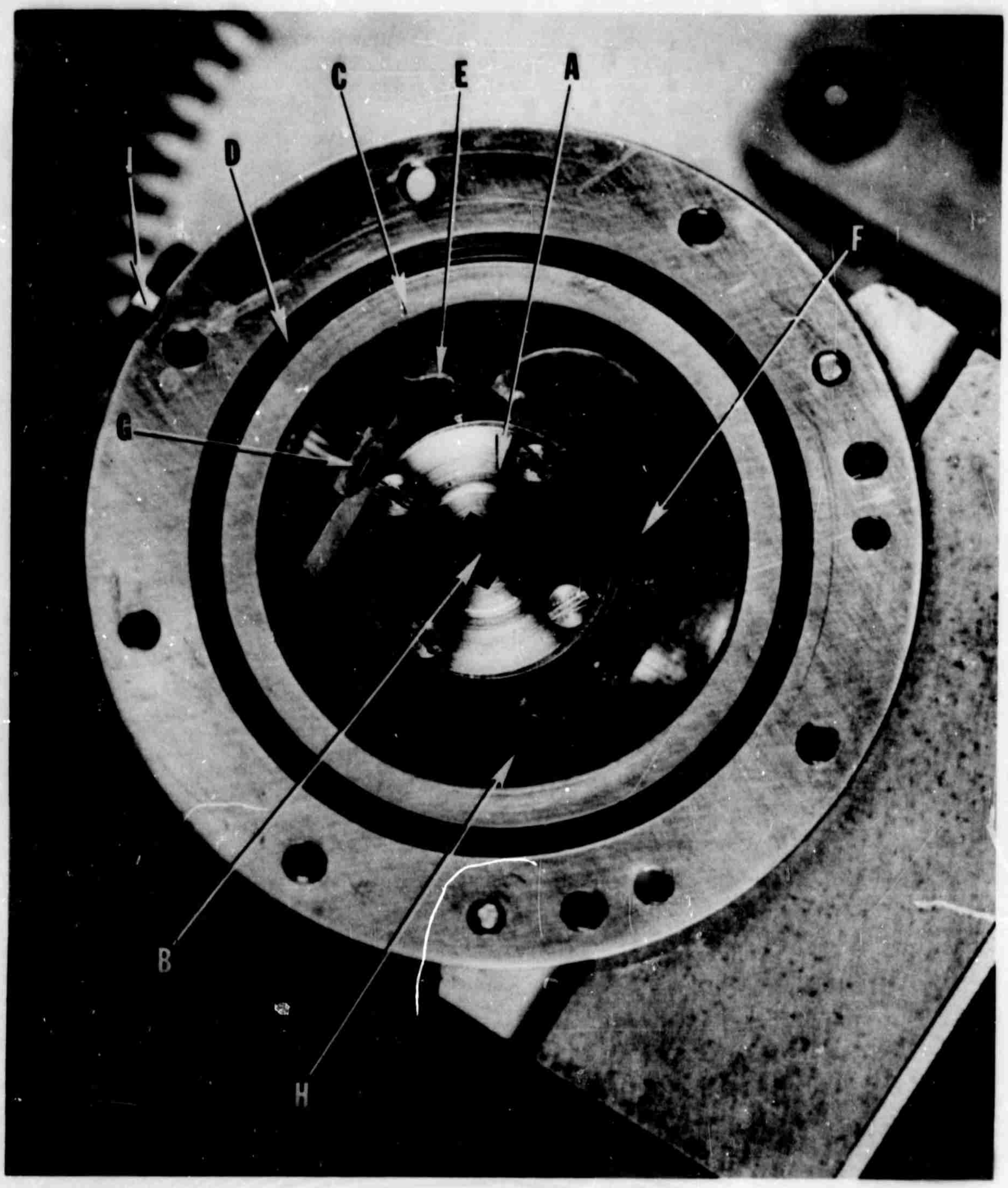


FIGURE 8 - Malaker Cryomite Mark XIV



A - Detector capsule
B - Detector sensitive area
C - Vacuum jacket
D - O-Ring vacuum seal
E - Detector signal lead
F - Cooler cold head
G - Temperature sensor
H - Vacuum space
I - Vacuum valve

