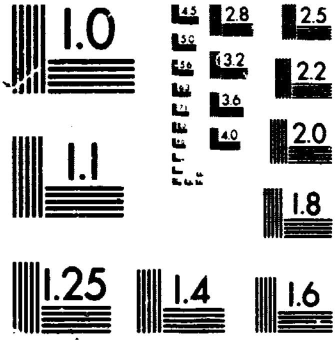

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS
STANDARD REFERENCE MATERIAL 1010a
(ANSI and ISO TEST CHART No. 2)

(NASA-CR-168112) DESIGN, CONSTRUCTION AND LONG LIFE ENDURANCE TESTING OF CATHODE ASSEMBLIES FOR USE IN MICROWAVE HIGH-POWER TRANSMITTING TUBES Interim Report (Watkins-Johnson Co.) 89 p HC A05/MF A01 G3/33

N84-10451 S9T

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NASA CR-168112

FIFTH INTERIM 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

December 1982

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

NASA-Lewis Research Center
Cleveland, Ohio 44135
Edwin G. Wintucky, Project Manager
Microwave Amplifier Section, Space Communications Division

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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, Microwave Amplifier Section, Space Communications Division, NASA-Lewis Research Center, as Project Manager.

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FIFTH INTERIM REPORT

1.0 SUMMARY

This Fifth Interim Report covers the period from April 1981 through November 1982 for a program to design, construct and life test cathode assemblies for use in microwave high-power transmitting tubes.

The objective of this continuing effort is to demonstrate and competitively evaluate the long life capabilities of several cathode types in beam testers that closely simulate a 12.2 GHz space TWT with an output of up to 4 kW CW.

To date, seven (7) cathode types have been tested:

	Type	Mix	Loading	# 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

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

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

The following parameters are 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).

Results obtained to date include the following:

1. Four of the five Tungstate cathodes, operating at 1000°C true, were removed from the test due to degraded emission after 2,600 to 6,800 hours of operation.

2. The Semicon Type S cathodes, operating at 1060°C to 1100°C true, typically degraded to 90% of initial emission after approximately 20,000 hours.

3. The Litton cathodes, at 1100°C true, show a little better activity than the above. Three units with 25,000 to 30,000 hours accumulated have emission levels from 92% to 97% of initial emission. One of these is continuing to run on life test (33,500 hours, 95% of initial emission).

4. Two of the four Philips Type B cathodes, operating at 1100°C true, have each accumulated 48,000 hours or more of life with emission levels at about 94% of initial. One of these units continues to run on test (54,800 hours, 94% of initial emission).

5. All four of the Philips Type M cathodes, operating at 1010°C true, have shown improved emission over the first 10,000 to 20,000 hours of life. This is in contrast to the observed behavior of the Type B cathodes, which show degrading emission from start of life. These four units have accumulated from 28,700 to 52,600 hours of life, with emission values of 98% of initial emission or better.

6. Three Spectra-Mat and three Semicon Type M cathodes have been put on test at $4A/cm^2$ cathode loading and at 1010°C true operating temperature. Accumulated running times on these units range from 11,800 to 18,300 hours. Unlike the Philips Type M units running at $2A/cm^2$, these units show only slight or no emission enhancement over the first 5,000 hours of life, with either steady or dropping emission after 5,000 hours. Emission values presently range from 96% to 99% of initial emission.

One of the significant observations resulting from this life test is the promising emission characteristics of the Type M cathode.

2.0 INTRODUCTION

This Interim Report covers the period from April 1981 through November 1982 for a program to design, construct and life test cathode assemblies for use in microwave high-power transmitting tubes. Previous reports covering the period from June 1971 through March 1981 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 objective of this investigation is 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 designed 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 types of cathodes, these have been primarily limited to diodes. A diode and high-power microwave tube are grossly different devices. A comparison of these two devices is provided in Table I. As seen on this table, a diode and high-power microwave tube are quite different; one could therefore assume different internal environments, especially in the cathode region. Therefore, in order to establish life capabilities of the cathodes just mentioned, they should be tested in a vehicle which has an internal environment similar to that of a high-power microwave tube.

*References 14, 15, 16 and 17.

TABLE I

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 solid 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 a 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 of operation. This objective has been modified to include cathodes operating at both $2A/cm^2$ and $4A/cm^2$ to meet a minimum designed life of 30,000 hours of continuous operation. These cathodes are of various types, and supplied by several different sources. Cathode types tested to date are as follows:

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[3, 6] 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 impregnate 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 Determination of Failure

For the purpose of this contract, the cathode end of life is defined as the time at which 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.

2.6 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.

3.0 CATHODE LIFE TEST UNITS AND TEST FACILITIES

The life test units were 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. Specification and operating conditions for the units are summarized in Table II. 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 ℓ/sec vac-ion pump. The cathode temperature can be measured pyrometrically by viewing through a sapphire window. 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 14 and 17.

TABLE II

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		0.6-0.65 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 (θ)		22 degrees	
Mean Cathode Loading	$2A/cm^2$		$4A/cm^2$
Maximum Cathode Density/ Minimum Cathode Density		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	

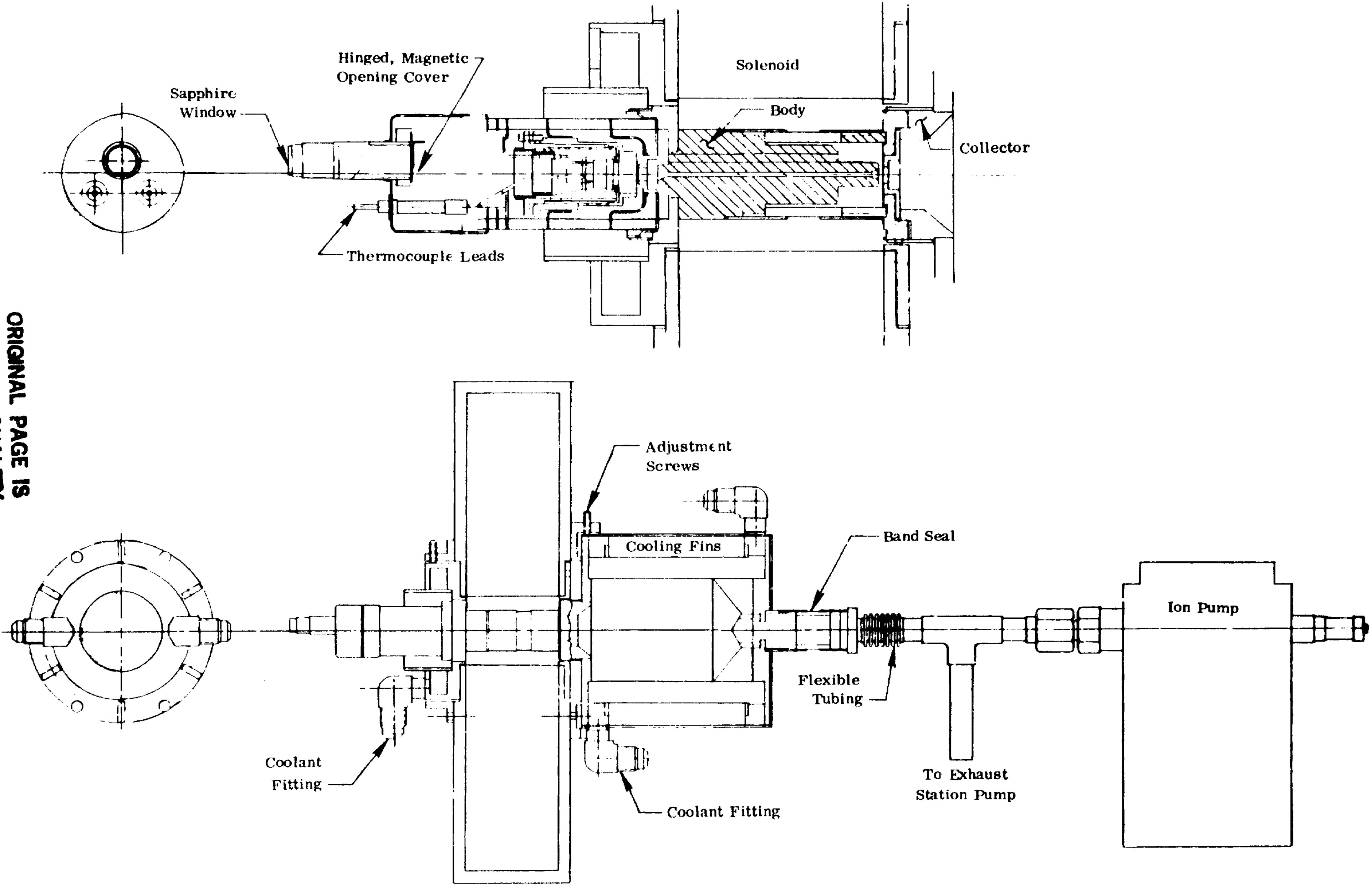
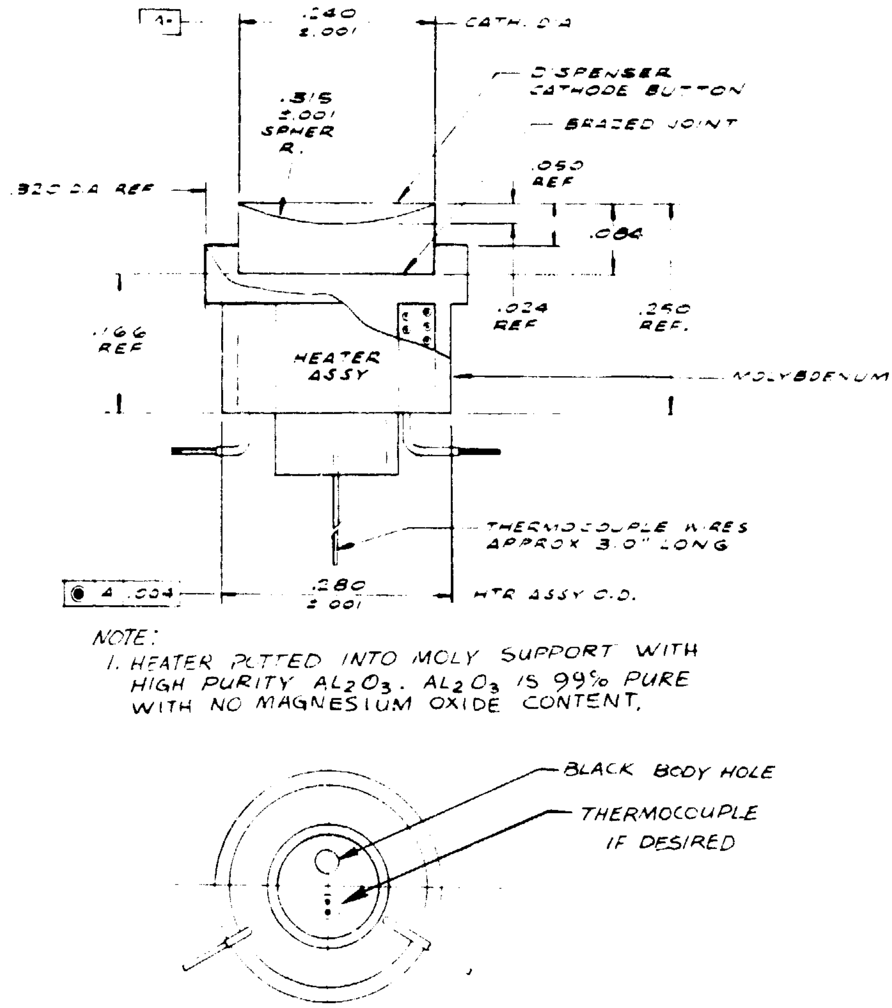
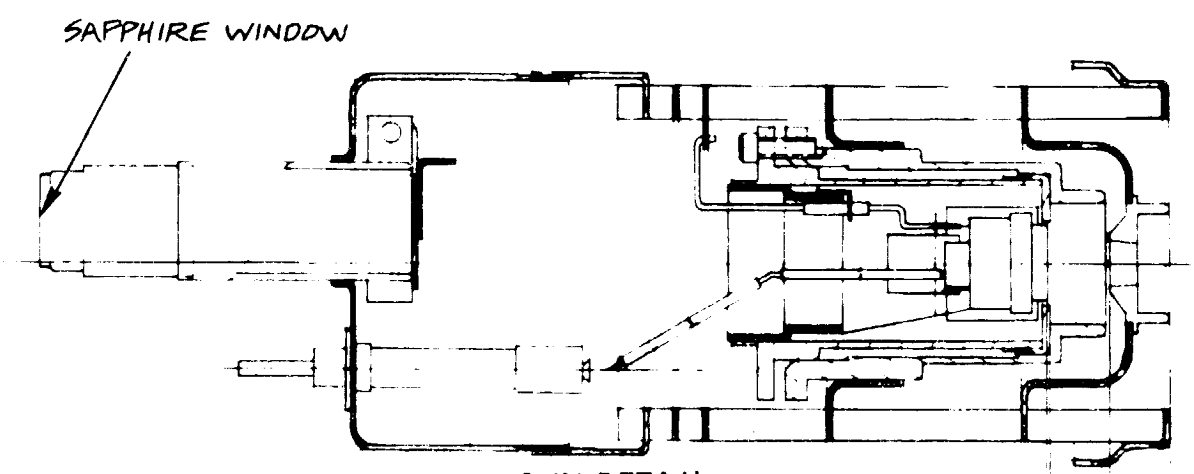


