NASA CR-175116

FINAL REPORT

DESIGN, CONSTRUCTION AND LONG LIFE ENDURANCE TESTING OF CATHODE ASSEMBLIES FOR USE IN MICROWAVE HIGH-POWER TRANSMITTING TUBES

By:

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Prepared For:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

September 1986

CONTRACT NAS 3-23346
(formerly NAS 3-22335)

NASA-Lewis Research Center
21000 Brookpark Road
Cleveland, Ohio 44135
Edwin G. Wintucky, Project Manager
Electron Beam Technology Branch, Space Communications Division

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16. Abstract

The cathode life test program sponsored by NASA Lewis Research Center at Watkins-Johnson Company has been in continuous operation since 1972. The primary objective of this program has been to evaluate the long life capability of barium dispenser cathodes to produce emission current densities of 2 A/cm^2 or more in an operational environment simulating that of a high-power microwave tube. The life test vehicles were equipped with convergent flow electron guns, drift space tubes with soldenoid magnets for electron beam confinement and water-cooled depressed collectors.

Over the years, a variety of cathode types have been tested, including GE Tungstate, Litton Impregnated, Philips Type B and M, Semicon Types S and M, and Spectra-Mat Type M. Recent emphasis has been on monitoring the performance of Philips Type M cathodes at 2 A/cm^2 and Sprectra-Mat and Semicon Type M cathodes at 4 A/cm^2. These cathodes have been operated at a constant current of 616 mA and a cathode/anode voltage on the order of 10 kV. Cathode temperatures were maintained at 1010°C true as measured from black body holes in the backs of the cathodes. This report presents results of the cathode life test program from July 1982 through April 1986. The results include hours of operation and performance data in the form of normalized emission current density versus temperature curves (Miram plots).

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FOREWORD

The work described herein was done at the Watkins-Johnson Company, under NASA Contract NAS 3-23346 (formerly NAS 3-22335) with Edwin G. Wintucky, Electron Beam Technology Branch, Space Communications Division, NASA-Lewis Research Center, as Project Manager.

The program is not currently active, having reached the end of the latest funding period. Its continuation will be the result of an open solicitation, in accordance with recently enacted government procurement regulations.

ABSTRACT

The cathode life test program sponsored by NASA Lewis Research Center at Watkins-Johnson Company has been in continuous operation since 1972. The primary objective of this program has been to evaluate the long life capability of barium dispenser cathodes to produce emission current densities of 2 A/cm^2 or more in an operational environment simulating that of a high-power microwave tube. The life test vehicles were equipped with convergent flow electron guns, drift space tubes with solenoid magnets for electron beam confinement and water-cooled depressed collectors.

Over the years, a variety of cathode types have been tested, including GE Tungstate, Litton Impregnated, Philips Type B and M, Semicon Types S and M, and Spectra-Mat Type M. Recent emphasis has been on monitoring the performance of Philips Type M cathodes at 2 A/cm^2 and Spectra-Mat and Semicon Type M cathodes at 4 A/cm^2. These cathodes have been operated at a constant current of 616 mA and a cathode/anode voltage on the order of 10 kV. Cathode temperatures were maintained at $1010^{\circ}C$ true as measured from black body holes in the backs of the cathodes. This report presents results of the cathode life test program from July 1982 through April 1986. The results include hours of operation and performance data in the form of normalized emission current density versus temperature curves (Miram plots).

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FINAL REPORT

1.0 SUMMARY

This final report covers the period from July 1982 through April 1986, for a program to life test cathode assemblies for use in microwave high-power transmitting tubes.

The primary objective of this program has been to evaluate the long life capability of barium dispenser cathode operating at current densities of $2A/cm^2$ and $4A/cm^2$ in an environment similar to that of high-power microwave tubes.

The table below summarizes the cathode types tested during this reporting period. All units used the 5:3:2 ($BaO:CaO:Al_2O_3$) impregnant mixture.

TABLE I

	Type	Loading	Quantity Tested	Unit Designations
1.	Philips (Type B) impregnated	$2A/cm^2$	1	P4
2.	Litton impregnated	$2A/cm^2$	1	L5
3.	Philips (Type M) impregnated	$2A/cm^2$	4	M-1, -3, -4, -6
4.	Spectra-Mat (Type M) impregnated	$4A/cm^2$	3	SP-2, -3, -4
5.	Semicon (Type M) impregnated	$4A/cm^2$	3	SM-1, -2, -3

The cathodes are incorporated into an electron gun of metal-ceramic construction. The electron beam is focused through a drift tube with a magnetic field. The electrons are finally collected on a liquid-cooled depressed collector.

The original activation schedules, cathode selection and life test procedures were formulated and approved by the manufacturer for each of the cathode types.

The following parameters were monitored during the test:

a) Cathode current (at constant cathode temperature and anode voltage);

b) Anode voltage needed for full emission (at constant cathode temperature);

c) T-80 temperature (cathode temperature which results in 80% of full emission at reference anode voltage);

d) Miram curves (these are normalized cathode current vs. temperature plots).

Results obtained to date include the following:

1. One Litton cathode (L-5N) successfully completed 39,230 hours of operation. Over its life emission decreased by 5%.

2. One Philips Type B cathode successfully completed 75,000 hours of operation. Over its life emission decreased by 7%.

3. All four of the Philips Type M cathodes, operating at 1010°C true, showed improved emission over the first 10,000 hours to 20,000 hours of life. Average operating time on these units is 62,055 hours (range 51,083 to 78,961 hours) with an average emission level of 95% (range 93% to 99%).

4. Two Spectra-Mat units (the third experienced a vacuum leak recently) ran on test at 1010°C true cathode temperature with $4A/cm^2$ loading. The behavior of these units is similar to Philips Type M cathodes. Operating time range on these units is 35,116 hours to 43,508 hours with cathode emission level from 93% to 94% of the original. There is a significant change in rounding of the knee.

5. Three Semicon Type M cathodes were on test at 1010°C true cathode temperature, with $4A/cm^2$ loading. The behavior of these units is also similar to Philips Type M cathodes. Operating time on these units varies from 23,606 hours to 42,704 hours and emission level from 94% to 96% of the original level. Knee temperature was stable over the operating life of 18,000 hours to 40,000 hours.

6. Miram curves have provided an excellent tool to get an insight into the condition of the cathodes. For stable cathode performance, the operating temperature should be such that emission is fully space charge limited (FSCL). These curves were analyzed to project the life of the cathodes (end of cathode life is defined as the time when knee temperature is equal to the operating temperature). As expected, the projected useful life is longer for lower current density at constant operating temperature. The projected life for various cathodes at $2A/cm^2$ is: Philips Type M, 64,000 hours to 80,000 hours; Spectra-Mat Type M, 60,000 hours to 111,000 hours; and Semicon Type M, 63,000 hours to 83,000 hours.

   Miram curves reflect the influence of several factors such as gun structure, uniformity of loading, perveance change and cathode performance. It is difficult to sort out the effect of each variable separately.

7. Type M cathodes from Philips, Spectra-Mat, and Semicon have demonstrated excellent performance stability as compared to all other types of cathode tested to date.

8. The status of various cathode types tested to date is included in Table II (NASA Life Test Data). M Type cathodes from Philips, Spectra-Mat and Semicon are the only ones that are presently active.

   For the sake of completeness, some results are presented for cathodes tested prior to the time period covered by this report.

Table II

NASA LIFE TEST DATA

April 1986

	S/N	Loading (A/cm^2)	Emission (% from Initial)	Operating Hours Total	Operating Temp (°C True)	Failed At
Semicon	S2	2	-12		1060-1100	23,073
Type S	S6	2	-11		1060-1100	20,530
(4:1:1)	S7	2	-9		1060	7,189
	S9	2	-12		1060-1100	21,242
Philips	P4	2	-7.1		1100	*** 75,394
Type B	P5	2	-6.5		1100	** 26,987
(5:3:2)	P6	2	-6.3		1100	** 47,933
	P7	2	-8		1100	26,932
Philips	M1	2	-7.1	78,961	1010	
Type M	M3	2	-6.0	56,629	1010	
(5:3:2)	M4	2	-1.0	61,548	1010	
	M6	2	-6.2	51,083	1010	
Litton	L-1N	2	-2.6		1100	*** 8,081
(5:3:2)	L-3N	2	-7.5		1100	*** 28,976
	L-5N	2	-5.0		1100	** 39,230
	L-6N	2	-9.4		1100	23,171
General	T1	2	-12		1000	6,807
Electric	T5	2	-10		1000	** 3,768
Tungstate	T7	2	-14		1000	2,636
	T8	2	-10		1000	4,924
	T10	2	-10		1000	4,628
Spectra-Mat	SP-2	4	-6.7		1010	** 38,781
Type M	SP-3	4	-6.2	43,508	1010	
(5:3:2)	SP-4	4	-6.0	35,116	1010	
Semicon	SM-1	4	-4.1	42,704	1010	
Type M	SM-2	4	-5.8	40,616	1010	
(5:3:2)	SM-3	4	-3.9	23,636	1010	

* Emission value not updated this period.
** Removed from test due to non-cathode failure.
*** Removed from test to allow another unit to be tested.

2.0 INTRODUCTION

This Final Report covers the period from July 1982 through April 1986 for a program to life test cathode assemblies for use in high-power microwave transmitting tubes. Previous reports covering the period from June 1971 through November 1982 contain additional information about the program.* The program is sponsored by National Aeronautics and Space Administration under Contract No. NAS 3-23346 (formerly NAS 3-22335).

2.1 Background

The NASA-Lewis Research Center has been conducting a number of studies leading toward development of reliable long-life power microwave transmitters for broadcasting from space. The life and reliability of the electron beam device is largely determined by the lifetime of the cathode thermionic emitter and the cathode-heater electron gun assembly. Improvement in performance and verification of life endurance tests performed on several cathode types is, therefore, of vital importance to long-life transmitter operation in space.

2.2 Objectives

The objectives of this investigation are to:

1. Demonstrate the ability of state-of-the-art cathode types to produce current densities of $2A/cm^2$ and $4A/cm^2$, respectively, over a minimum design life of 30,000 hours of continuous operation without failure; and

2. To competitively evaluate the performance of the state-of-the-art cathode types by endurance testing while operating under identical electrical, geometrical, and vacuum conditions that realistically duplicate the operating conditions present in a transmitter tube.

2.3 Program Approach

Although there has been considerable life testing done on high current density cathodes, these have been primarily limited to diodes. A diode and a high-power microwave tube are grossly different devices. A comparison of these two devices is provided in Table III. Based on the differences identified in the table, one could assume different internal environments, especially in the cathode region. Therefore, in order to establish life capabilities of the cathodes described, they should be tested in a vehicle which has an internal environment similar to that of a high-power microwave tube.

*References 3, 4, 5, 6 and 7.

TABLE III

COMPARISON OF A DIODE AND

A HIGH-POWER MICROWAVE TUBE

Items	Diode	High-Power Tube
Electrode Spacings	Close	Wide
Operating Voltage	Usually Low	High
Ion Barrier	No	Yes
Beam Collection	On Anode	On a Depressed Collector
Type of Electron Gun	Planar Diode	Convergent Flow
Electron Beam Focusing	No	Yes, with Magnetic Field
Type of Construction	Usually glass but can be metal-ceramic	Metal-Ceramic

This life test program uses a cathode life tester which is essentially the same as a high-power microwave tube. The only difference between the cathode life test unit and a high-power microwave tube is that the former uses a metal drift tube in place of the RF interaction circuit employed in the latter. The cathode life test unit has a convergent-flow electron gun. The electron beam is focused through the drift tube by a solenoid which produces the correct magnetic field in the gun region for confined-flow focusing. The anode potential is operated above the body, providing an ion barrier to the cathode region. A depressed collector is used to collect the electron beam emerging from the body. An ion vacuum pump is attached to the collector to ensure low residual gas pressure.

The cathode life test unit design is of all metal-ceramic construction. Wherever possible (e.g., the gun header), well-proven designs which were evolved at Watkins-Johnson Company are used in the test units. All vacuum junctions are conservatively designed to assure a rugged and reliable configuration.

2.4 Cathode Types Tested

Cathode types to be tested were originally selected based on the criterion that those chosen would be capable of operation at $2A/cm^2$ for over 20,000 hours. This objective has been modified to include cathodes operating at both $2A/cm^2$ and $4A/cm^2$ to meet a minimum design life of 30,000 hours continuous operation. These cathodes are of various types, and supplied by several different sources. Cathode types tested to date are summarized in Table IV below.

TABLE IV

	Type	Mix	Loading	Quantity Tested
1.	Philips (Type B) impregnated	5:3:2	$2A/cm^2$	4
2.	Semicon (Type S) impregnated	4:1:1	$2A/cm^2$	4
3.	General Electric Tungstate	----	$2A/cm^2$	5
4.	Litton impregnated	5:3:2	$2A/cm^2$	4
5.	Philips (Type M) impregnated	5:3:2	$2A/cm^2$	4
6.	Spectra-Mat (Type M) impregnated	5:3:2	$4A/cm^2$	3
7.	Semicon (Type M) impregnated	5:3:2	$4A/cm^2$	3

2.4.1 Semicon Type S. This is a standard impregnated tungsten cathode supplied by Semicon Corporation. The Type S cathode uses a 4:1:1 ($BaO:CaO:Al_2O_3$) impregnant mixture. The density of this cathode is 86% of true tungsten density.

2.4.2 Philips Type B. This is a standard impregnated tungsten cathode supplied by Philips Metalonics. The Type B cathode uses a 5:3:2 ($BaO:CaO:Al_2O_3$) impregnant mixture. The density of this cathode is 83% of true tungsten density.

2.4.3 General Electric Tungstate. This is a cathode type developed at General Electric Company[1, 2] and consists of a mixture of approximately 90% tungsten, 9% tungstate compound ($Ba_5Sr(WO_6)_2$), and 1% ZrH_2, which is pressed and sintered into a matrix at high temperature.

2.4.4 Litton Impregnated. This is an impregnated cathode similar to the Philips Type B, using a 5:3:2 mixture. Litton Industries does not normally fabricate cathodes except for use in their own products. However, Litton has supplied high-power space TWTs to NASA which incorporate these cathodes. Therefore, it was felt that life test information on this cathode type would be of great value.

2.4.5 Philips Type M. This is a standard impregnated cathode (Philips Type B, 5:3:2 mixture) which has been sputter deposited with a coating of osmium and ruthenium. As a result, the work function of the material is lowered so that operation at lower temperatures is possible.

2.4.6 Semicon and Spectra-Mat Type M. These Type M cathodes are both similar to the Philips Type M, but are presently obtainable from existing manufacturers, unlike the Philips Type M. Both use a 5:3:2 impregnant mixture. These Type M cathodes are designated to be run at $4A/cm^2$ cathode loading.

2.5 Identification of Cathode Life Test Units

Prefix identification of the life test units is as follows:

"T" - General Electric Tungstate
"S" - Semicon Type S
"L" - Litton
"P" - Philips Type B
"M" - Philips Type M
"SP" - Spectra-Mat Type M
"SM" - Semicon Type M

In each case, the prefix is followed by a numeral to denote the individual life test unit.

2.6 Definition of Failure (End of Life)

For the purpose of this contract, the cathode end of life is defined as the time when the cathode emission has dropped by 10% or more from the initial value due to the failure of the cathode itself, the heater, or the entire electron gun assembly.

3.0 CATHODE LIFE TEST UNITS AND TEST FACILITIES

The life test units were originally designed to simulate the environment of a 12.2 GHz TWT operating at up to 4 kW CW. The units are solenoid focused and incorporate an electron gun, drift space, and depressed collector similar to those used in a TWT. Specifications and operating conditions for the units are summarized in Table V. Note that the $4A/cm^2$ cathode emitter surface area is half that of the $2A/cm^2$ cathode. Thus, the cathode loading is exactly doubled on the $4A/cm^2$ units for the same cathode current. Only minor design changes were necessary to incorporate this smaller cathode into the existing life test vehicle. Figures 1, 2 and 3 show construction details of both types of life test vehicles. Figures 4 and 5 picture the life test vehicles in the test stations. Figure 6 outlines the life test station circuitry.

Each unit is fitted with a 5 liter/sec vac-ion pump. The cathode temperature can be measured pyrometrically by viewing through a sapphire window located behind the cathode. A hinged metal flap protects the inside surface of the view-ports from deposits when not in use; it can be opened with a magnet. A small blackbody hole is drilled into the back of each cathode to allow measurement of the true temperature. Additional details of the design and construction of the life test units, as well as the life test facility, are given in previous reports on this project.*

*References 3 and 6.

TABLE V

PARAMETERS FOR THE CATHODE LIFE TEST UNITS

	$2A/cm^2$		$4A/cm^2$
Anode Voltage		Approx. 10,000V	
Cathode Current		0.616 A	
Gun Perveance		0.60-0.65 micropervs	
Cathode Diameter	0.240 inches (6.10 mm)		0.170 inches (4.32 mm)
Cathode Curvature Radius	0.315 inches (8.00 mm)		0.223 inches (5.66 mm)
Cathode Half Angle		22 degrees	
Mean Cathode Loading	$2A/cm^2$		$4A/cm^2$
Max./Min. Cathode Density Ratio		1.175	
Minimum Beam Diameter	0.029 inches (.737 mm)		0.032 inches (.813 mm)
Beam Area Convergence Ratio	67:1		28:1
Brillouin Field		1745 gauss	
Body (Drift Tube) Voltage		6-8 kV	
Collector Voltage		Approx. 4 kV	
Focusing Type		Confined Flow 86% Cathode Flux Immersion	
Maximum Magnetic Field		Approx. 3000 gauss	
Collector		Liquid Cooled	

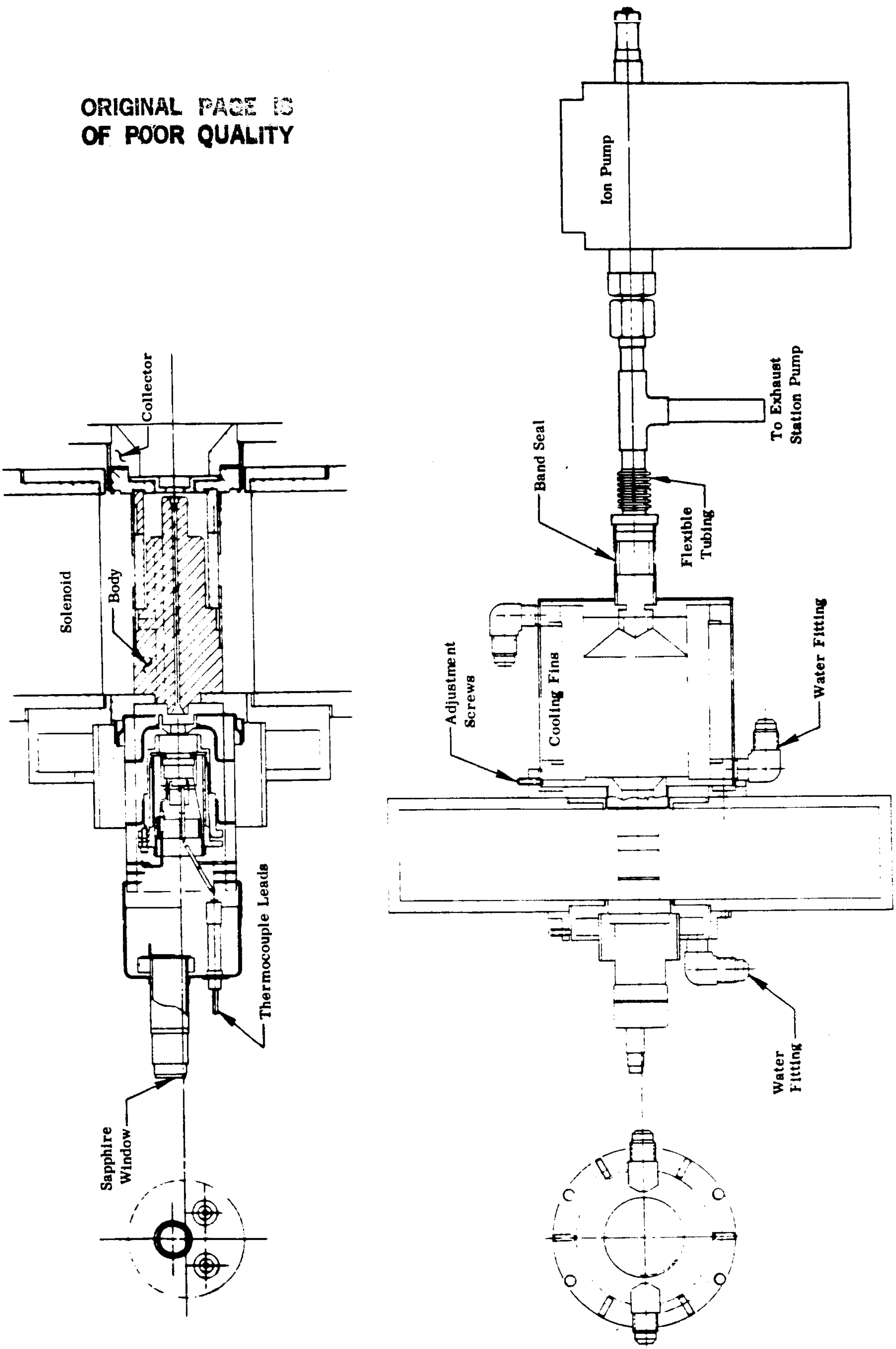

Figure 1. Design Layout of the Cathode Life Test Unit

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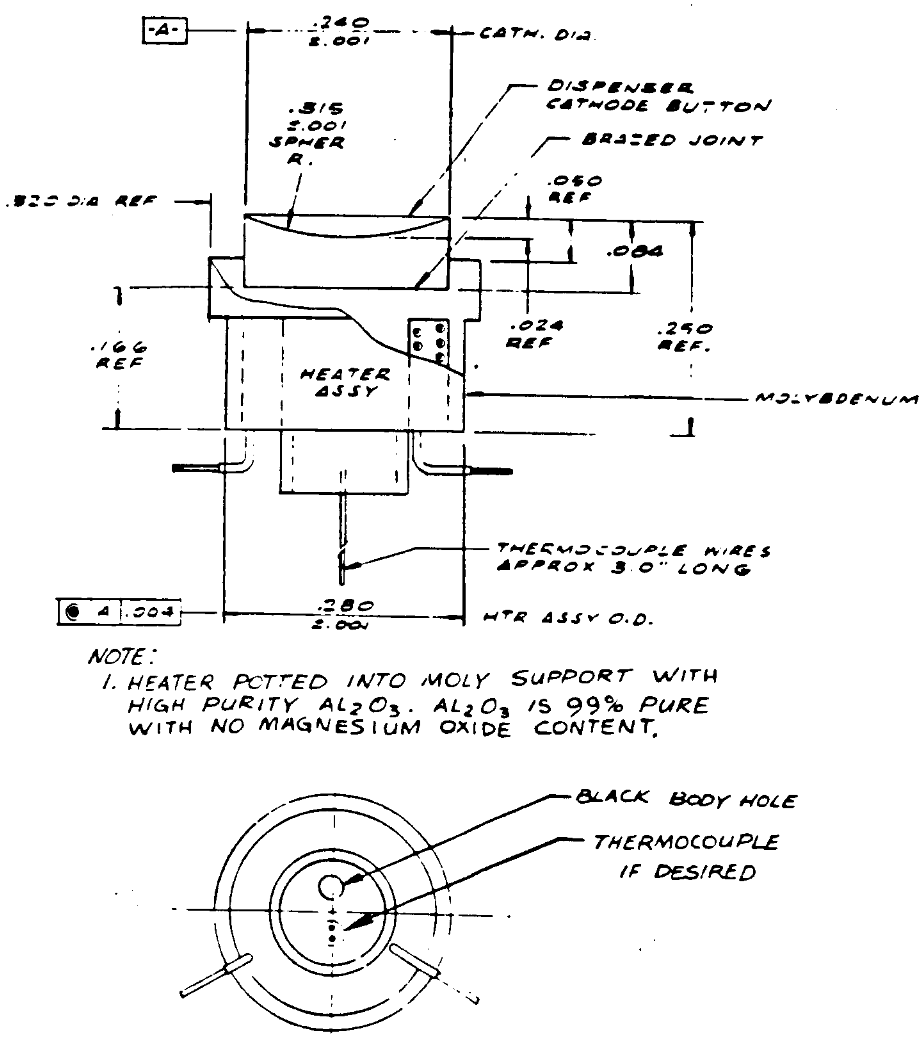
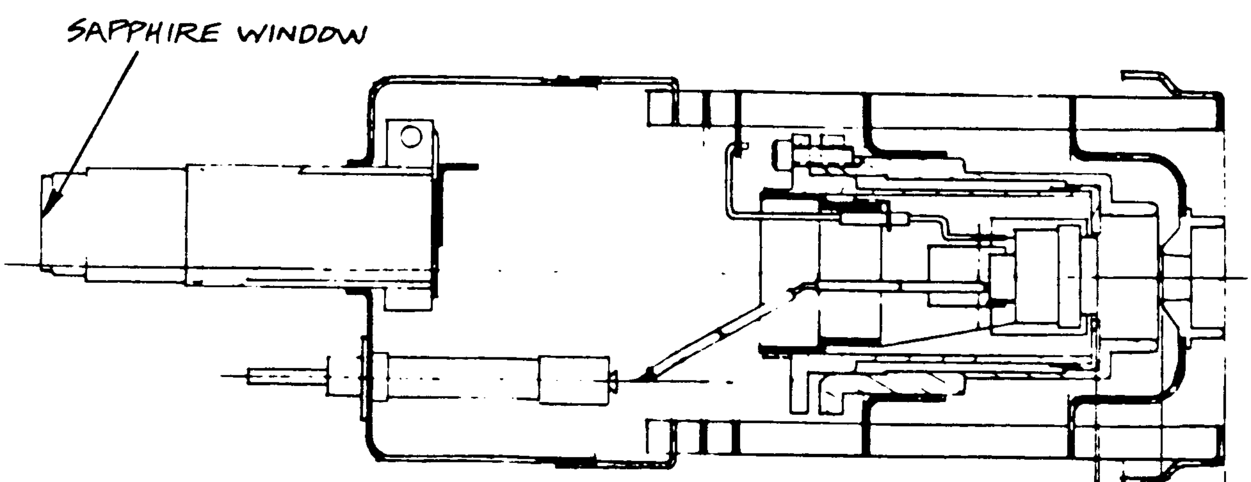


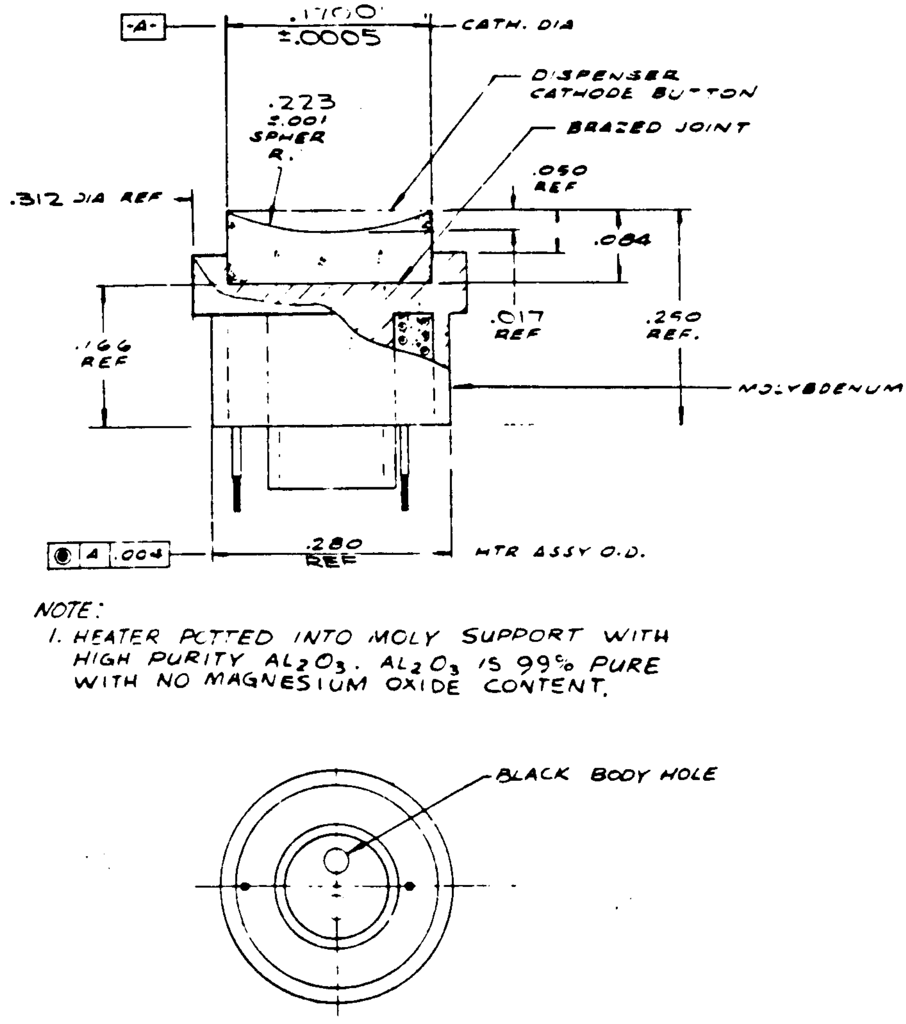
CATHODE DETAIL



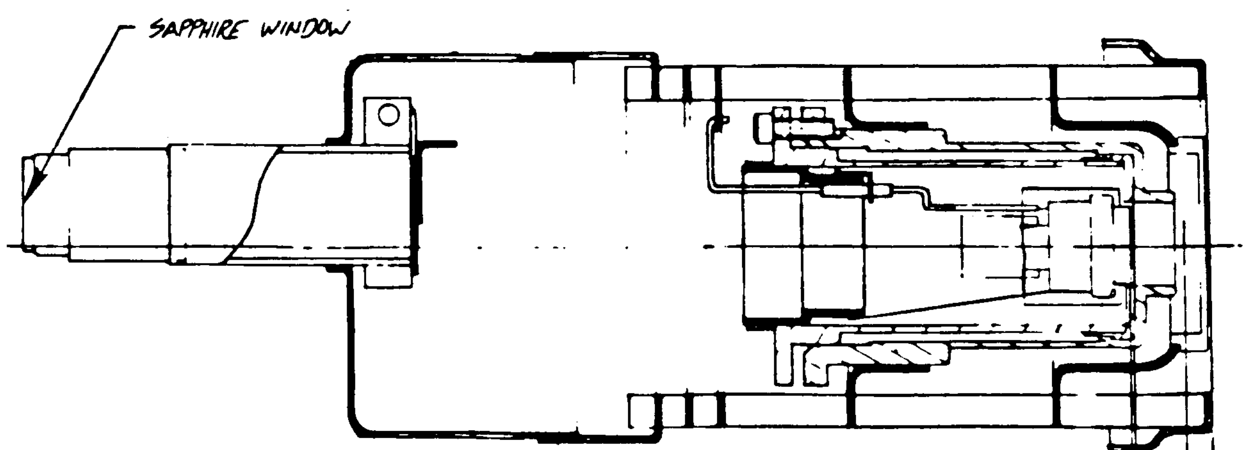
GUN DETAIL

Figure 2. Cathode and Gun Construction Detail ($2A/cm^2$)

aa24967 B



CATHODE DETAIL



GUN DETAIL

Figure 3. Cathode and Gun Construction Detail (4A/cm^2)

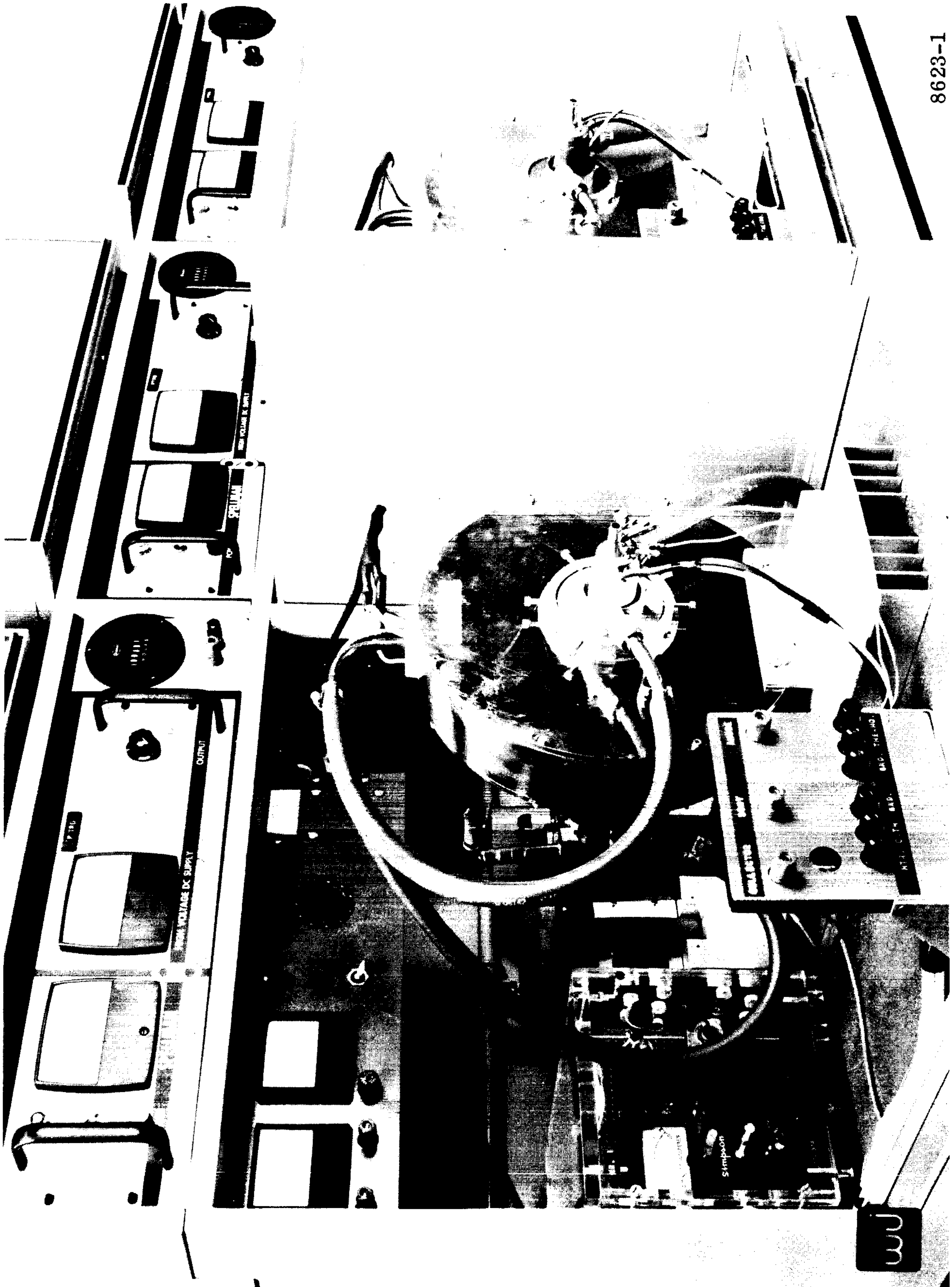


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Figure 4 - Photograph of a Cathode Life Test Unit Installed in the Life Test Station

PAD-339/14

8623-2

Figure 5 - Photograph of the Life Test Station Showing the Benches in Various Stages of Assembly

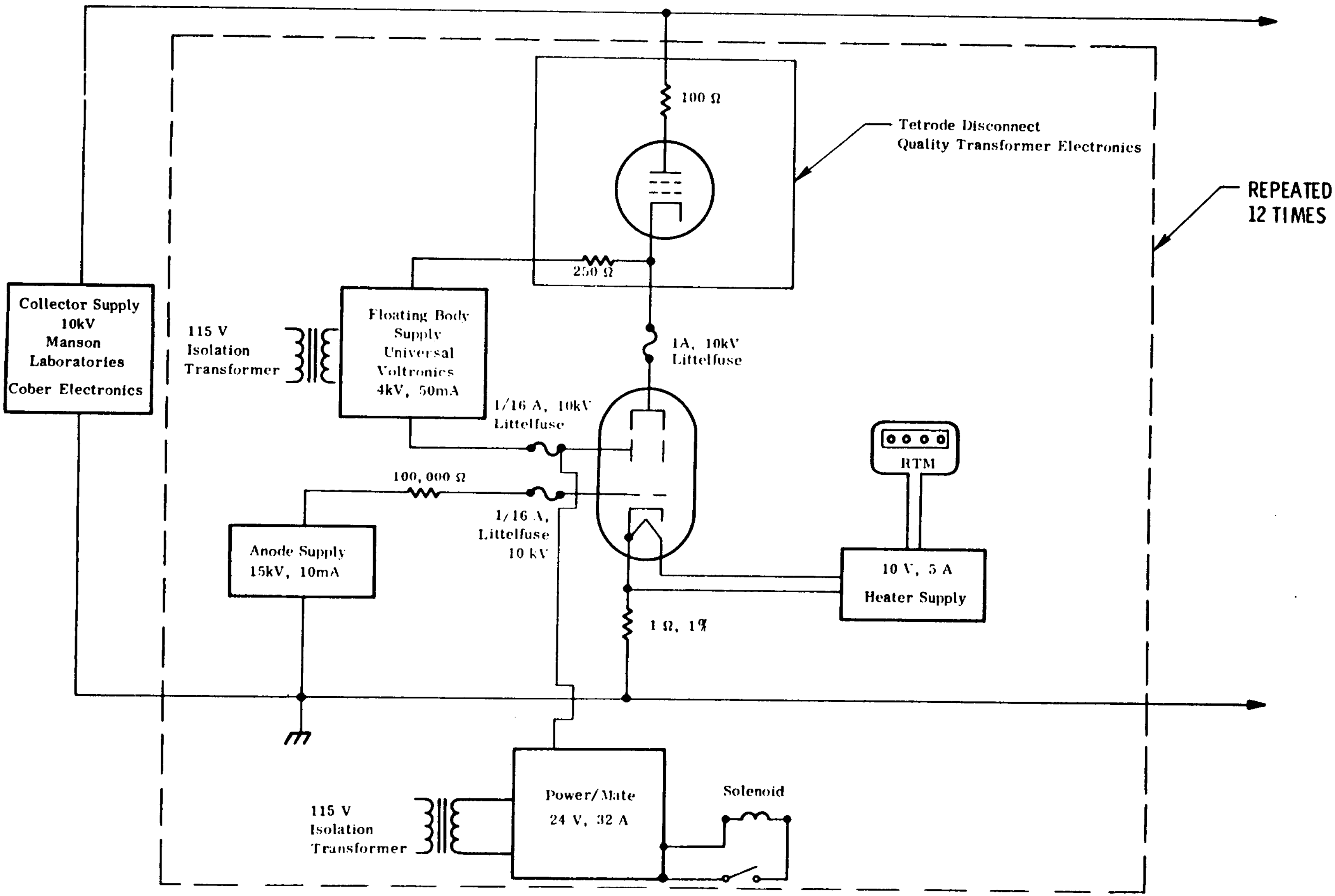

Figure 6. Block Diagram Showing Circuit and Power Supply Arrangement

4.0 LIFE TEST PROCEDURE

Throughout the operation of this life test, three types of periodic tests are performed, as follows:

1. Daily Checks - Brief visual checks are made of the tubes and equipment in order to assure no abnormalities have occurred since the previous check.

   A daily performance check consisting of the following is done on each unit.

   a) Reset voltages if required.

   b) Record filament voltage and current, cathode current, anode and body voltages and currents, and collector voltage.

   c) Record date and accumulated running hours.