FIGURE 9 - Infrared Detector Mounted on Cold Finger of Cryogenic Refrigerator

APPENDIX A

CLOSED-CYCLE COOLER INFORMATION SHEETS

Manufacturer	Malaker Corporation
Trade Name/Model	Cryomite Mark VII C
Type	Air cooled, single stage, Stirling cycle
Configuration	Inline
Serial Number	70
Contract Number	N62269-2575
Contract Date	21 May 1964
Delivery Date	9 July 1964
Time Operated	546 hours
Cost	$7320 (with "Cryodial" ML 1400A temperature regulator)
Volume	1115 cu in. (including temperature regulator)
Weight	40.5 pounds (including temperature regulator)
Input Power at Minimum Temperature	530 watts (including temperature regulator)
Minimum Temperature Achieved	22° K
Cool-Down Time to 25° K	15 minutes
Cooling Power at 25° K	1.0 watt
Working Gas and Pressure	Helium at 250 PSIG
Working Gas Hold Time	6 months
Vacuum Hold Time	4 to 5 days

Remarks

Induces some noise in the output of some infrared detectors.
High acoustic noise level, some vibration.
Compact, rugged, generally reliable.
Maintains temperature well.
Experienced considerable airborne use.
Successfully operated and maintained by fleet personnel for more than two years.
Operates successfully with air pressures up to 10 torr in vacuum chamber.
Minute helium leaks found between vacuum chamber and high pressure helium volume.
Tends to lose helium charge at ambient temperatures below -20° C.
"Cryodial" ML 1400A temperature regulator is a separable electronic device designed to control the temperature of the cold finger to within 0.02° K of any desired, dial-adjustable temperature over the range of 20° to 300° K.

Manufacturer	Malaker Corporation	
Trade Name/Model	Cryomite Mark VII C	
Type	Air cooled, single stage, Stirling cycle	
Configuration	Inline	
Serial Numbers	75	76
Contract Numbers	N62269-2845	N62269-3030
Contract Dates	24 September 1964	5 March 1965
Delivery Dates	29 September 1964	1 March 1965
Time Operated	472 hours	361 hours
Cost	$5370	
Volume	265 Cu in.	
Weight	18.5 pounds	
Input Power at Minimum Temperature	440 watts	
Minimum Temperature Achieved	22° K	
Cool-down Time to 25° K	15 minutes	
Cooling Power at 25° K	1.5 watts	
Working Gas and Pressure	Helium at 250 PSIG	
Working Gas Hold Time	6 months	
Vacuum Hold Time	4 to 5 days	

Remarks

Induces some noise in the output of some infrared detectors.
High acoustic noise level, some vibration.
Compact, rugged, generally reliable.
Maintains temperature well.
Experienced considerable airborne use.
Successfully operated and maintained by fleet personnel for more than two years.
Operates successfully with air pressures up to 10 torr in vacuum chamber.
Minute helium leaks found between vacuum chamber and high pressure helium volume.
Tends to lose helium charge at ambient temperatures below -20° C.

Manufacturer	Malaker Corporation
Trade Name/Model	Cryomite Mark VII C
Type	Air cooled, single stage, Stirling cycle
Configuration	Single side fan
Serial Numbers	115 116 117
Contract Number	N62269-2858 with HRB-Singer, Incorporated
Contract Date	2 November 1964
Delivery Date	Delivered as parts of AN/AAR-32 infrared detecting sets. First delivery in February 1966.
Time Operated	- 338 313 hours
Cost	$5395
Volume	265 cu in.
Weight	19.0 pounds
Input Power at Minimum Temperature	440 watts
Minimum Temperature Achieved	24° K
Cool-Down Time to 25° K	15 minutes
Cooling Power at 25° K	1.0 watt
Working Gas and Pressure	Helium at 250 PSIG
Working Gas Hold Time	6 months
Vacuum Hold Time	4 to 5 days

Remarks

Induces some noise in the output of some infrared detectors.
High acoustic noise level, some vibration.
Compact, rugged, generally reliable.
Maintains temperature well.
Experienced considerable airborne use.
Successfully operated and maintained by fleet personnel for one year.
Operates successfully with air pressures up to 10 torr in vacuum chamber.
Minute helium leaks found between vacuum chamber and high pressure helium volume.
Tends to lose helium charge at ambient temperatures below -20° C.
Passed MIL-T-5422E environmental tests (Class 1A equipments) of temperature and altitude, vibration, shock, humidity, salt spray, and explosive atmosphere except that the unit fails to cool properly at ambient temperatures below -26° C and the maximum acceleration required in the vibration test was reduced from 10g to 5g.