Figure 1 - Design Layout of the Cathode Life Test Unit



CATHODE DETAIL



GUN DETAIL

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

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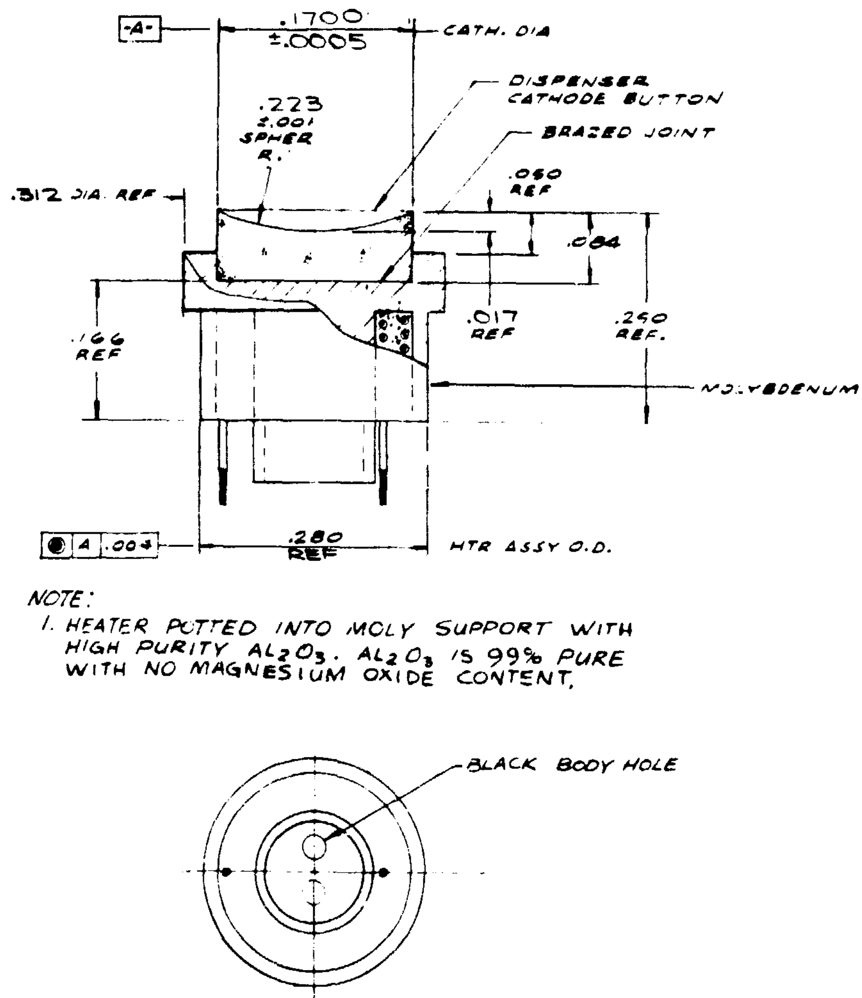

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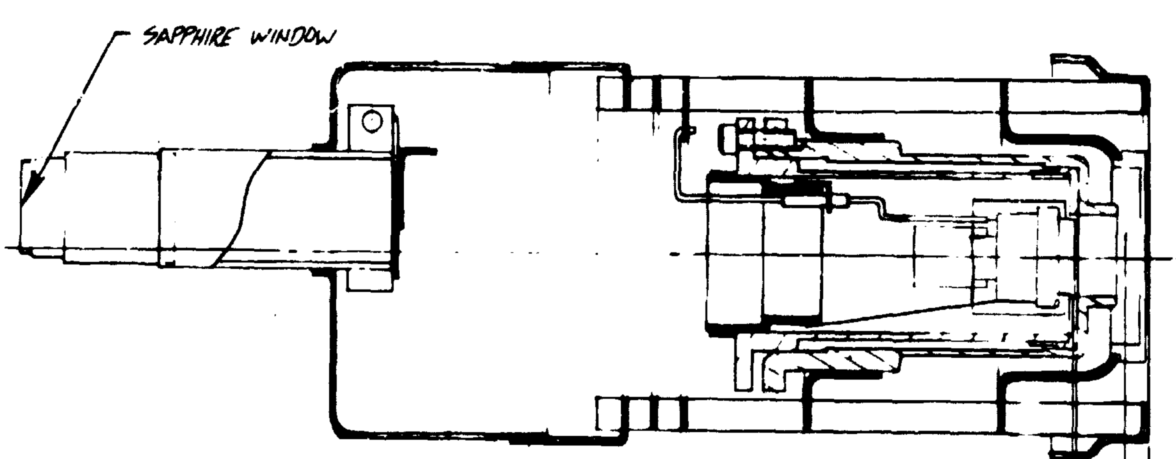