2. T-80 Test - This test, performed monthly on each unit, is done as follows:

   a) With cathode at the correct operating temperature, adjust anode voltage to achieve $2A/cm^2$ or $4A/cm^2$ loading (616 mA cathode current in either case), and record this anode voltage.

   b) With cathode still at operating temperature, change anode voltage to the reference anode voltage. (Reference anode voltage is that value of voltage which was required to give full emission early in the tube's life. The value is then used in every T-80 test done thereafter.) Record resulting cathode current.

   c) With reference anode voltage set, reduce filament voltage to lower cathode temperature. When cathode current falls to 500 mA (80% of full 616 mA current), measure cathode temperature pyrometrically and record.

   d) Return cathode to correct operating temperature, and reset anode voltage to that required for 616 mA cathode current.

3. Miram Curves - Since June of 1983, Miram curves have been taken for each cathode. These are normalized cathode current vs. temperature plots. These curves are an excellent tool to gain an insight into the operating conditions of the cathode. Change in knee temperature is used to project the useful life of the cathode at a given current density. These curves are scheduled to be taken at approximately six-month intervals.

The following four sections explain in further detail the procedure for current, voltage, temperature, T-80 measurements and the Miram curves.

4.1 Voltage and Current Measurements

a) In interpreting voltage and current measurements, allowance should be made for the following:

(1) Collector voltage is obtained from an unregulated power supply which also produces considerable ripple voltage. The tetrode disconnect unit in series with this supply also contributes a variable voltage drop depending on the characteristics of the tetrode pass tube; this varies from tube to tube and changes with time.

(2) At various times during the test, it is necessary to perform maintenance on the test station, as for example when a coolant leak develops. Such maintenance is likely to disturb the mechanical alignment of the life test unit in the solenoid.

(3) Some units develop leakage current during the tests.

(Items 1 and 2 represent conditions which affect focusing.)

b) Measurements

(1) Anode Voltage and Current - Anode voltage is obtained from a regulated DC power supply which can be reliably set with an accuracy of $\pm 1\%$. Anode voltage is measured by using an accurate voltage divider and a calibrated digital voltmeter.

Anode current is measured directly from the anode power supply panel meter and is considered accurate to ± 0.1 mA. Anode current may be due to leakage, beam interception, or back streaming of secondary electrons.

(2) Cathode Current - Cathode current is monitored by noting the voltage drop across a 1 ohm $\pm 0.1\%$ precision resistor in series with the cathode lead. These readings are considered to be accurate to better than $\pm 1\%$ and cathode current is setable to better than 1% by means of the anode voltage. Cathode current is maintained at 616 mA (2A/cm^2 or 4A/cm^2, depending on unit) by means of adjustment of anode voltage at fixed cathode operating temperature.

(3) Heater Voltage and Current - Heater voltage and current are obtained from an ac power supply that is powered from a regulated line source. Heater voltage is measured using a calibrated voltmeter. Current is read from the power supply panel meter. Voltage readings are considered accurate to within ± 0.02 V. Current readings are considered accurate to within ± 0.1 amp.

(4) Collector and Body Current and Voltage - Collector voltage is supplied by a common collector supply at a nominal 5000 V. However, as previously noted, there is a 500-1500 volt drop through the tetrode disconnect units. Ripple is also high. Body current also may be due to leakage, interception, electron backstreaming or secondary emission. This last effect may contribute a negative component to the body current.

Body and collector voltages are monitored by means of a voltage divider and calibrated voltmeter. Body current is read from the body supply panel meter and is considered accurate to within ± 0.25 mA.

4.2 Optical Pyrometer Measurements

Cathode temperature is, in principle, measurable to an accuracy of $\pm 3^{o}C$ by viewing through the sapphire window with an optical pyrometer. A blackbody hole is provided in the rear of the cathode for this purpose. It has been found, however, that measurements of this accuracy are very difficult to obtain in practice. A realistic accuracy is probably $+5^{o}C$ and $-15^{o}C$; i.e., it is unlikely that measurements are more than $5^{o}C$ higher than true temperature, but measurements of as much as $15^{o}C$ lower than the true temperature may occur. In addition, there is a correction ($10^{o}C \pm 1^{o}C$) that must be made for the sapphire window; true temperatures quoted in this report are $10^{o}C$ higher than those actually read from the pyrometer. Sources for error in these temperature measurements are as follows:

4.2.1 Misalignment of Pyrometer with Life Test Unit. This can cause a partial blockage of the field of view and can lead to measurement of temperature of $10^{o}C$ to $20^{o}C$ lower than true temperature.

4.2.2 Operator Inexperience. Following a change of personnel it has been noted that temperature readings are not always consistent with previous measurements and may be erratic. Considerable practice is required in order to obtain consistent results with the pyrometer.

4.2.3 Dirty Optical Windows. Although the sapphire view ports are routinely dusted and periodically cleaned, a thin surface film is sometimes not noticed. This can result in a lower reading.

4.3 T-80 Measurements

The quantity T-80 which has been selected as a measure of cathode activity is measured as follows: Following a 200 hour burn-in, a reference anode voltage is established that results in a cathode current of 616 mA ($2A/cm^2$ or $4A/cm^2$ loading, depending on unit) at operating temperature. T-80 is defined as that temperature for which the cathode current has dropped to 500 mA (80% of full emission). This quantity is measured by setting the anode to the reference anode voltage and slowly lowering the heater power until the cathode current is stable at 500 mA. The cathode temperature is then measured and recorded.

4.4 Miram Curves

Actual measurements are started with cathode temperature higher than the operating temperature. This prevents an insufficiently outgassed device from changing cathode performance during the measurements. Anode voltage is adjusted to obtain a current density of 2 or $4A/cm^2$. Cathode temperature is lowered and emission is measured at the previously determined anode voltage. A sufficient number of data points is taken to generate a smooth curve. The data for successive emission current density versus temperature measurements is obtained by repeating this procedure. The cathode temperature is initially adjusted to the same high value and then the anode voltage is adjusted to obtain a space charge limited current density which is 50% of the previous value.

The projected time at which the knee temperature intersects the operating temperature gives a conservative measure of end-of-life of the cathode. Note that it is a more stringent criterion than the definition of failure in paragraph 2.6, where ten percent drop in emission from the initial value defines a cathode failure. For plotting the curve, cathode current is normalized with the highest current measured. Knee temperature is defined as the intersection of the tangents along the space charge limited and the temperature-limited regions. End of useful life of the cathode can be projected by plotting knee temperature with time, and is defined as the time when knee temperature is equal to the operating temperature.

5.0 LIFE TEST RESULTS

This life test originally began with the testing of four each of the following cathode types: General Electric Tungstate, Semicon Type S, and Philips Type B. As failures occurred, the original units were replaced by Litton Impregnated and Philips Type M units. More recently, Type M cathodes manufactured by Spectra-Mat and Semicon have been put on test. During this reporting period, the following cathode types were tested: Litton Impregnated, Philips Type B, Philips Type M, Spectra-Mat Type M and Semicon Type M. Included in this section is a detailed discussion of each unit tested during this reporting period. Detailed information on individual units not discussed here can be found in previous reports.*

Figures 7 through 57 show graphed life test data and Miram curves for the cathodes tested during the period of time covered by this report. Additionally, some units were not operated during the period covered by this report, however, their plots are included for completeness. In these graphs, data taken at the monthly T-80 checks and Miram curves taken every six months are plotted as a function of operating hours. The graphed data can be described as follows:

1. T-Op (Operating Temperature) - This is the true temperature at which the tube normally operates.

2. T-80 - This is the temperature at which the cathode current has fallen to 80% of full emission with the anode set at the reference anode voltage.

3. Cathode Current at Reference Anode Voltage - This is the cathode current measured at the reference anode voltage with cathode at operating temperature.

4. Anode Voltage Required for Constant Cathode Current - This is the anode voltage required to maintain full emission (616 mA) at the cathode operating temperature.

Miram curves, when presented at several cathode current levels, provide highly useful insight into the operating condition of a cathode. While at a high current density, (e.g., 4.0 A/cm^2) it might be technically beyond the end of useful life, i.e., in the FTL or transition regions, at a lower density it could still be in the FSCL region with considerable margin remaining between the operating and the knee temperatures.**

In a similar manner, the plots of knee temperature versus operating hours, shown parametrically for various current levels, indicate the expected useful lifetime at various current densities. This assumes that the projection of linear change in knee temperature with operating time is valid. These observations underscore the fact that even though a cathode is being operated at given current density, the Miram curves taken at other (generally lower) densities, permit extrapolation of the remaining lifetime at any current density, or even at intermediate current levels, by interpolation.

The following is a discussion of the present status of the life test units tested to date, with reference to Figures 7 through 57.

*References 3, 4, 5.
**References 8 and 9.

5.1 Philips Type B Life Test Units

The cathode temperature for all of these life test units was set at 1100°C true from start of life. This cathode temperature was able to sustain the cathode loading of $2A/cm^2$. The activation schedule for this cathode is set forth in Appendix I. Figures 7 through 13 show the data accumulated for the four Type B cathodes tested. Unit P-4 operated successfully for 75,394 hours. Details on the individual units are to be found in the following discussion.

Results to date indicate that the Type B cathode is suitable for operation at $2A/cm^2$ for well over 20,000 hours, and that individual units could operate satisfactorily beyond 40,000 hours. However, a gradual decline in emission capability can be seen. This decline can be translated into a decrease in perveance of the electron beam. In a typical microwave tube this may cause some defocusing and performance degradation with life, the severity depending on the operating conditions of the particular device. Unit P-4 is the only Philips Type B cathode tested during this reporting period.

5.1.1 Unit P-4. This unit experienced a fairly intense arc at about 200 hours of life. The external arc on this unit was sufficiently severe that the electron gun had to be repotted. A high anode leakage current required that this tube be removed from test at about 9,000 hours. This condition was subsequently corrected using high voltage pulses to "burn off" the leakage.

This cathode was removed from test after 75,394 hours of operation to allow another unit to be tested. Emission drop over its life of 75,394 hours was 7.1%. During its life T-80 either held steady or increased gradually as shown in Figure 7.

The FSCL region has significant positive slope. It indicates there was a differential thermal motion between the cathode and gun electrodes. Miram curves in the FTL region are approximately evenly spaced, implying there were no cathode emission problems.

The knee is fairly rounded, indicating very uneven cathode loading or wide variation in the work function distribution. From 58,031 to 74,748 hours of operation of the cathode, the knee temperature changed by 12°C (from 1075°C to 1097°C). There is a minor change in rounding of the knee over the time span indicated above (Figures 8 and 9). Figure 10 shows minor changes in knee temperature with operating time.

5.1.2 Unit P-5. This unit developed a leak during initial processing at 500°C. The leak was sealed and the unit subsequently rebaked at 250°C. The unit was extremely gassy during initial life, but cleaned up sufficiently to allow life testing to begin. The unit operated satisfactorily until 27,000 hours of life, showing the characteristic upward trend of T-80 temperature and gradual decrease of cathode emission over time, see Figure 11. At 27,000 hours of operation, this unit developed a vacuum leak, and life testing had to be terminated. By this time, cathode emission had fallen to 93.5% of its initial value.

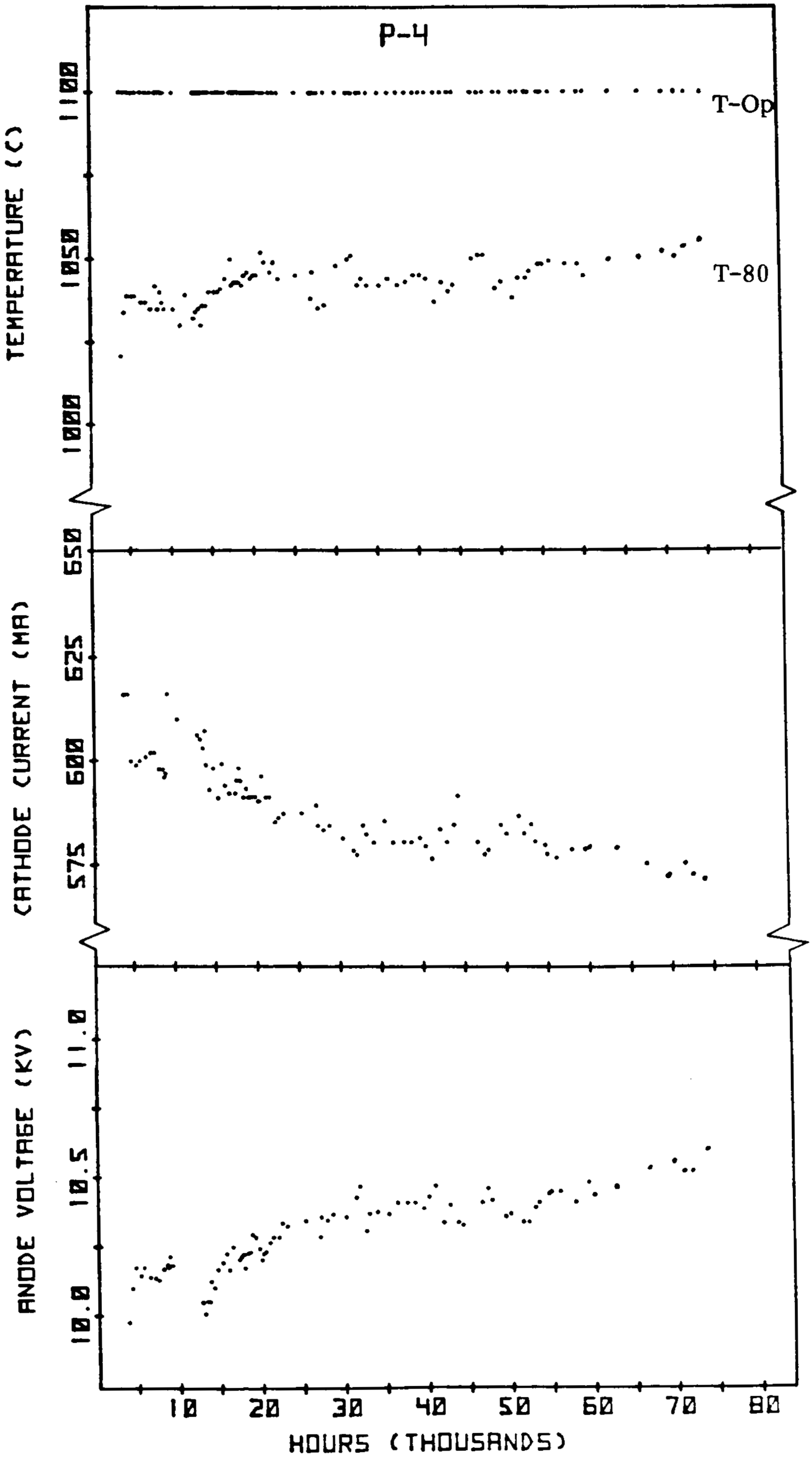

Figure 7. Life Test Data for Unit P-4

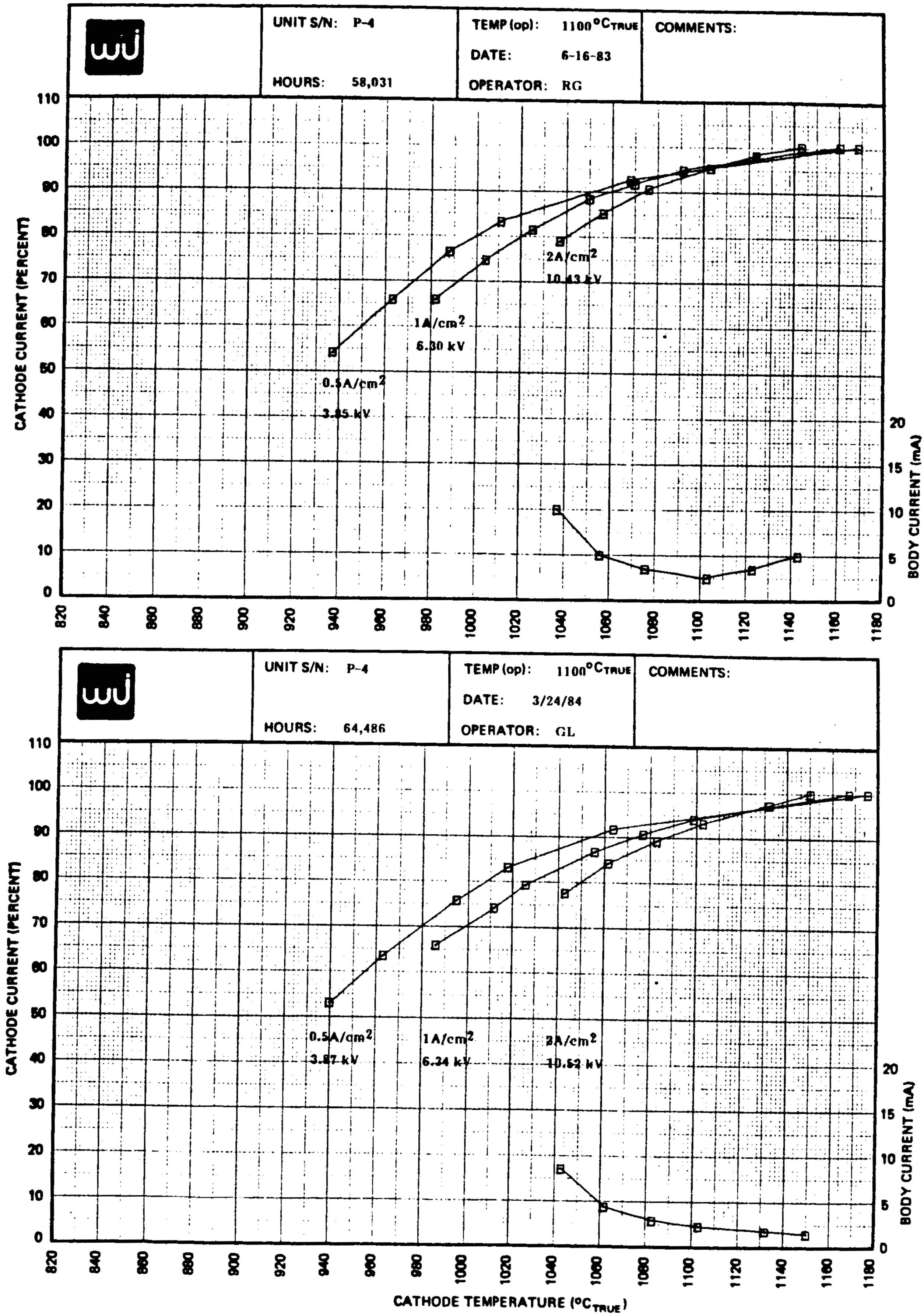

Figure 8. Miram Curves for Unit P-4

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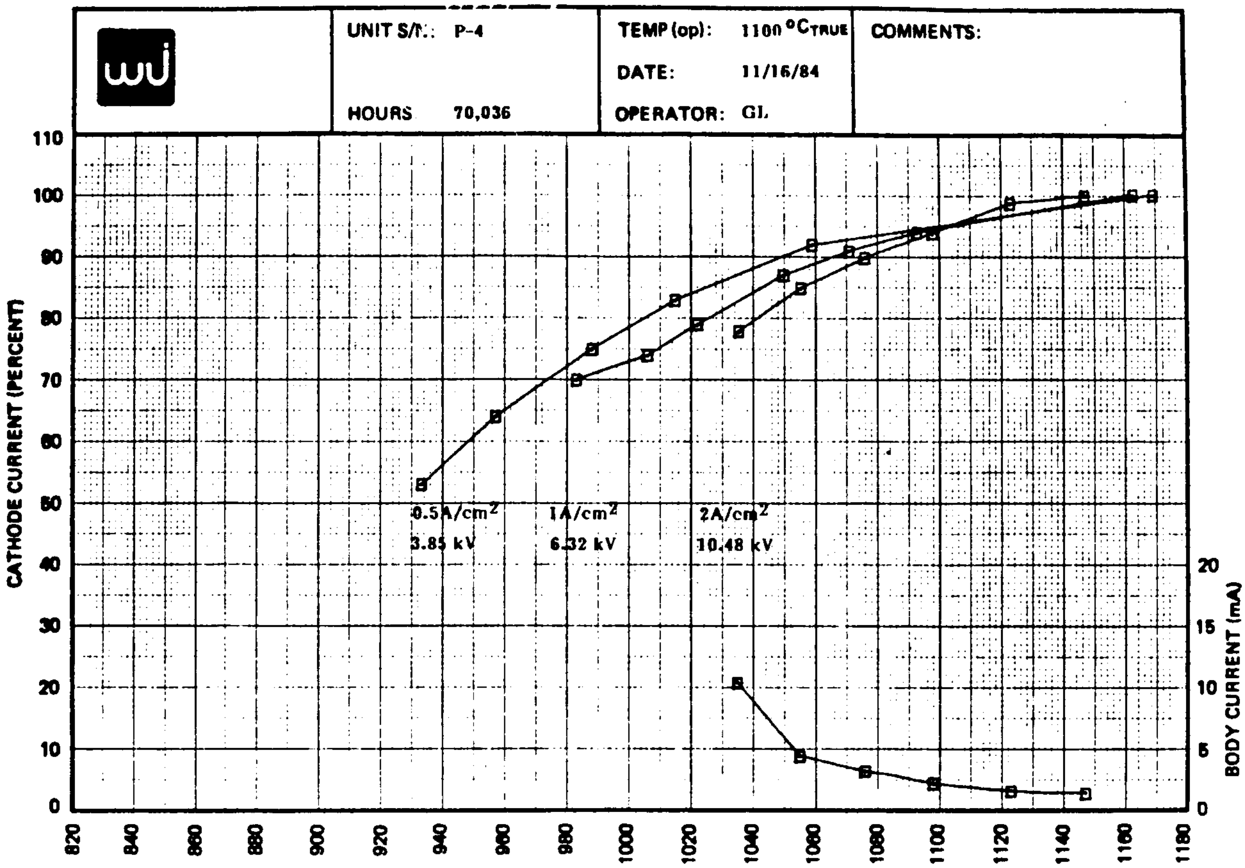

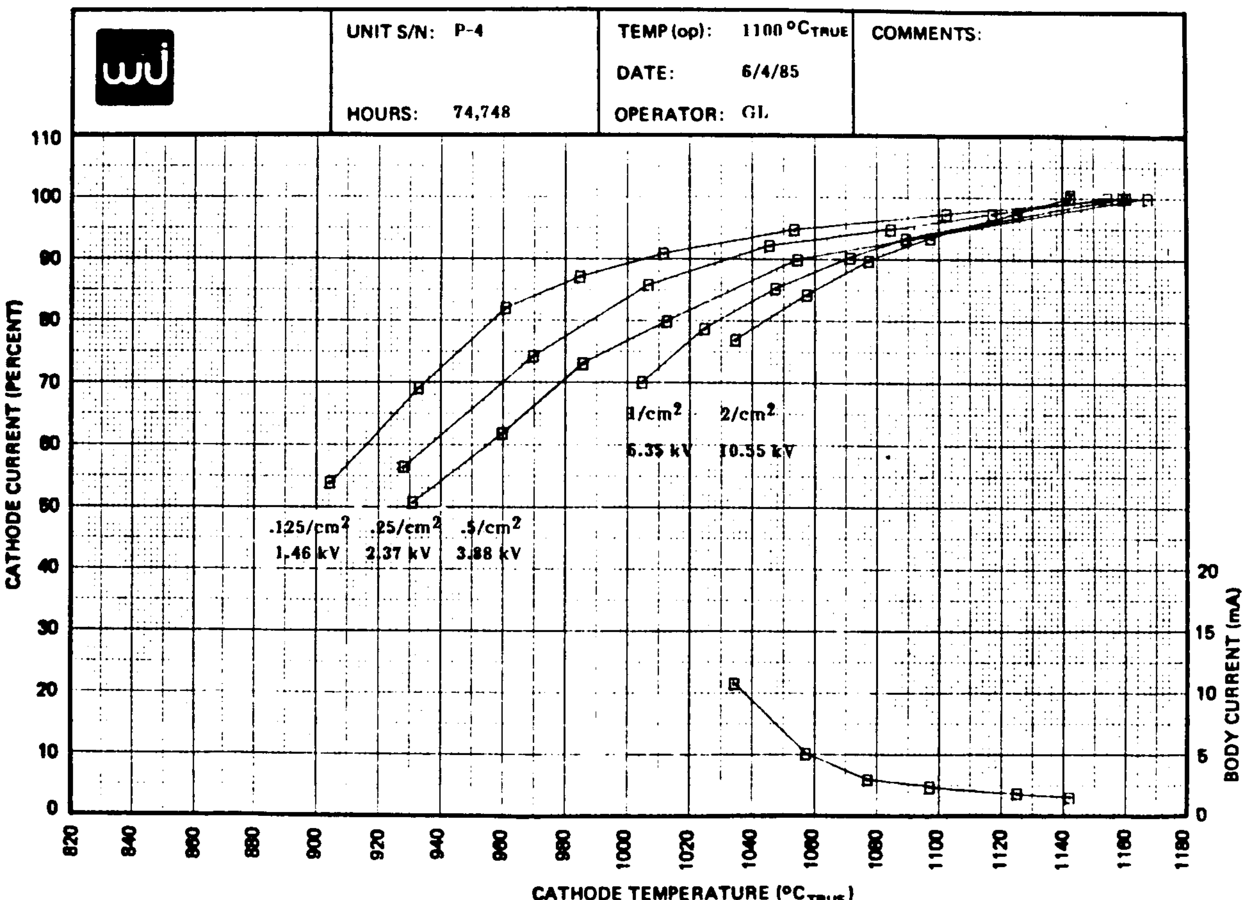

Figure 9. Miram Curves for Unit P-4 (Continued)

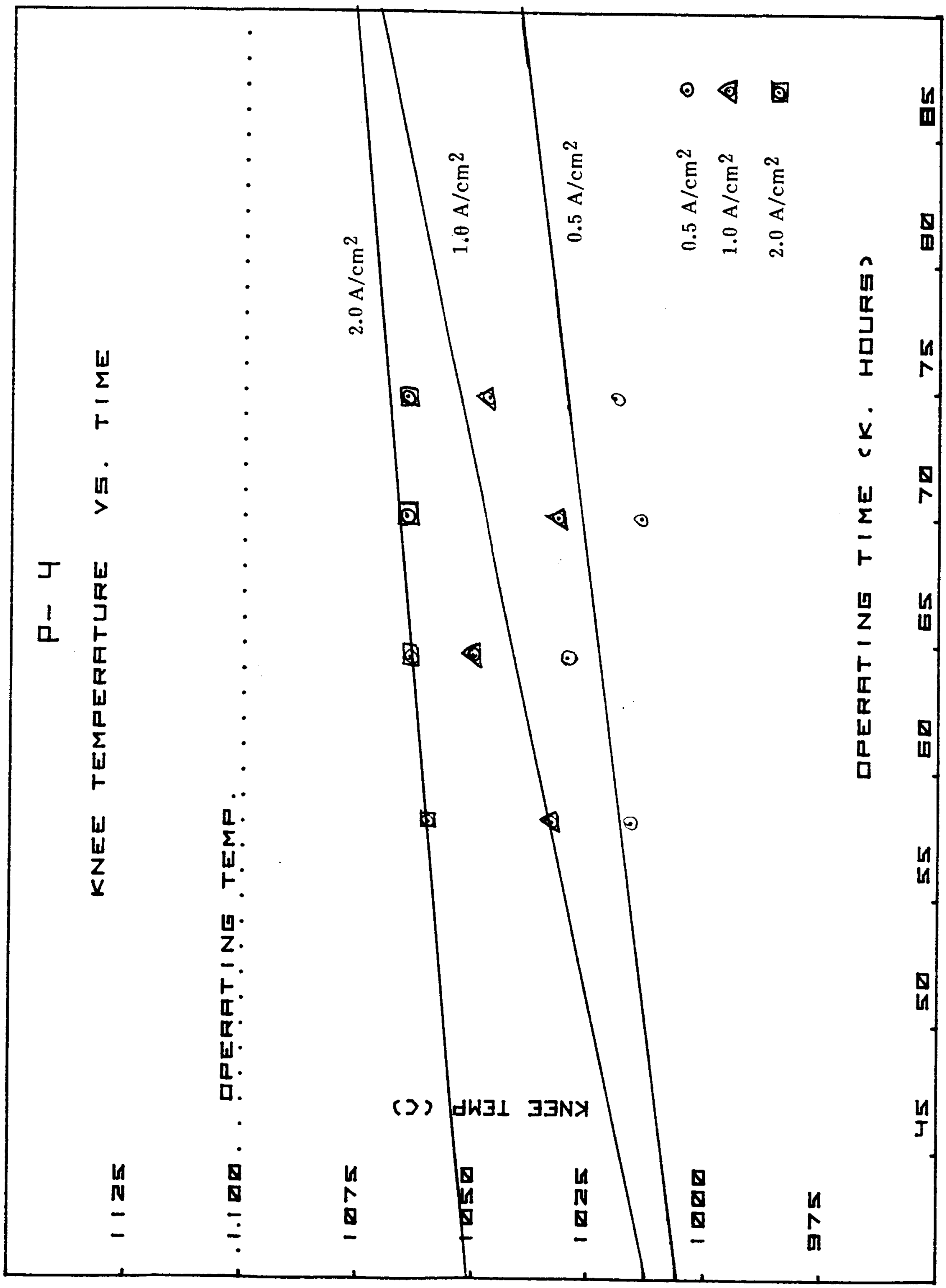

Figure 10. Knee Temperature for Unit P-4

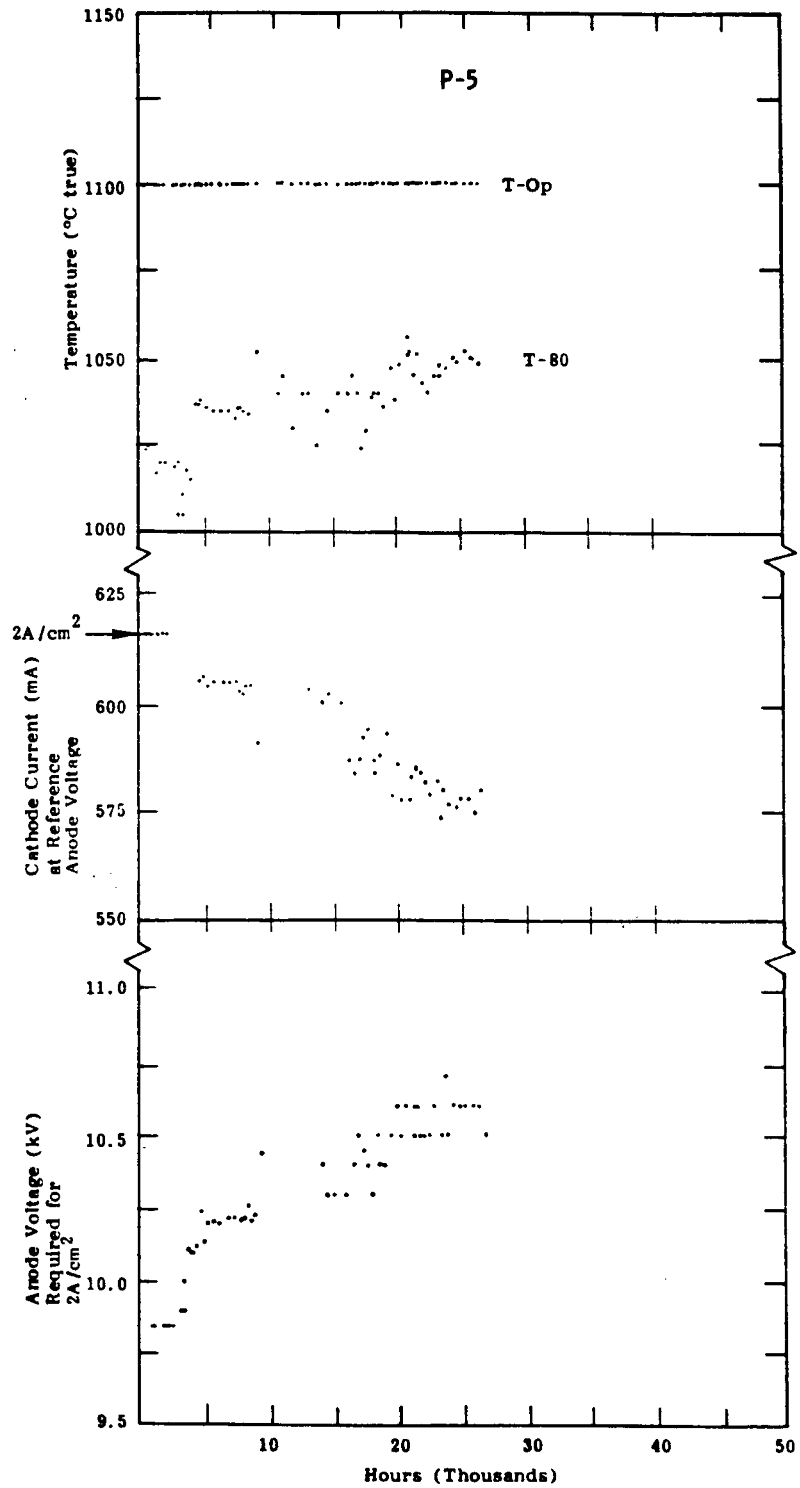

Figure 11. Life Test Data for Unit P-5

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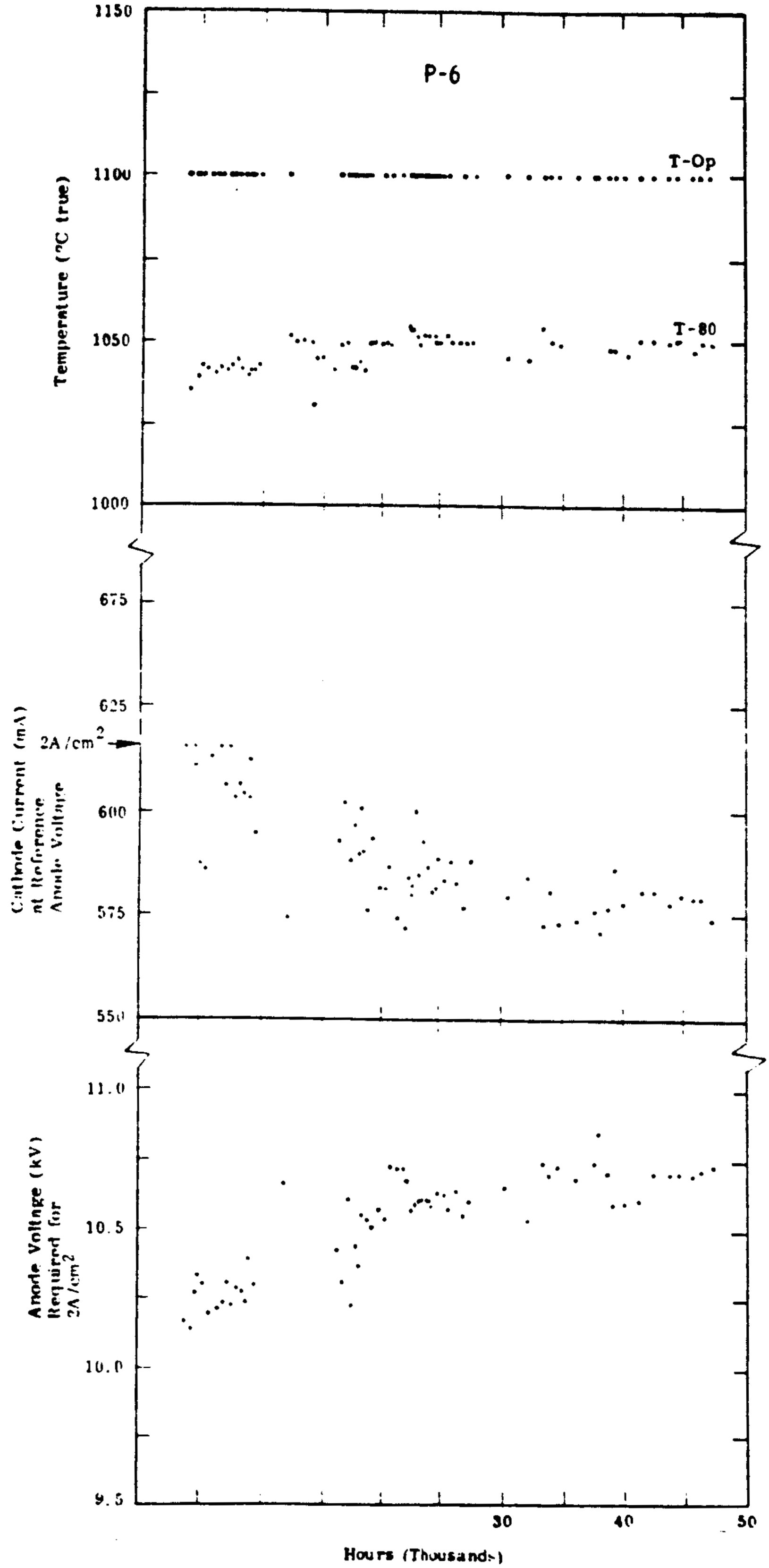

Figure 12 - Life Test Data for Unit P-6

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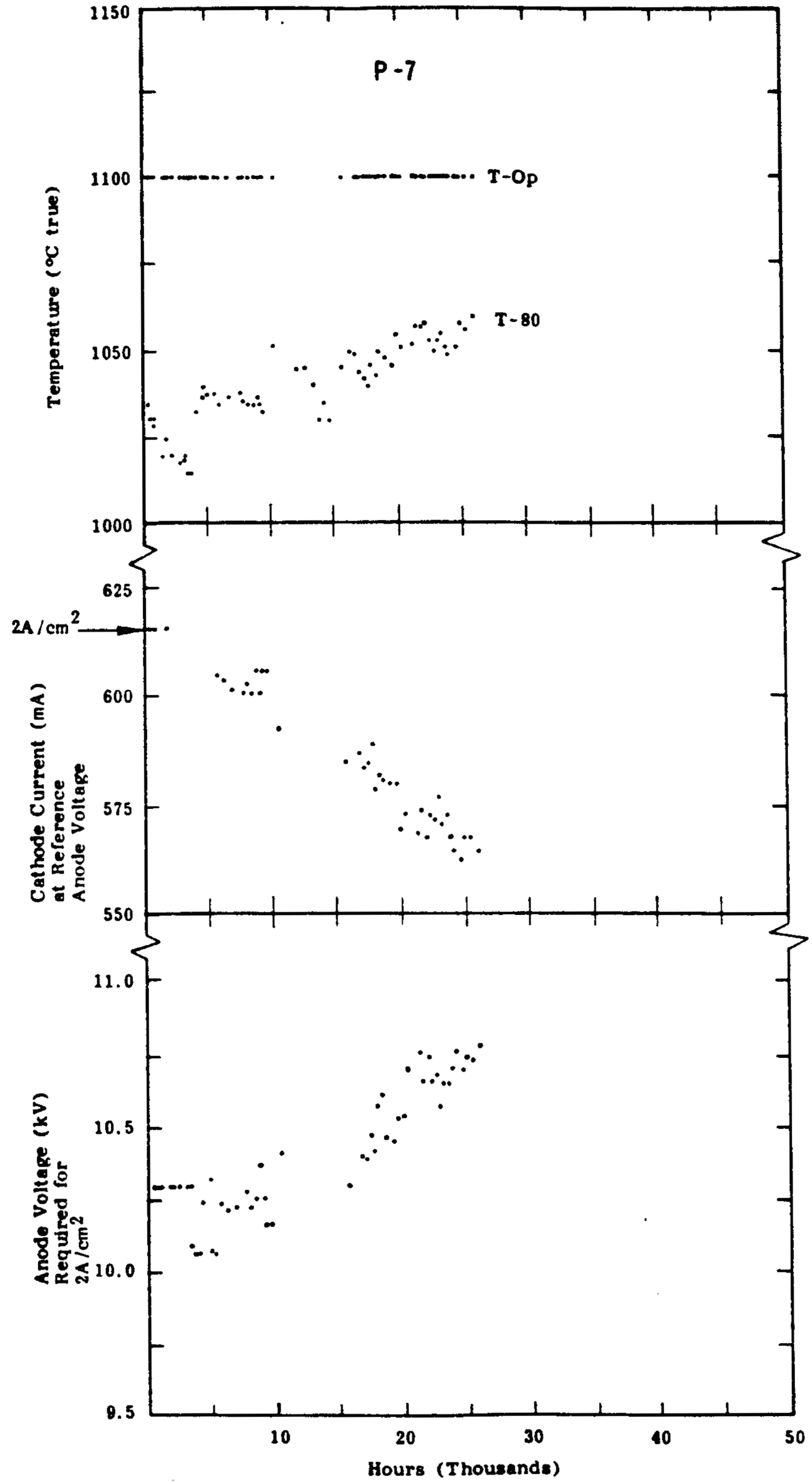

Figure 13. Life Test Data for Unit P-7

5.1.3 Unit P-6. With the exception of a spurious high frequency sawtooth signal noted at the anode during the first 150 hours of life, this unit operated satisfactorily for 48,000 hours. As Figure 12 indicates a gradual increase in T-80 temperature and gradual decline in emission over time can be seen up to about 30,000 hours, after which stabilization seems to occur.