Manufacturer	Malaker Corporation	
Trade Name/Model	Cryomite Mark VII C	
Type	Air cooled, single stage, Stirling cycle	
Configuration	Double side fan	
Serial Numbers	118, 119, 120, 121, 122	148
Contract Numbers	DA-28-043-AMC-01672(Y)	N62269-67-C-0398
Contract Dates	-	13 February 1967
Delivery Dates	Delivered as parts of AN/AAD-2(XE-2) infrared detecting sets. First delivery in October 1966.	13 April 1967
Time Operated	Range of values from 50 to 322 hours	
Cost	-	$6050
Volume	240 cu in.	
Weight	18.5 pounds	
Input Power at Minimum Temperature	480 watts	
Minimum Temperature Achieved	21° K	
Cool-Down Time to 25° K	12 minutes	
Cooling Power at 25° K	1.5 watts	
Working Gas and Pressure	Helium at 250 PSIG	
Working Gas Hold Time	6 months	
Vacuum Hold Time	4 to 5 days	

Remarks

Induces some noise in the output of some infrared detectors.
High acoustic noise level, some vibration.
Compact, rugged, generally reliable.
Maintains temperature well.
Experienced considerable airborne use.
Successfully operated and maintained by fleet personnel for more than two years in an operational environment.
Operates successfully with air pressures up to 10 torr in vacuum chamber.
Minute helium leaks found between vacuum chamber and high pressure helium volume.

Manufacturer	Malaker Corporation
Trade Name/Model	Cryomite Mark XIII
Type	Air cooled, single stage, Stirling cycle
Configuration	Right angle with separate starter box
Serial Number	3
Contract Number	N62269-3251
Contract Date	24 June 1965
Delivery Date	30 November 1965
Time Operated	194 hours
Cost	$7885
Volume	285 cu in. (including starter box)
Weight	21.0 pounds
Input Power at Minimum Temperature	440 watts
Minimum Temperature Achieved	23° K
Cool-Down Time to 25° K	16 minutes
Cooling Power at 25° K	1.0 watt
Working Gas and Pressure	Helium at 250 PSIG
Working Gas Hold Time	4 months
Vacuum Hold Time	4 to 5 days

Remarks

Generally induces a higher noise level in the output of infrared detectors than Mark VII C.
High acoustic noise level, more vibration than Mark VII C.
Compact, rugged, reliable.
Maintains temperature well.

Manufacturer	North American Philips Company, Incorporated
Trade Name/Model	Cryogem Model 42325
Type	Liquid cooled, two stage, Stirling cycle
Configuration	Right angle with separate heat exchanger
Serial Numbers	F-95 F-96
Contract Number	N62269-2372
Contract Date	2 December 1963
Delivery Date	30 January 1964
Time Operated	389 hours 189 hours
Cost	$7465
Volume	520 cu in. (including heat exchanger)
Weight	26 pounds (including heat exchanger)
Input Power at Minimum Temperature	650 watts (including heat exchanger)
Minimum Temperature Achieved	19° K
Cool-Down Time to 25° K	12 minutes
Cooling Power at 25° K	1.0 watt
Working Gas and Pressure	Helium at 125 PSIG
Working Gas Hold Time	20 hours of operation
Vacuum Hold Time	1 day

Remarks

Induces little noise in the output of infrared detectors.
Subject to helium contamination and leakage.
High acoustic noise level, some vibration.
Liquid cooled, separate heat exchanger. Design inconvenient.
Consistently exhibits temperature increase with operating time.
Will operate successfully with air pressures up to 10 torr in vacuum chamber.
Working gas hold time is limited by helium contamination.
Refrigerator must be purged and recharged after 20 hours of operation to restore indicated performance.