GUN DETAIL

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

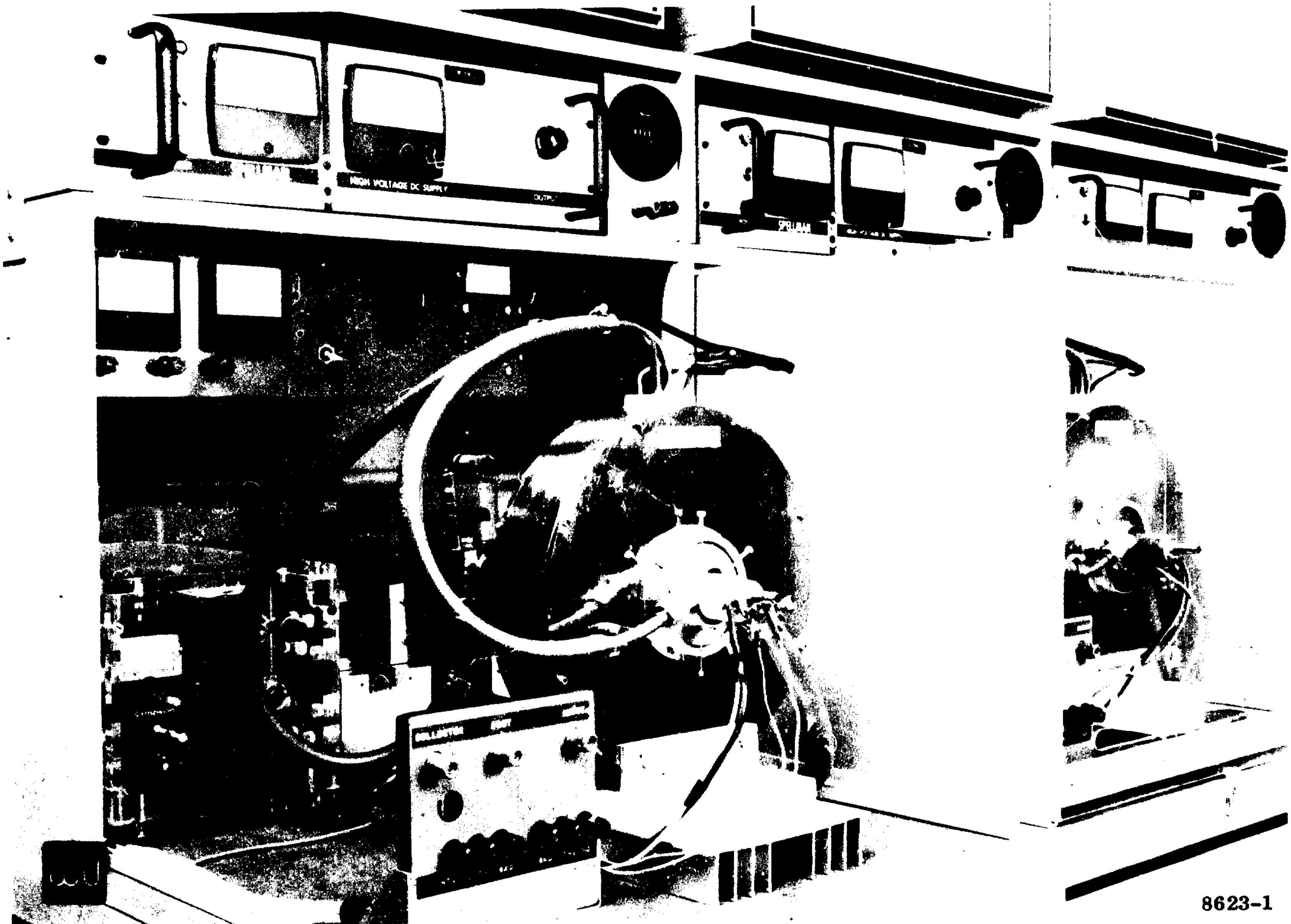

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Figure 4 - Photograph of a Cathode Life Test Unit Installed in the Life Test Station

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

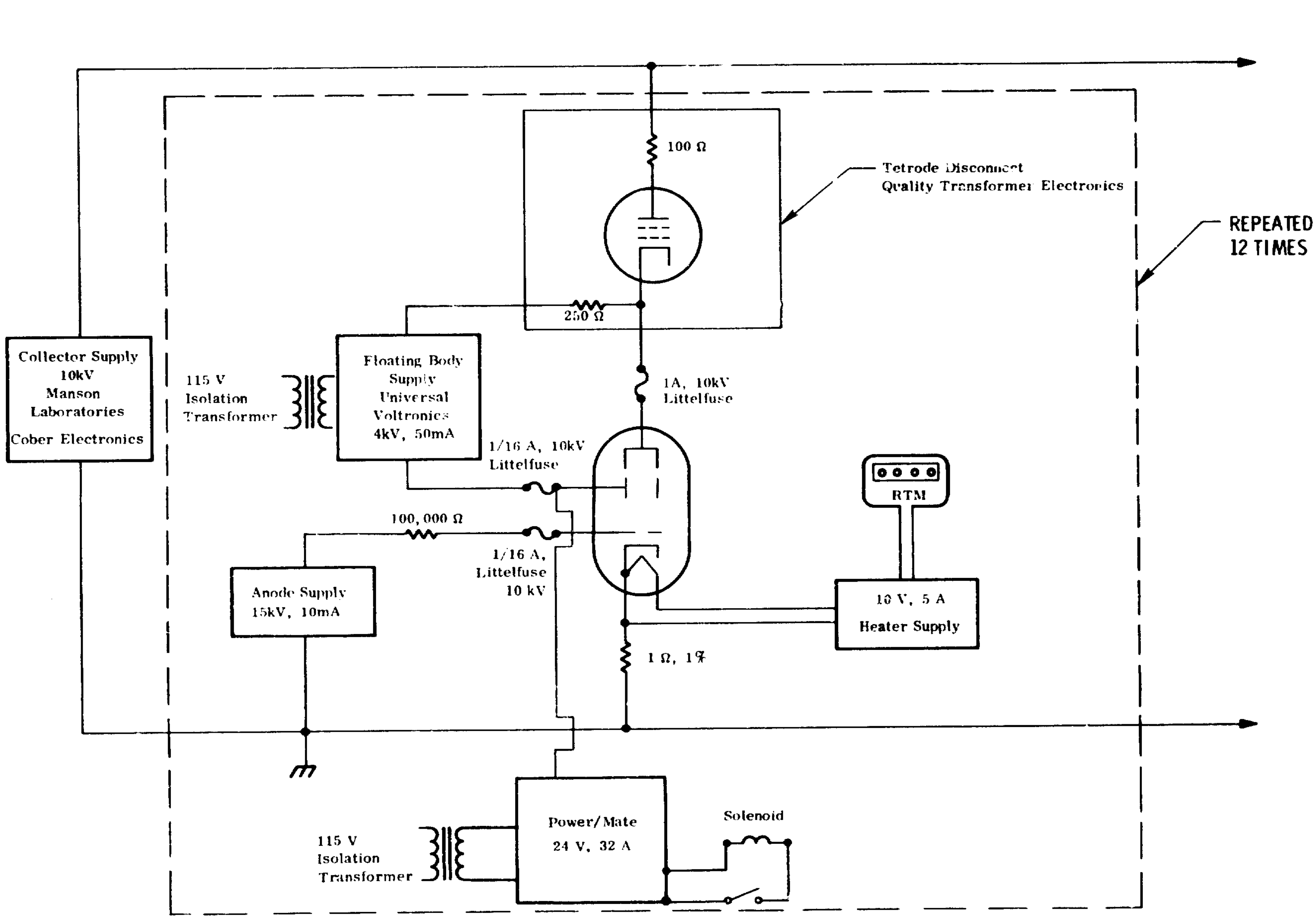

Figure 6 - Life Test Unit Block Diagram Showing Presently-Used Circuit

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.

   Also, since January of 1978, a daily performance check has been done on each unit. The daily check consists of the following:

   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 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. Dip Test - Since the Fall of 1980, dip testing of several of the life test units has been done. The value of this test is that it gives information on cathode activity over the life span of the unit in a format different than that in the T-80 test. Dip testing is scheduled on an infrequent basis - several times during the first 10,000 hours, then once every 5,000 hours thereafter. See below for additional details on the dip test procedure.

The following four sections explain in further detail the various data items mentioned above:

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 backstreaming 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 settable to better than 1% by means of the anode voltage. Cathode current is maintained at 616 mA ($2 A/cm^2$ or $4 A/cm^2$, 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 ±3°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°C and -15°C; i.e., it is unlikely that measurements are more than 5°C higher than true temperature, but measurements of as much as 15°C lower than the true temperature may occur. In addition, there is a correction (10°C ±1°C) that must be made for the sapphire window; true temperatures quoted in this report are 10°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 temperatures of 10°C to 20°C lower than true temperatures.

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 noted. 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 Dip Testing

All twelve life test stations were wired for dip testing in the Fall of 1980. The dip test method used incorporates a pushbutton switch to momentarily open the heater circuit, clip-on leads to measure cathode current and body interception current, and an X-Y recorder to plot cathode and body currents over the time the heater circuit is open. The plot is then analyzed for the time that the temperature limited "knee" occurs after the heater circuit is opened. The dip test measurement is planned to be used merely as an adjunct to the regularly scheduled monthly T-80 measurement.

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 report period, therefore, 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 will be a detailed discussion of each unit tested during this report period, as well as general comments on each of the seven cathode types tested from the beginning of the program. Detailed information on individual units not discussed here can be found in previous reports.*

Figures 7 through 30 show graphed life test data for two representative Tungstate units and all of the other units tested from the inception of this program. In these graphs, data taken at the monthly T-80 checks 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.

The following is a discussion of the present status of the life test units tested to date, with reference to Figures 7 through 30.

5.1 General Electric Tungstate Life Test Units

The cathode temperature for these units was to be set approximately at 1000°C true. This temperature is certainly higher than the original estimated value of 900°C to 925°C for this type of cathode. The higher cathode temperature was necessary to insure space-charge limited emission when the cathode was loaded at $2A/cm^2$. All Tungstate units showed severely degraded emission characteristics after less than 7,000 hours of life test and were removed from test.

Figures 7 and 8 show life test data taken on two representative Tungstate units, T-1 and T-7. Unit T-1 ran for 6,800 hours and unit T-7 ran for only 2,600 hours. Further comments concerning each individual Tungstate unit can be found in previous reports.* In general, the data point to the conclusion that the Tungstate cathodes tested are not suitable for long life operation at $2A/cm^2$.

*References 14, 15 and 16.