In July 1980, the collector power supply for this unit failed, tripping off the unit. The failure was compounded by inadvertently trying to turn the unit back on without collector voltage. After the power supply problem was corrected, this unit was turned on but was badly defocused. The unit would not focus with physical adjustment of the solenoid, nor with a new solenoid. After pulse testing the unit, it was decided that unit P-6 experienced internal damage during or after the power supply failure; it was subsequently taken off test. Cathode emission had fallen to 93.7% of its initial value after 48,000 hours of operation.

5.1.4 Unit P-7. This unit developed a leak after initial processing and was sealed and rebaked at 250°C. The tube appeared gassy on initial turn-on and later was found to have a faulty ion pump. The ion pump had a leakage resistance, and hence indicated a probable false high pressure. The leakage resistance was burned off and this process may have introduced additional gas to the unit. After 100 hours of aging, the pump current was essentially zero.

Figure 13 shows that, as with the other Philips Type B cathodes tested, the T-80 temperature had increased and the emission had fallen since start of life. This unit was removed from test at 26,932 hours (cathode emission at 92% of initial value).

5.2 Litton Impregnated Life Test Units

Four of these units were placed on life test, each operating at 1100°C. One was removed after 8,000 hours of operation to allow another type unit to be tested; the other three each accumulated more than 20,000 hours of life. Data for these four units are presented in Figures 14 through 18. The graphs show that, compared to the Philips Type B cathode, the Litton units exhibited a similar increase in T-80 temperature over time, and a similar decrease in cathode emission which started at the beginning of life. Of the three units accumulating more than 20,000 hours of operational life, two that were close to failure were removed to allow new type units to be tested. In general, the data suggest that the Litton cathodes tested are suitable for 20,000 hours minimum operation at $2A/cm^2$. Microwave tubes using Litton Impregnated cathodes would be expected to show a decrease in perveance, along with some defocusing and possible performance degradation with life.

L-5N was the only Litton impregnated cathode tested during this reporting period.

5.2.1 L-1N. This unit ran for 8,000 hours before it was removed from the test bench to allow another type unit to begin testing. The graphs show the cathode emission falling off rather sharply from the beginning of life. At 8,000 hours, cathode emission had fallen to 97.4% of its initial value (see Figure 14).

5.2.2 L-3N. Data for this unit show a rise in T-80 temperature after about 10,000 hours, and a moderate decline in cathode emission from beginning of life. After 29,000 hours of operational life, this unit was removed from test to allow another unit to be tested. Cathode emission had fallen to 92.5% of initial emission at that time (see Figure 15).

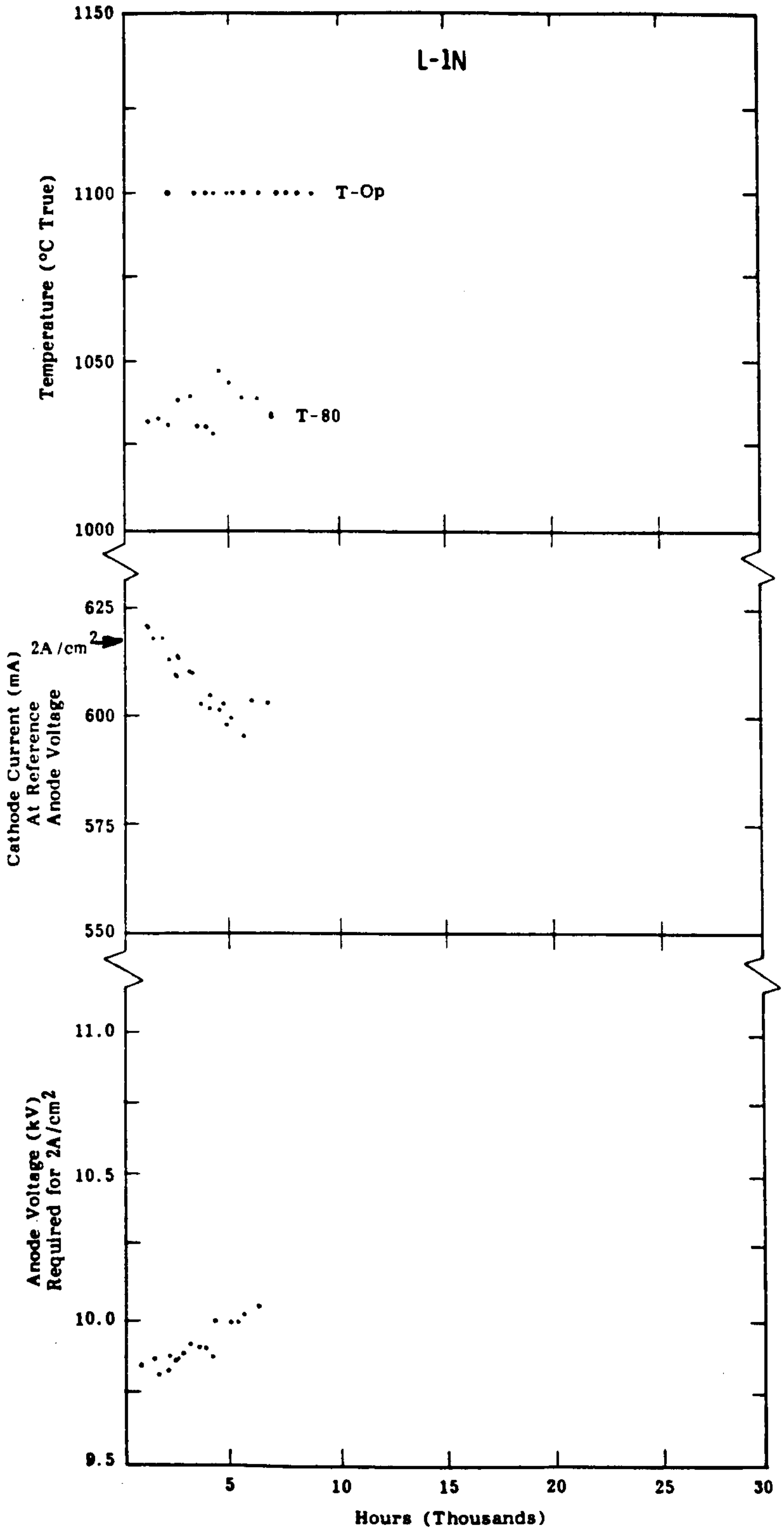

Figure 14. Life Test Data for Unit L-1N

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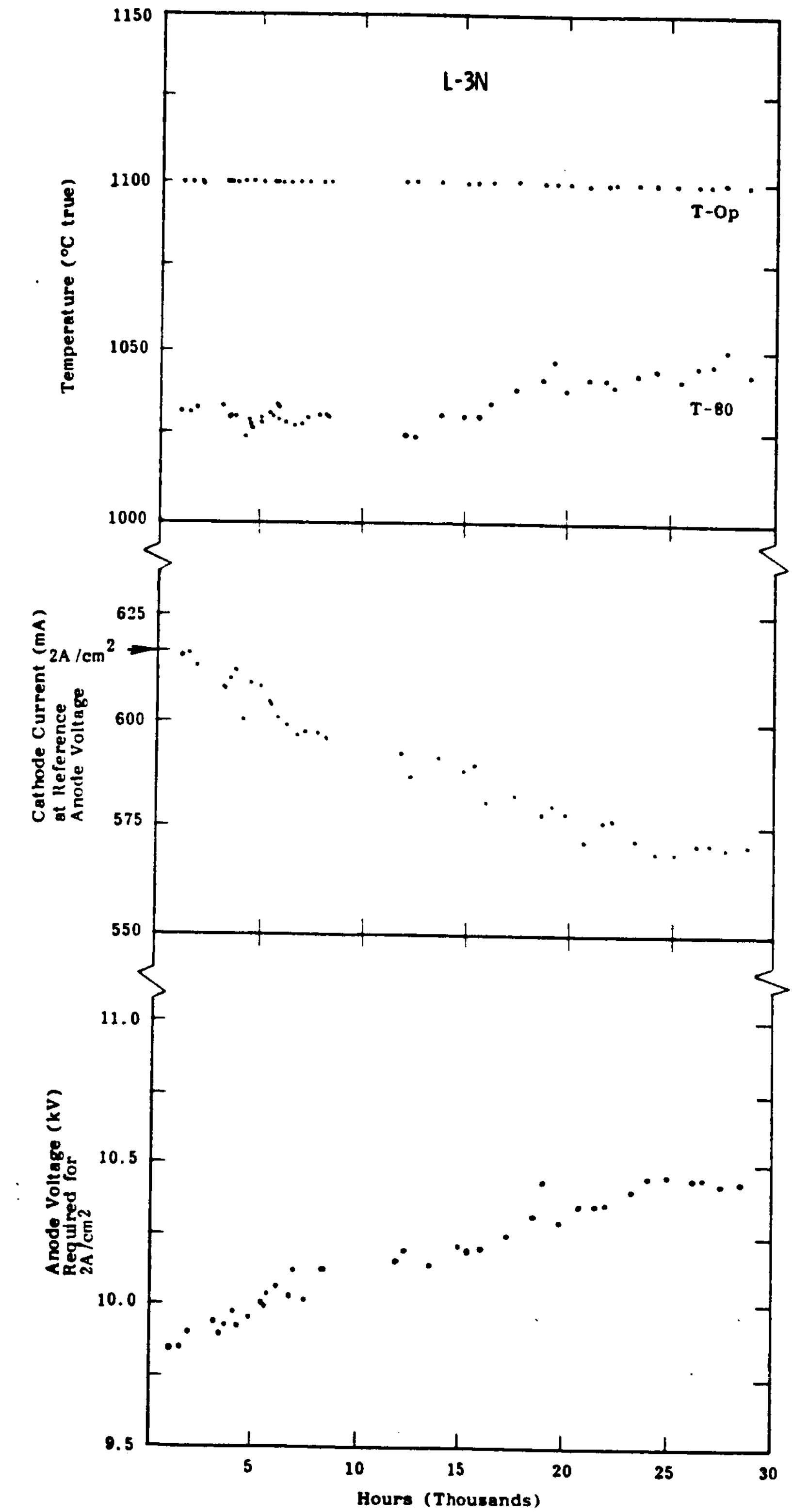

Figure 15. Life Test Data for Unit L-3N

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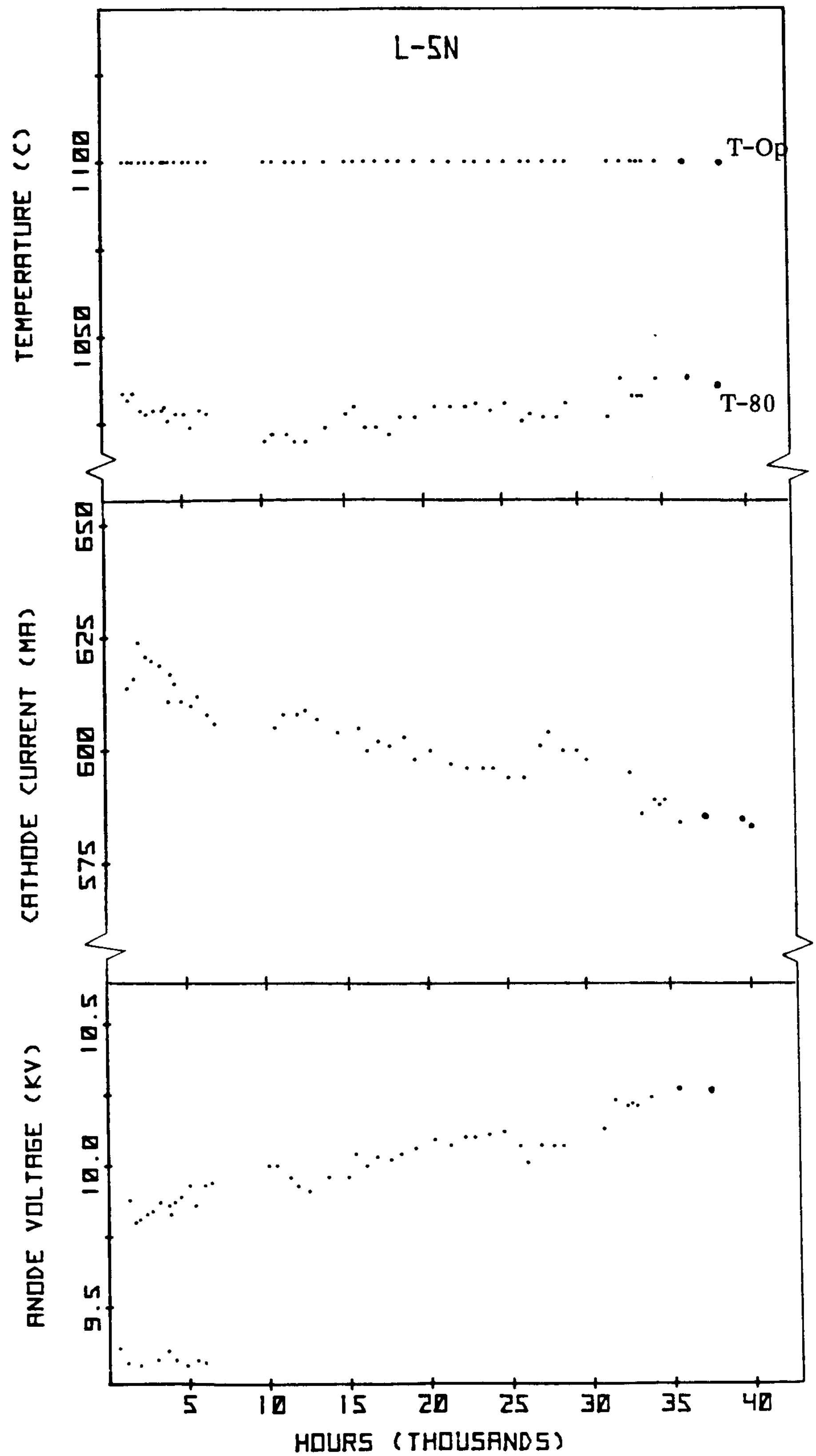

Figure 16. Life Test Data for Unit L-5N

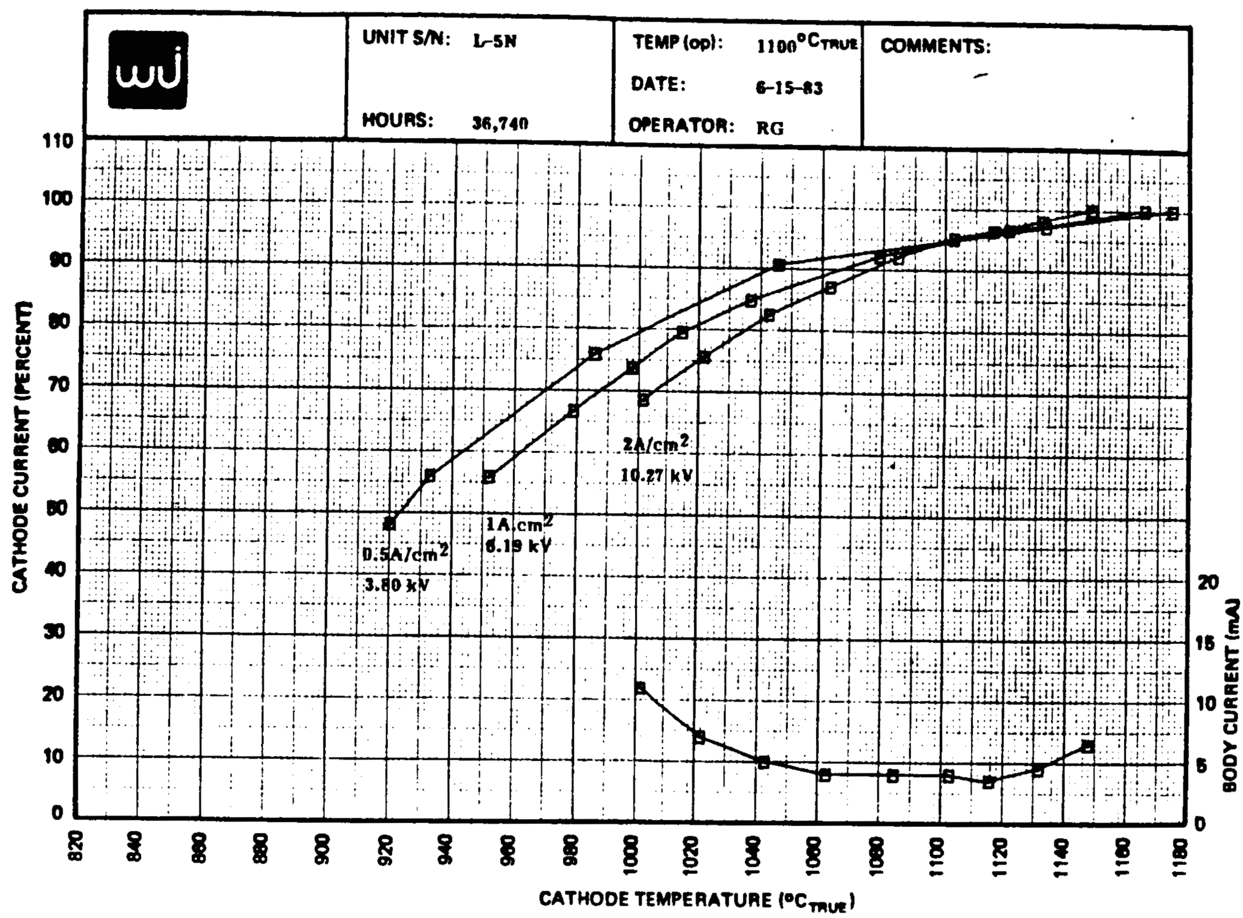

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Figure 17. Miram Curves for Unit L-5N

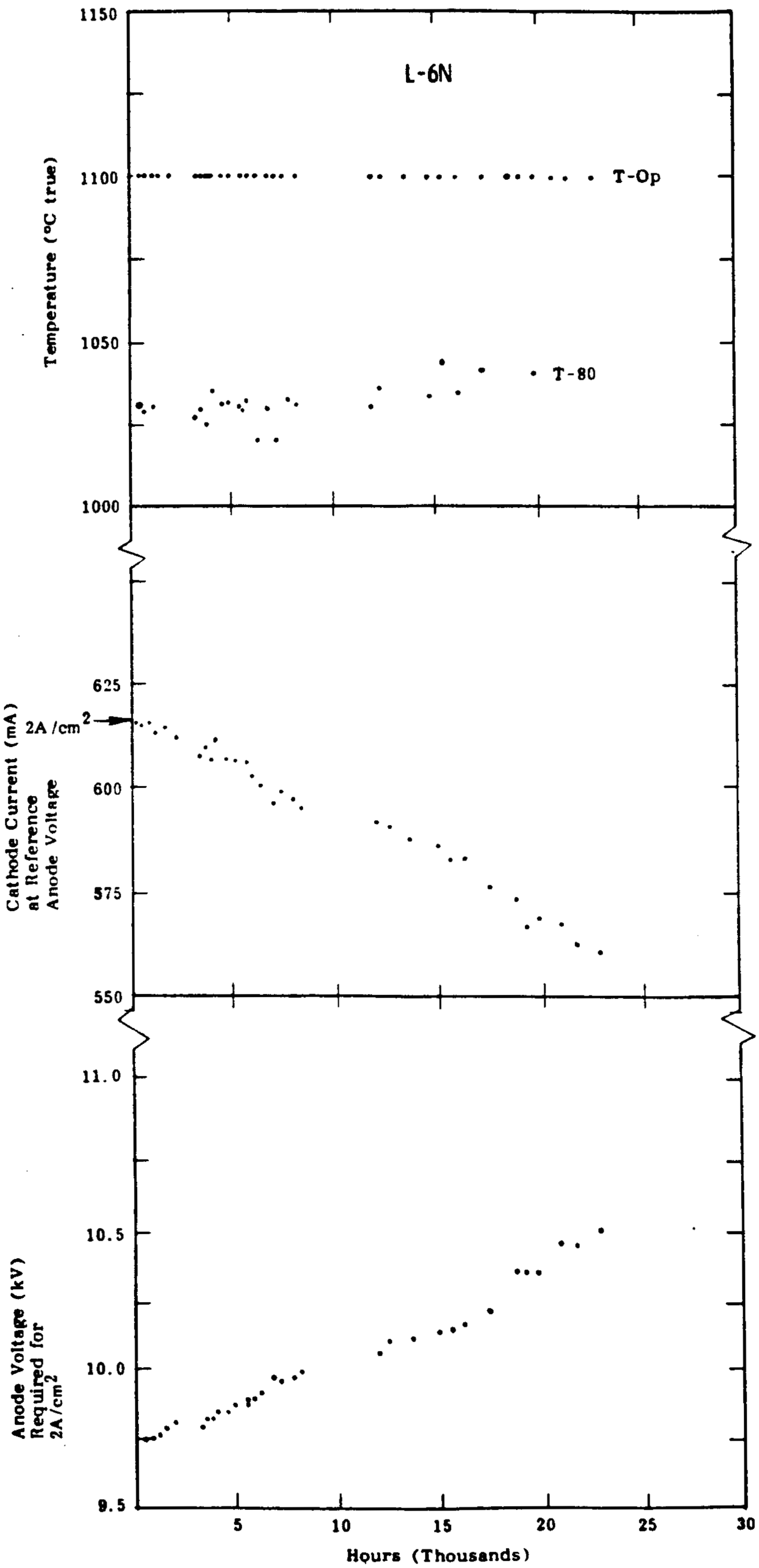

Figure 18. Life Test Data for Unit L-6N

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5.2.3 L-5N. This unit was taken off test in October 1983, because of declining interest in this type of cathode. Over its life of 39,230 hours, the cathode emission dropped by 5%. In contrast to the other three units, T-80 declined for the initial 5,000 hours of operation, after which it held fairly steady (see Figure 16).

The FSCL region has significant positive slope. It indicates there is a differential thermal motion between the cathode and gun electrodes. Miram curves in the FTL region are approximately evenly spaced, implying there are no cathode emission problems.

The knee is fairly rounded, indicating very uneven cathode loading or wide variation in the work function distribution. After 36,740 hours of operation the knee temperature was 1070^{o}C (see Figure 17). The knee region is fairly rounded.

5.2.4 L-6N. The data for this unit show a rise in T-80 temperature after about 10,000 hours, and a steep decline in cathode emission from beginning of life. After 23,000 hours of life, with cathode emission at 90.6% of its initial value, unit L-6N was removed from test to allow testing another unit (see Figure 18).

5.3 Philips Type M Life Test Units

Four Philips Type M cathodes were tested at 1010^{o}C true cathode temperature. M1 successfully accumulated 78,961 hours of operating time. Figures 19 through 34 contain the data for these four units. Cathode current for these Type M units was steady or increased for the first 15,000 hours. Emission improved approximately 2 to 5% during this time on each of the four units tested.

This steady or increasing cathode activity observed from start of life has been one of the more significant findings of this life test study. Results to date indicate that the Philips Type M cathode appears to be well suited for operation of at least 62,000 hours at 2A/cm^{2}. Unit M1 operated satisfactorily for 78,961 hours based on the 10% drop in emission criterion for cathode failure. Miram curves indicate that the cathode since 76,000 hours of operation was not in the stable temperature zone (operating temperature higher than knee temperature; see Appendix II). The Miram curves reflect the influence of gun structure, type of loading, perveance change, plus cathode performance. It was not possible to quantitatively determine the affects of each of these factors separately. Additional details on these four units are given below (see Figures 19 to 34).

5.3.1 M-1. Unit M-1 was the longest-running of the Type M cathodes on test with 78,961 hours of operating time. Data for this unit is presented in Figures 19 to 22. The variations in operating temperature during the first 5,000 hours of life resulted from an uncertainty about what the correct operating temperature should be. Philips' recommendation was to operate at 1050^{o}C true. However, it was decided that operation at 1010^{o}C provided adequate margin for stable operation. Subsequently, this and all other Type M units have been operating at 1010^{o}C true.

The data in Figure 19 shows that the cathode emission increased from start of life to a peak value of almost 104% of initial value at around 22,000 hours. The emission decrease over its life of 78,961 hours was 7.1%. T-80 temperature held steady for the first 20,000 hours, after which it gradually increased.

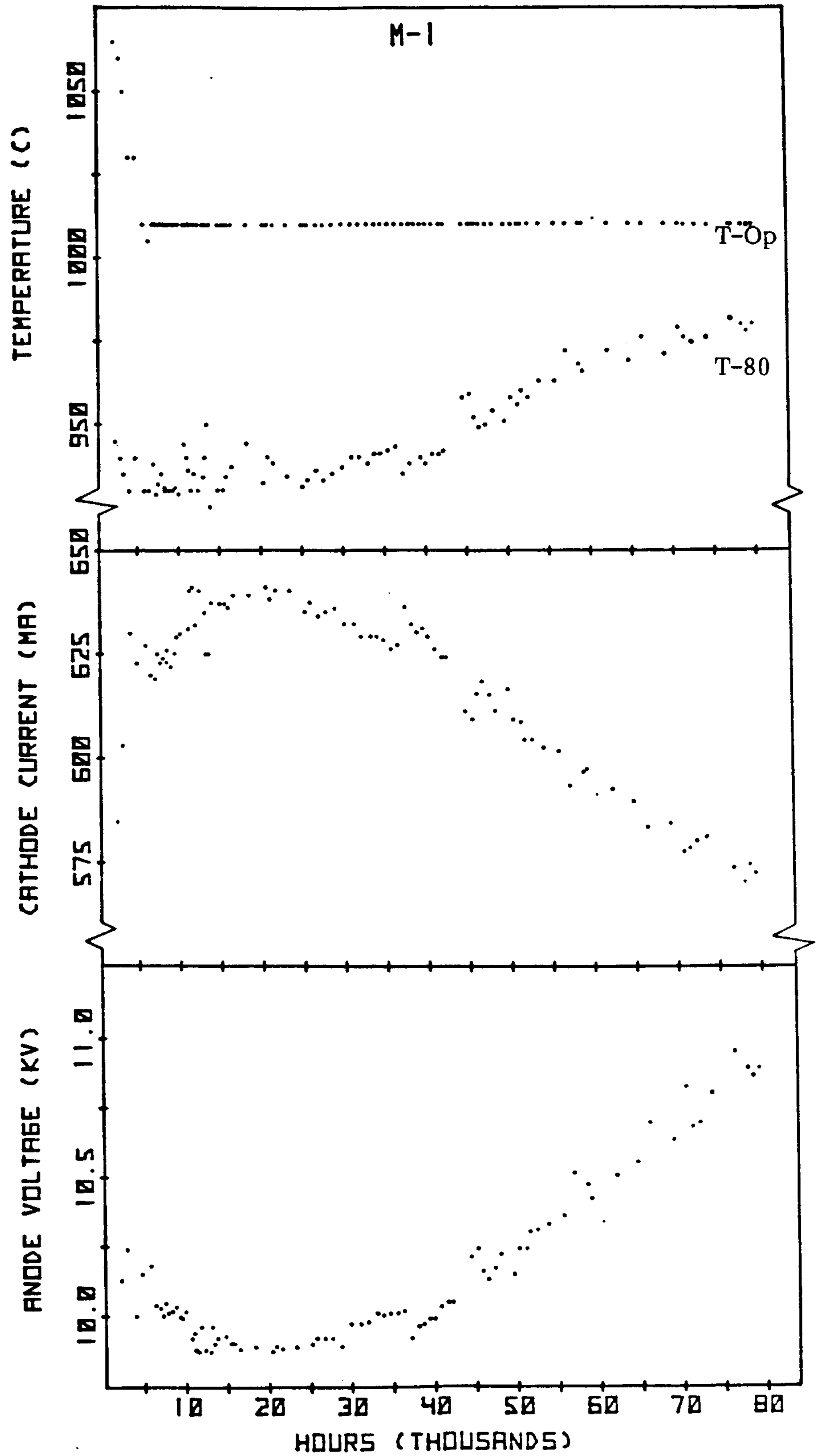

Figure 19. Life Test Data for Unit M-1

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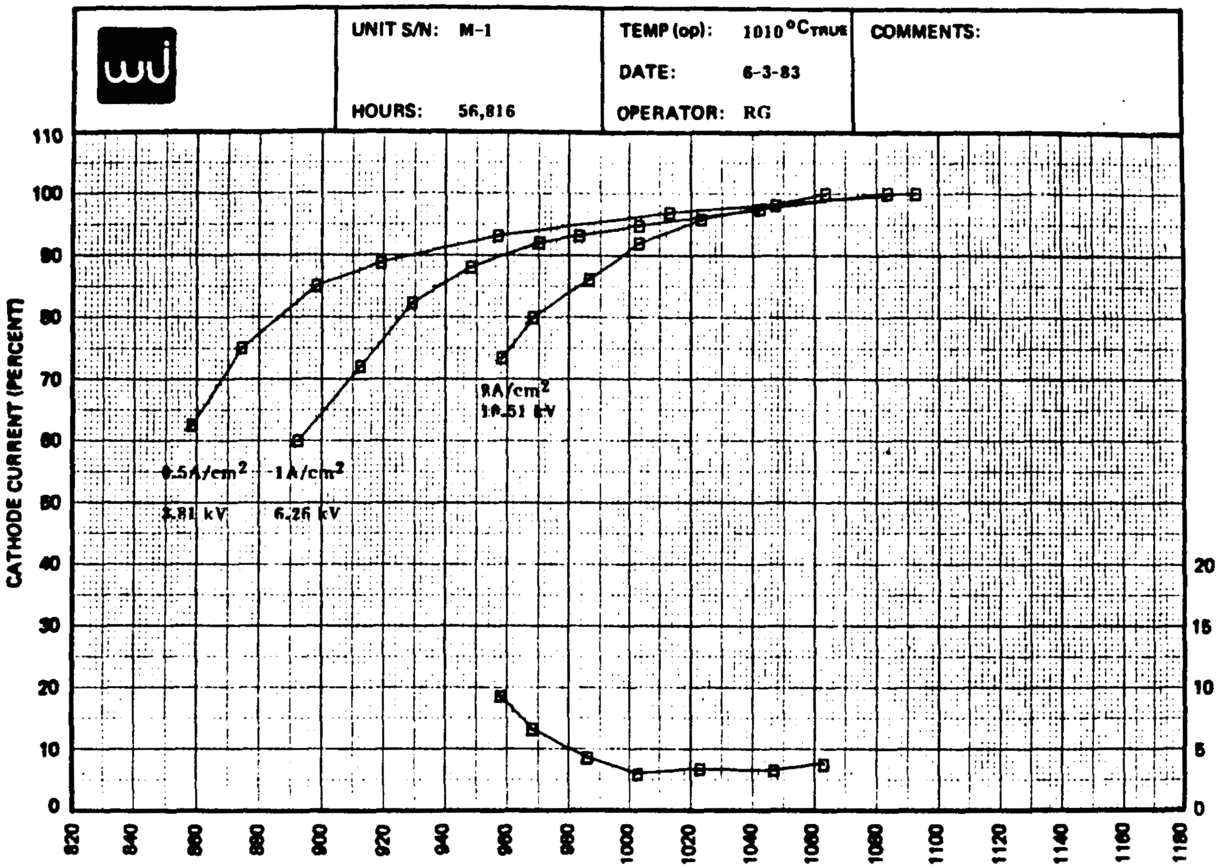

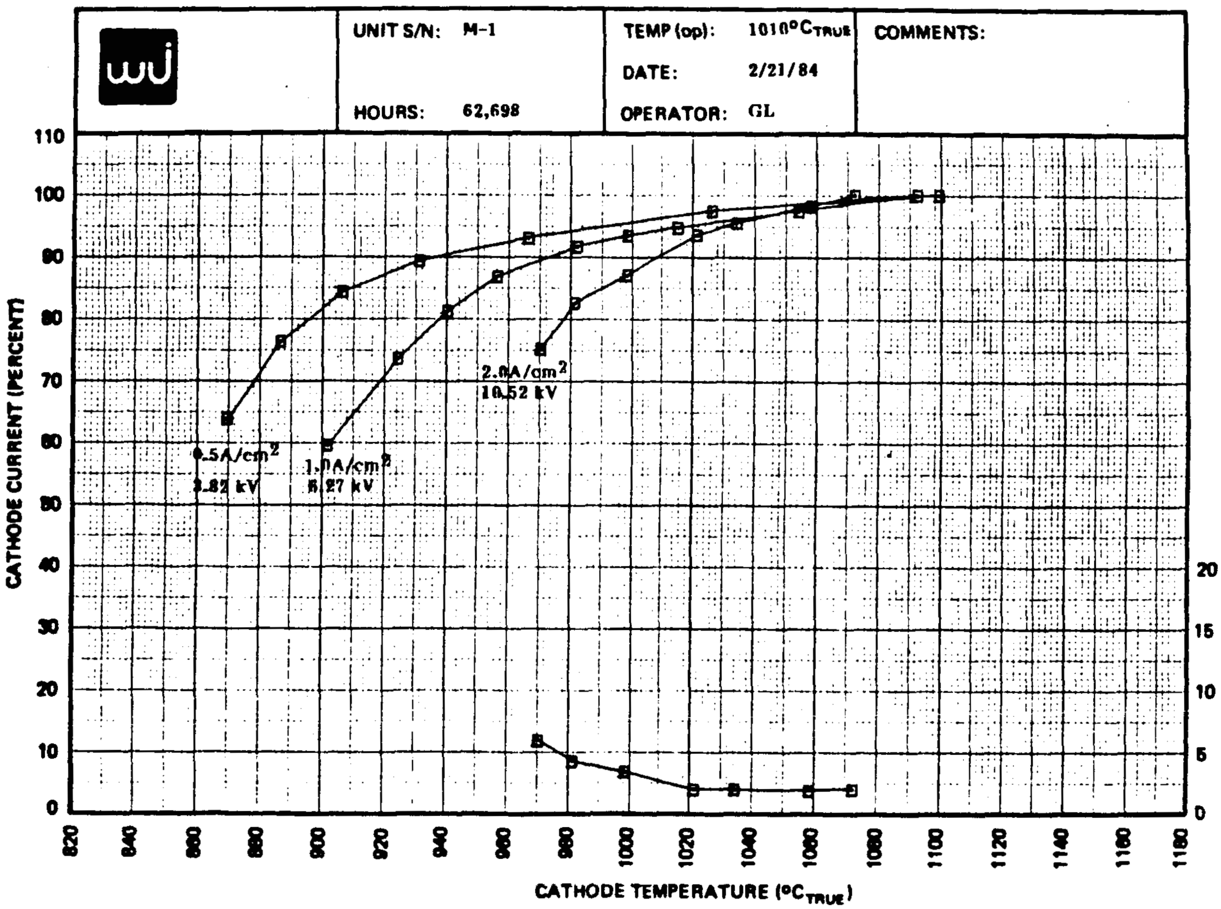

Figure 20. Miram Curves for Unit M-1

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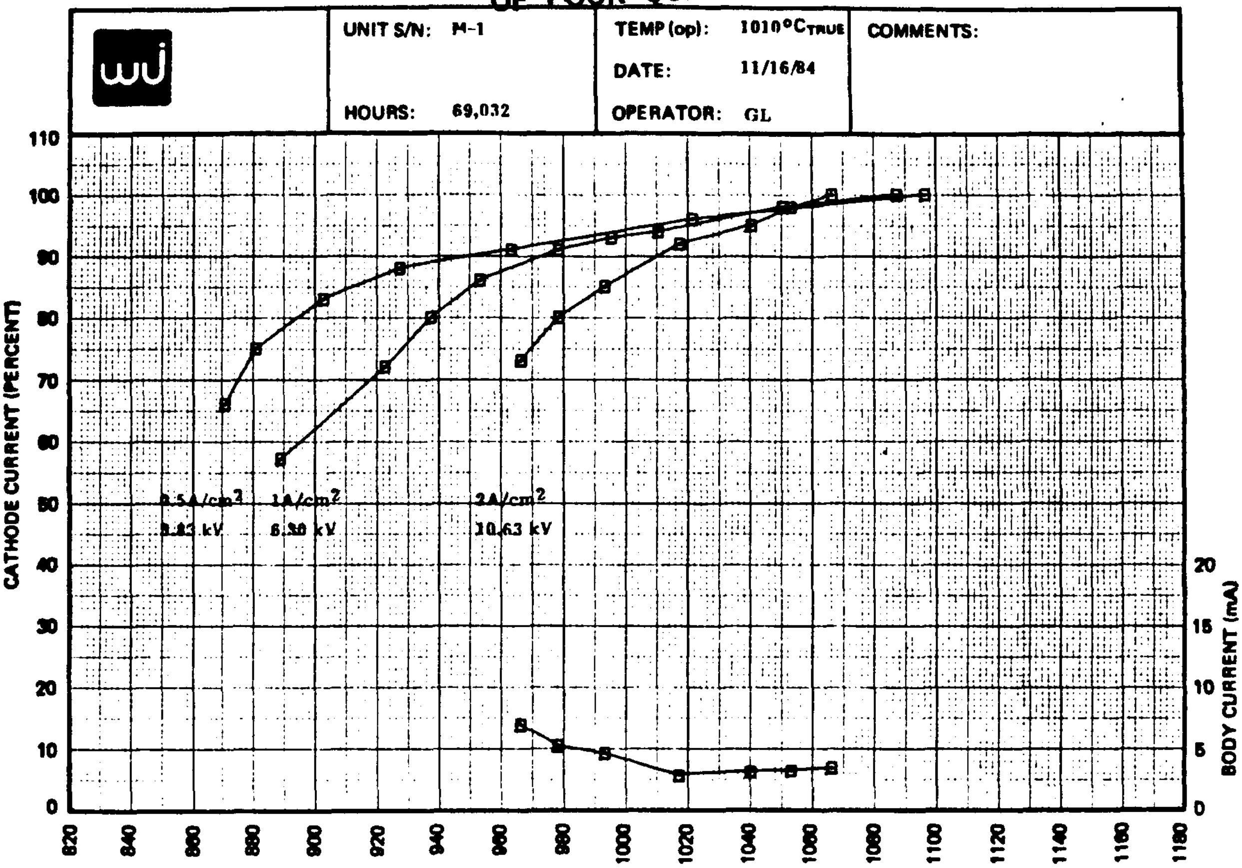