Manufacturer	North American Philips Company, Incorporated
Trade Name/Model	Cryogem Model 42145
Type	Air cooled, two stage, Stirling cycle
Configuration	Right angle
Serial Number	F-427
Contract Number	N62269-3293
Contract Date	30 August 1965
Delivery Date	26 July 1966
Time Operated	135 hours
Cost	$7850
Volume	290 cu in.
Weight	15 pounds
Input Power at Minimum Temperature	416 watts
Minimum Temperature Achieved	19° K
Cool-Down Time to 25° K	12 minutes
Cooling Power at 25° K	1.0 watt
Working Gas and Pressure	Helium at 125 PSIG
Working Gas Hold Time	1 month
Vacuum Hold Time	10 to 15 days

Remarks

Induces excessive noise in the output of infrared detectors.
Slight helium leakage.
High acoustic noise level, excessive vibration.
Compact.
Maintains temperature.

Manufacturer	Hughes Aircraft Company
Trade Name/Model	Model X461307 Mark IV/25
Type	Air cooled, two stage, Stirling cycle
Configuration	Right angle with slip-on detector-dewar
Serial Number	1
Contract Number	N62269-3262
Contract Date	30 June 1965
Delivery Date	24 June 1966
Time Operated	237 hours
Cost	$27,130 (including two Ge:Hg detectors)
Volume	260 cu in. (including detector-dewar)
Weight	14 pounds (including detector-dewar)
Input Power at Minimum Temperature	632 watts
Minimum Temperature Achieved	23° K (with detector-dewar)
Cool-Down Time to 25° K	12 minutes (with detector-dewar)
Cooling Power at 25° K	1.0 watt
Working Gas and Pressure	Helium at 140 PSIG
Working Gas Hold Time	2 months
Vacuum Hold Time	At least 1 year expected with sealed dewar

Remarks

Induces little noise in the output of infrared detectors.
Slight helium leakage.
Water collects in air space between cold finger and dewar; dewar must be removed after several runs to be cleaned.
Glass dewar somewhat fragile.
Cooler-dewar unit fairly rugged, reliable, compact.
Maintains temperature well.
Has experienced considerable airborne use.

Manufacturer	Fairchild Stratos Corporation
Trade Name/Model	Dual Loop Cryostat and Compressor System
Type	Air cooled, cascaded dual loop, Joule-Thomson system
Configuration	Separate cryostat and compressor
Serial Number	0012
Contract Number	N62269-2437
Contract Date	19 February 1964
Delivery Date	29 September 1964
Time Operated	112 hours
Cost	$15,244
Volume	1765 cu in.
Weight	52 pounds
Input Power at Minimum Temperature	1000 watts
Minimum Temperature Achieved	23° K
Cool-Down Time to 25° K	50 minutes
Cooling Power at 25° K	0.5 watt
Working Gas and Pressure	Nitrogen at 60-70 PSIG Hydrogen at 35-40 PSIG
Working Gas Hold Time	4 months
Vacuum Hold Time	1 day

Remarks

Induces no noise in the output of infrared detectors.
Subject to plugged gas lines and orifices, gas leaks.
High acoustic noise level, considerable vibration from compressor.
Vibrationless cold head.
Heavy, cumbersome.
Maintains temperature well.
Refrigeration capacity is marginal.
Operated in laboratory only.

Manufacturer	Malaker Corporation
Trade Name/Model	Cryomite Mark XIV
Type	Air cooled, single stage, Stirling cycle
Configuration	Inline with separate starter box
Serial Number	51
Contract Number	N62269-67-C-0376
Contract Date	19 December 1966
Delivery Date	27 November 1967
Time Operated	17 hours
Cost	$9115
Volume	81 cu in. (including starter box)
Weight	6.5 pounds
Input Power at Minimum Temperature	88 watts
Minimum Temperature Achieved	45° K
Cool-Down Time to 77° K	9 minutes
Cooling Power at 77° K	2.2 watts
Working Gas and Pressure	Helium at 150 PSIG
Working Gas Hold Time	Not known
Vacuum Hold Time	Not known

Remarks

Induces little noise in the output of an infrared detector.
Low acoustic noise level, little vibration.
Compact.
Data given are preliminary.

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13. ABSTRACT

Miniature closed-cycle cryogenic refrigerators are required to maintain photoconductive and photovoltaic infrared detectors used in airborne passive infrared surveillance devices at their proper operating temperatures in the range of 21° to 90° K. Characteristics, methods of evaluation, results of tests, and photographs of nine such cryostats are presented.

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