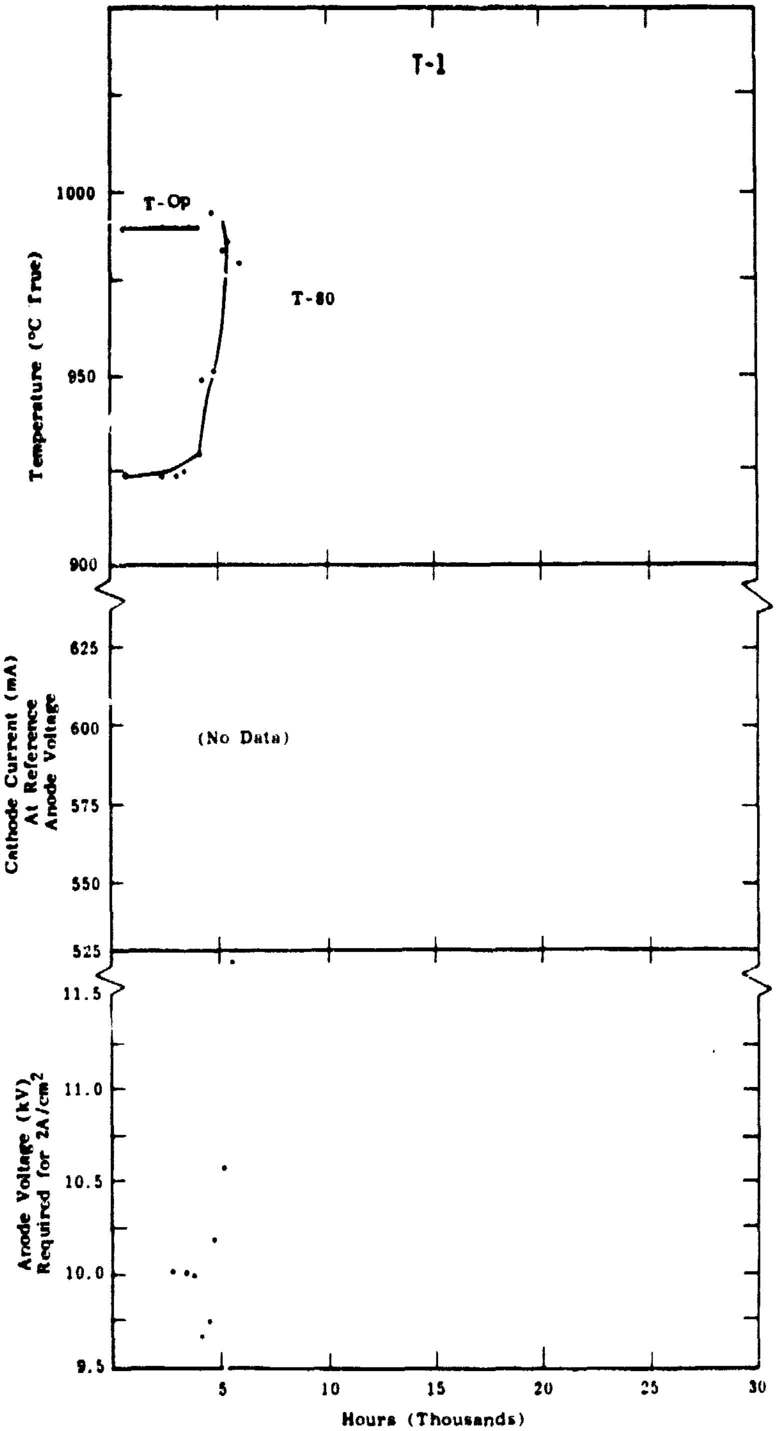

Figure 7 - Life Test Data for Unit T-1

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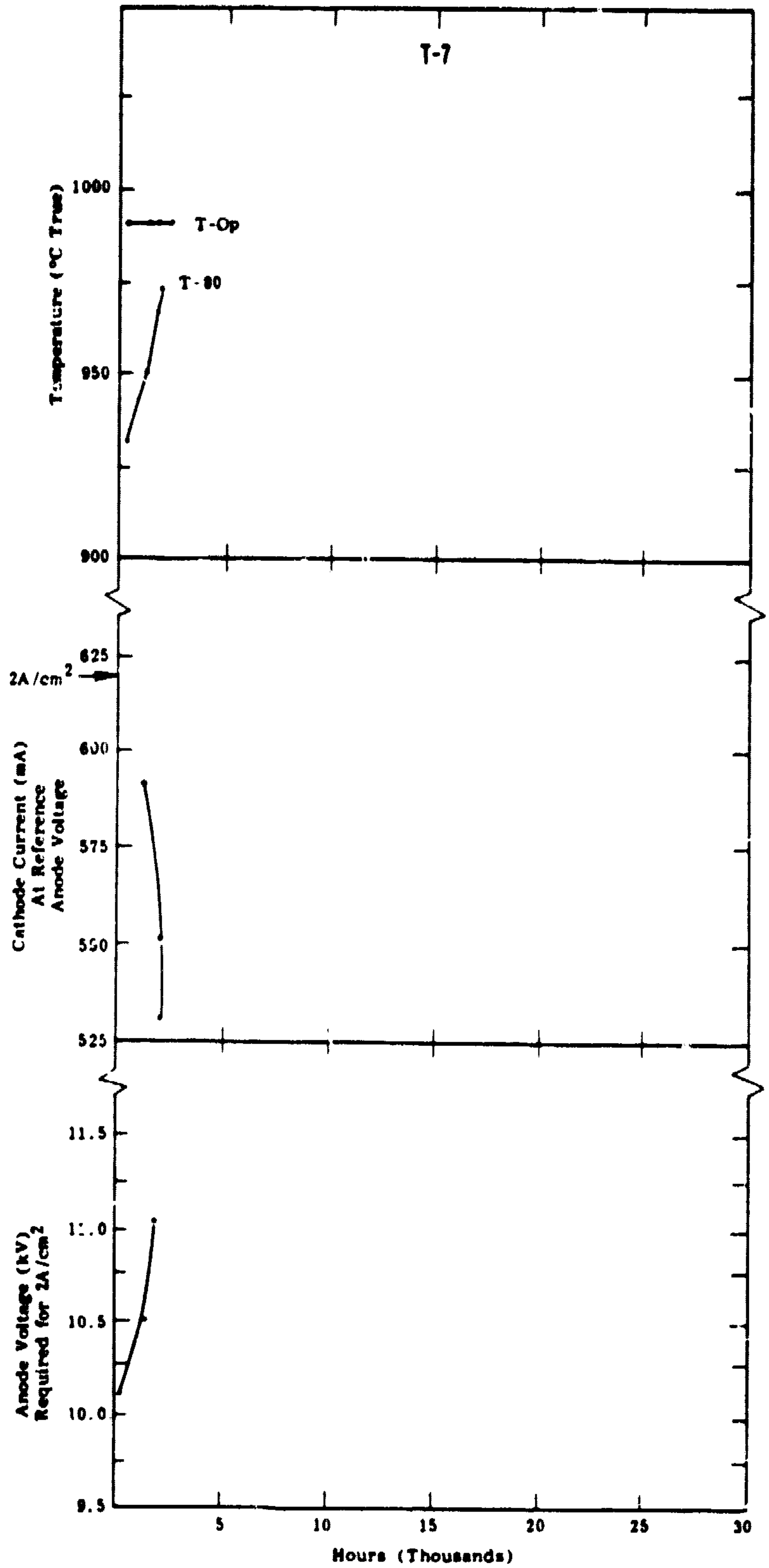

Figure 8 - Life Test Data for Unit T-7

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5.2 Semicon Type S Life Test Units

The cathode temperature for all of these cathode life test units was initially to be set approximately to 1050°C true. During testing, the cathode temperatures were set to run at 1060°C true to insure stable emission. However, all units exhibited a fairly steep decrease in cathode activity at 1060°C true, as can be seen in Figures 9 through 12. In order to continue life testing these units, the operating temperature of three out of the four original units was increased to 1100°C true. Operating at this high temperature, the units continued to show fairly steep degradation in cathode activity but did meet the original criterion of 20,000 hours of operation with less than 10% drop in cathode emission. Data on these Type S units show that this cathode type is marginally acceptable for reliable operation at 2A/cm^2 for up to 20,000 hours. However, the degradation in emission capability that was observed might disqualify use of these units in many microwave tube applications.

5.2.1 Unit S-2. End of life for this unit occurred at 23,073 hours. As noted above, at the initial operating temperature of 1060°C, end-of-life would have occurred at slightly over 10,000 hours. However, the operating temperature for this unit was increased gradually to 1100°C in order to maintain emission. Note the gradual increase in the T-80 temperature, accompanied by a gradual decline in emission capability; emission had fallen to 88% of its initial value by end-of-life.

5.2.2 Unit S-6. This unit showed emission characteristics with life similar to S-2. Again, the operating temperature was increased to 1100°C true to maintain emission. End of life for this unit occurred at 20,530 hours, at which time the cathode emission was at 89% of the initial value.

5.2.3 Unit S-7. Emission characteristics for this unit were similar to those of the other Type S cathodes tested. The operating temperature was not increased, however, so that end-of-life occurred at 7,189 hours (cathode emission at 91% of initial value).

5.2.4 Unit S-9. This unit developed a leak after initial processing. The leak was sealed and the unit was rebaked at 250°C. The unit was slightly gassy during initial turn-on, but cleaned up rather quickly. As in the case of the other units, operating temperature was increased in order to maintain emission. End-of-life occurred at 21,242 hours, with emission at 88% of initial value.