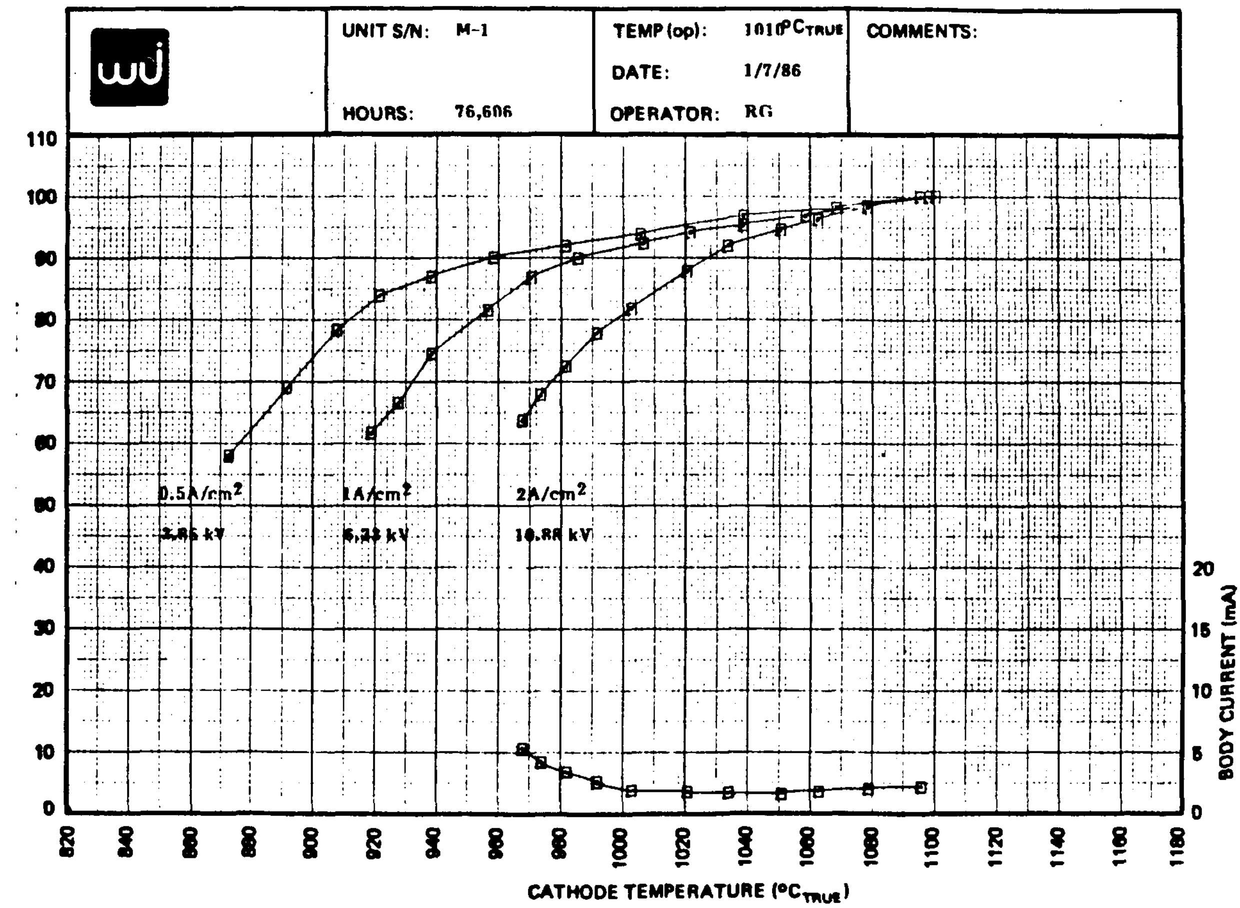

Figure 21. Miram Curves for Unit M-1 (Continued)

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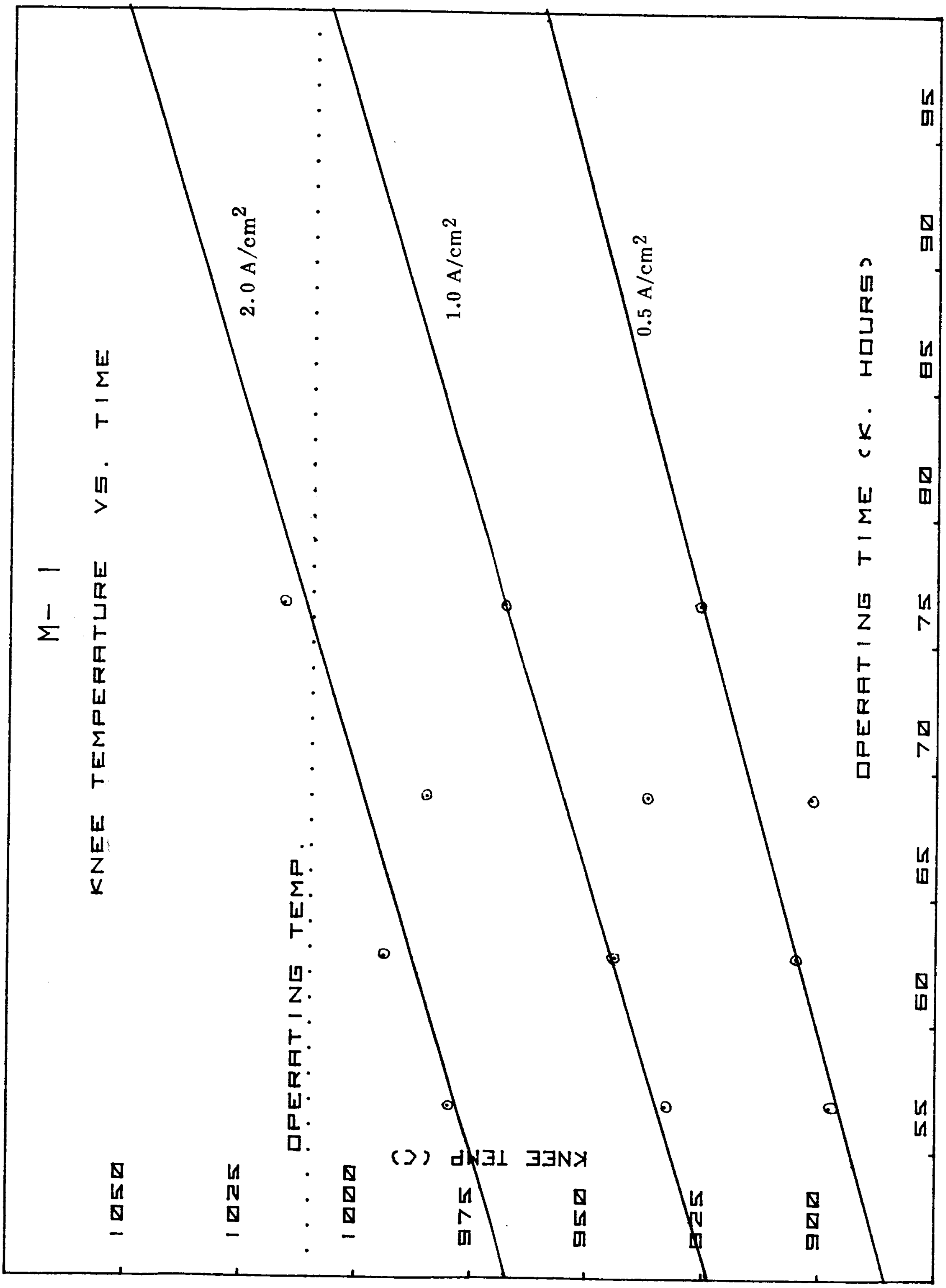

Figure 22. Knee Temperature for Unit M-1

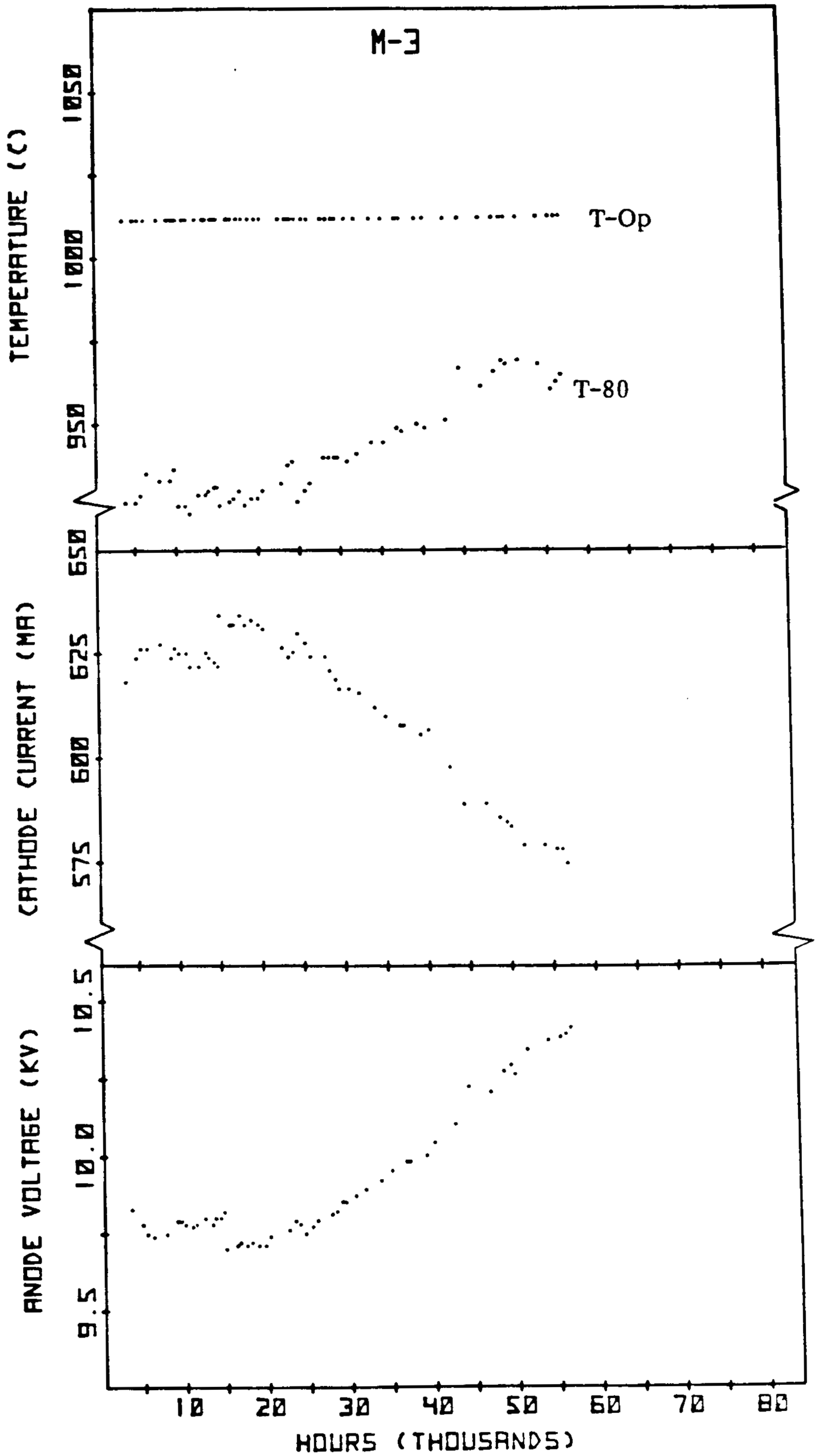

Figure 23. Life Test Data for Unit M-3

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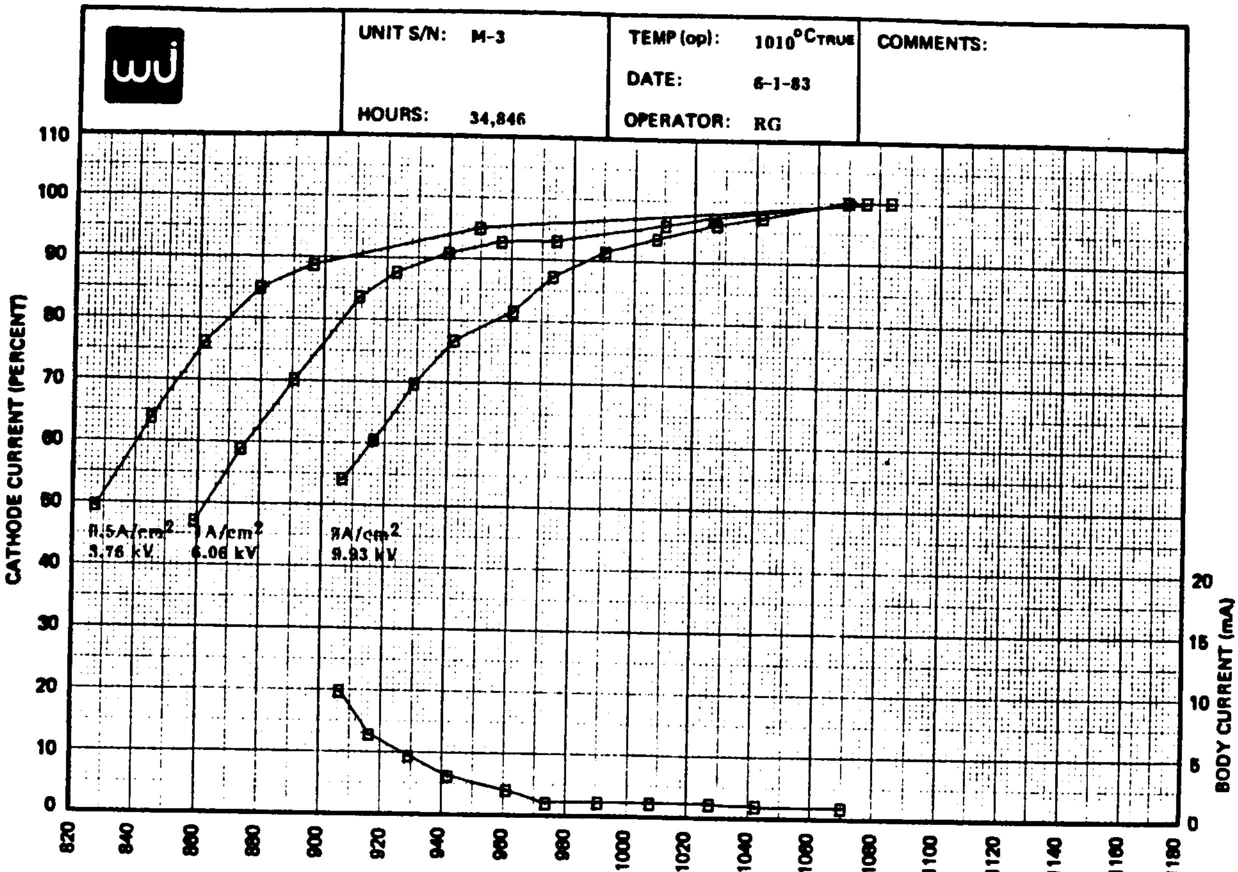

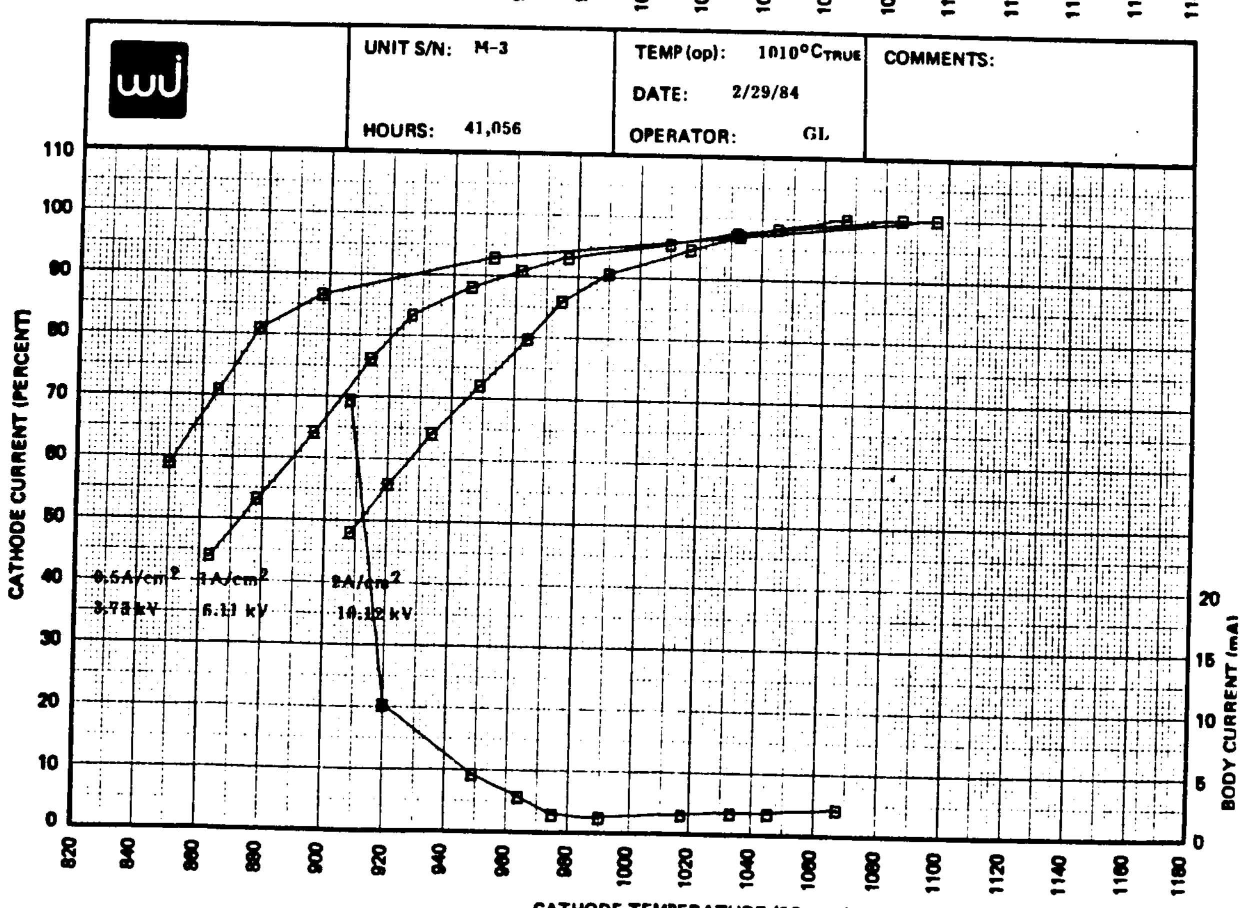

Figure 24. Miram Curves for Unit M-3

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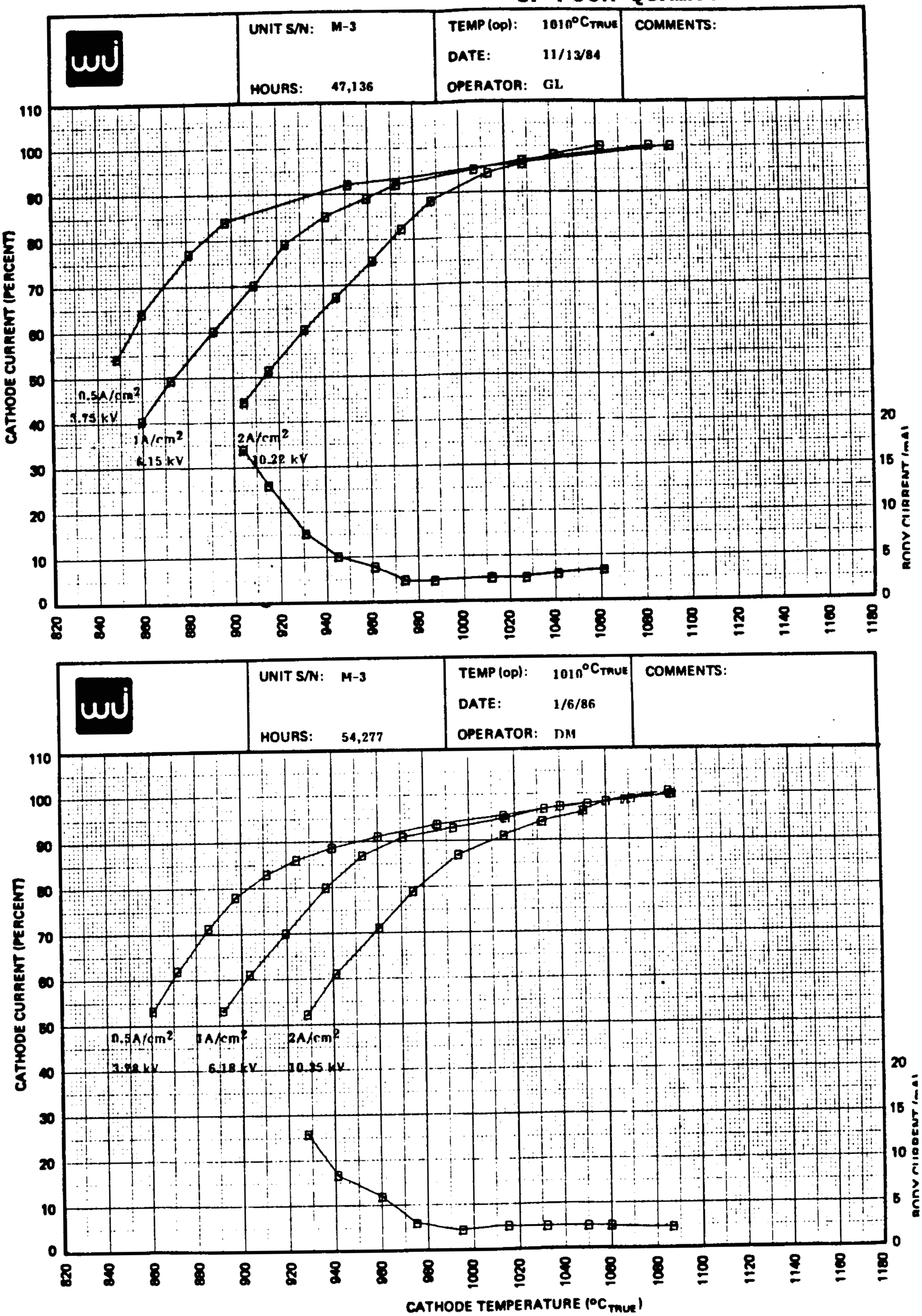

Figure 25. Miram Curves for Unit M-3 (Continued)

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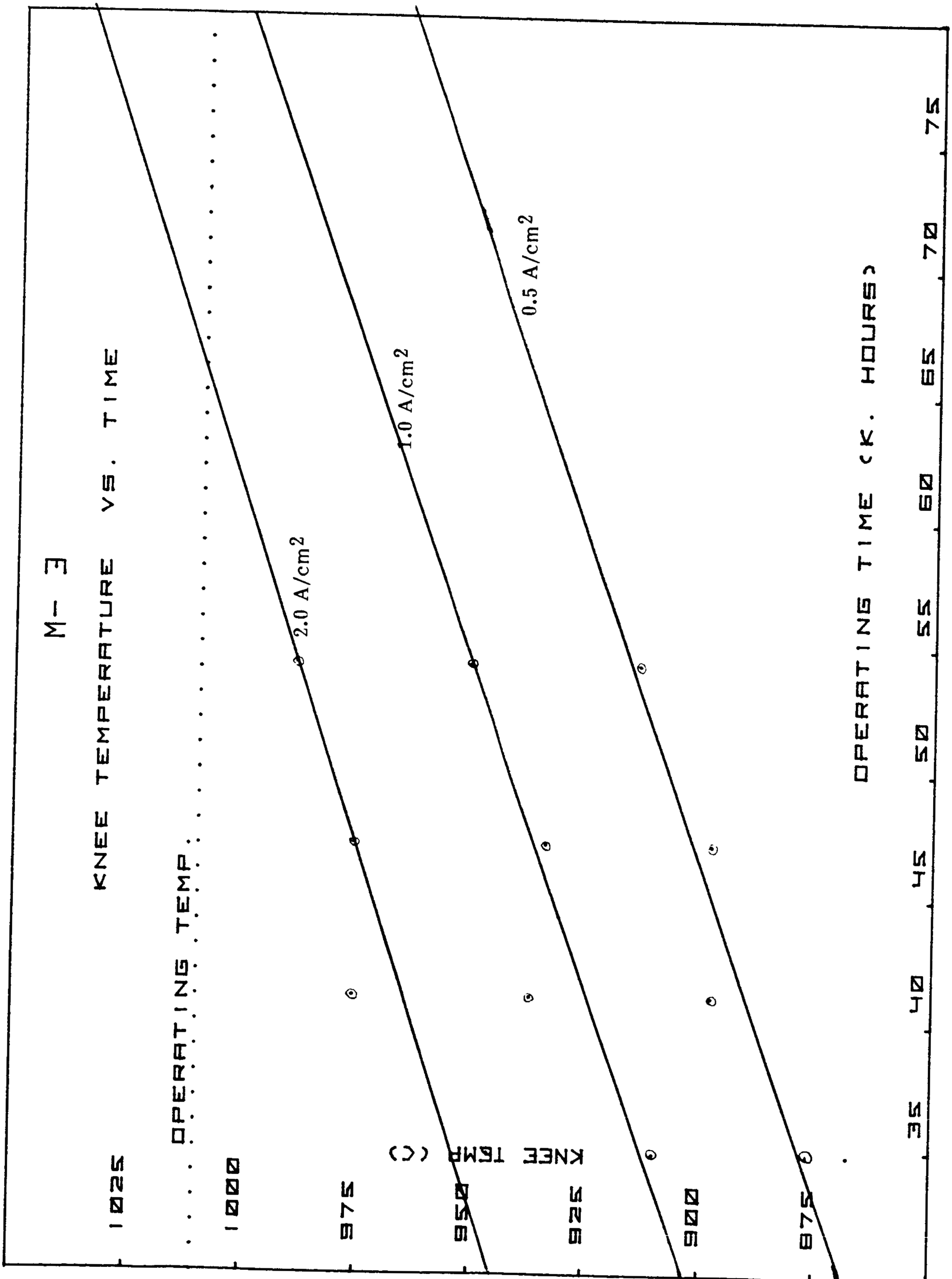

Figure 26. Knee Temperature for Unit M-3

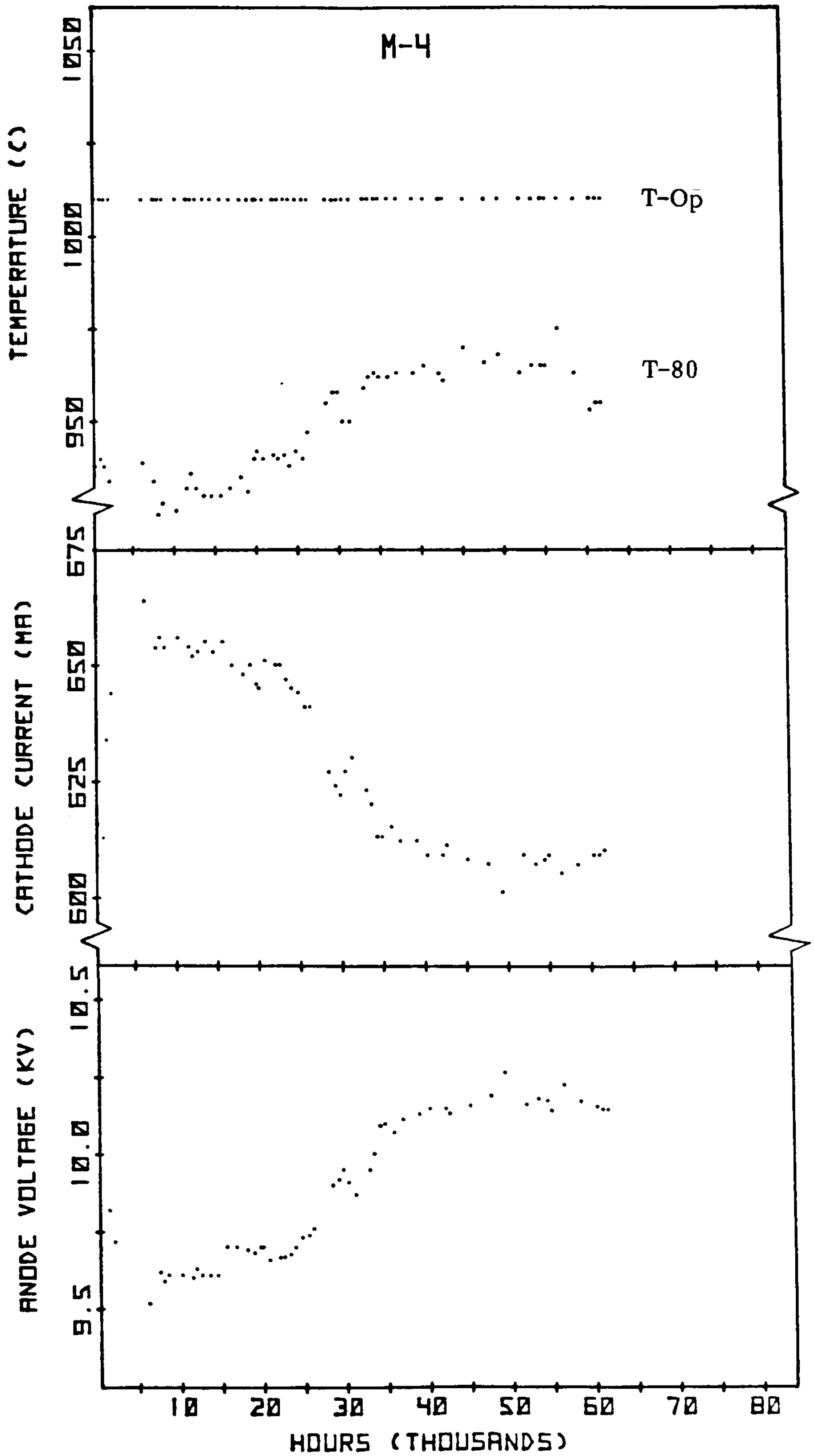

Figure 27. Life Test Data for Unit M-4

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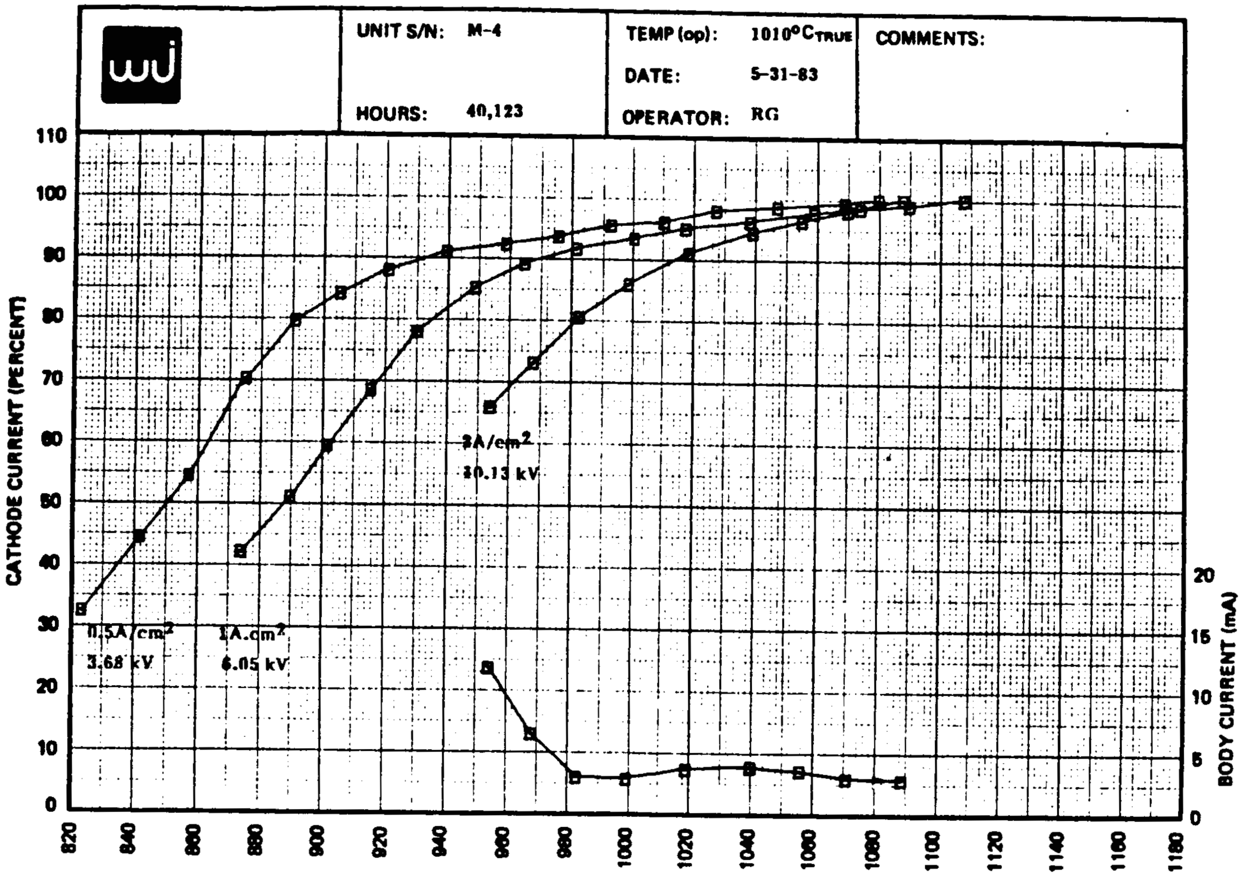


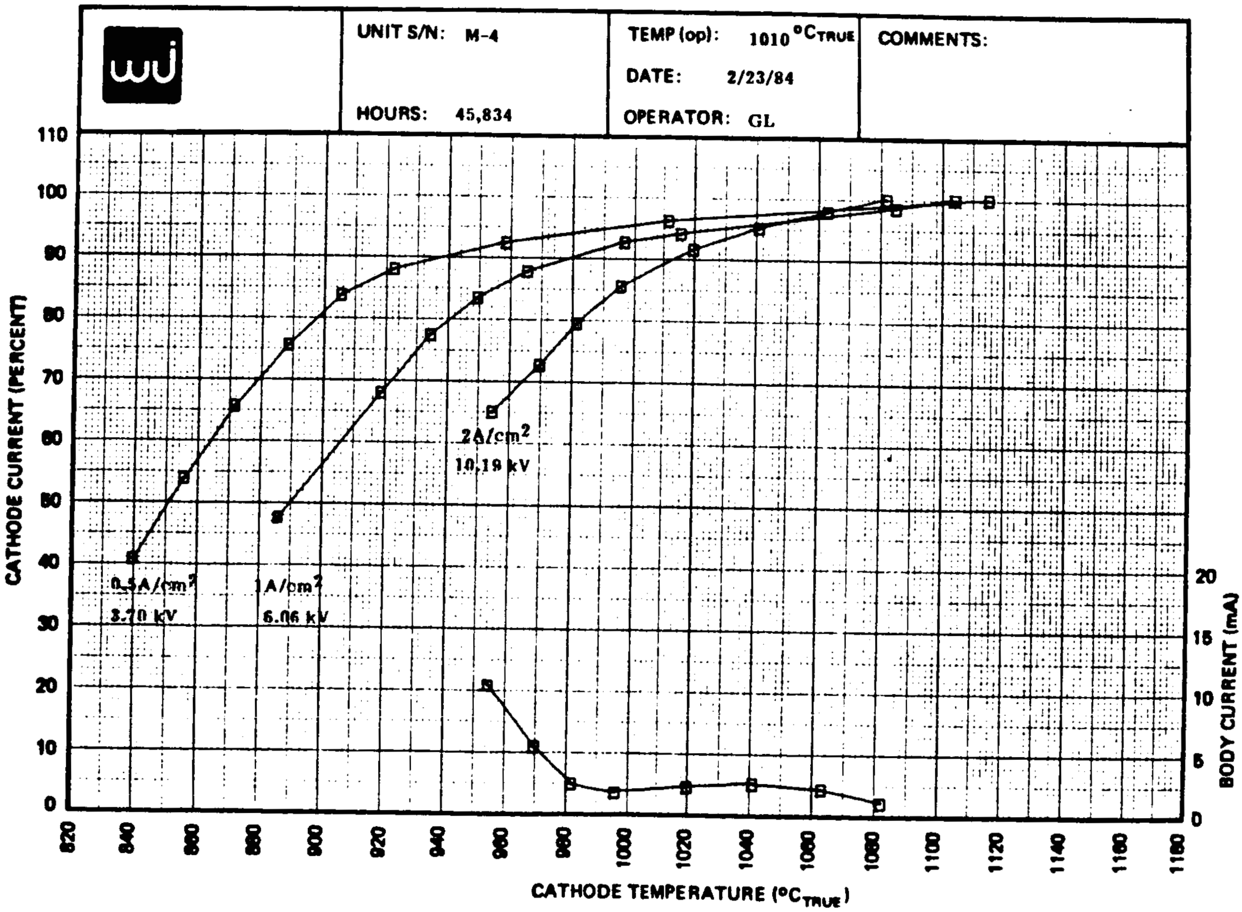
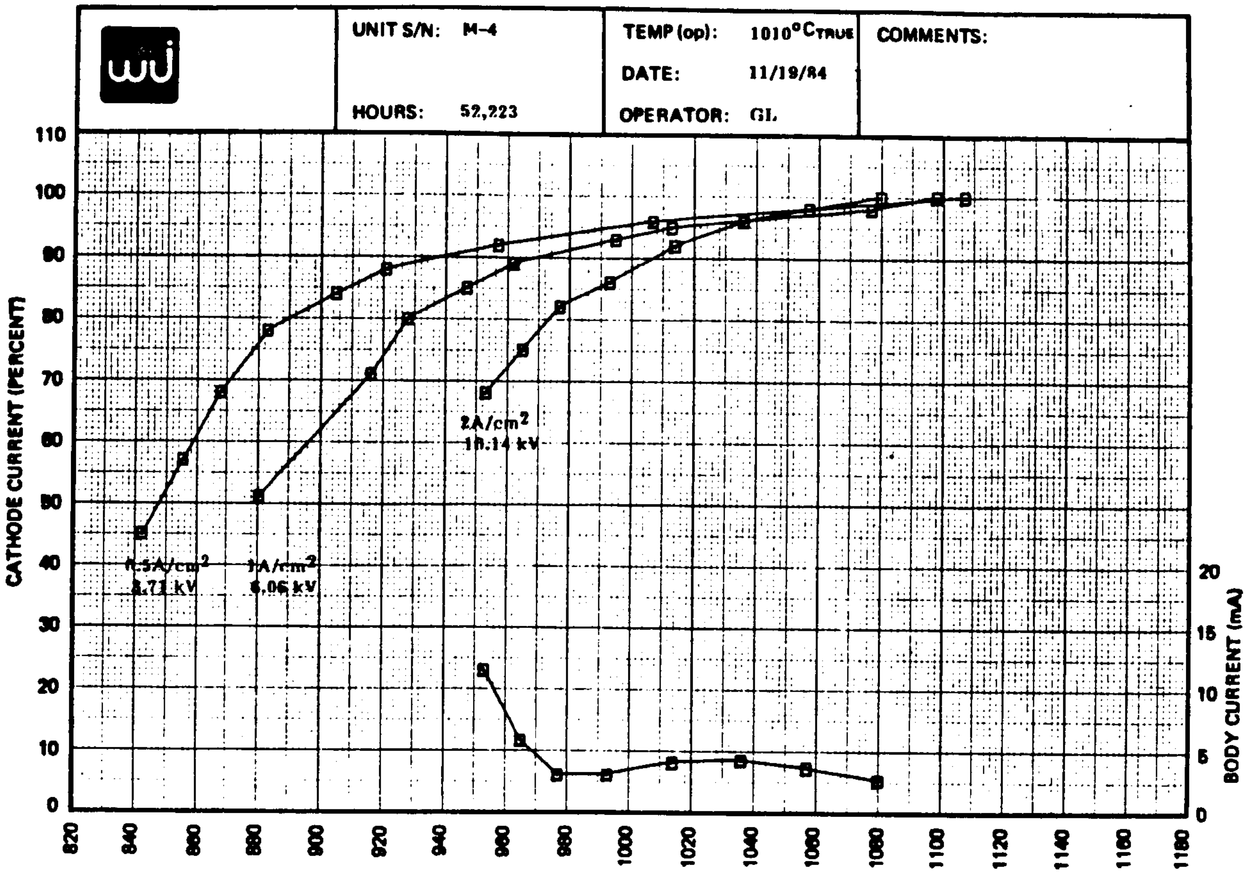