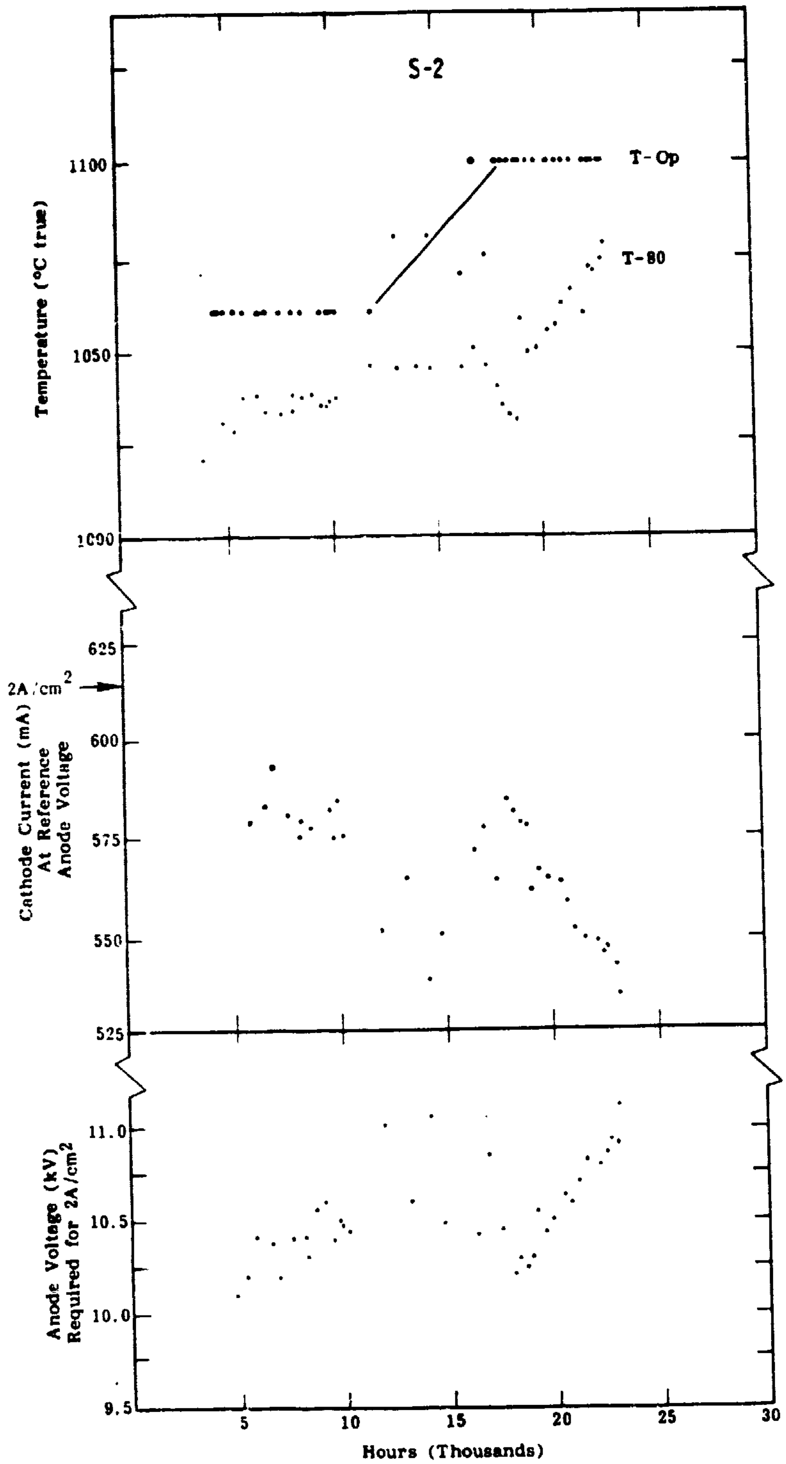

Figure 9 - Life Test Data for Unit S-2

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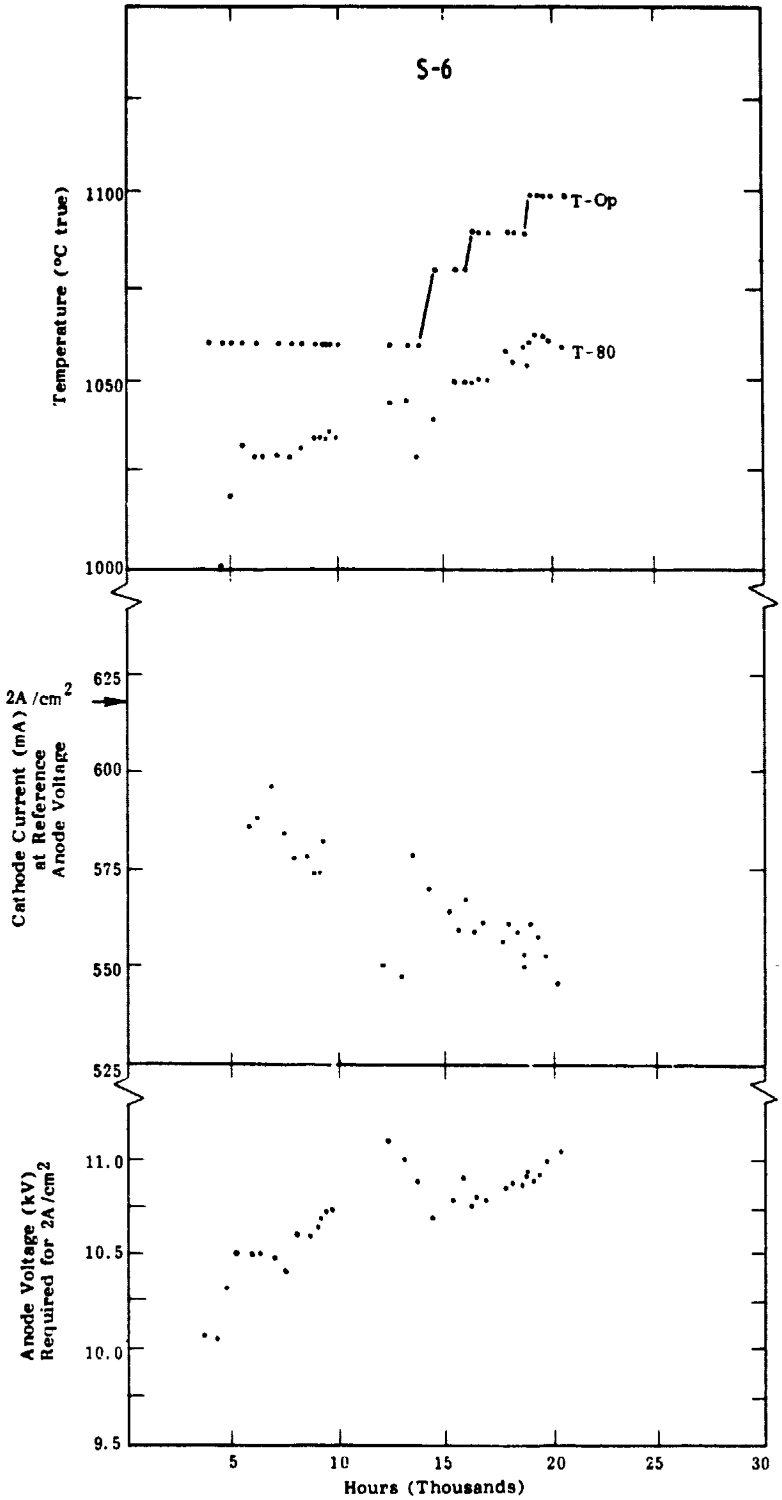

Figure 10 - Life Test Data for Unit S-6

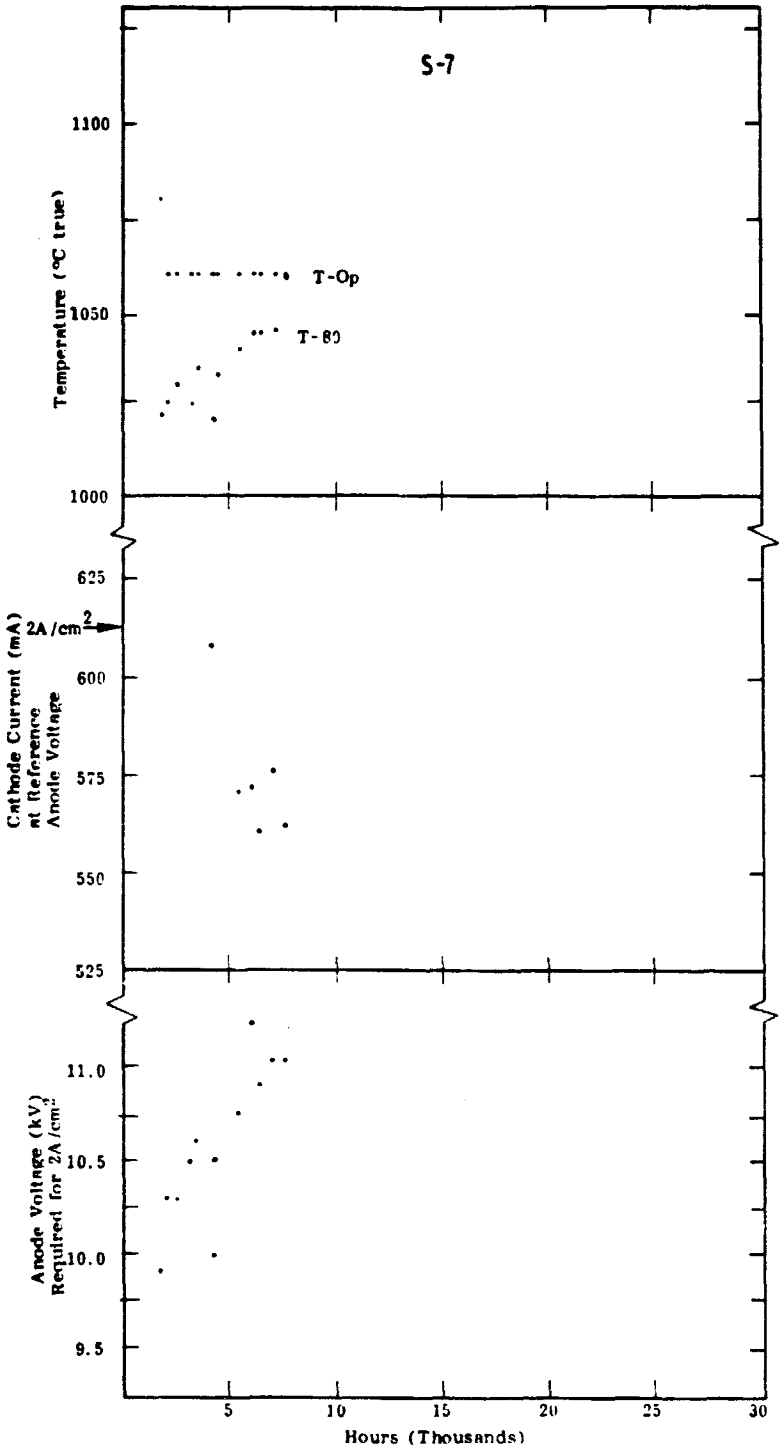

Figure 11 - Life Test Data for Unit S-7

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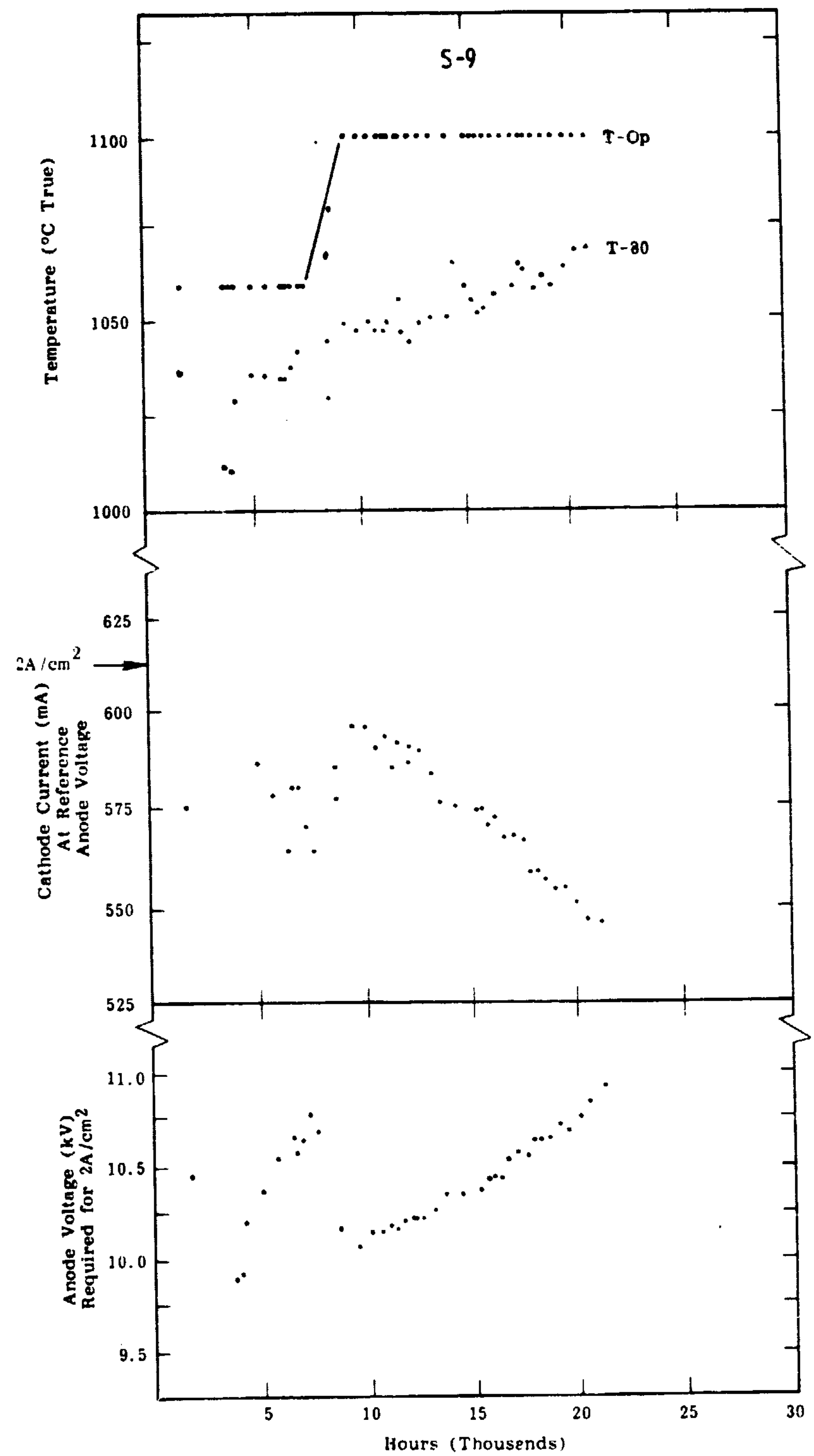

Figure 12 - Life Test Data for Unit S-9

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5.3 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 $2A/cm^2$ and agreed with the schedule set forth in the activation schedule. Figures 13 through 16 show the data accumulated on the four Type B cathodes tested. One unit continues on life test with 54,800 hours of operation accumulated. 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 can be expected to 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.

5.3.1 Unit P-4. This unit experienced a fairly intense arc at about 200 hours of life. The external arc on this unit was severe enough so that the electron gun area 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. The unit is now operating satisfactorily and has accumulated 54,800 hours. It is of interest to note that the T-80 temperature has increased gradually over time, accompanied by a gradual fall off in emission at operating temperature, up to about 30,000 hours; after this time, both parameters appear to stabilize. Cathode emission of unit P-4 is at 94% of its initial value.

5.3.2 Unit P-5. This unit developed a leak during initial processing at 500°C. The leak was sealed and subsequently rebaked at 250°C. The unit was extremely gassy during initial life, but cleaned up to allow life testing to begin. The unit operated satisfactorily up until 27,000 hours of life, showing the characteristic upward trend of T-80 temperature and gradual decrease of cathode emission over time. 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.

5.3.3 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. 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 in 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.

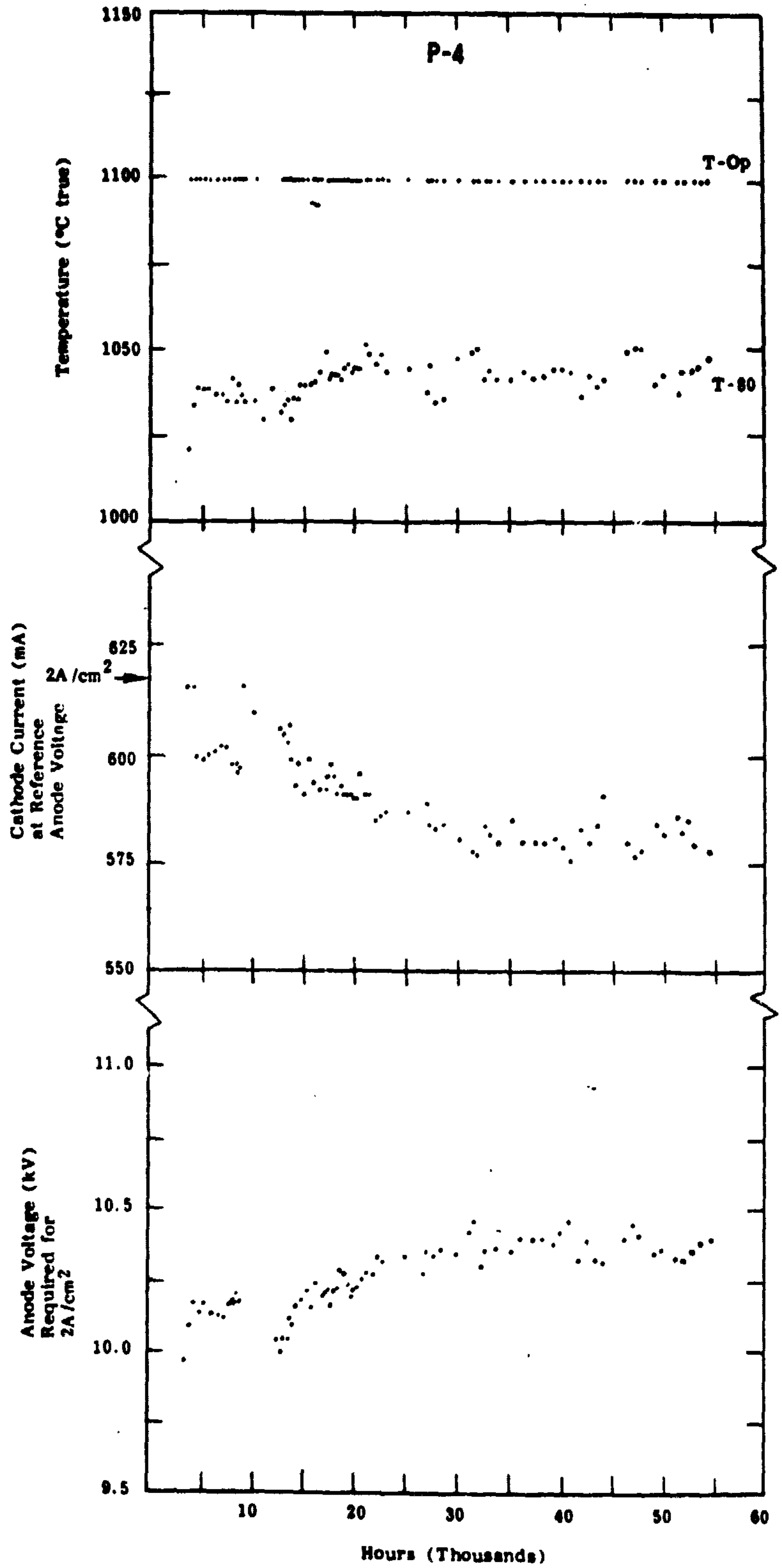

Figure 13 - Life Test Data for Unit P-4

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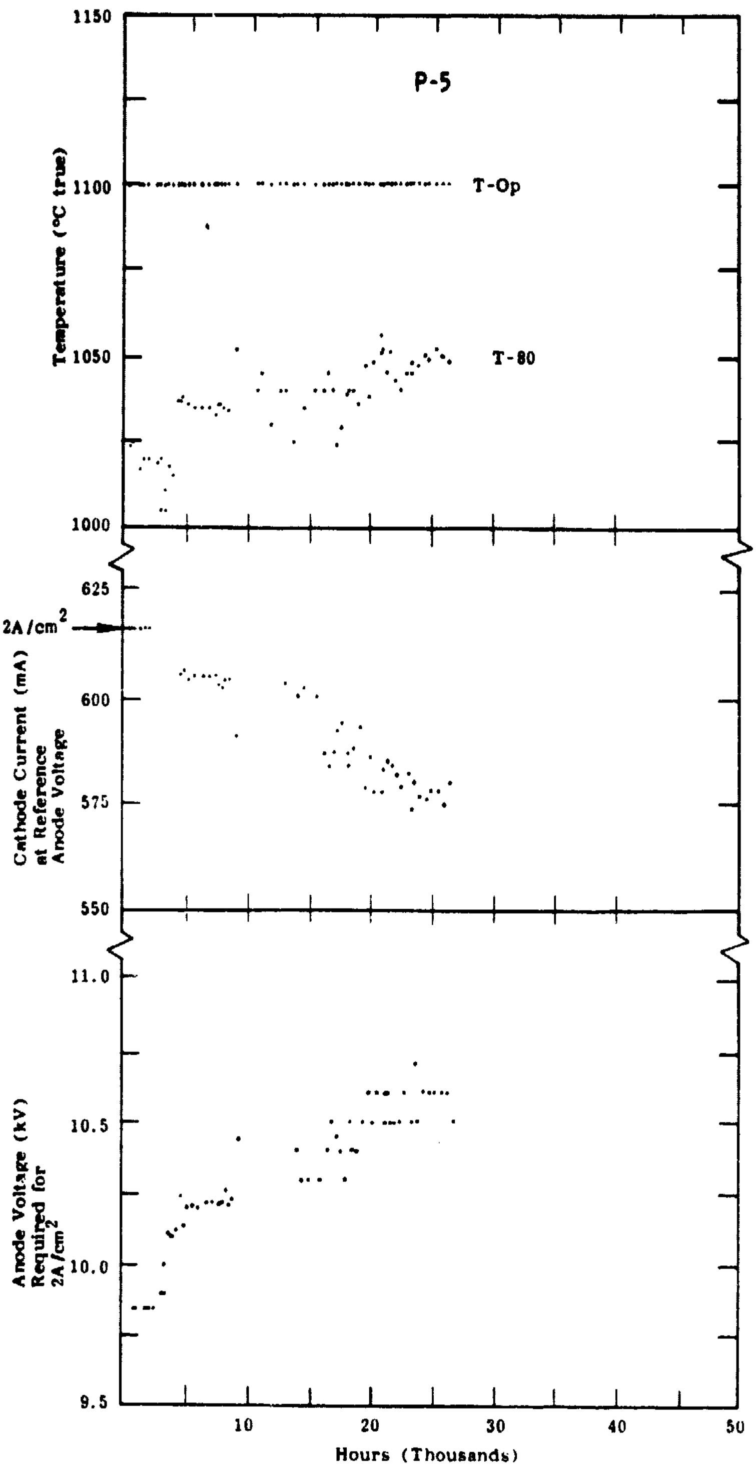