Figure 28. Miram Curves for Unit M-4



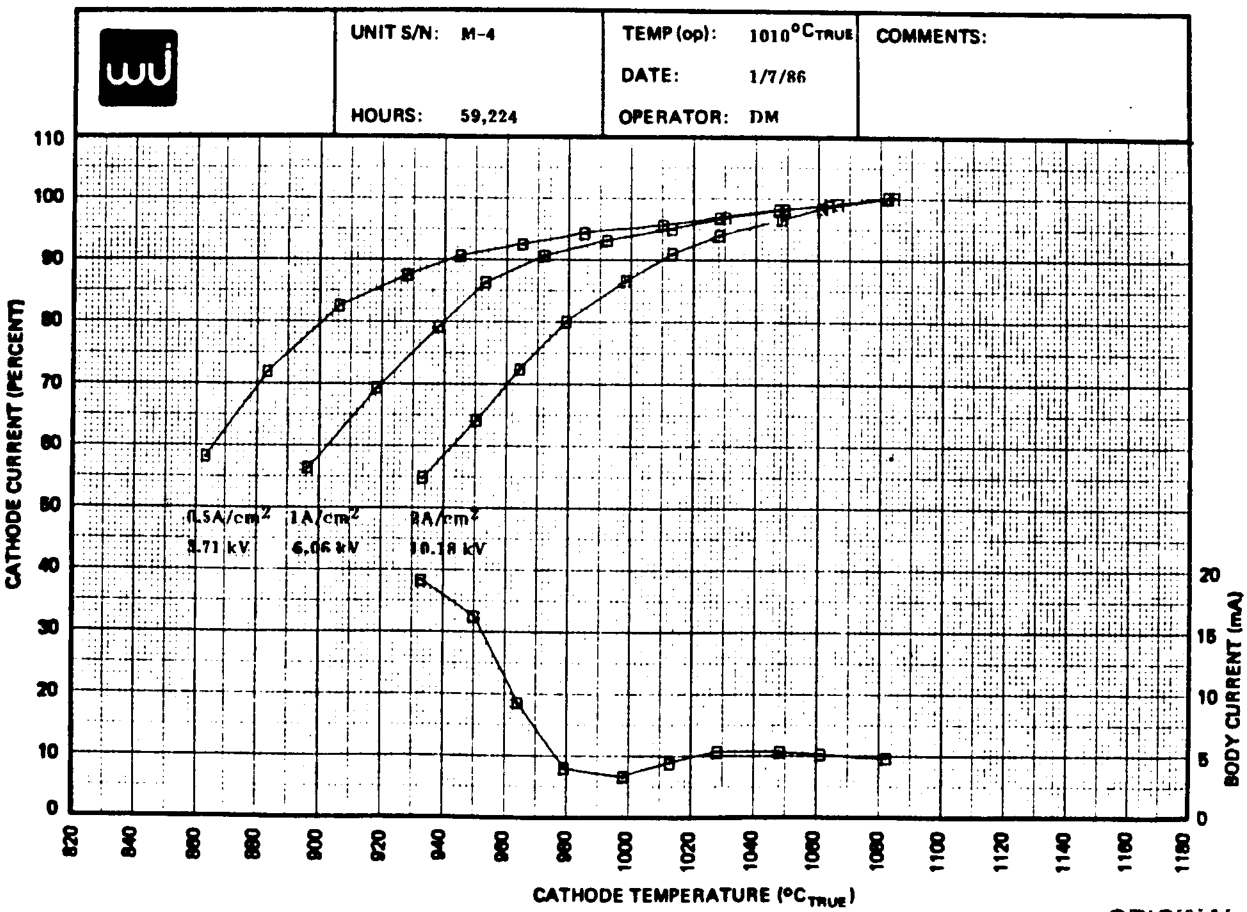


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Figure 29. Miram Curves for Unit M-4 (Continued)

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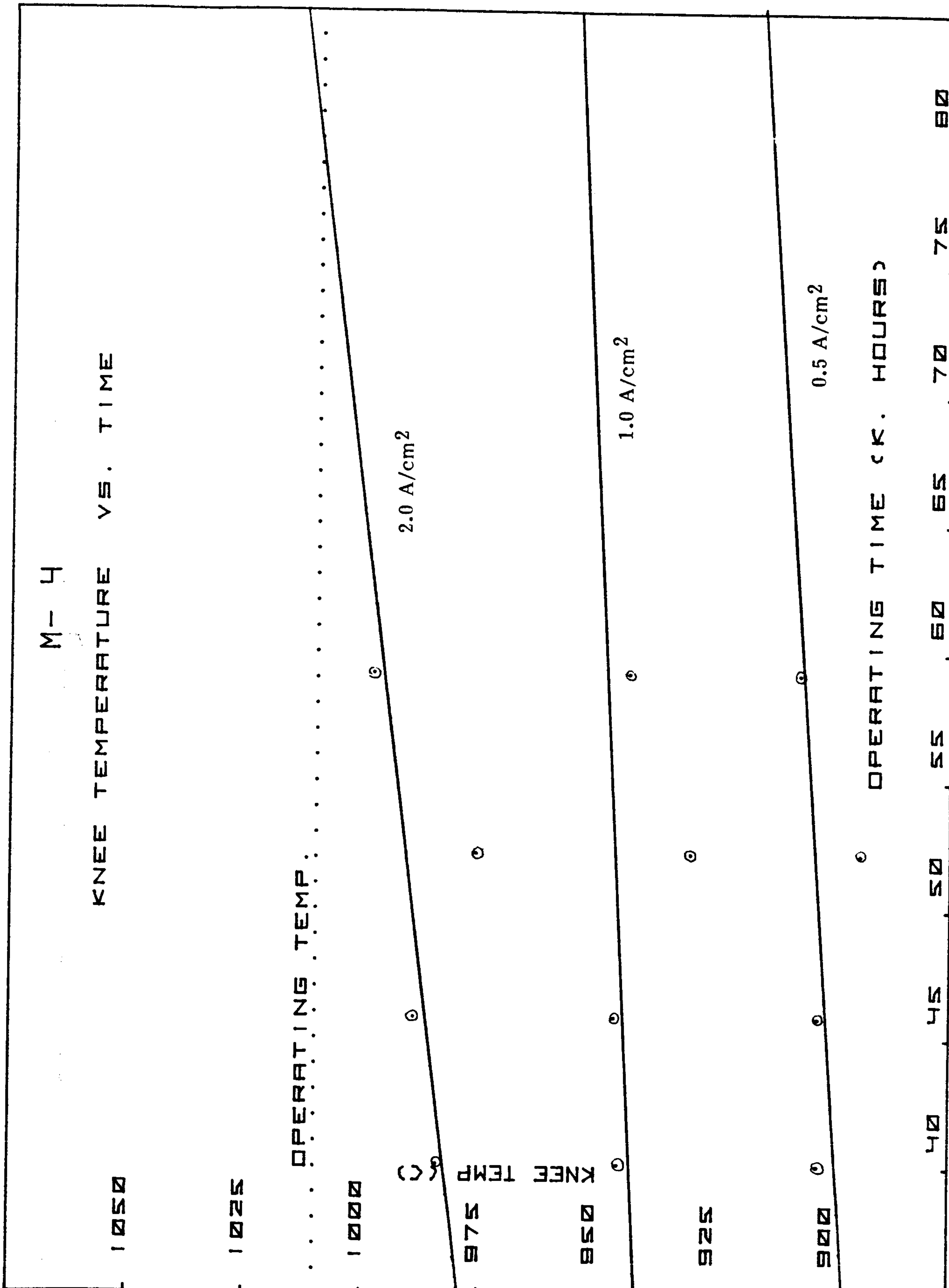


Figure 30. Knee Temperature for Unit M-4

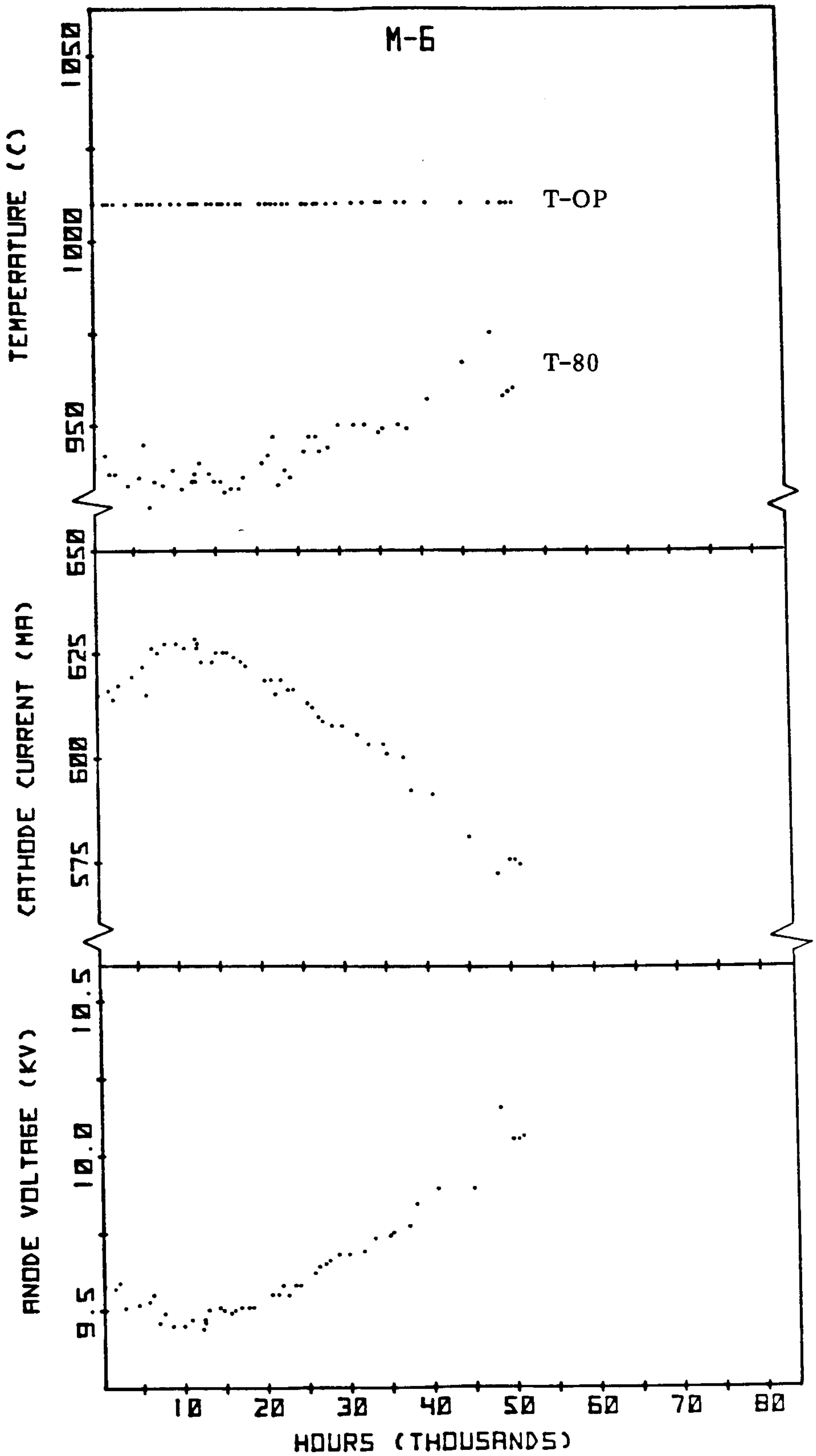
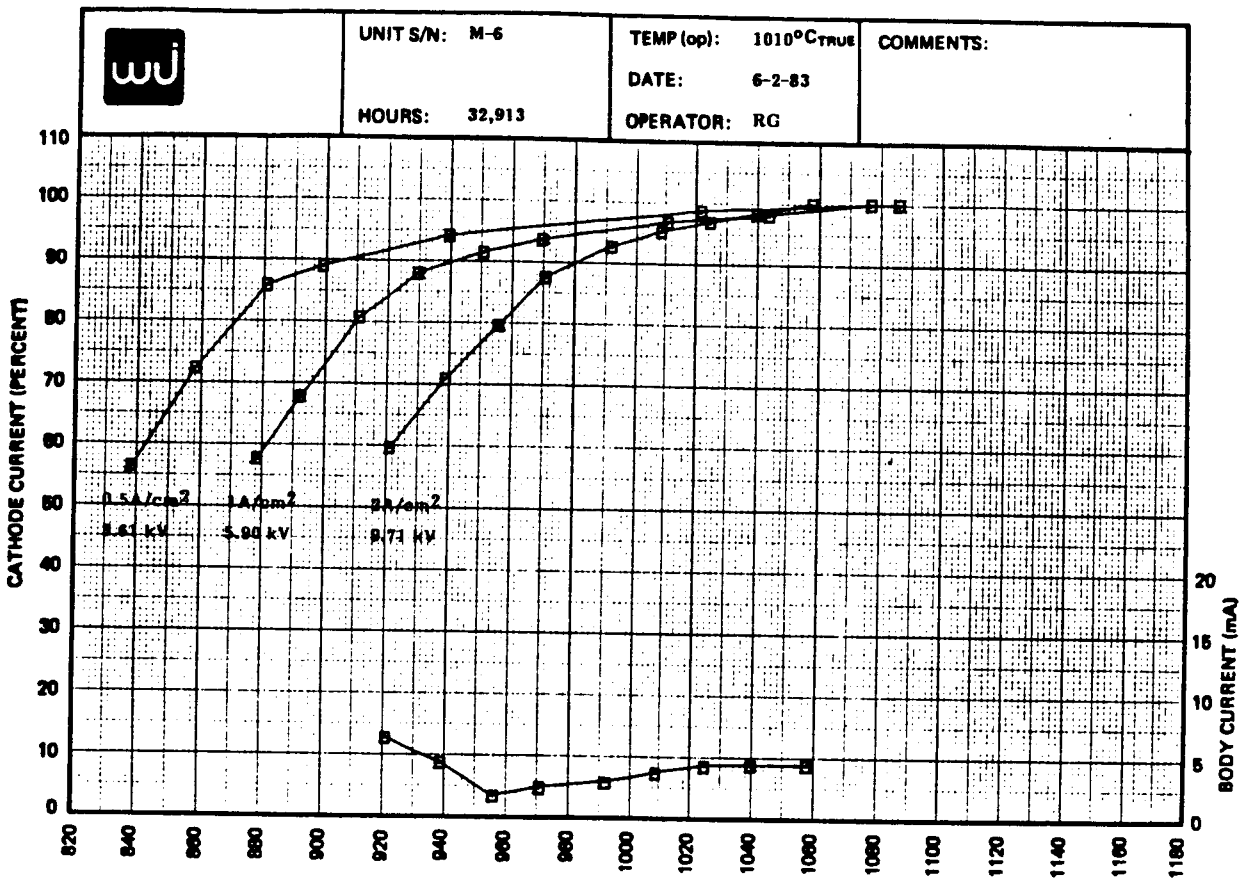


Figure 31. Life Test Data for Unit M-6



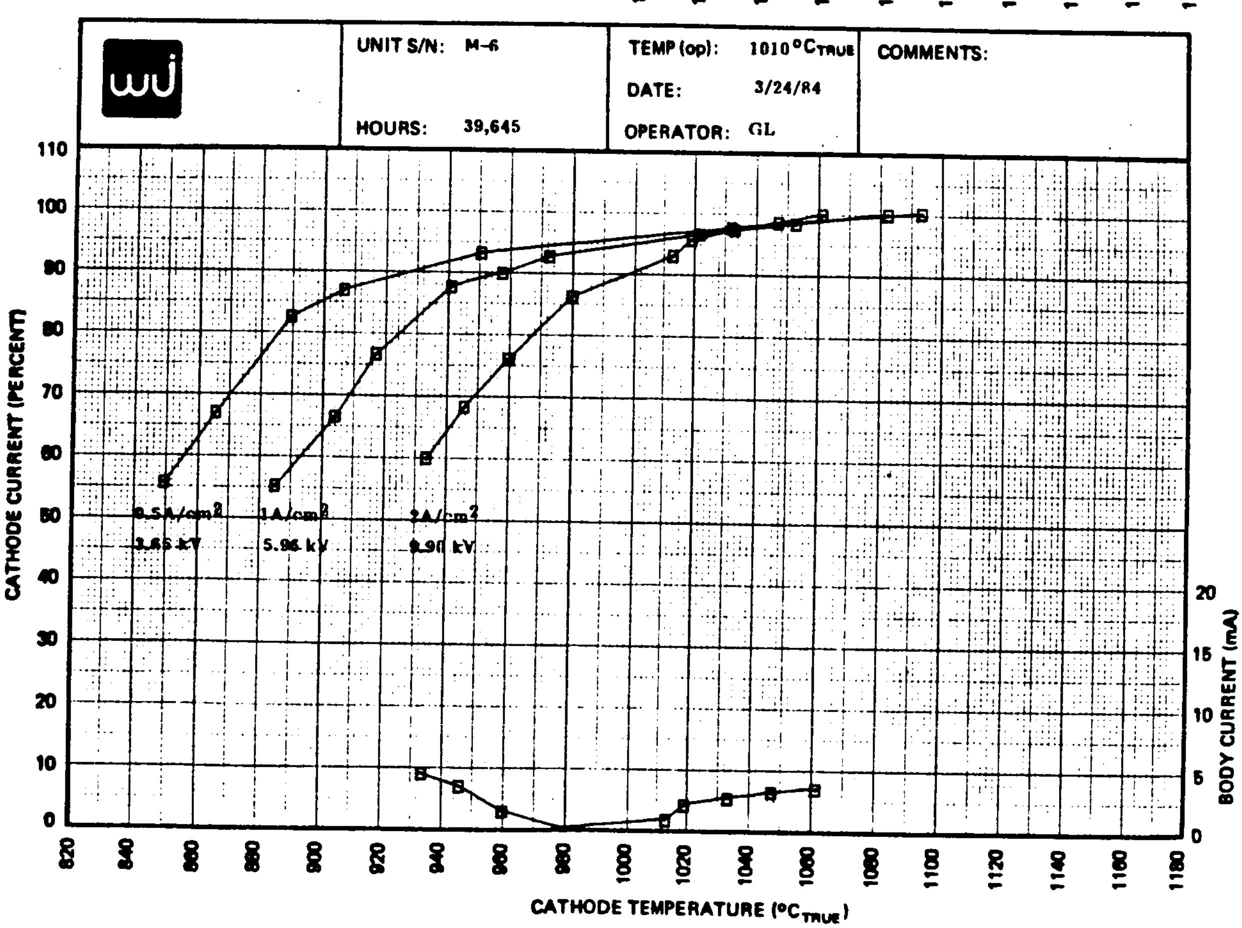


Figure 32. Miram Curves for Unit M-6

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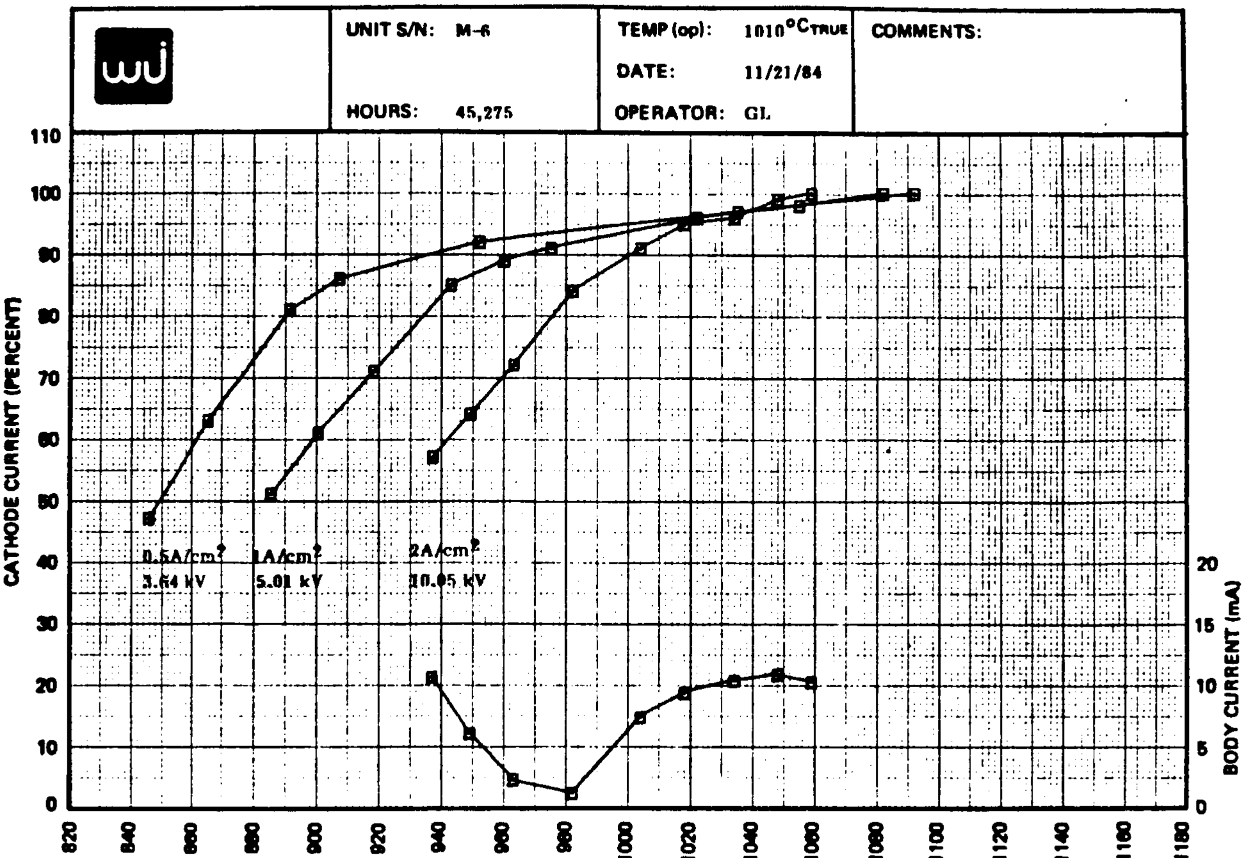

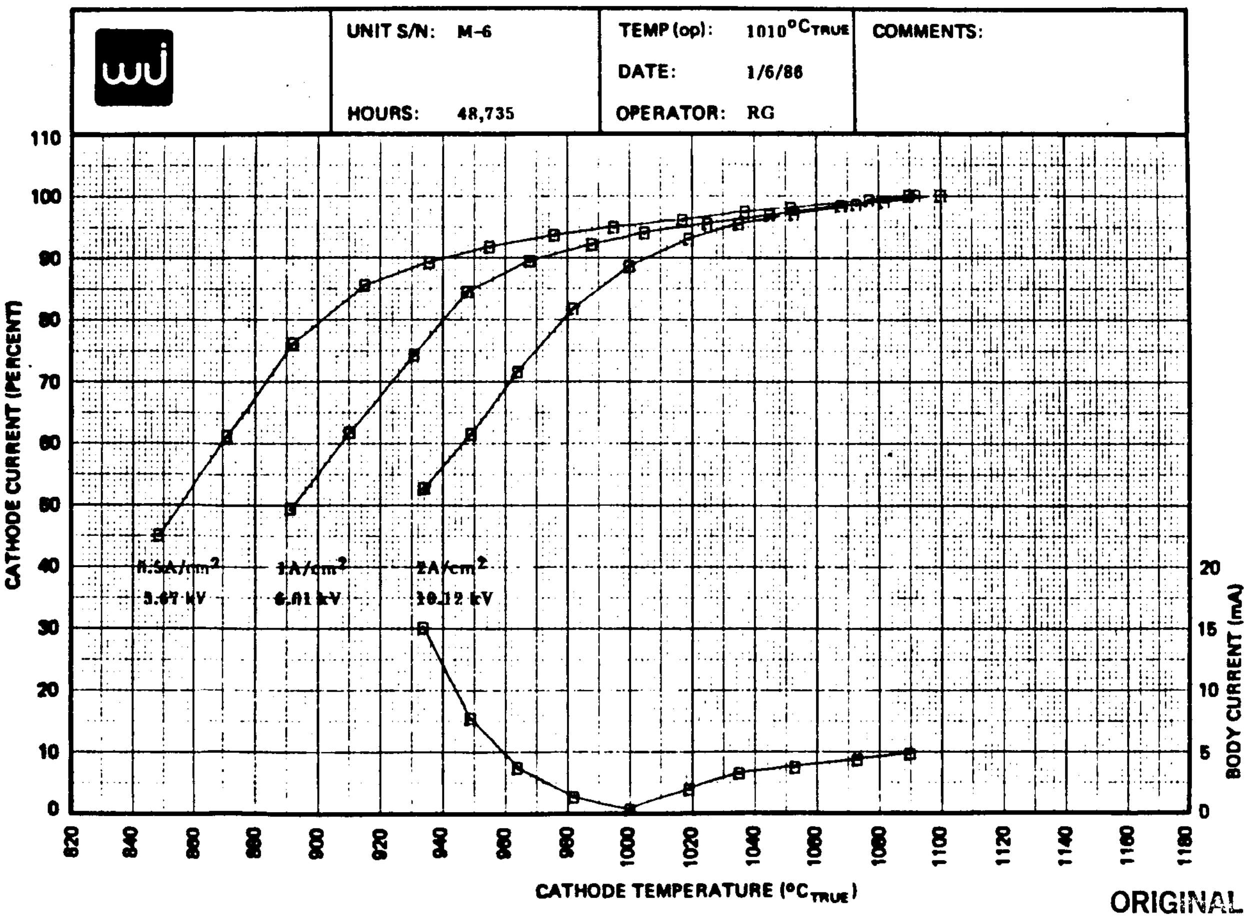

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Figure 33. Miram Curves for Unit M-6 (Continued)

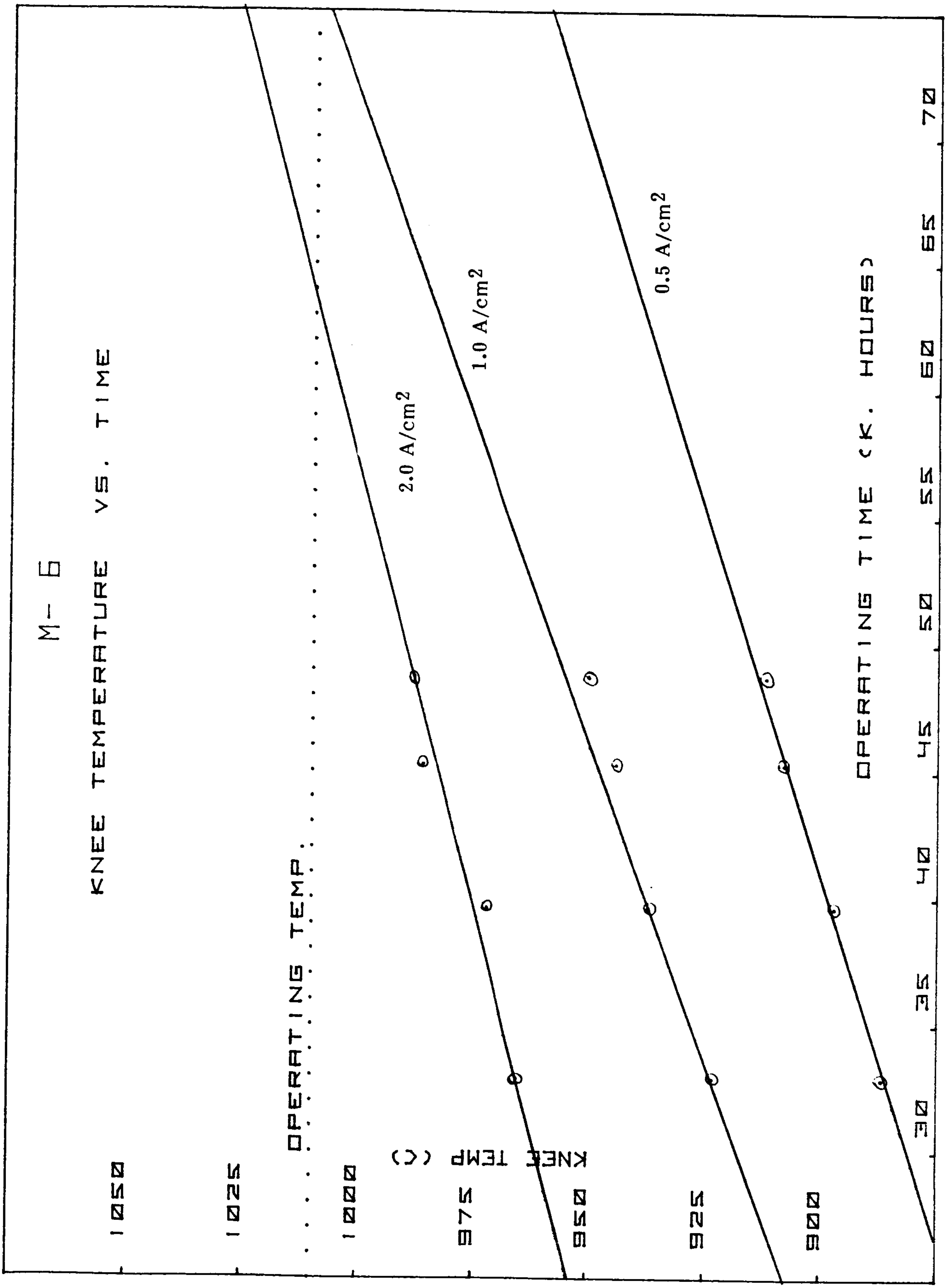

Figure 34. Knee Temperature for Unit M-6

The knee temperature over the period of operation from 56,816 hours to 76,606 hours increased from 980°C to 1016°C at 2.0 A/cm^2 (see Appendix II and Figure 22). The latter temperature is greater than the operating temperature (1010°C), indicating that the unit had exceeded its defined useful life. There is a minor change in rounding of the knee with age (see Figures 20 and 21).

5.3.2 M-3. Unit M-3, with 56,629 hours of operation exhibited behavior similar to M-1. Cathode emission held steady at 101% of the original value during the initial 10,000 hours of operation. Over its life of 56,629 hours, cathode emission dropped by 6%. T-80 held steady during the initial 20,000 hours of operation (see Figure 23).

The knee temperature over the period of operation from 34,846 to 54,277 hours increased from 946°C to 989°C (see Appendix II and Figure 26). The Miram curves in Figure 24 and 25 show a significant change in rounding of the knee with age, which in turn indicates a large change in the work function distribution.

5.3.3 M-4. This cathode accumulated 61,548 hours of operation with only a 1% drop in cathode emission. Emission increased by 8% during first 7,000 hours of operation. It then stabilized at 106% of initial emission for 5,000 hours. The T-80 temperature dropped during the initial 10,000 hours, after which it gradually increased (see Figure 27).

The knee temperature over 19,101 hours (from 40,123 to 59,224 hours) changed by 14°C (984° to 998°C) (see Appendix II and Figure 30). There was a minor change in the rounding of the knee region with age. This implies a minor change in the work function distribution with age (Figures 28 and 29).

5.3.4 M-6. The behavior of this cathode was similar to the other Philips Type M cathodes. Cathode emission increased to 104% of initial value during the first 10,000 hours. Over its life of 51,083 hours emission dropped by 6.2%. T-80 held steady for the initial 20,000 hours of operation (see Figure 31).

From 32,900 hours to 48,700 hours, the knee temperature changed by 29°C (965°C to 994°C) (see Appendix II and Figure 34). There was a minor change in the rounding of the knee with age (see Figures 32 and 33).

5.4 Spectra-Mat and Semicon Type M Life Test Units

Because of the encouraging data obtained from life testing the Philips Type M cathodes, it was decided to further test the Type M under higher loading conditions, i.e., 4A/cm^2. The Philips Company has discontinued manufacturing cathodes in the United States since the first Type M units went on test in this program. Therefore, it became necessary to look for other sources of Type M cathodes. Two domestic manufacturers, Semicon Associates in Lexington, Kentucky and Spectra-Mat in Watsonville, California, have supplied cathodes for the continuation of this life test program at higher cathode loading. As mentioned in an earlier section of this report, the area of the emitting surface of the 4A/cm^2 cathodes is half that of the cathodes operating at 2A/cm^2. Thus, the same cathode current of 616 mA can be drawn from these new cathodes, but at twice the current density. Figures 35 through 57 show the graphical data for these units.

5.4.1 Spectra-Mat Type M Cathodes. The Spectra-Mat Type M cathodes were operated at 1010°C true cathode temperature and $4A/cm^2$ loading. Of these the longest running cathode (SP-3) accumulated 43,508 hours of operating time. The behavior of these units was similar to Philips Type M cathodes.

The FSCL region has significant positive slope, indicating a differential thermal motion between the cathode and gun electrodes. Miram curves in the FTL region are approximately evenly spaced, implying there were no cathode emission problems.

The knee region is quite rounded, indicating very uneven cathode loading or wide variation in the work function distribution.

a) SP-2

This unit was removed from test due to a vacuum leak. Its emission dropped by 6.7% over its operating life of 38,781 hours. T-80 temperature gradually increased with age (see Figure 35).

The FSCL region show a very large positive slope (see Figure 36 and 37), indicating a substantial thermal motion between the cathode and gun electrode. The Miram curve in figure 37 for $4\ A/cm^2$ indicates that the cathode is definitely not SCL and has degraded to where it is not useful at this current density. It is not certain what effect the vacuum leak, which occurred at the time of the measurement, might have had on the results. There is a substantial change in the knee with age, indicating a major change in the work function distribution over this time span (see Figure 38).

SP-3

Unit SP-3 accumulated 43,508 hours of operation with a 6% drop in cathode emission. Throughout its life it had periods of as much as a few thousand hours where cathode emission held steady or increased. T-80 declined for the initial 7,000 hours and since then it gradually increased (see Figure 39).

The knee temperature from 22,600 hours to 34,088 hours has increased by 38°C (983 to 1023°C), (see Figure 42). There is a substantial change in rounding of the knee with age. This implies a significant change in work function distribution (see Figures 40 and 41).

b) SP-4

Unit SP-4 logged 35,116 hours with a 6.0% decline in cathode emission, similar to SP-3, for the initial 5,000 hours T-80 gradually decreased or held steady, and there after it gradually increased, with interim periods in which it decreased or held steady.

The knee temperature over the cathode life from 19,562 hours to 32,759 hours increased from 978°C to 993°C (see Appendix II and Figure 46). There is a minor change in the rounding of the knee with age, implying small changes in work function distribution (see Figures 44 and 45).

5.4.2 Semicon Type M Cathodes. Three of these cathodes were operated at 1010°C true cathode temperature, with $4A/cm^2$ cathode loading. The longest running cathode accumulated over 42,000 hours of operation. Two units out of three showed a decrease in T-80 for the initial 5,000 hours.

a) SM-1

Unit SM-1 experienced an increase in cathode emission for the initial 5,000 hours of operation. Overall cathode emission dropped by 4.1% over 42,704 hours of operation. T-80 decreased by 3% during the initial 5,000 hours and then gradually edged up (see Figure 47).

The knee temperature changed by 15°C over 20,000 hours (from 18,882 to 40,356 hours) (see Appendix II and Figure 50). There is a significant amount of change in rounding of the knee region with age, meaning substantial change in the work function distribution (see Figures 48 and 49).

b) SM-2

Unit SM-2 accumulated 40,616 hours of operation with a 5.8% drop in cathode emission. For the initial 10,000 hours emission either increased or alternately held steady. T-80 decreased approximately 2% during the initial 5,000 hours of operation, after which it gradually increased (see Figure 51). This cathode behaved similarly to SM-1.

The knee temperature changed by 20°C over its operating life (from 18,980 to 38,225 hours) (see Appendix II and Figure 54). There is a significant amount of change in rounding of the knee region with age, meaning substantial change in the work function distribution (see Figure 52 and 53).

c) SM-3

During its first 5,000 hours cathode SM-3 behaved differently than SM-1 or SM-2. Cathode emission gradually decreased since beginning of life, as compared to the other two units, whose cathode emission either increased or held steady for the initial 5,000 to 10,000 hours. Over 23,636 hours of operation, cathode emission decreased by 4%. T-80 increased by 2% during the initial 5,000 hours. T-80 behavior is like that of SM-1 or SM-2 except during the initial 5,000 hours (see Figure 55).

From 16,072 hours to 21,267 hours the knee temperature changed by 24°C (976°C to 1000°C) (see Figure 57). There is a minor change in the rounding of the knee with age (see Figure 56).

The knee region itself is fairly rounded, indicating wide variation in the work function distribution.