Figure 14 - Life Test Data for Unit P-5

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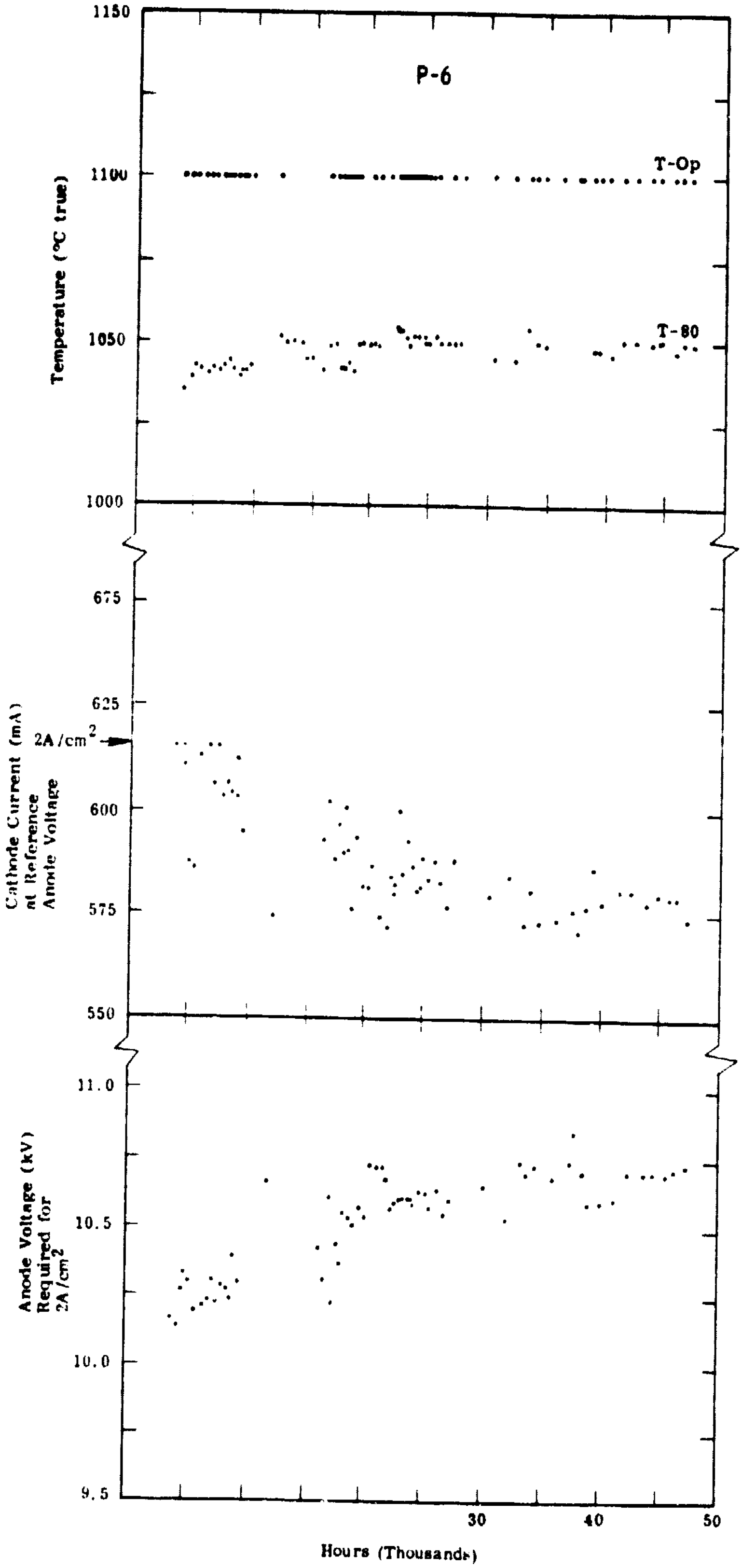

Figure 15 - Life Test Data for Unit P-6

ab44902

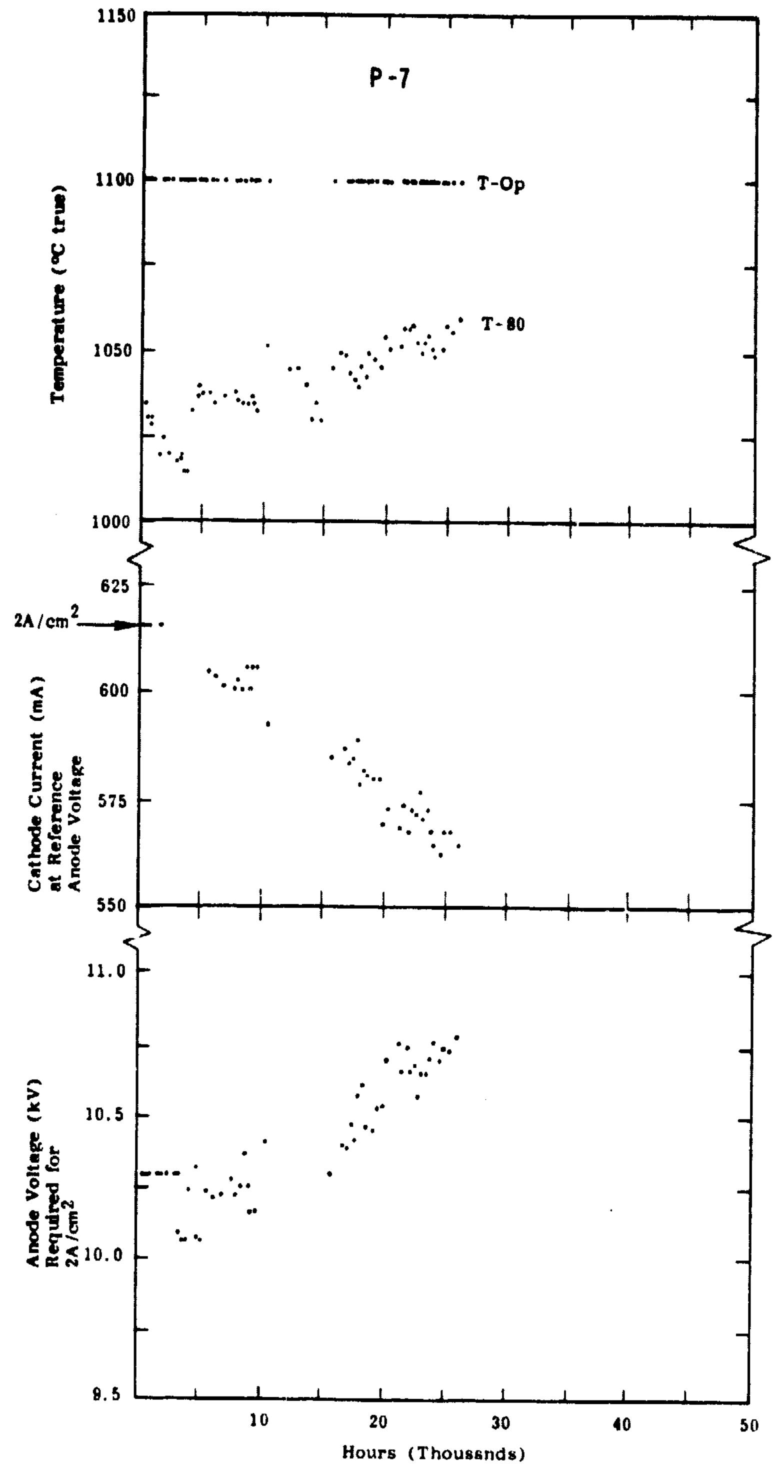

Figure 16 - Life Test Data for Unit P-7

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5.3.4 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.

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

5.4 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 have each accumulated more than 20,000 hours of life. Data for these four units are presented in Figures 17 through 20. The graphs show that, compared to the Philips Type B cathode, the Litton units exhibit a similar increase in T-80 temperature over time, and a similar decrease in cathode emission which starts 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; one continues on life test. 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.

5.4.1 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.

5.4.2 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.

5.4.3 L-5N. In contrast to the other three units, data on this unit show a decline in T-80 temperature for the first 10,000 hours before it began to gradually rise, and a gradual decline in cathode emission from beginning of life. This unit shows behavior similar to that of the Philips Type B units described previously. Unit L-5N is still running with 33,600 hours of operating life accumulated. Cathode emission is at 95.3% of its initial value.