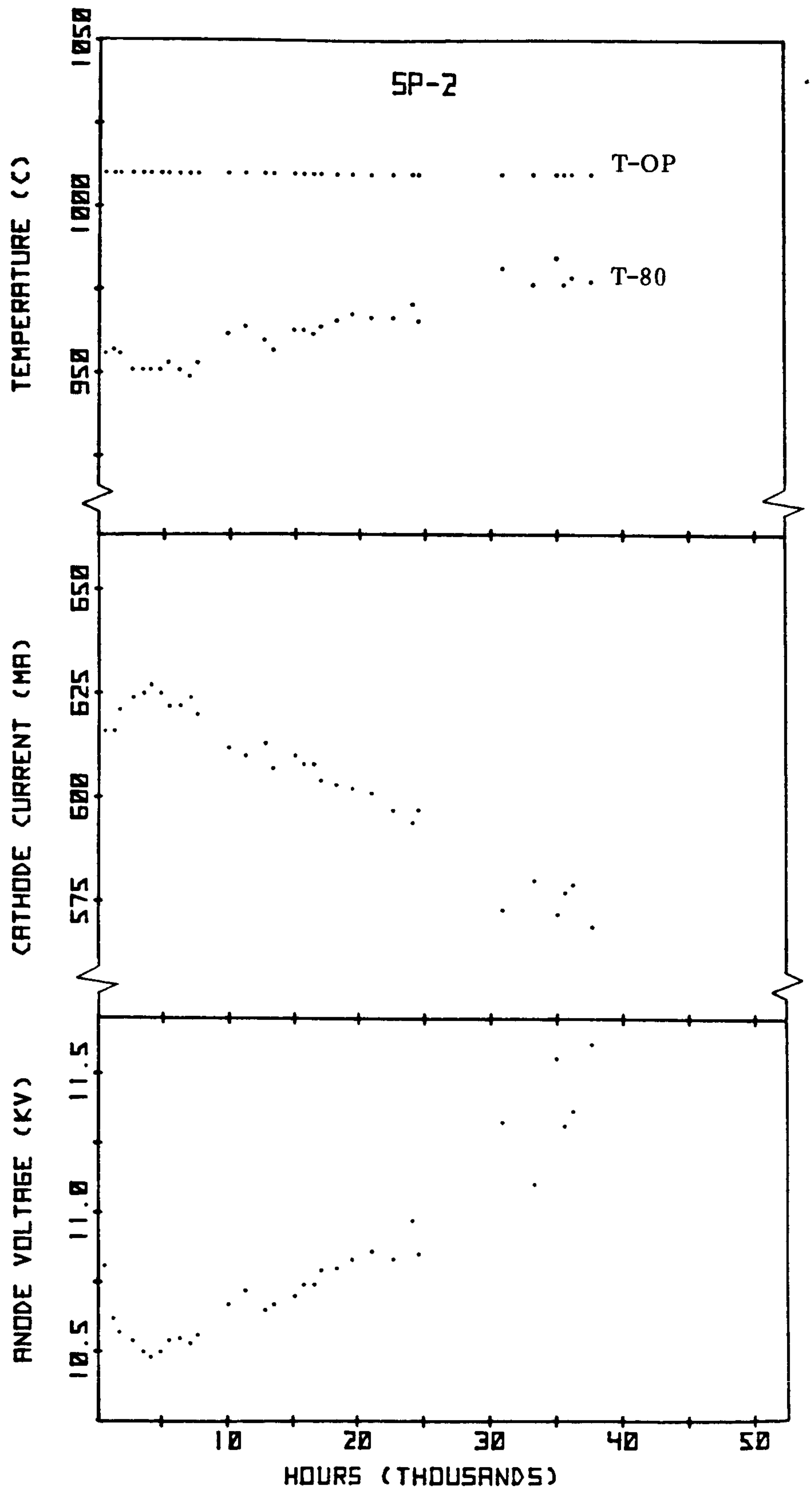

Figure 35. Life Test Data for Unit SP-2

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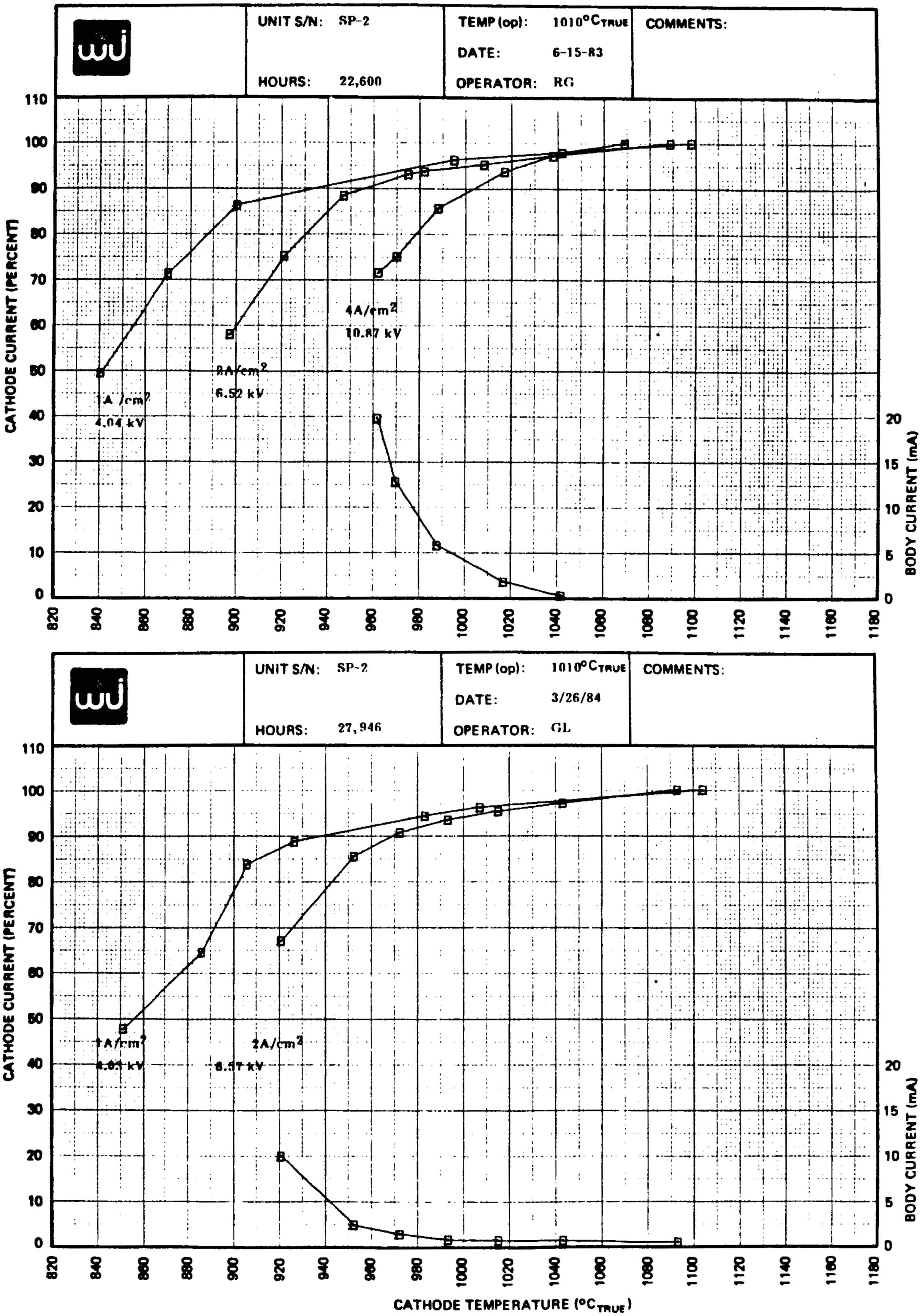

Figure 36. Miram Curves for Unit SP-2

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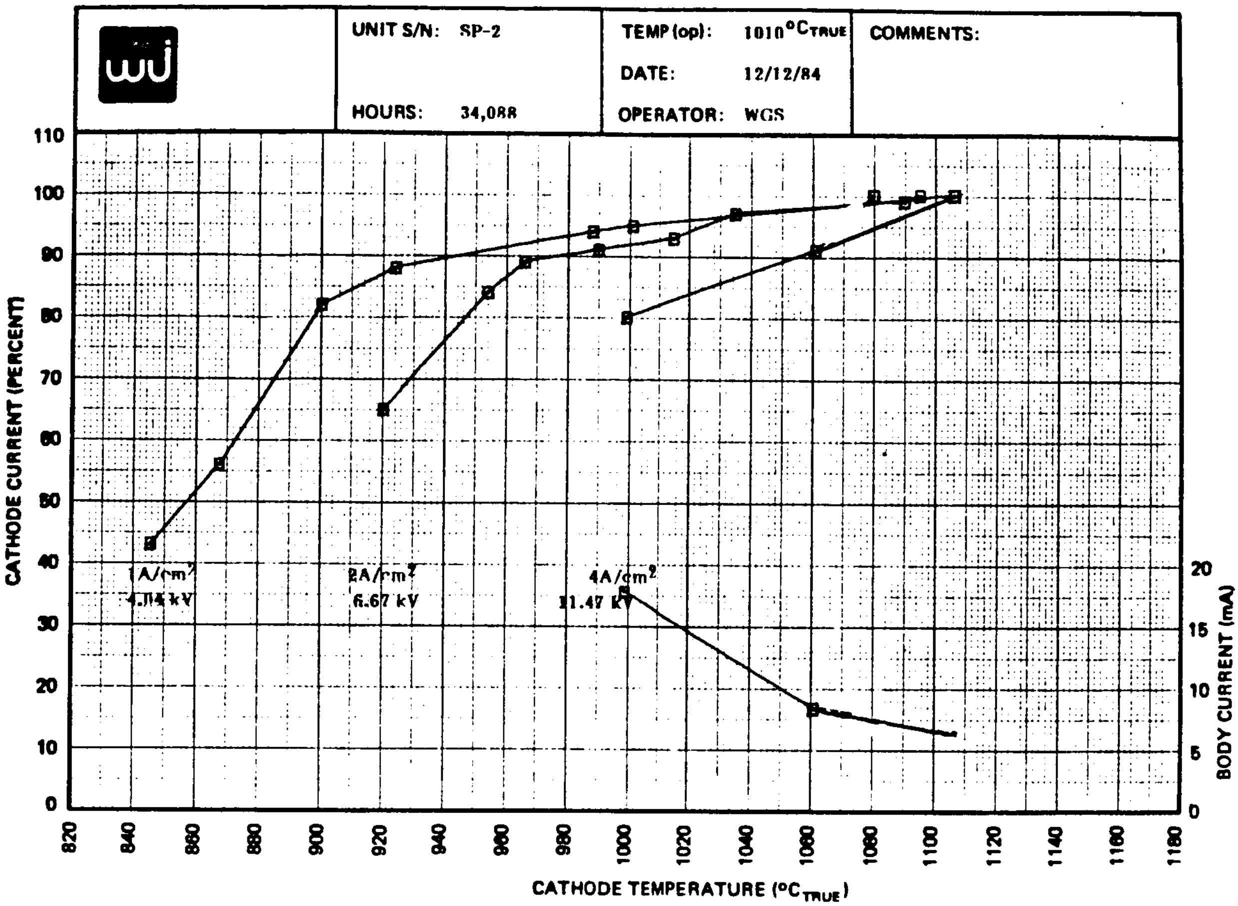

Figure 37. Miram Curves for Unit SP-2 (Continued)

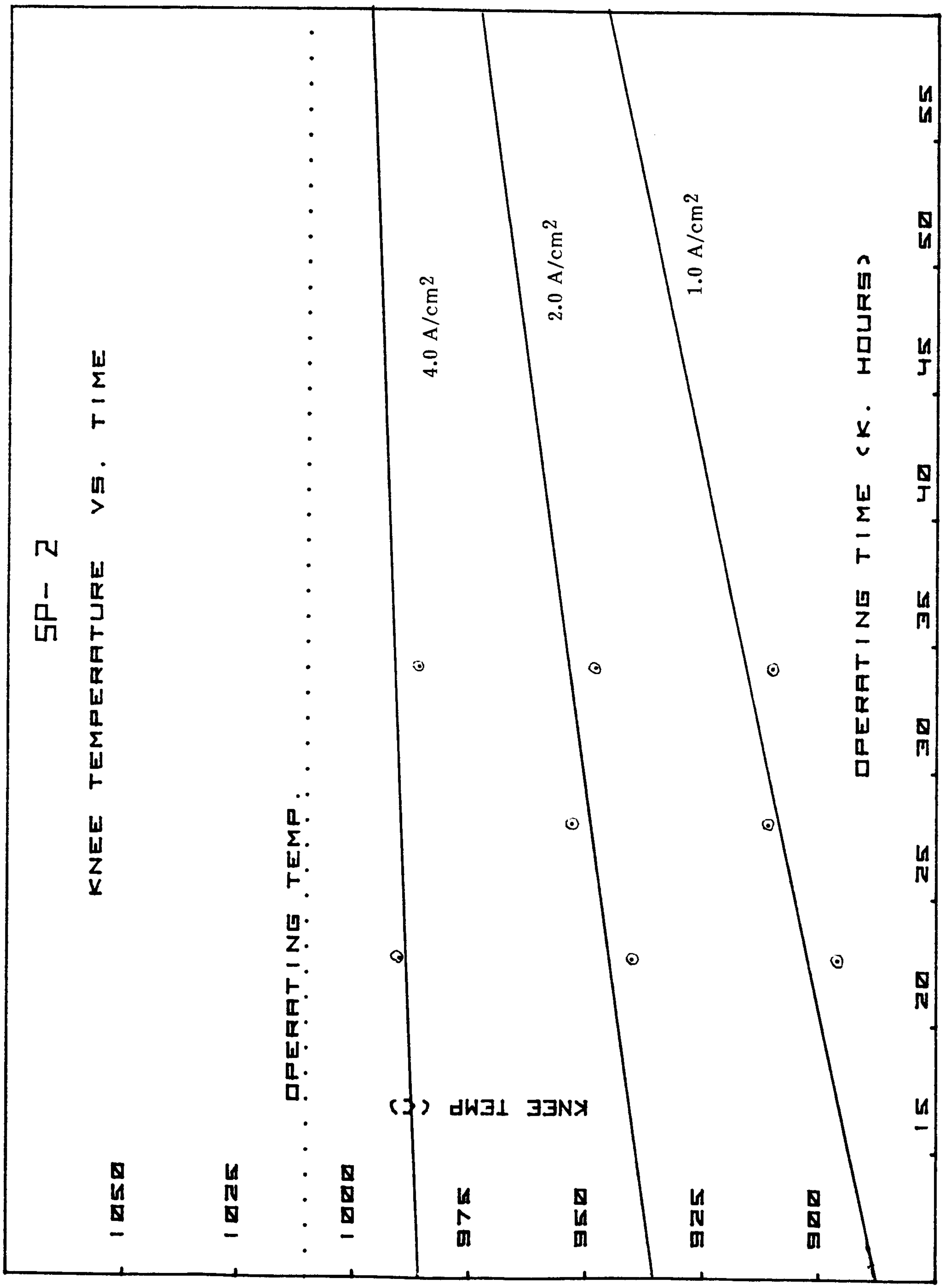

Figure 38. Knee Temperature for Unit SP-2

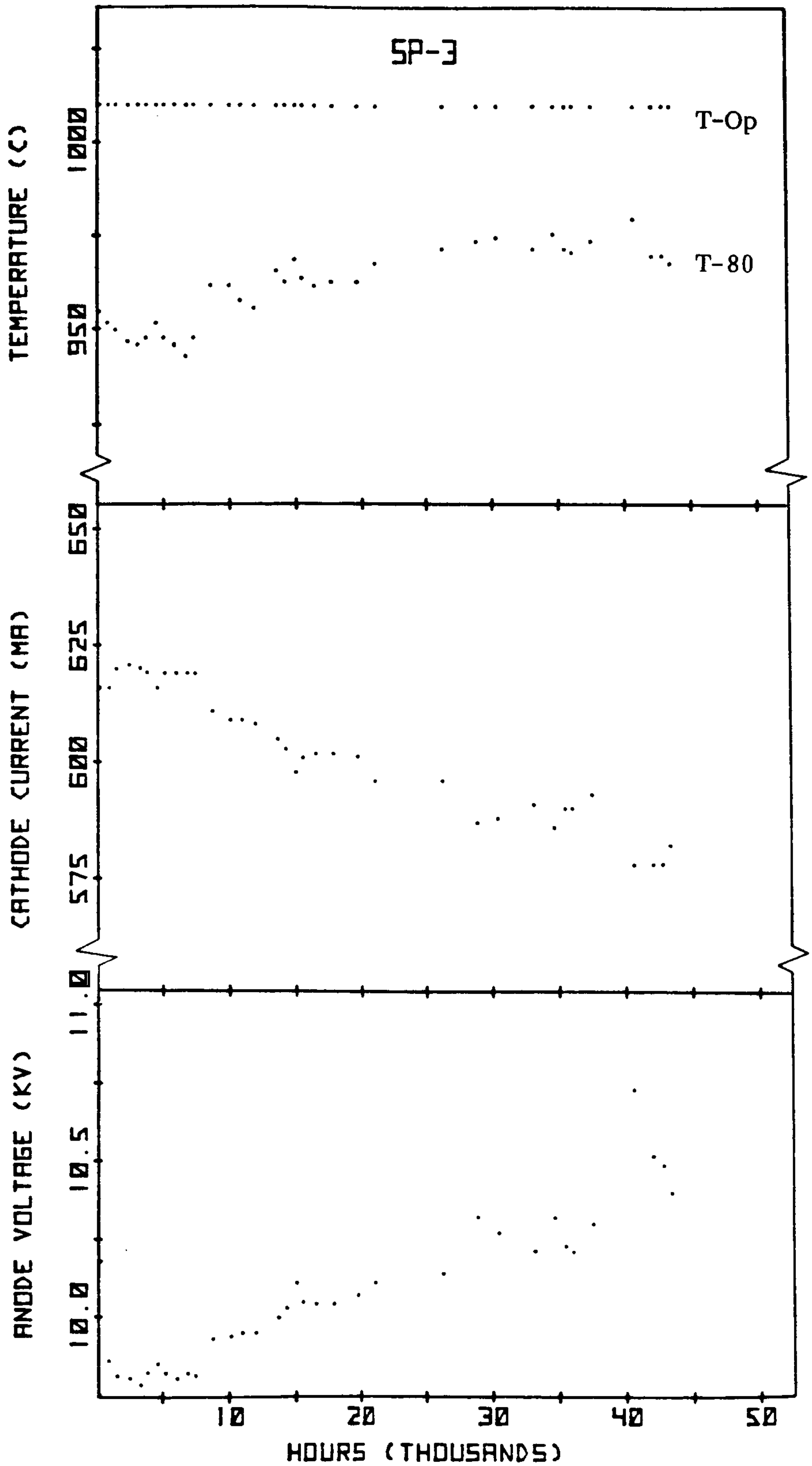

Figure 39. Life Test Data for Unit SP-3

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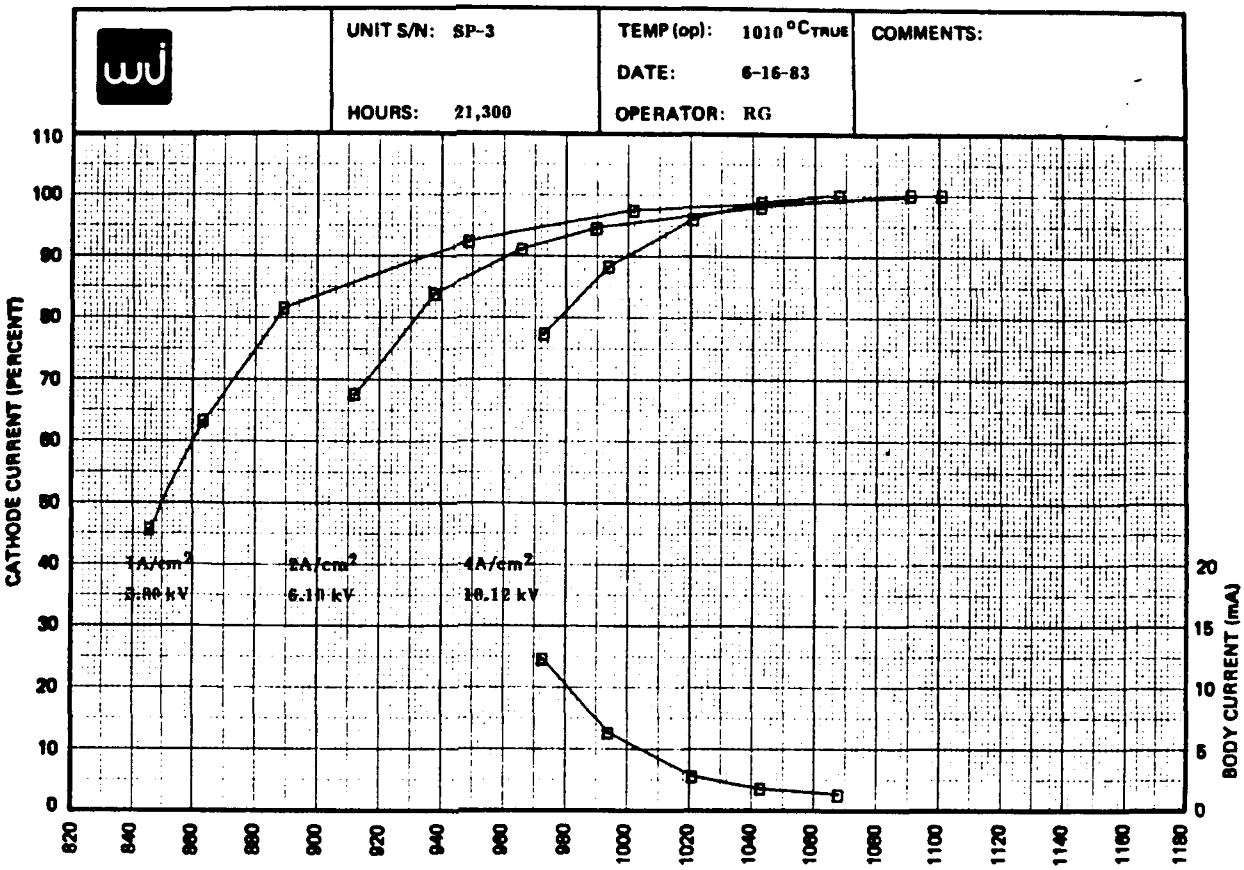

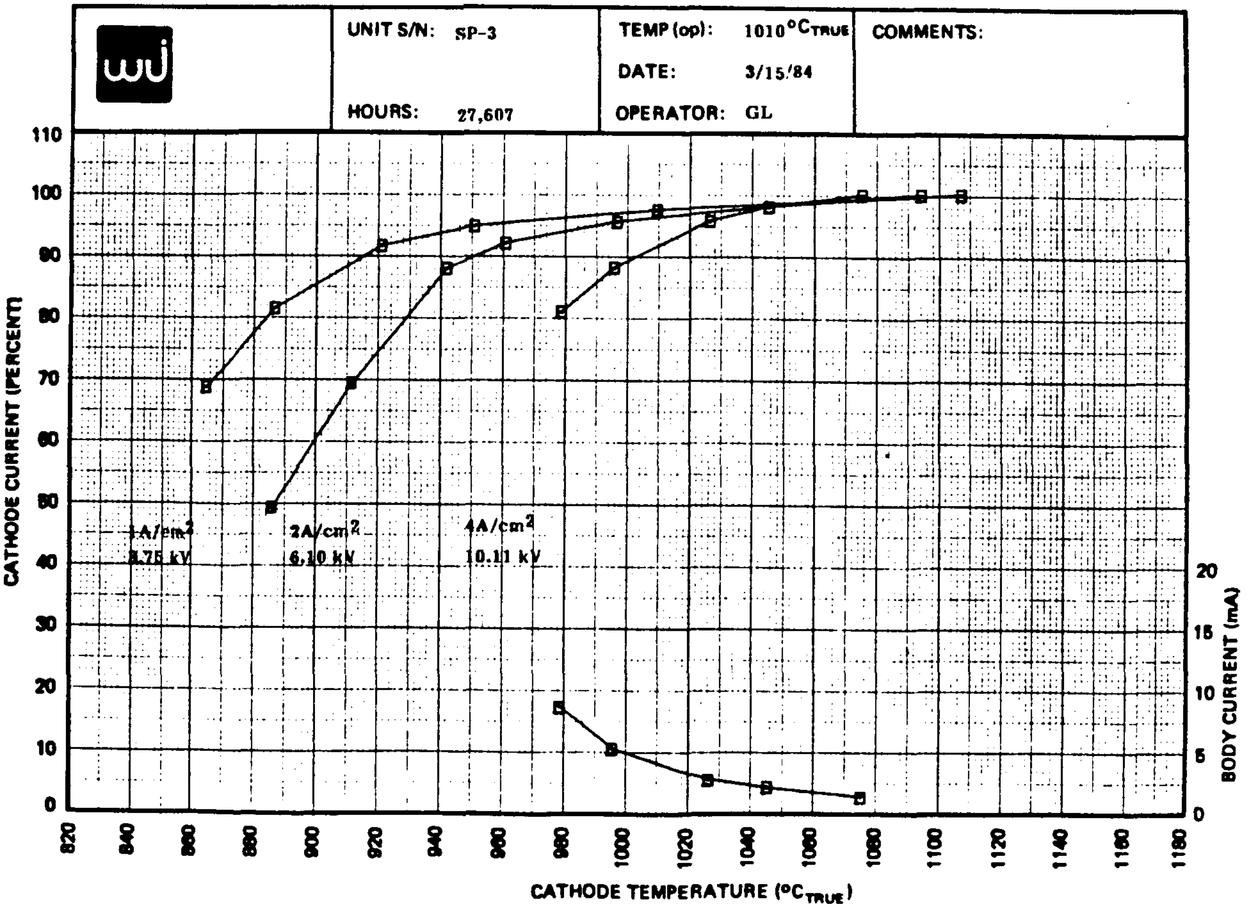

Figure 40. Miram Curves for Unit SP-3

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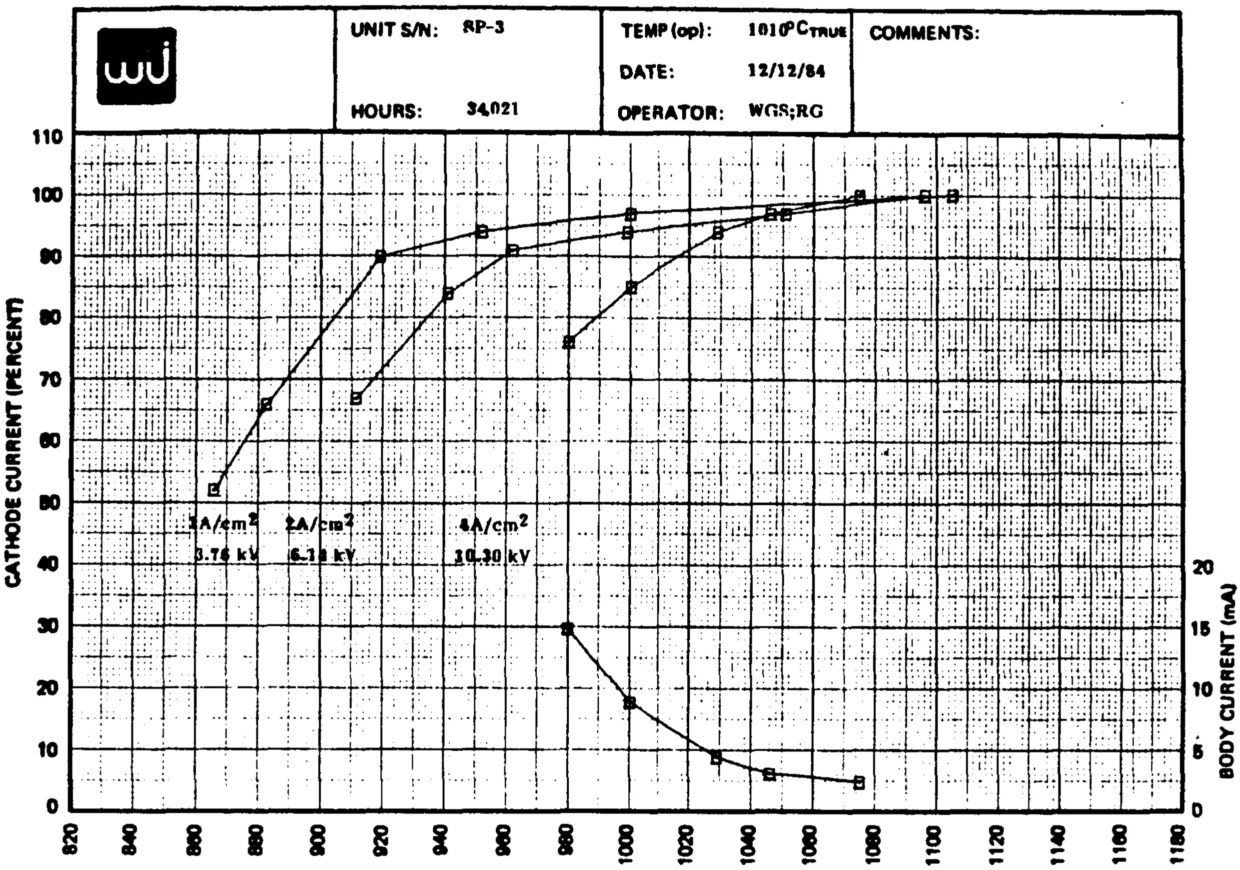


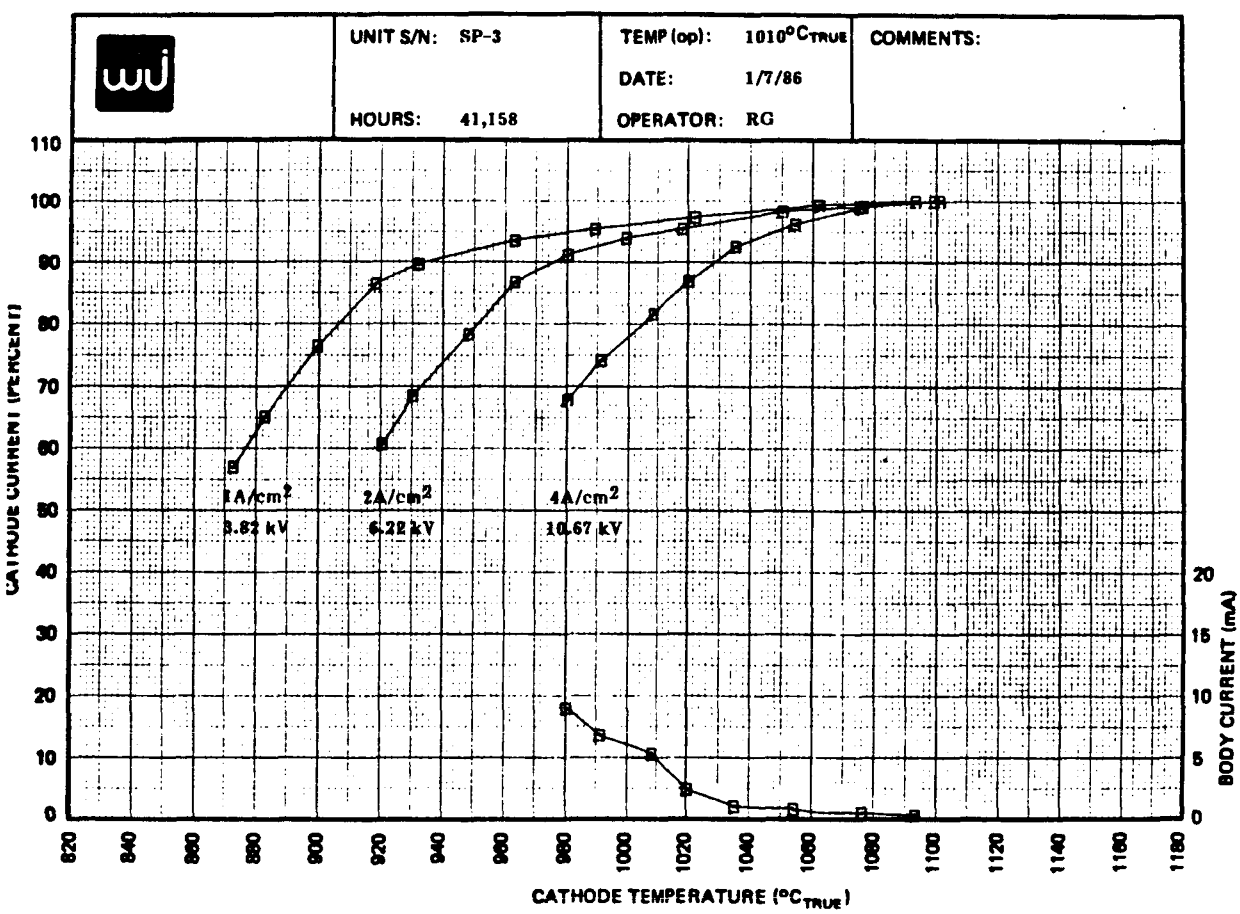


Figure 41. Miram Curves for Unit SP-3 (Continued)

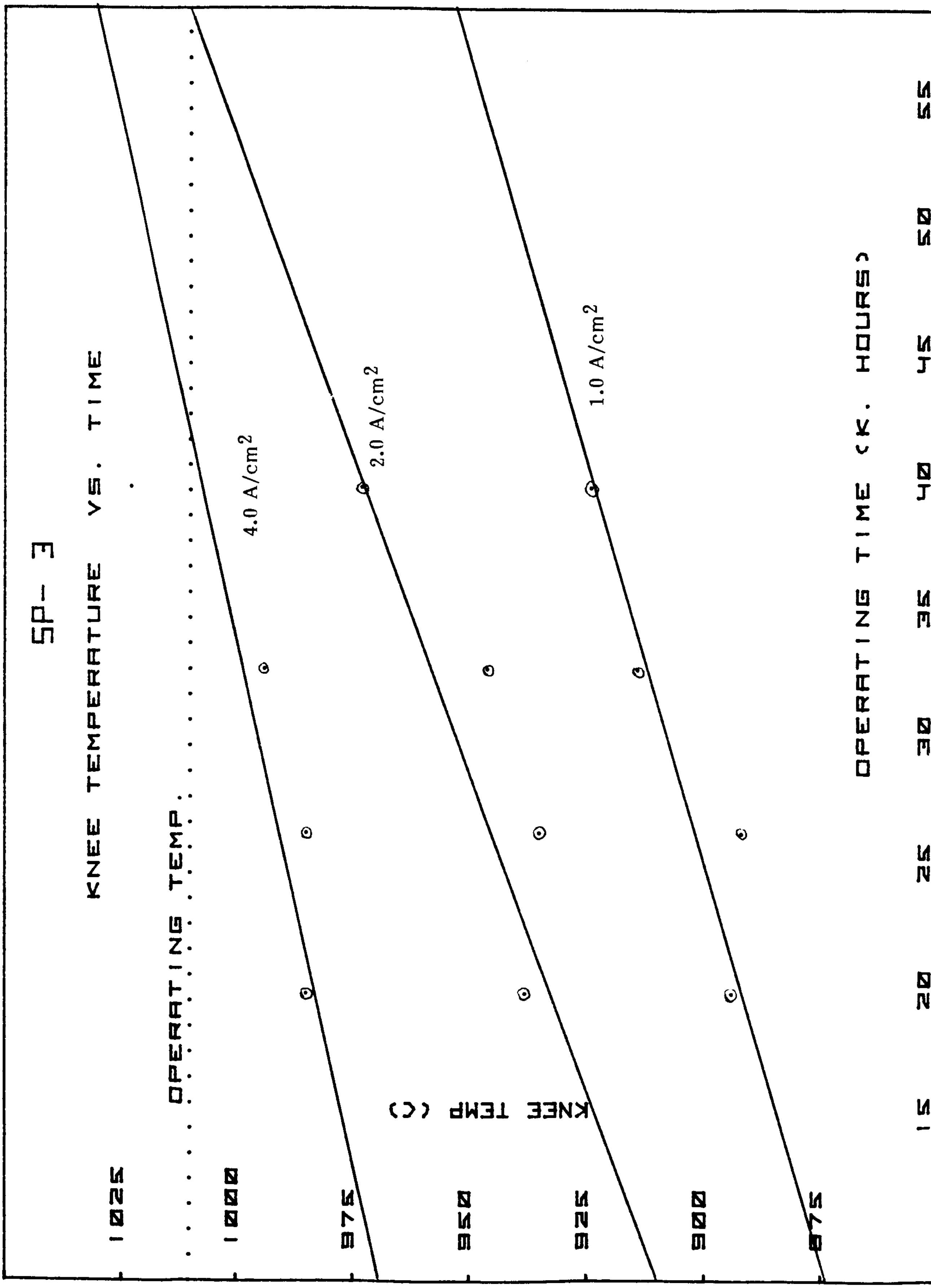


Figure 42. Knee Temperature for Unit SP-3

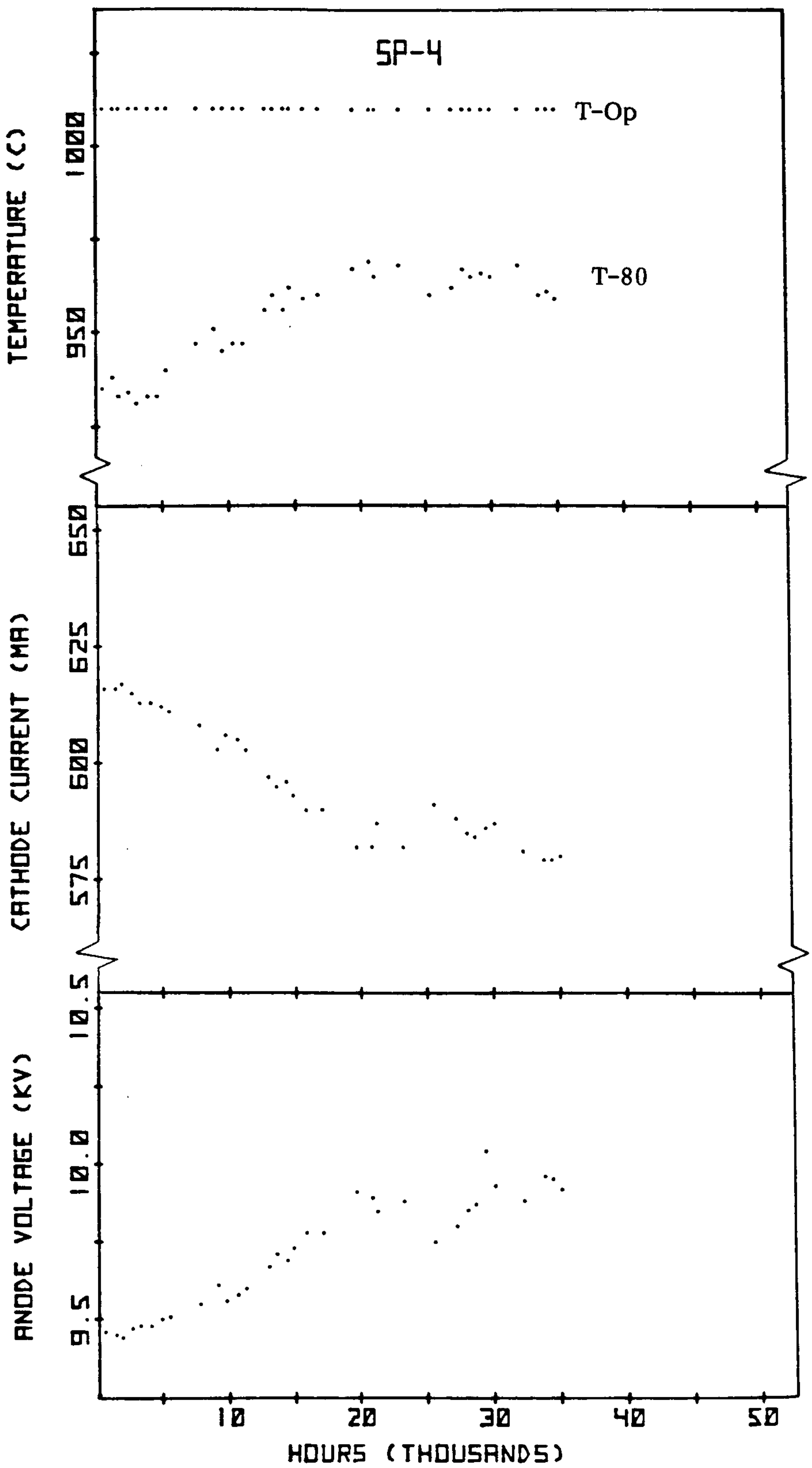
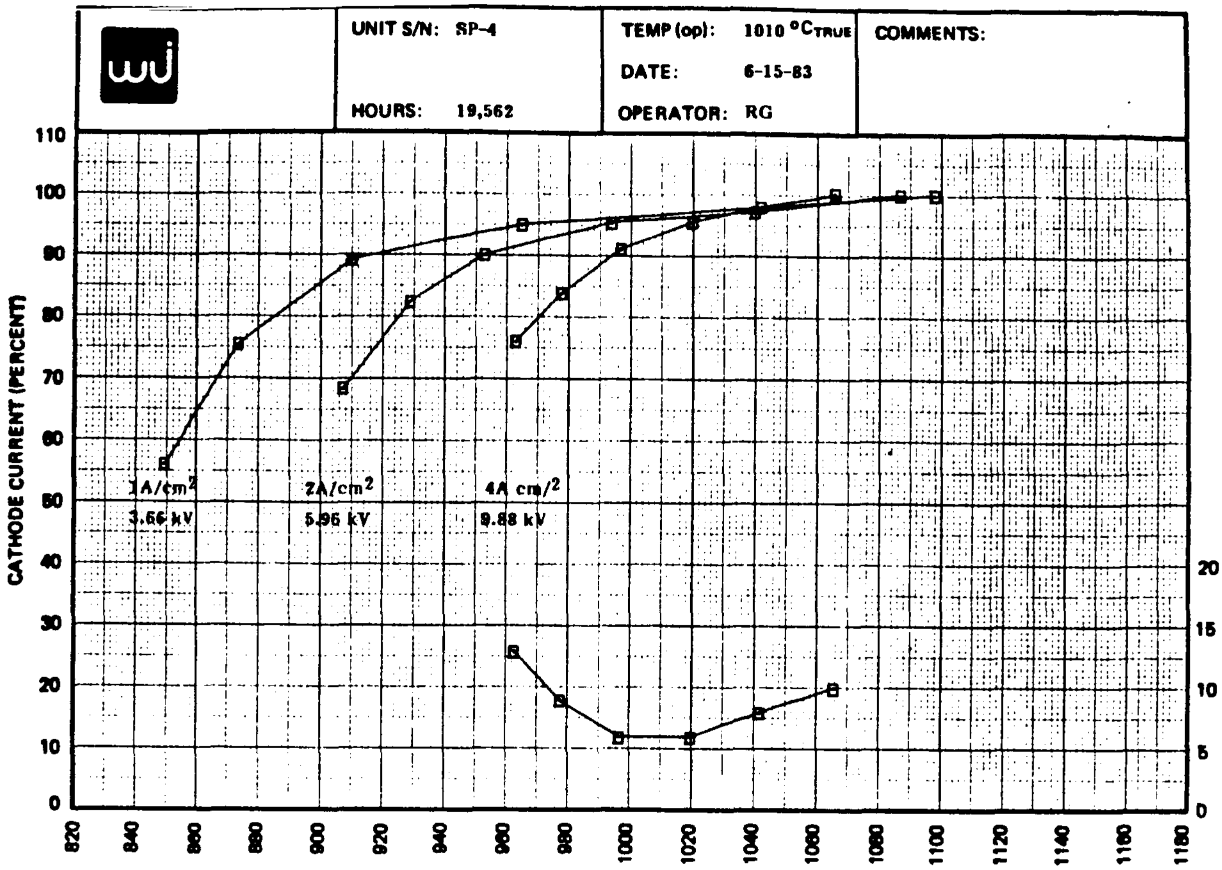


Figure 43. Life Test Data for Unit SP-4



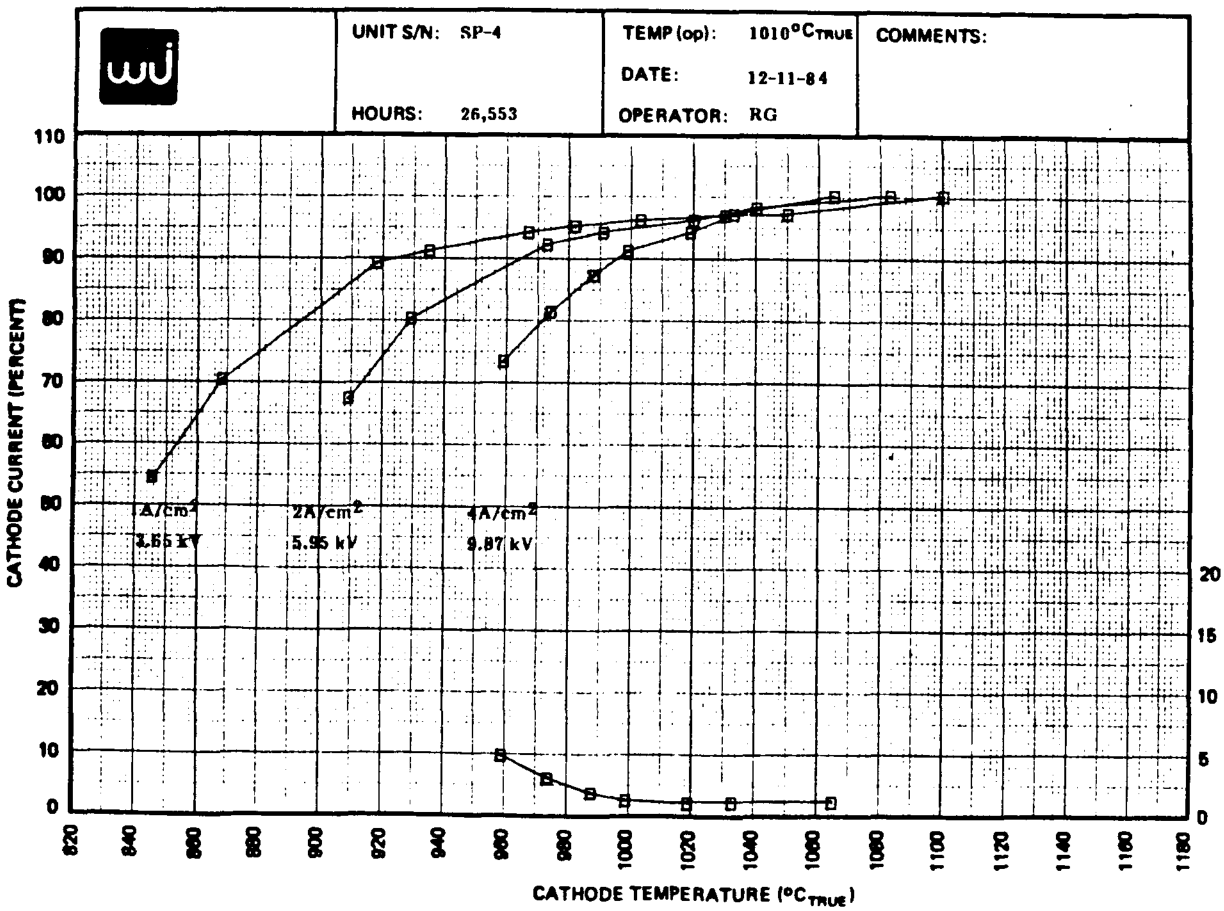


Figure 44. Miram curves for Unit SP-4

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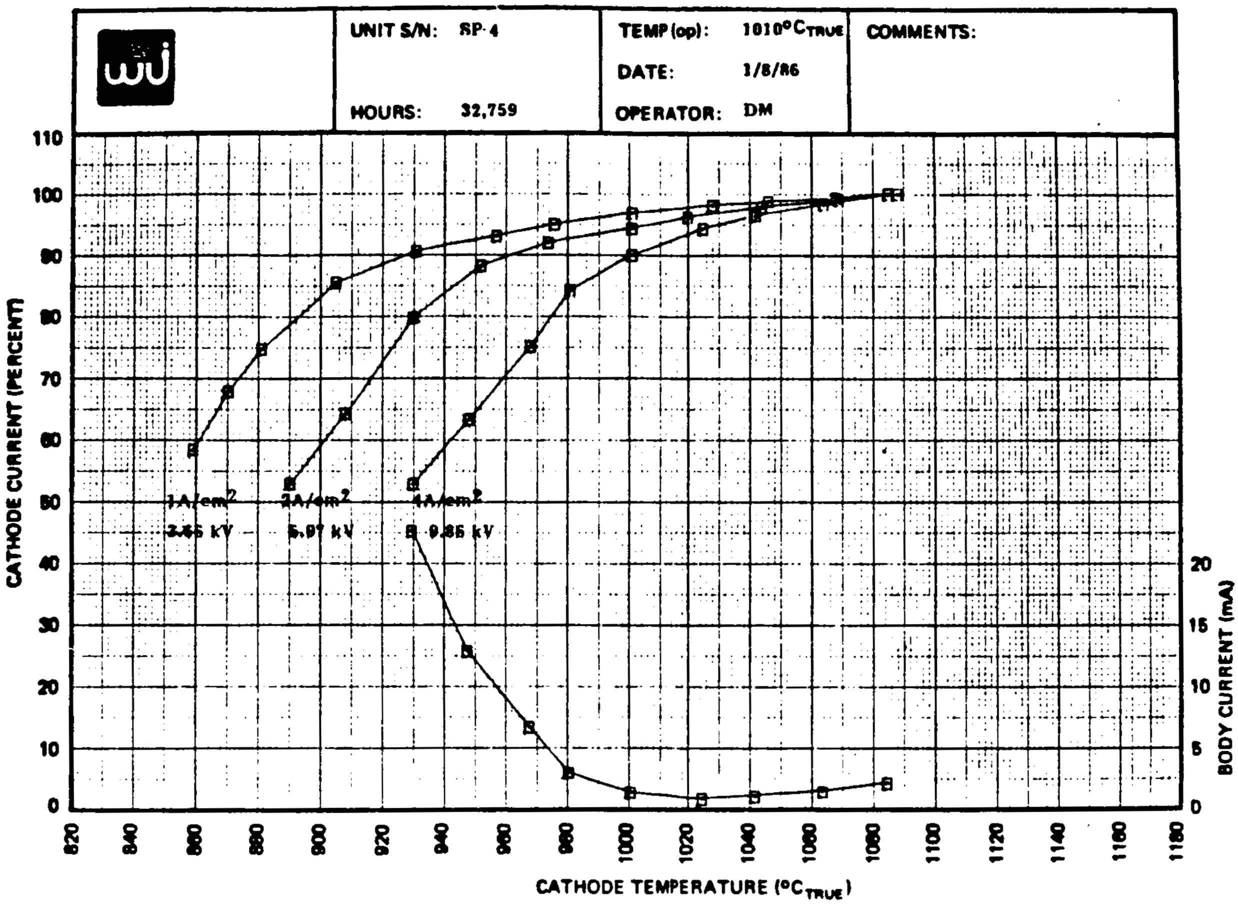

Figure 45. Miram Curves for Unit SP-4 (Continued)

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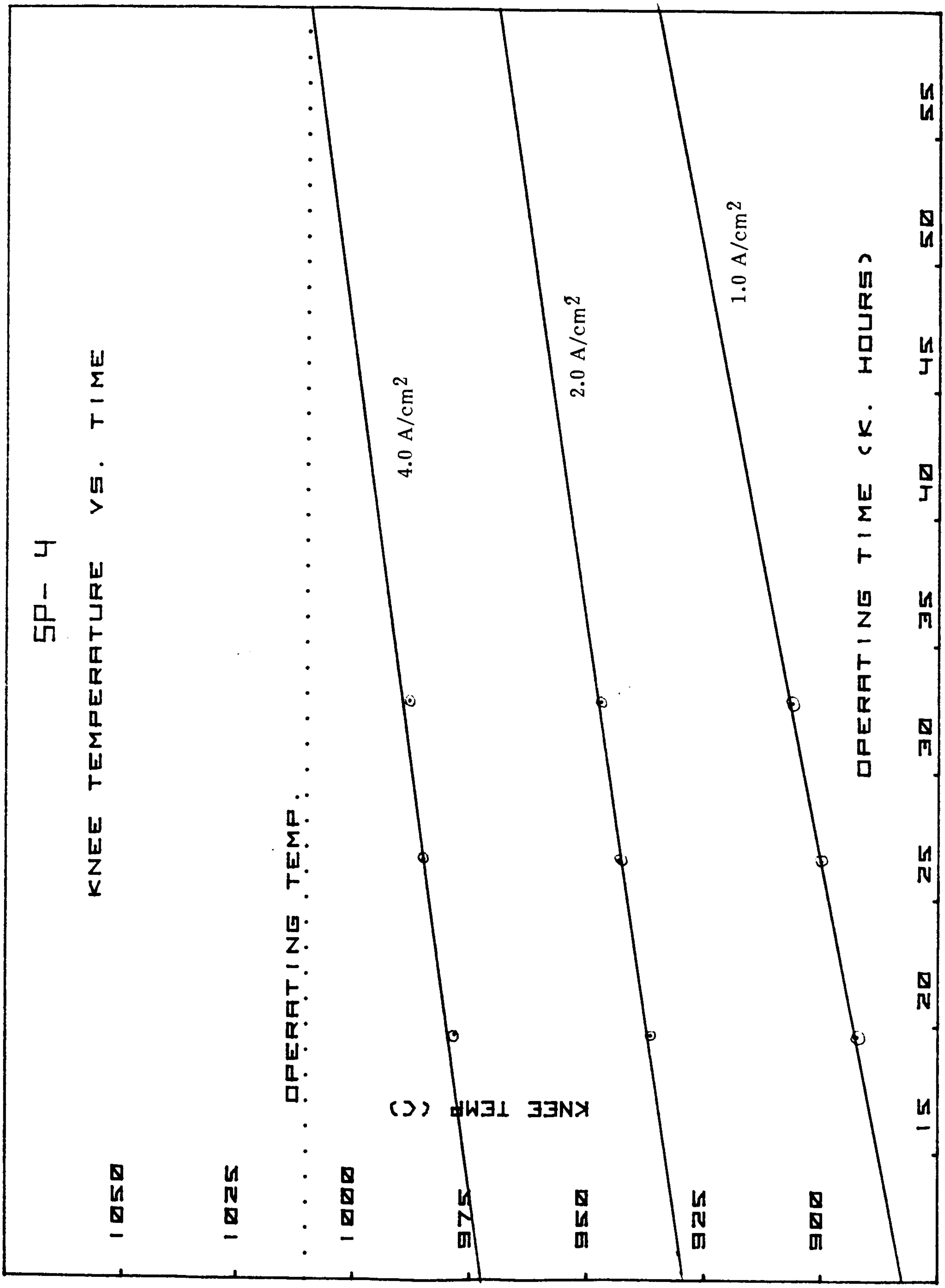

Figure 46. Knee Temperature for Unit SP-4

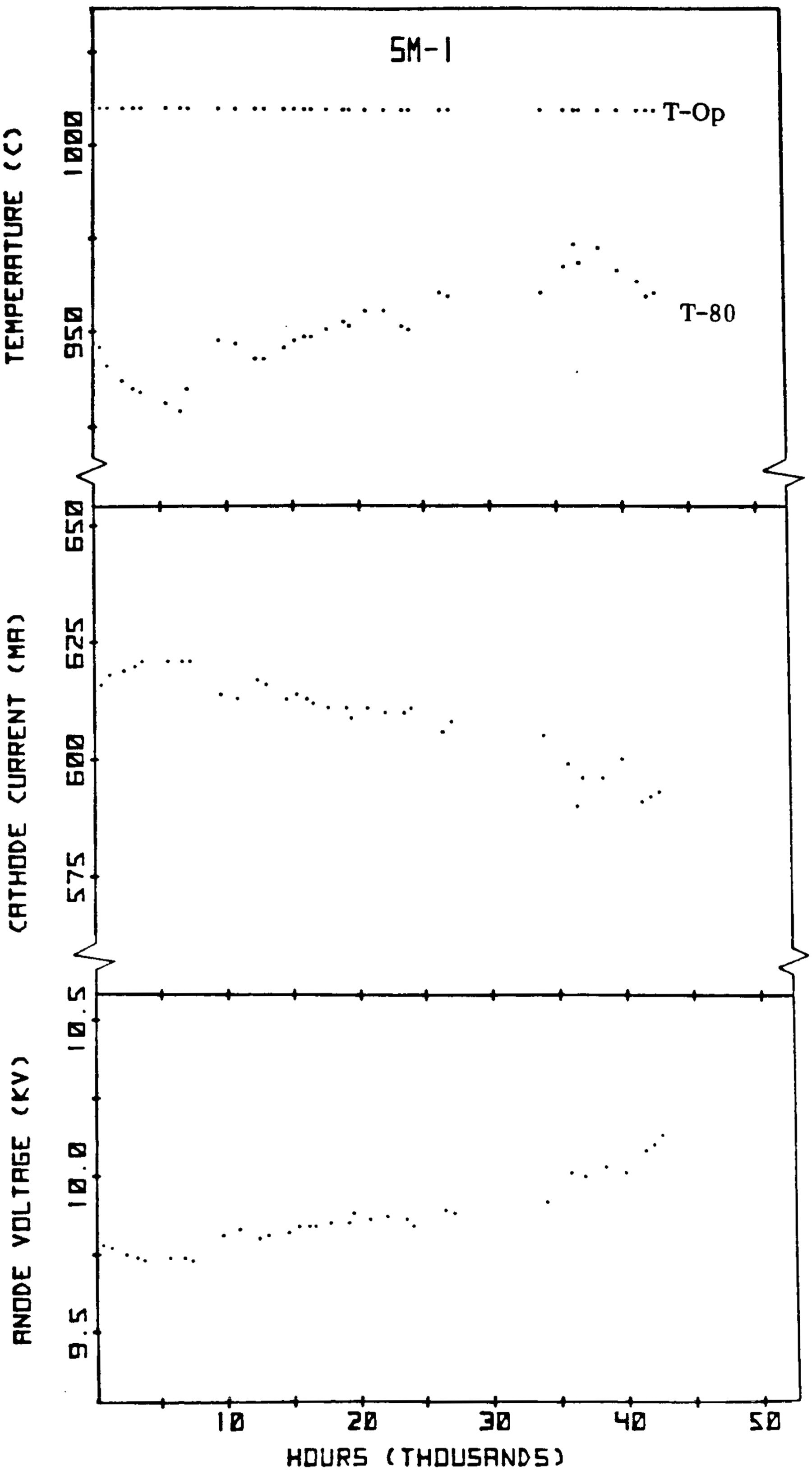

Figure 47. Life Test Data for Unit SM-1

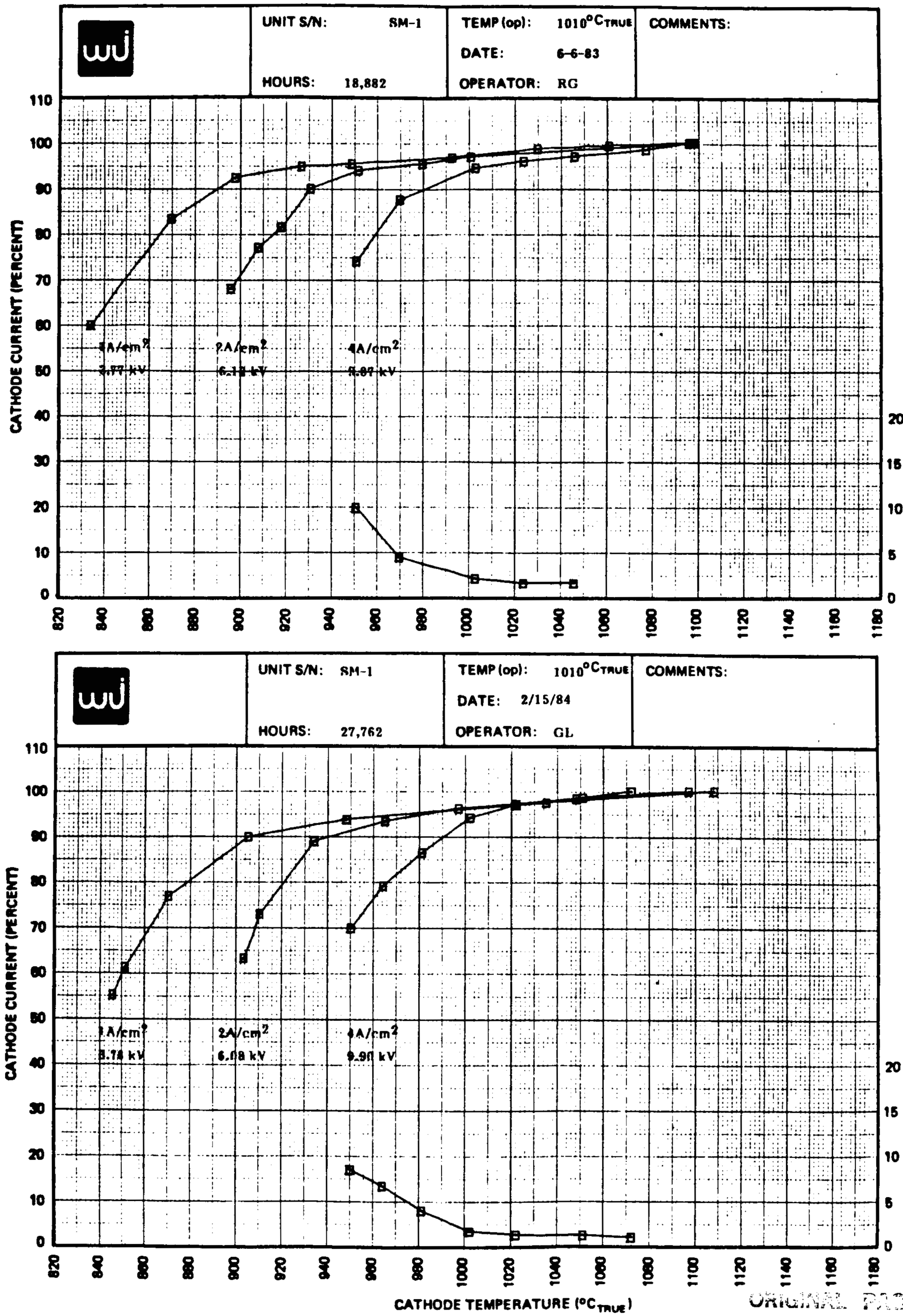

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Figure 48. Miram Curves for Unit SM-1

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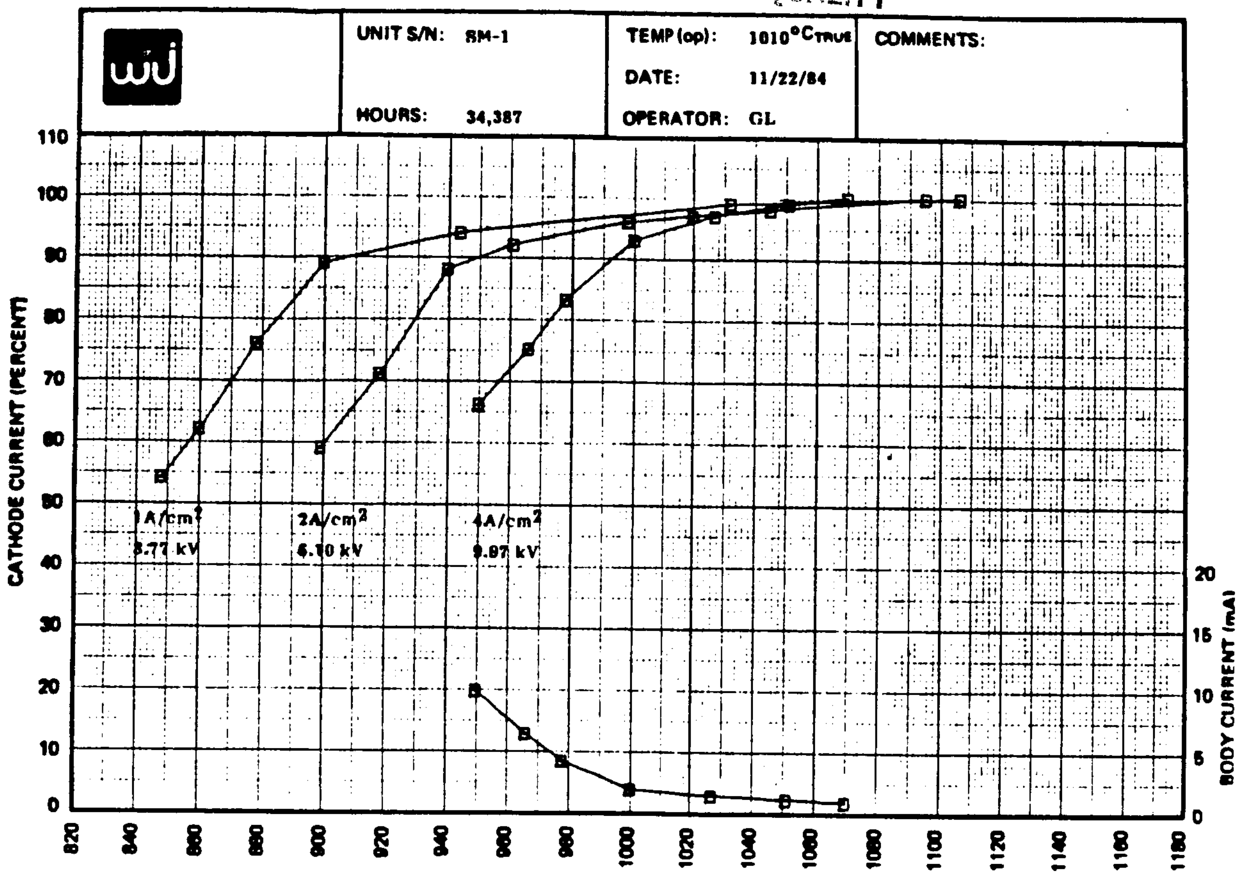


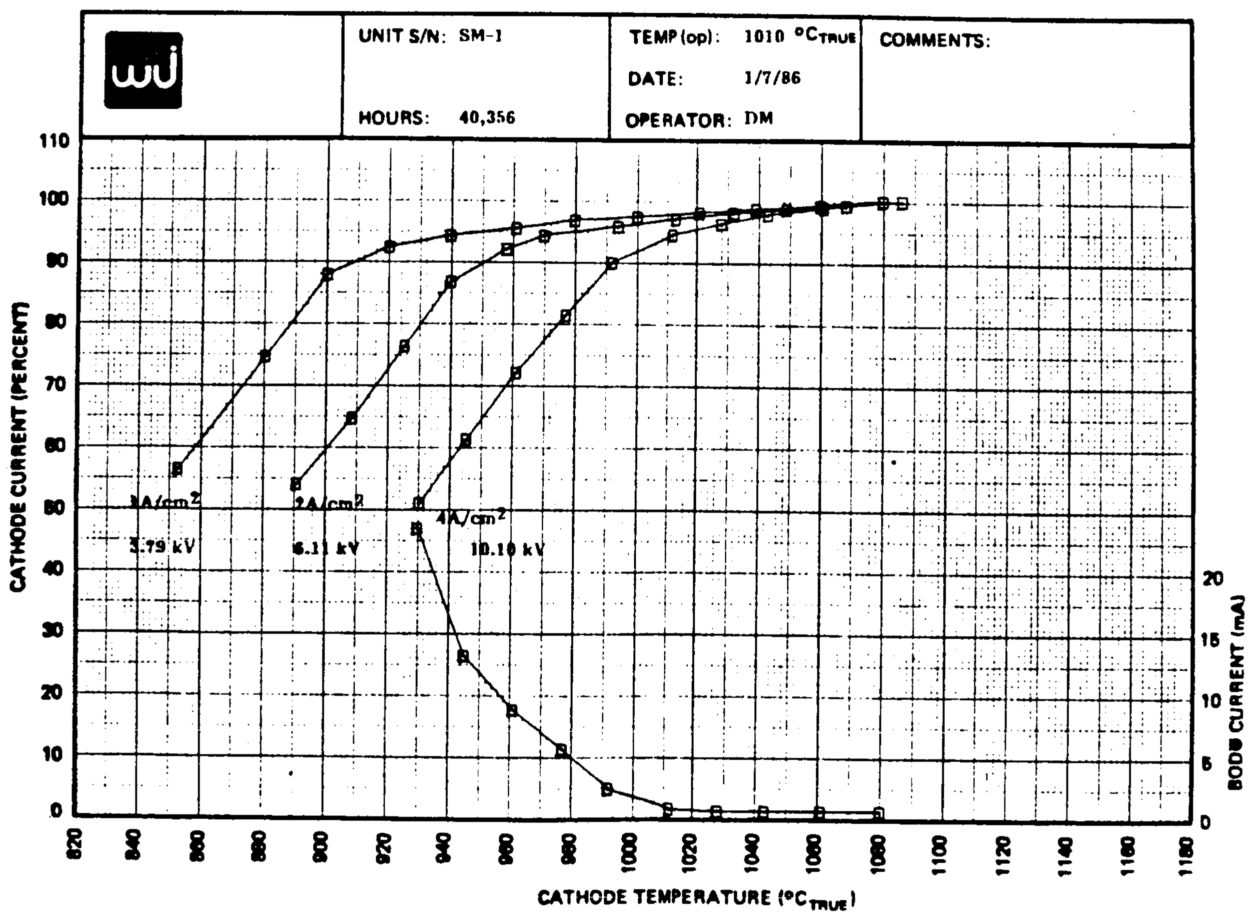


Figure 49. Miram Curves for Unit SM-1 (Continued)

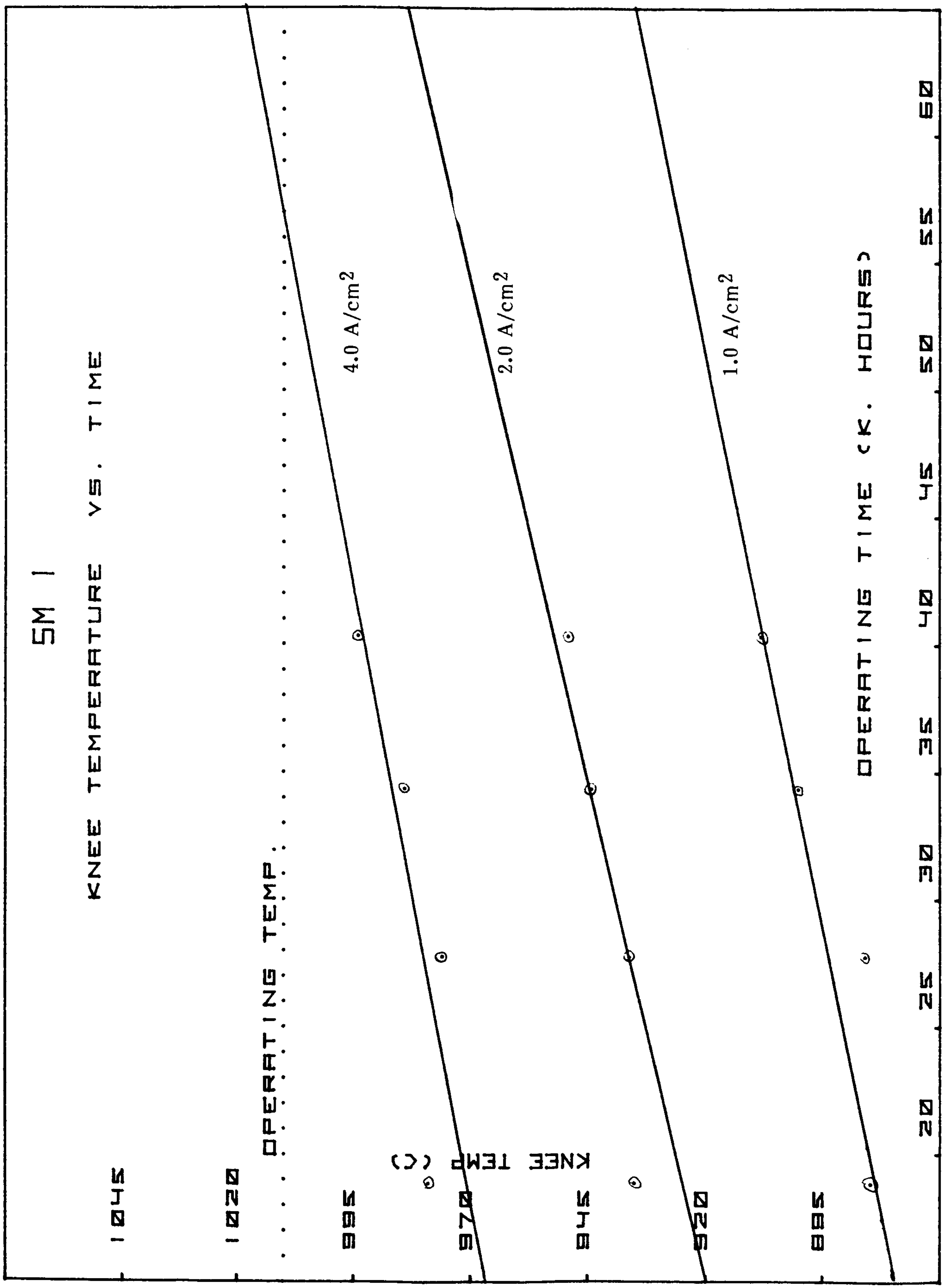


Figure 50. Knee Temperature for Unit SM-1

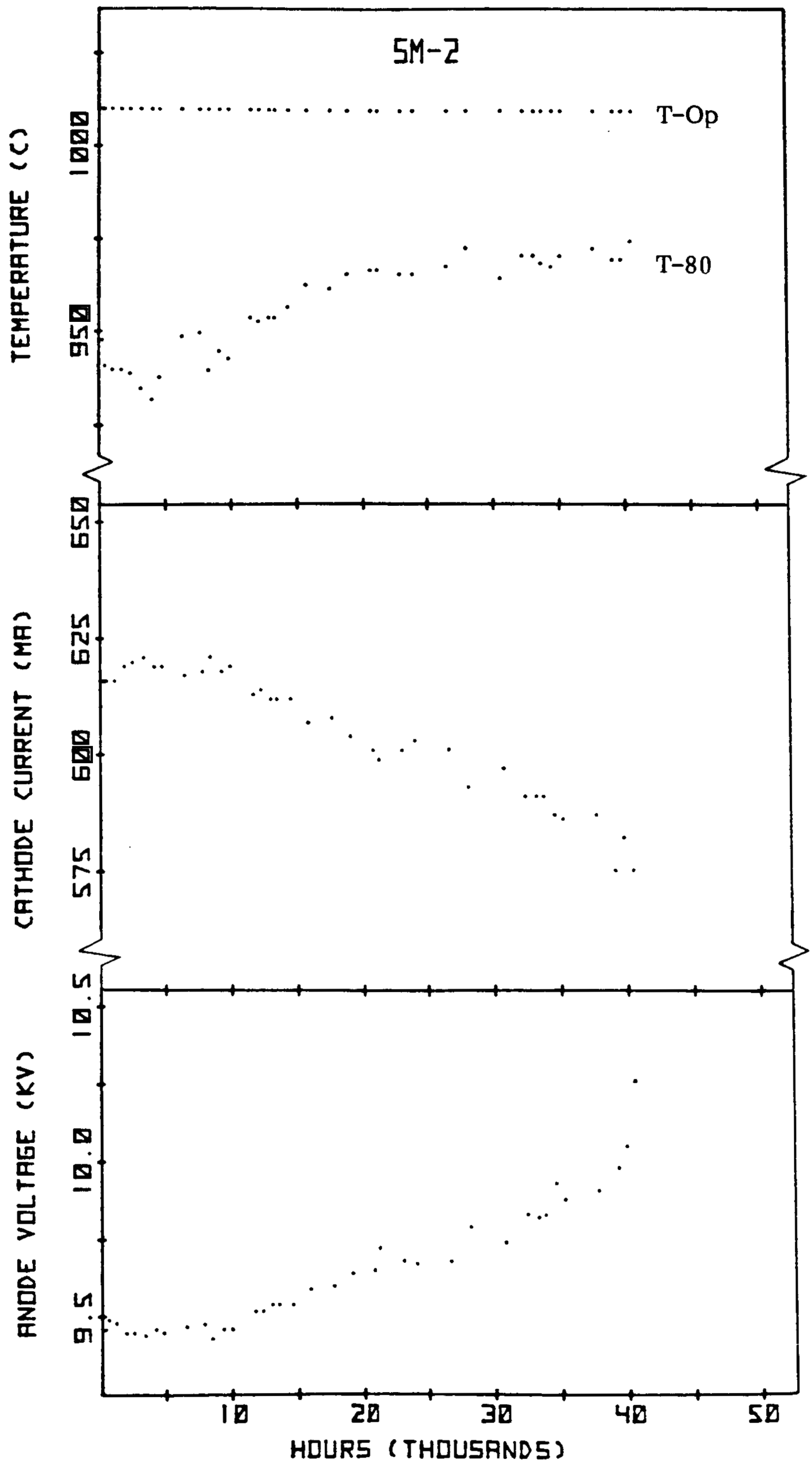
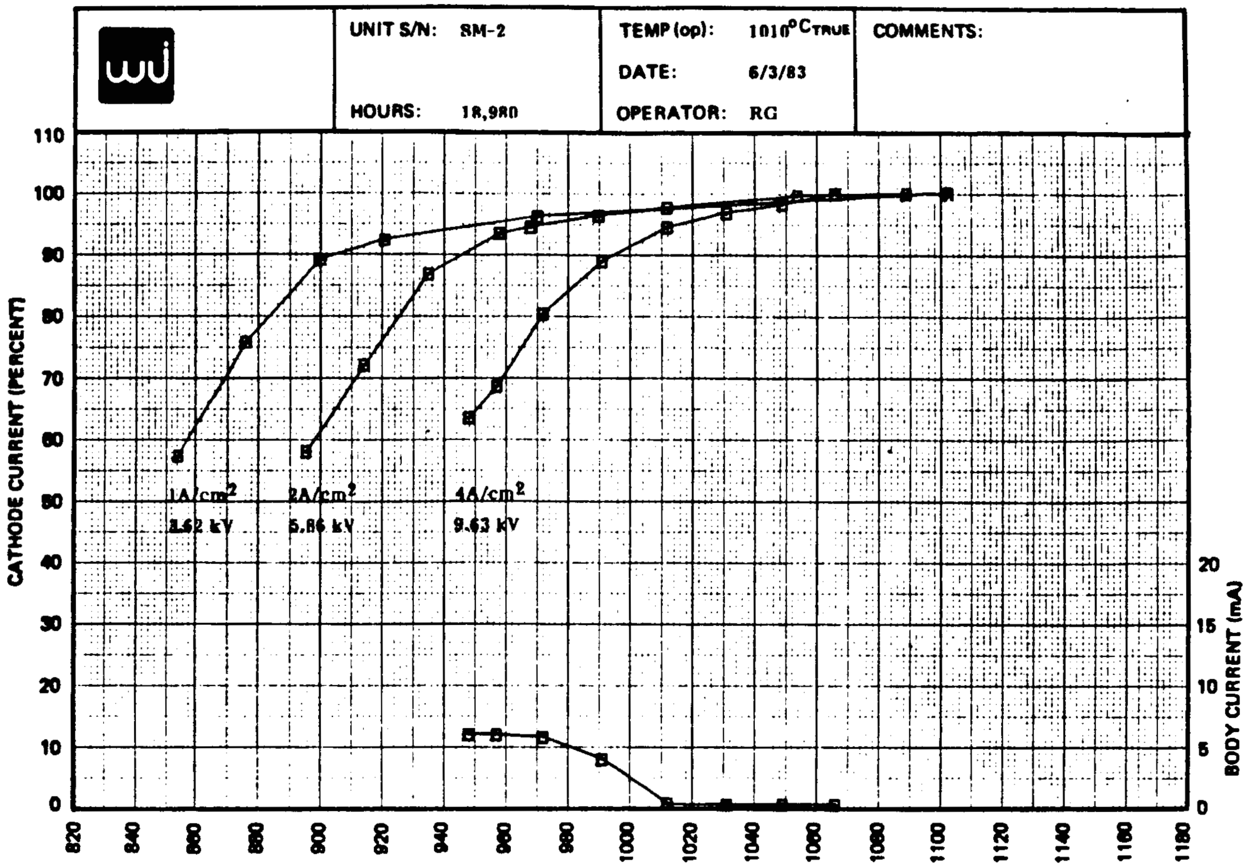


Figure 51. Life Test Data for Unit SM-2



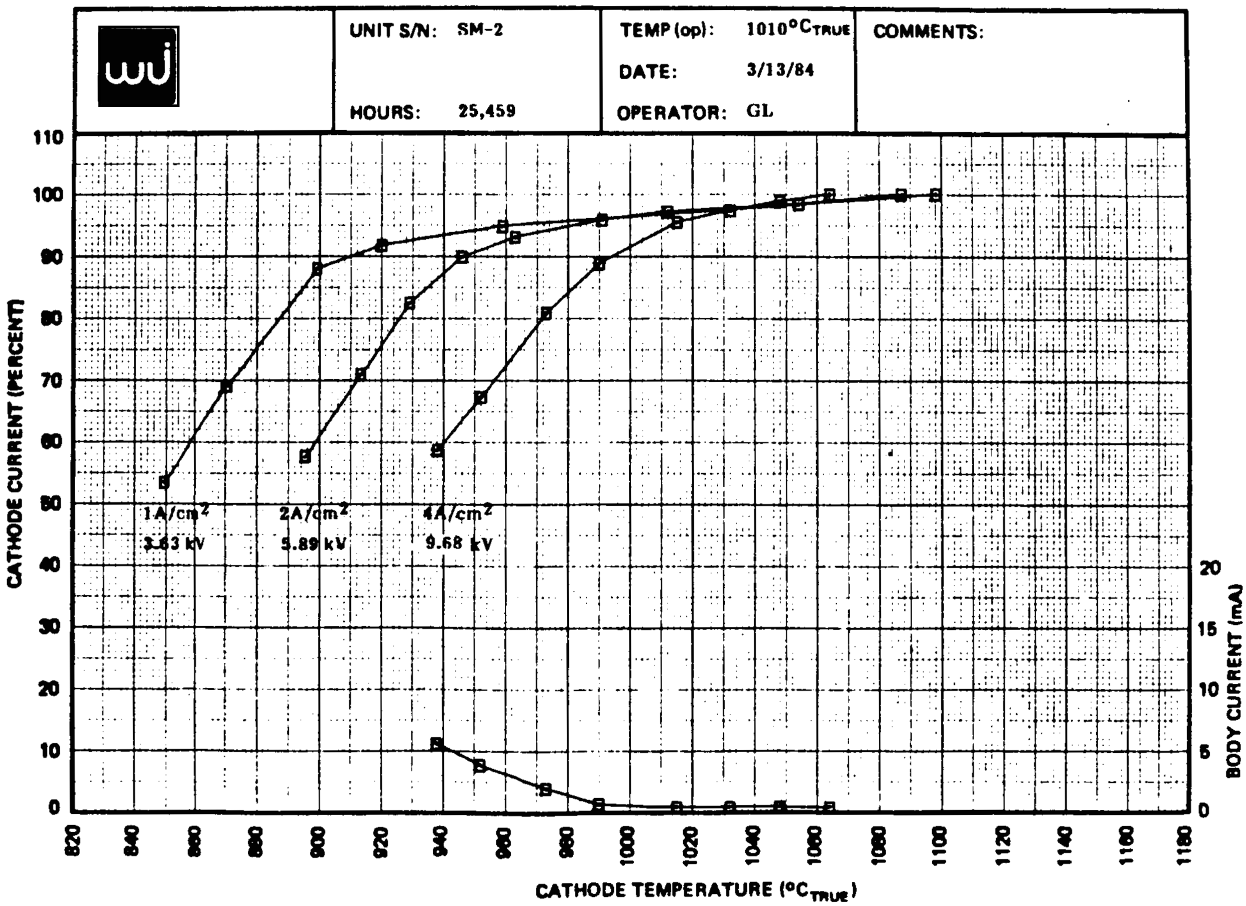


Figure 52. Miram Curves for Unit SM-2

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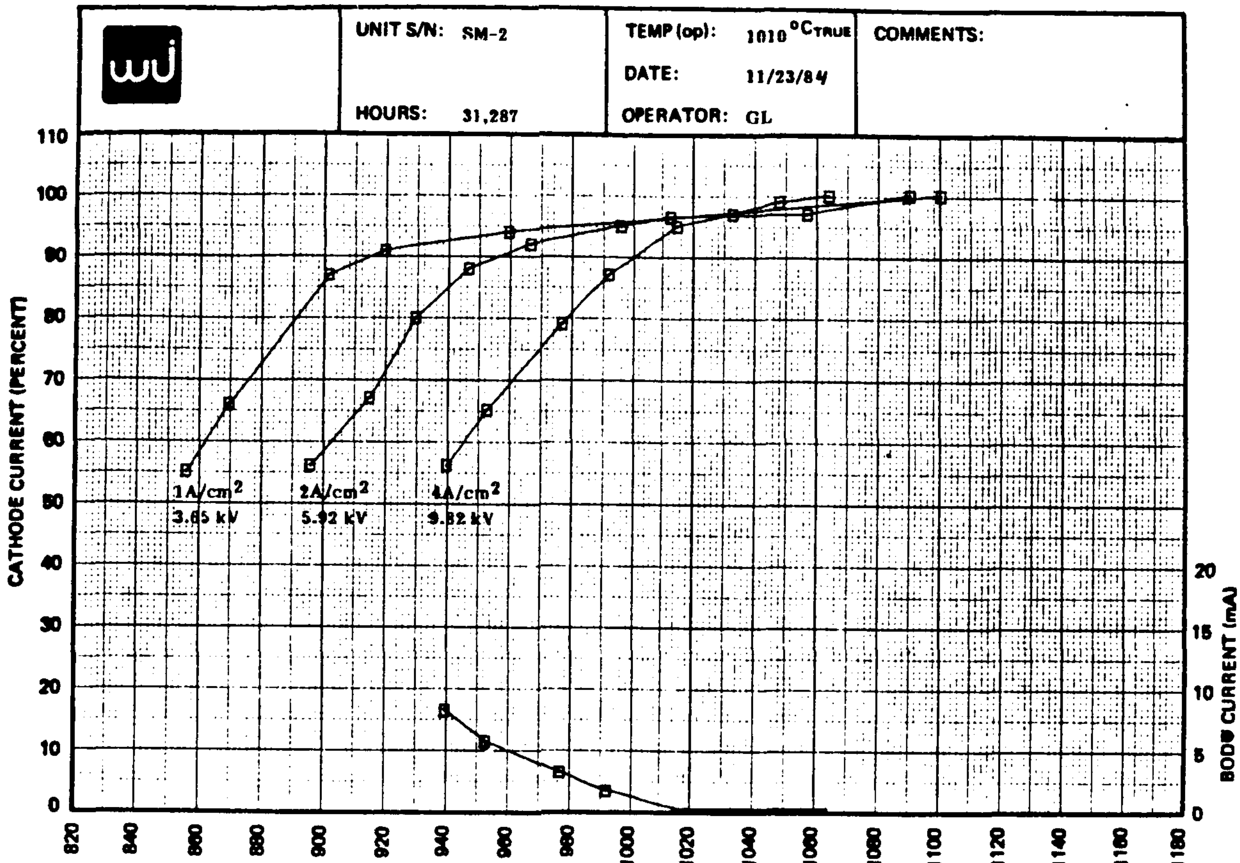


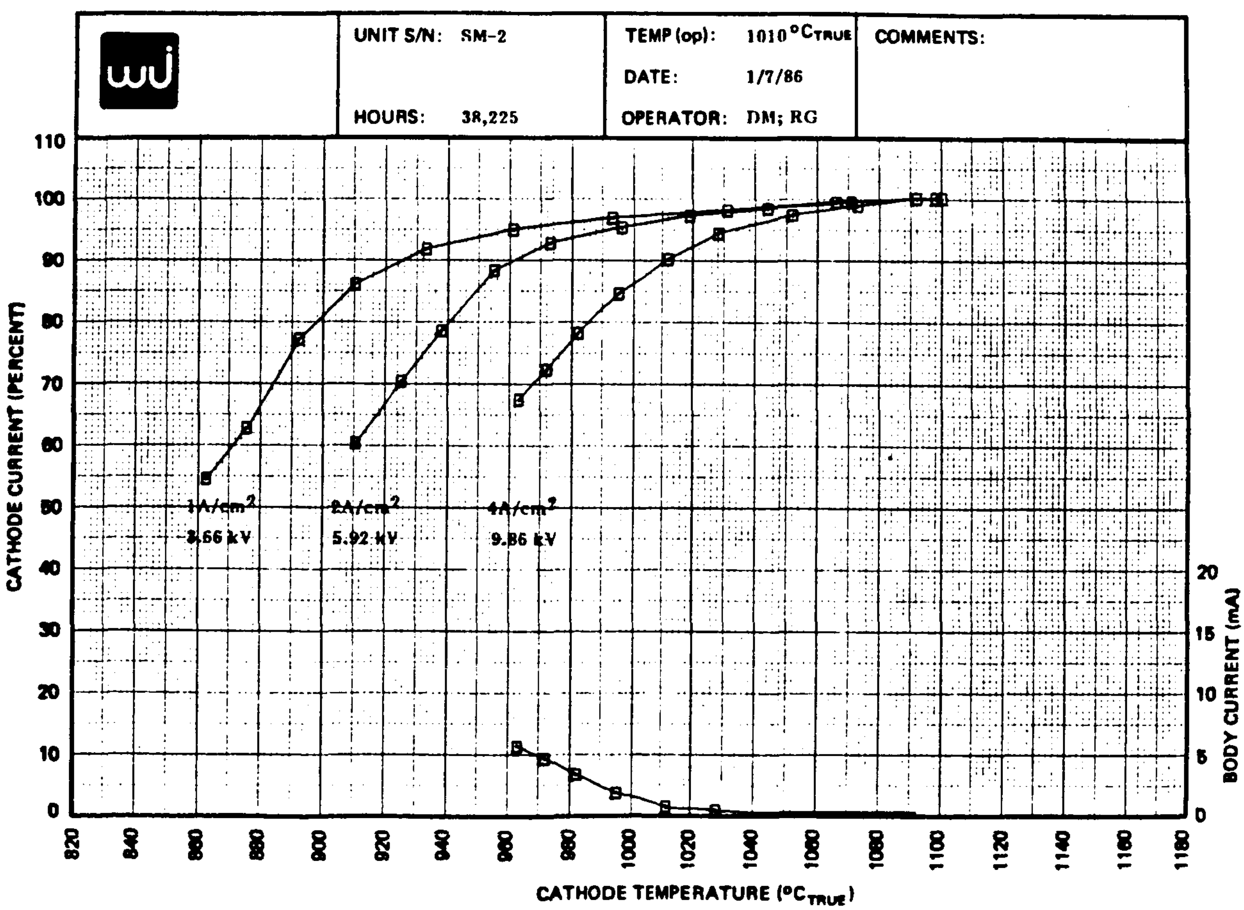


Figure 53. Miram Curves for Unit SM-2 (Continued)

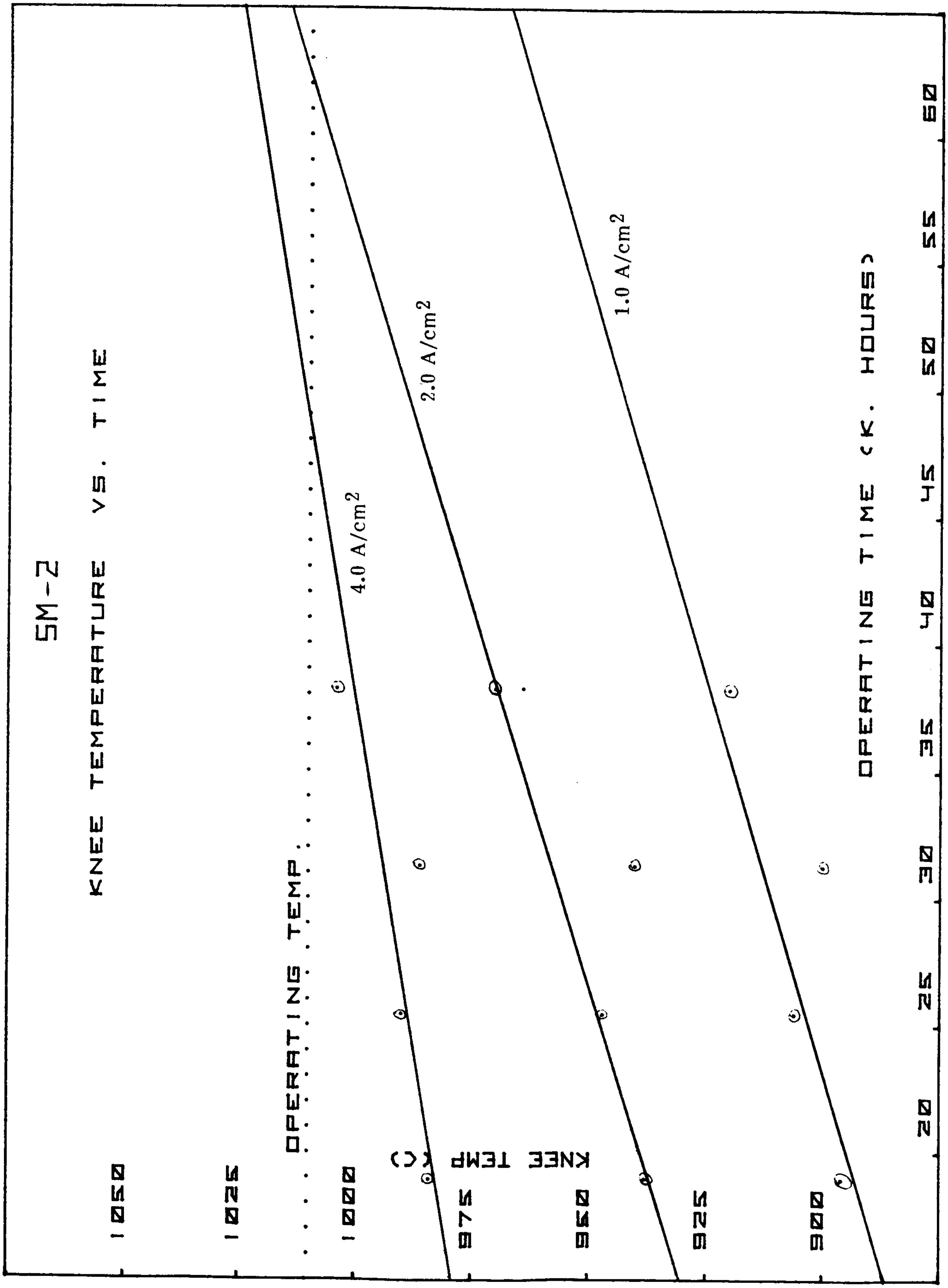


Figure 54. Knee Temperature for Unit SM-2

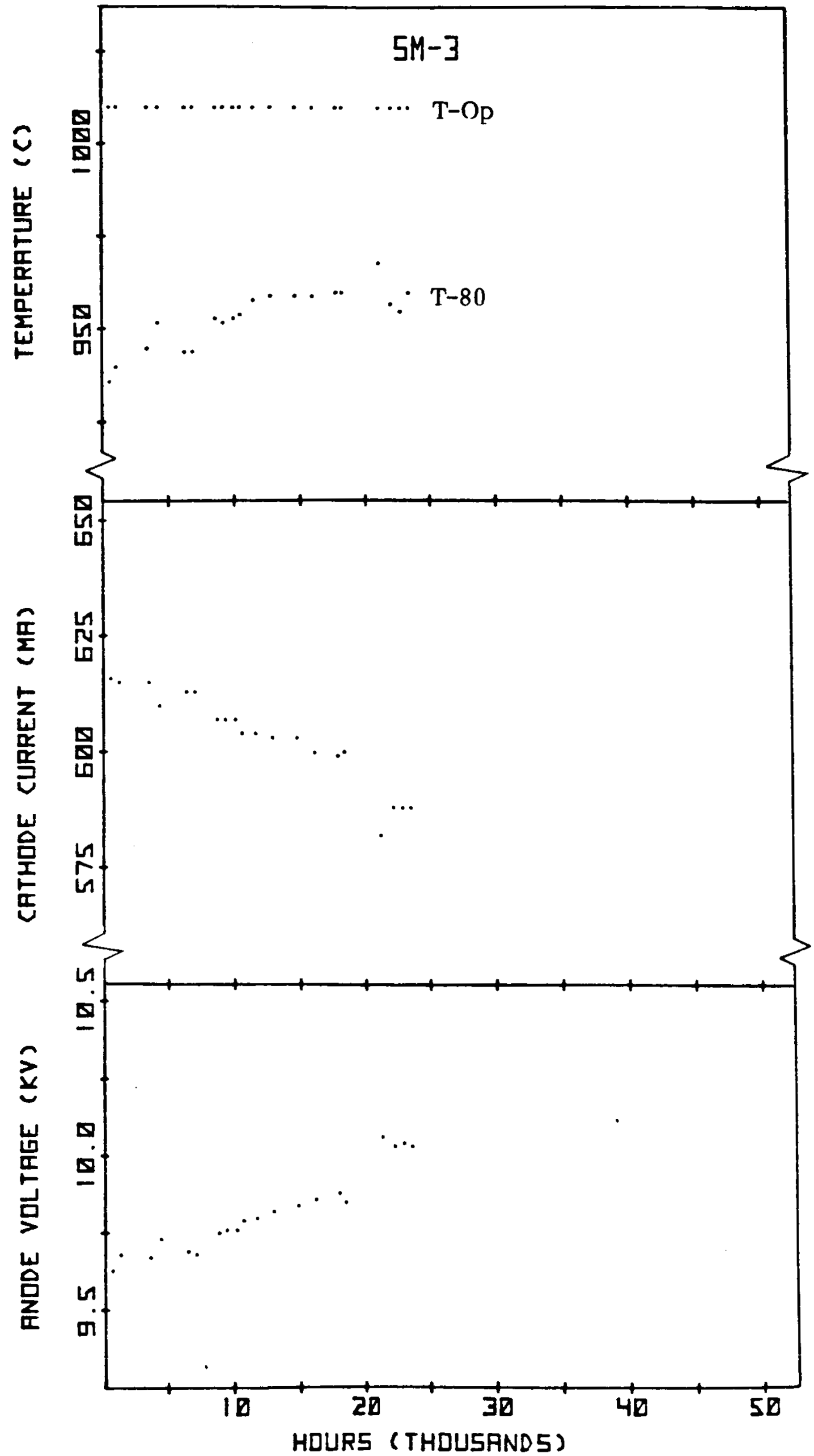
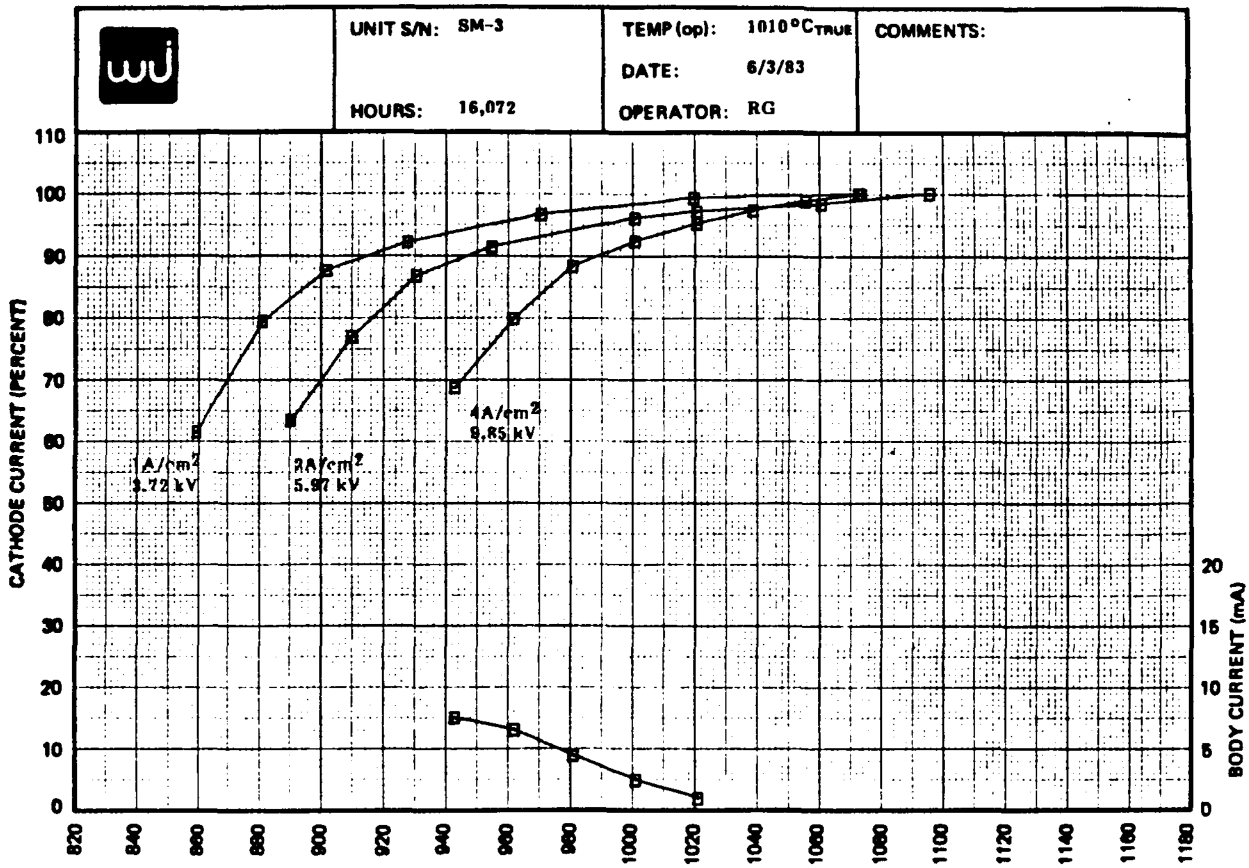


Figure 55. Life Test Data for Unit SM-3



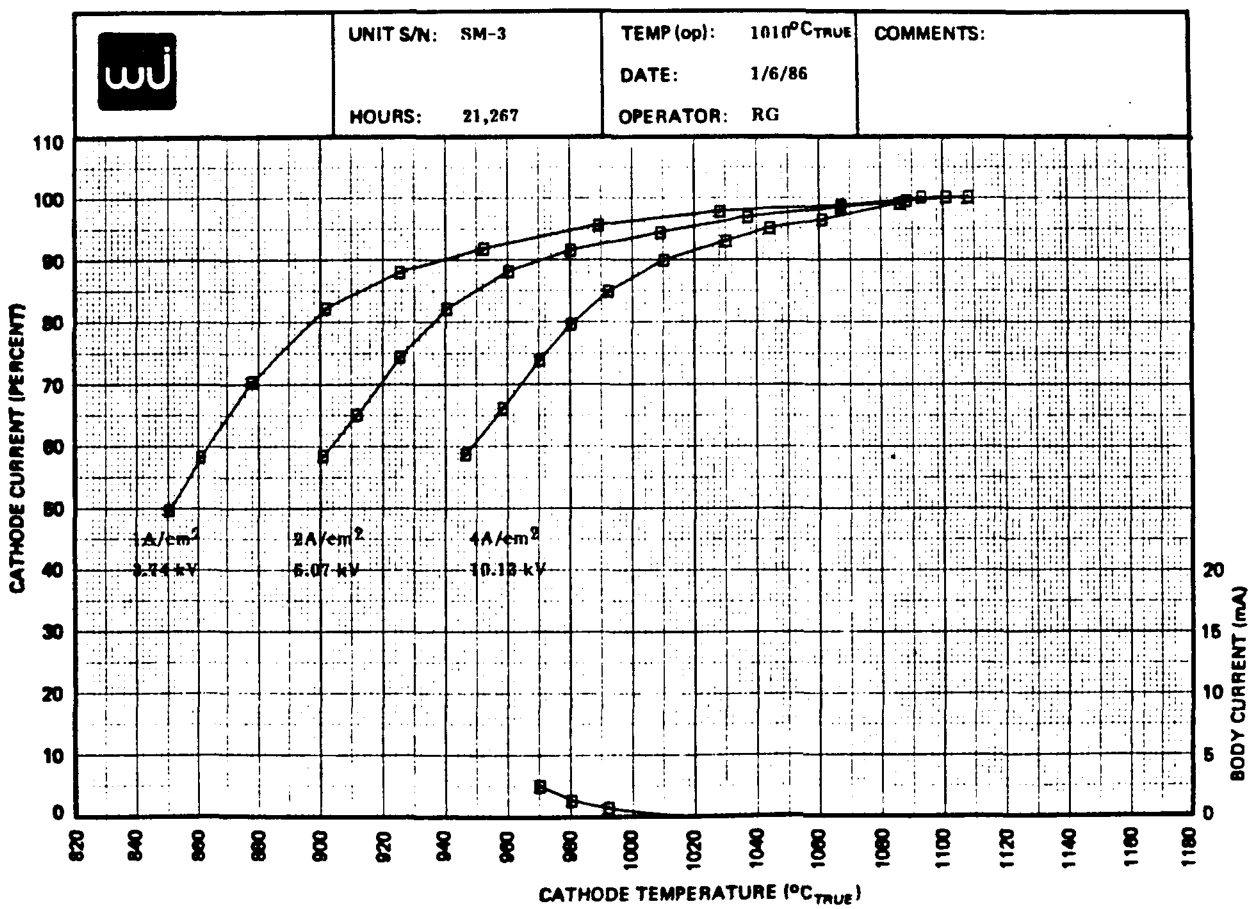


Figure 56. Miram Curves for Unit SM-3

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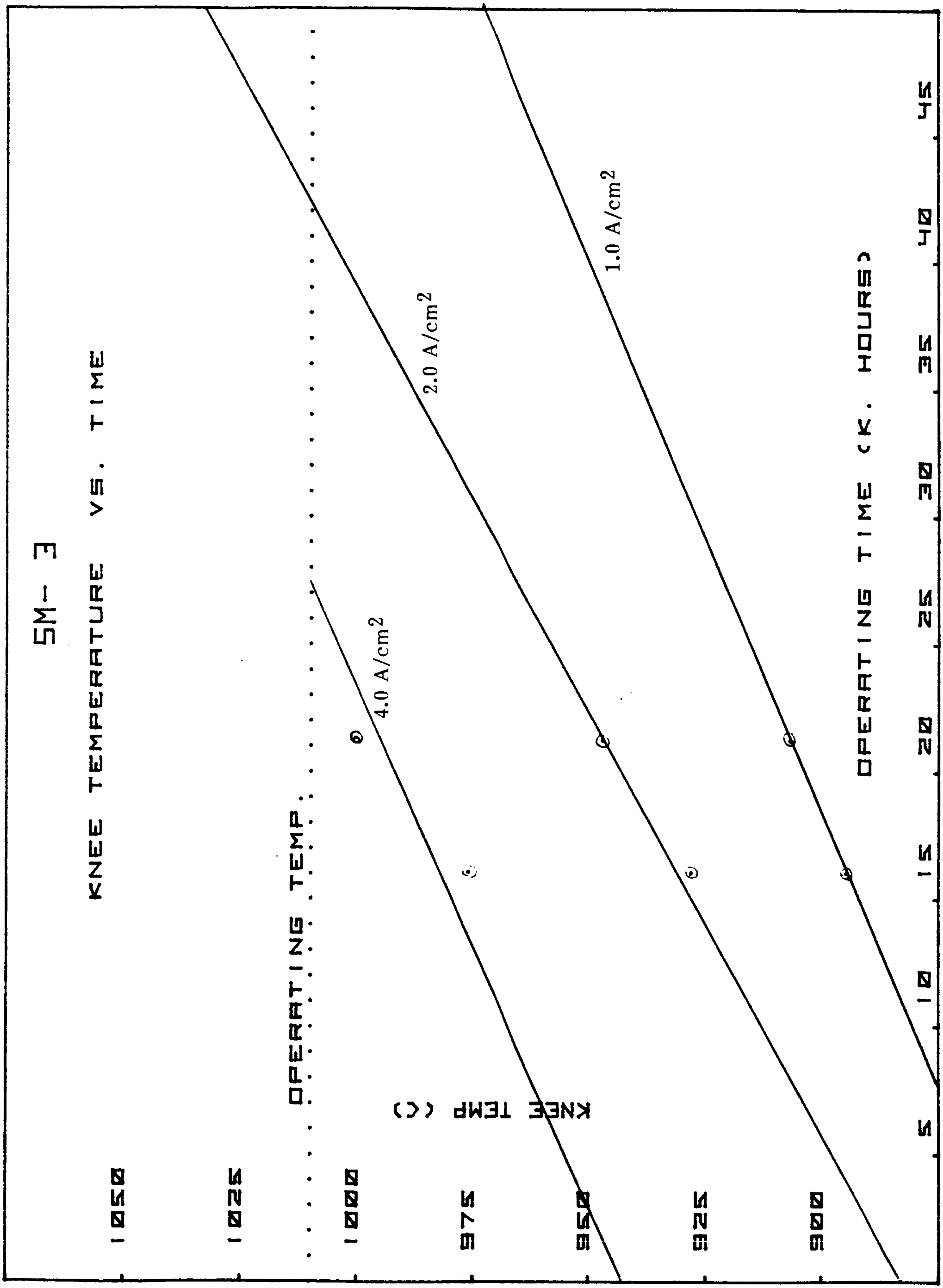

Figure 57. Knee Temperature for Unit SM-3

6.0 CONCLUSIONS AND RECOMMENDATIONS

The life test results for the period covered by this report for the cathode types tested show the following:

6.1 Conclusions

1. The Philips Type B cathodes tested at 1100°C true would be suitable for operation in a microwave power tube environment at $2A/cm^2$ with an expected operating life of over 40,000 hours. However, a gradual decline in emission capability would be expected during life which could affect device performance.

2. The Litton impregnated cathodes showed characteristics similar to the Philips Type B. Operating at 1100°C and at $2A/cm^2$, this type would be suitable for a 20,000 hour application.

3. The Philips Type M cathodes tested show great promise for microwave tube application. Operating at 1010°C true, these units show better stability with respect to the emission characteristics measured than any of the other cathode types tested. The projected end-of-life for the cathode operating at 1010°C, and $2A/cm^2$ is 71,750 hours (see Appendix III).

4. Spectra-Mat Type M cathodes were operated at 1010°C true and $4A/cm^2$. The behavior of these units was similar to that of the Philips Type M cathode. These cathodes successfully operated for an average of 35,000 hours.

5. The behavior of the Semicon Type M cathodes operating at 1010°C true and at $4A/cm^2$ was similar to that of Philips Type M cathodes. These cathodes successfully operated for an average of 30,000 hours.

6. Philips Type M cathodes showed an increase in emission in the early stages of life. Based on our recent experience, we believe the activation schedule used for these cathodes was not sufficient. Starting with insufficient activation, their activity level gradually improved, with resulting increased emission, until full activation was attained.

7. For all Type M cathodes tested there is a wide variation in the projected end of useful life, based on knee temperature vs. time. At $1A/cm^2$ and $2A/cm^2$ projected cathode life range is 83,000 hours to 297,000 hours and 60,000 hours to 111,000 hours respectively. One reason for this variation in projected life is the limited number of roll off data points available.

8. The techniques and test procedures utilized on this life test program have proven to provide a useful method to obtain long-life information on different cathode types. The volume of data obtained to date will be extremely useful in that a basis is provided for comparison of different cathode types operating in the same environment. As these tests continue, these data therefore take on additional significance because of this comparative aspect, which is a very important feature of this test program. The resulting information should prove to be of considerable importance to space missions in the future.

6.2 Recommendations

1. The existing cathode life test should be continued to determine the ultimate life capability of these cathodes at both high and low emission densities. This body of data represents a significant contribution to our understanding of the long-term behavior of high-current-density cathodes. Information which is obtainable over the next few years in showing the validity of life projections is vital to many programs where long life is paramount.

2. If there are any new Type M cathodes to be life tested, these should be processed at higher temperature, with part of the process being at 1200^{o}C for 1 hour.

3. To have more confidence in the projected useful life of the cathode, roll-off curves should be taken more often, e.g., once a month, as compared to the existing practice of once every six months.

4. An automatic cathode emission current measurement device, of the type manufactured by ETM Electromatic should be incorporated into the life test for more efficient and accurate acquisition of Miram curve data.

APPENDIX I

CATHODE ACTIVATION SCHEDULES

For a listing of activation schedules for all cathode types processed for life testing before this report period, refer to previous reports on this project.* Six Type M cathodes, designated for testing at $4A/cm^2$, were already on life test when this contract started in July 1983. Three of these cathodes were supplied by Spectra-Mat and the other three by Semicon Associates, Inc. The activation schedule used for these and Philips Type B and Type M cathodes was based on our (Watkins-Johnson Company) and the vendor's experience. The activation schedules for the different cathode types are given below:

*References 3, 4, and 5.

SPECTRA-MAT AND SEMICON TYPE M CATHODES EXHAUST AND ACTIVATION PROCEDURE

1. Attach the tube to the exhaust station using standard approved techniques. (A bell jar type oven is used to create a vacuum enclosure around the tube during the bakeout procedure.)

2. When the tube has reached a pressure of 5×10^{-7} torr or less and the bell jar vacuum is less than 50 microns, turn oven on to 200°C.

3. Raise the oven temperature in increments of 100°C per hour while keeping the station pressure under 9×10^{-6} torr.

4. When bakeout temperature of 450°C has been reached, apply 2.0 Vdc to the filament and continue bakeout for a minimum of 12 hours. (24 to 36 hours would be better.)

5. Cool the tube at a rate of 100°C per hour until the oven is at 125°C or lower.

6. Shut off filament supply.

7. Vent the bell jar enclosure around the tube with nitrogen and monitor the tube pressure. If there are no apparent vacuum leaks in the tube, proceed to activate the cathode.

8. Tube pressure during activation should not be allowed to be more than 5×10^{-7} torr.

9. Apply 2.0 Vdc to filament and hold for 10 minutes.

10. Increase filament voltage in 1.0 volt increments at 10 minute intervals and monitor station pressure. If the pressure increases drastically, either decrease the voltage or hold the voltage if maximum pressure has not been reached.

11. When 750°C on the cathode has been reached, monitor the temperature using an optical pyrometer on the "blackbody" hole.

Spectra-Mat Type M Cathode Activation Continuation:

12. Continue to raise filament voltage until 1050°C true has been obtained and hold for five minutes.

13. Reduce temperature to 1010°C true and proceed with low voltage age.

14. Begin low voltage age. Ground body and anode. Cathode and filaments to be at -900 Vdc with respect to body and anode. Current should be approximately 18 to 20 milliamps. Hold for one hour and record data. Turn on tube's appendage pump. Allow tube to cool for 30 minutes and pinch off tube. Monitor and record data.

15. If full emission cannot be achieved, raise cathode temperature to 1100°C true for five minutes and then lower to 1010°C and check emission. If full emission has been achieved, then age for 1 hour. If full emission has not been achieved, then raise temperature in 50 degree steps (not to exceed 1230°C maximum) and recheck at each level for emission as in Step 14 above.

Semicon Type M Cathode Activation Continuation:

(Steps 1 through 11, as on previous page.)

12. Continue to increase the filament voltage until 1200°C true has been reached. Continue to monitor and record all data.

13. Hold cathode at 1200°C true for five minutes and reduce voltage to achieve 1100°C true for one hour.

14. Begin low voltage age. Ground body and anode. Cathode and filaments to be at -900 Vdc with respect to body and anode. Current should be approximately 18 to 20 milliamps. Hold for one hour and record data. Turn on tube's appendage pump. Allow tube to cool for 30 minutes and pinch off tube. Monitor and record data.

15. During Step 14, if emission is low or begins to drop, increase cathode temperature to 1200°C true for up to a maximum of 15 minutes while continuing to draw cathode current. If, in doing this, pressure increases, process further by slowly increasing anode-cathode potential until pressure subsides (outgas anode and body elements). When pressure decreases, or when time at 1200°C true is up, lower cathode temperature to 1100°C true and continue to age as in Step 14. (Maximum cumulative time at 1200°C true for any one cathode is not to exceed 30 minutes.)

PHILIPS TYPE B AND TYPE M DISPENSER CATHODES EXHAUST AND ACTIVATION PROCEDURE

1.0 BAKEOUT

1.1 Place thermocouples on gun stack and collector. Maximum allowable station pressure: 5×10^{-7} torr, maximum. (Note: pressure at tube is estimated to be 10^{-5} for a pump pressure of 5×10^{-7} torr.)

1.2 Turn oven up to give 110°C on assembly and hold until station pressure remains level or on down swing. Reduce oven temperature if pressure exceeds maximum. Continue when pressure permits.

1.3 Turn oven up to give 165°C on assembly and hold until station pressure remains level or on down swing.

1.4 Increase oven temperature in 50°C steps to give 500°C on assembly. Make sure maximum pressure limit is observed and pressure has leveled off or decreased before increasing the oven temperature.

1.5 Hold assembly at 500°C for 24 hours minimum.

1.6 Station pressure should be 10^{-8} scale before completion of bakeout. Turn off oven and let cool to 150°C before venting guard vacuum.

Note: No heater power on tube from step 1.1 through 1.6.

2.0 ACTIVATION PROCEDURE

2.1 Oven: at room temperature with bell raised

2.2 Station pressure should be in low 10^{-8} scale before beginning activation.

2.3 Maximum allowable station pressure: goal, 10^{-7} torr; 2 x 10^{-7} torr, maximum. If pressure exceeds 10^{-7} torr, reduce filament voltage to suitable level and continue schedule.

2.4 During the following schedule set filament voltage at a given value then record time of adjustment. After pressure has stabilized or peaked, record voltage, current and maximum pressure.

2.5 Cathode temperature shall be determined by the thermocouple voltage, verified, if required, by an optical pyrometer reading of "black body hole" on the back side of the cathode.

2.6 Activation for Philips Type B Cathodes.

2.6.1 Slowly raise the cathode temperature to 800°C and then increase temperature to 1200°C true, at a rate not exceeding 100°C in 20 minutes.

2.6.2 Increase cathode temperature to 1250°C true. Apply -900 Vdc to cathode. Operate cathode under these conditions for 10 minutes or until emission stabilizes. Emission current will gradually raise to approximately 16 - 18 mA (.05 A/cm^2).

2.6.3 Remove cathode voltage and reduce temperature to 1200°C true and hold for three hours.

2.6.4 Remove filament power.

2.7 Turn on 5 liter/second appendage pump. Pinch off tube at room temperature and with vacuum station pressure in 10^{-9} scale. Monitor pump pressure during pinch off.

2.6 Activation For Philips Type M Cathodes.

(Steps 1.0 to 2.5 as on previous page)

2.6.1 Bring cathode temperature slowly to 1100°C (brightness on moly) with pressure below 10^{-6} mm Hg.

2.6.2 Activate cathode at 1200 degrees C true (1100°C brightness on moly, 1140°C brightness on Tungsten) for 10 minutes.

2.6.3 Lower temperature by 50°C and hold for three hours.

2.7 Pinch off tube at room temperature and pressure $\sim 10^{-9}$ mm Hg. 5 L/S appendage pump in operation from this point on.

2.7.1 Age tube for three hours at 1140°C true at full current (2 A/cm^2) at room temperature in solenoid.

2.7.2 Reduce Philips cathode temperature to 1050°C (true) and evaluate against Philips data.

APPENDIX II

KNEE TEMPERATURE

PHILIPS TYPE M CATHODES: KNEE TEMPERATURE

S/N	Reading	Operating Hours	Knee Temperature at Loading of 0.5 A/cm^2	1.0 A/cm^2	2.0 A/cm^2
M-1					
	1	56,816	898	933	980
	2	62,698	905	944	994
	3	69,032	902	937	985
	4	76,606	926	968	1016
M-3					
	1	34,846	878	910	946
	2	41,056	898	937	976
	3	47,136	898	934	976
	4	54,277	914	951	989
M-4					
	1	40,123	903	945	984
	2	45,834	903	946	989
	3	52,223	894	930	976
	4	59,224	907	943	998
M-6					
	1	32,913	887	923	965
	2	39,645	897	937	972
	3	45,275	908	944	986
	4	48,735	912	958	994

SEMICON TYPE M CATHODES: KNEE TEMPERATURE

S/N	Reading	Operating Hours	Knee Temperature at Loading of 1.0 A/cm²	2.0 A/cm²	4.0 A/cm²
SM-1					
	1	18,882	885	935	979
	2	27,762	886	936	976
	3	34,387	900	944	984
	4	40,356	908	949	994
SM-2					
	1	18,980	896	938	984
	2	25,459	906	947	990
	3	31,287	900	940	986
	4	38,225	920	970	1004
SM-3					
	1	16,072	895	928	976
	2	21,267	907	950	1000

SPECTRA-MAT TYPE M CATHODES: KNEE TEMPERATURE

S/N	Reading	Operating Hours	Knee Temperature at Loading of 1.0 A/cm^2	2.0 A/cm^2	4.0 A/cm^2
SP-2					
	1	22,600	896	940	990
	2	27,946	911	953	N/A
	3	34,088	910	948	986
SP-3					
	1	21,300	894	938	985
	2	27,607	892	935	985
	3	34,021	914	946	994
	4	41,158	924	973	1023
SP-4					
	1	19,562	892	936	978
	2	26,553	900	943	985
	3	32,759	906	949	993

PHILIPS TYPE B CATHODES: KNEE TEMPERATURE

S/N	Reading	Operating Hours	Knee Temperature at Loading of 0.5 A/cm^2	1.0 A/cm^2	2.0 A/cm^2
P-4					
	1	58,031	1016	1033	1060
	2	64,486	1030	1050	1064
	3	70,036	1014	1032	1065
	4	74,748	1020	1047	1065

APPENDIX III

PROJECTED END OF CATHODE USEFUL LIFE

Cathode	Projected End of Cathode Life (Kilohours) at				
S/N	0.5 A/cm^2	1.0 A/cm^2	2.0 A/cm^2	4.0 A/cm^2	
Philips Type M					
M-1	134	102	76		
M-3	104	86	67		
M-4	349	297	80		
M-6	104	78	64		
Semicon Type M					
SM-1		134	83	57	
SM-2		92	63	49	
SM-3		66	43	27	Based on two data points
Spectra-Mat Type B					
SP-2		117	110	122	Based on two data points
SP-3		97	60		
SP-4		131	111	61	
Philips Type B					
P-4	174	115	137		

Projected end of cathode useful life is determined by plotting knee temperature vs. operating time. End of life is defined as the time when knee temperature is equal to the operating temperature (See Figures 22, 26, 30, 34, etc.)

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APPENDIX IV

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