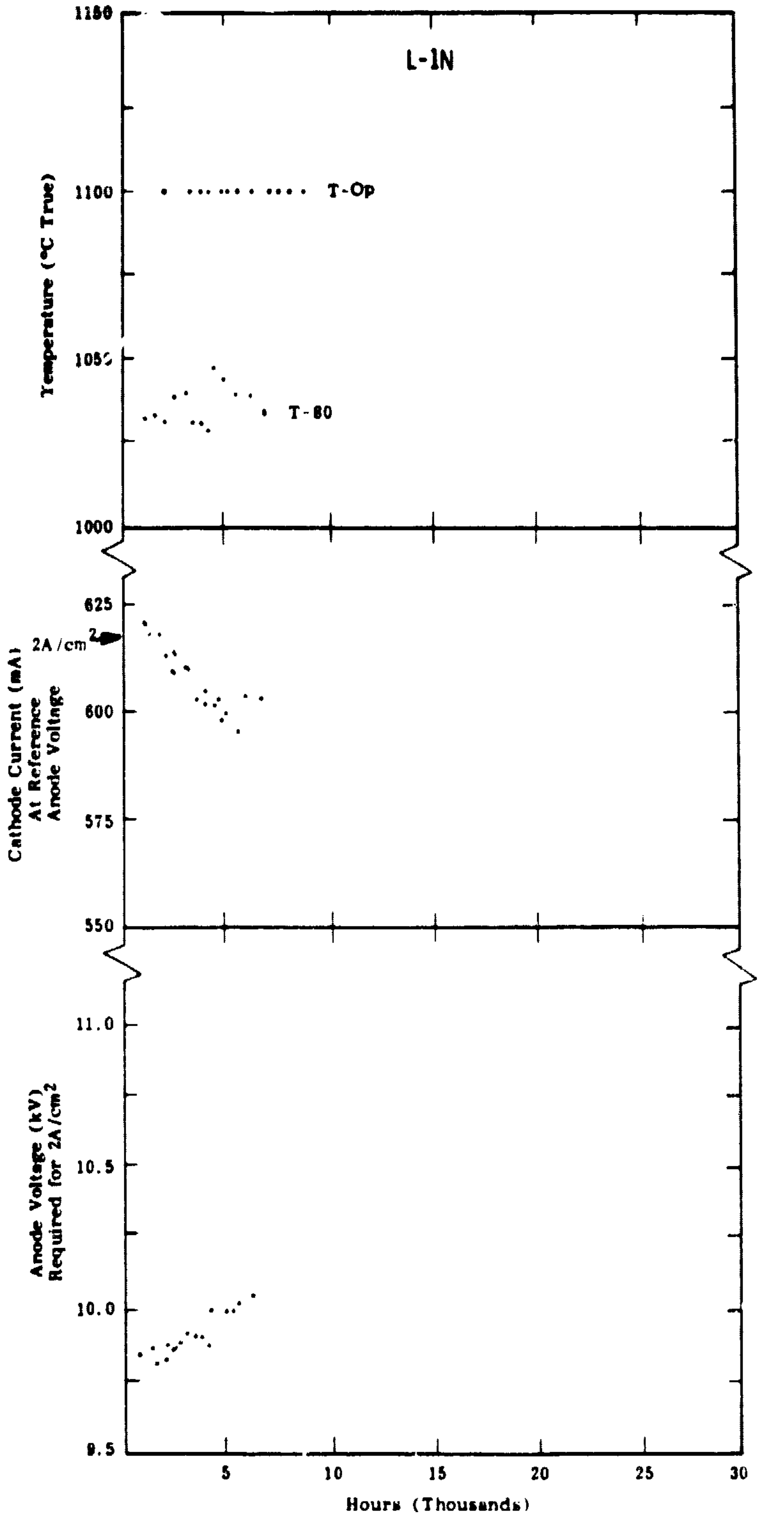

Figure 17 - Life Test Data for Unit L-1N

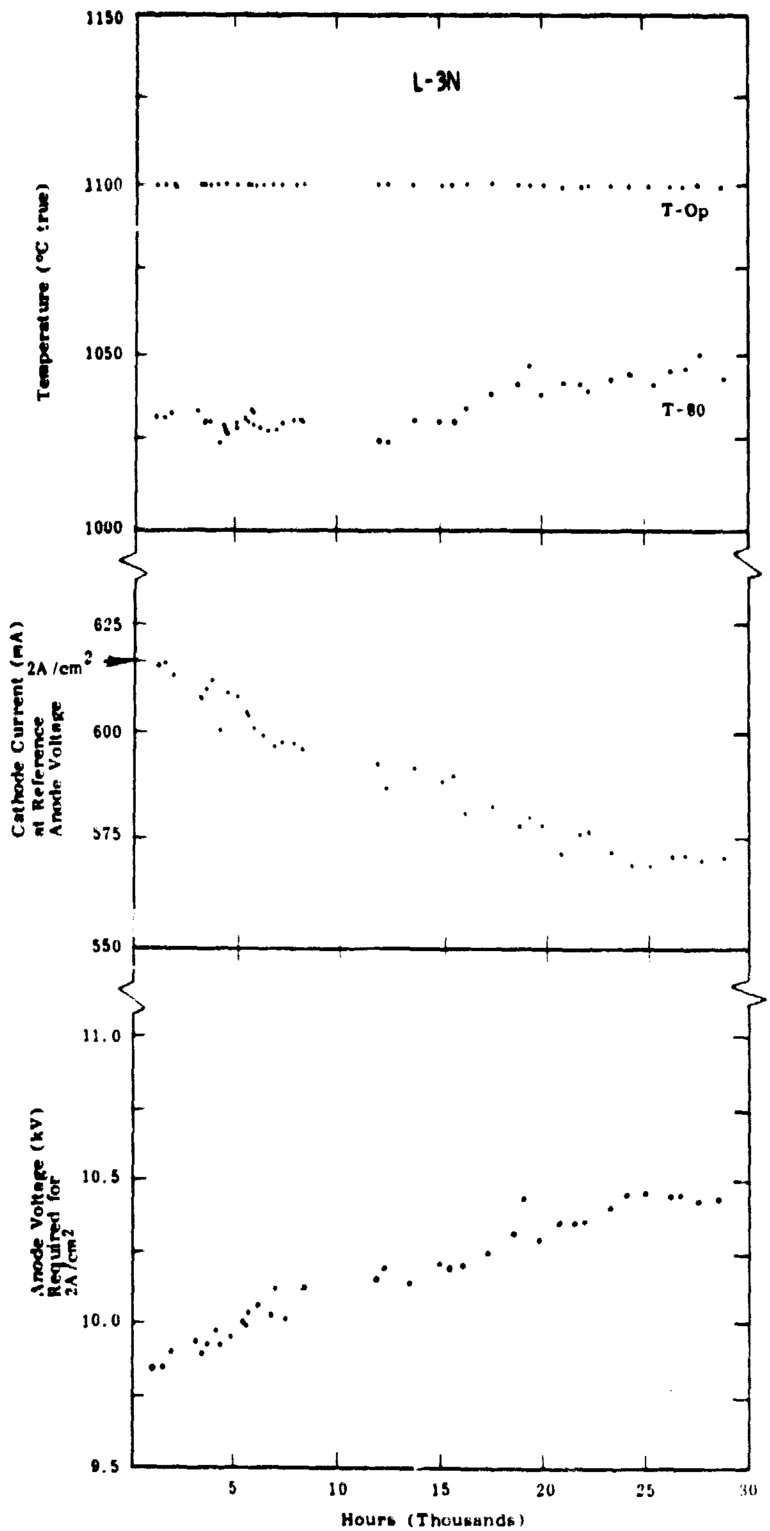

Figure 18 - Life Test Data for Unit L-3N

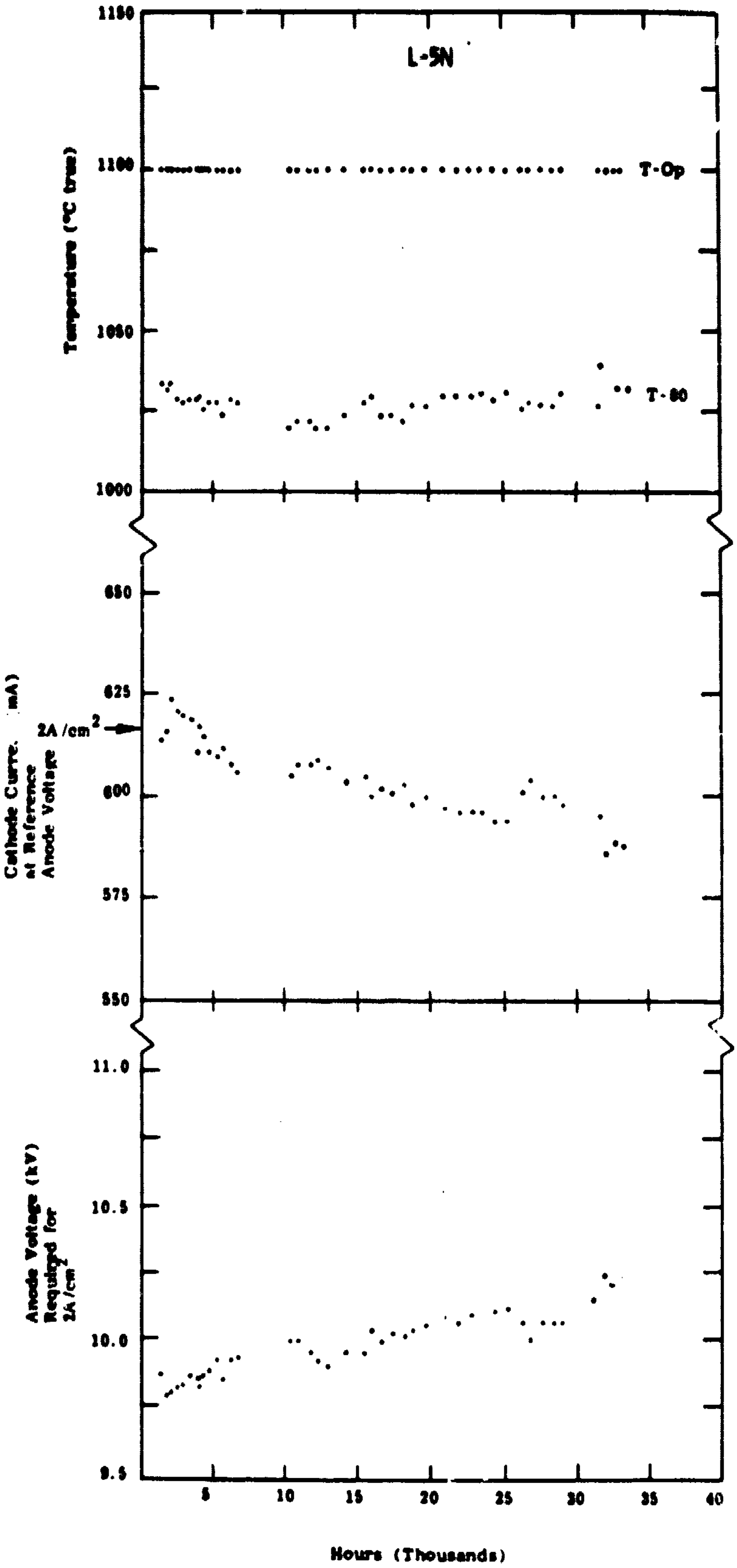

Figure 19 - Life Test Data for Unit L-5N

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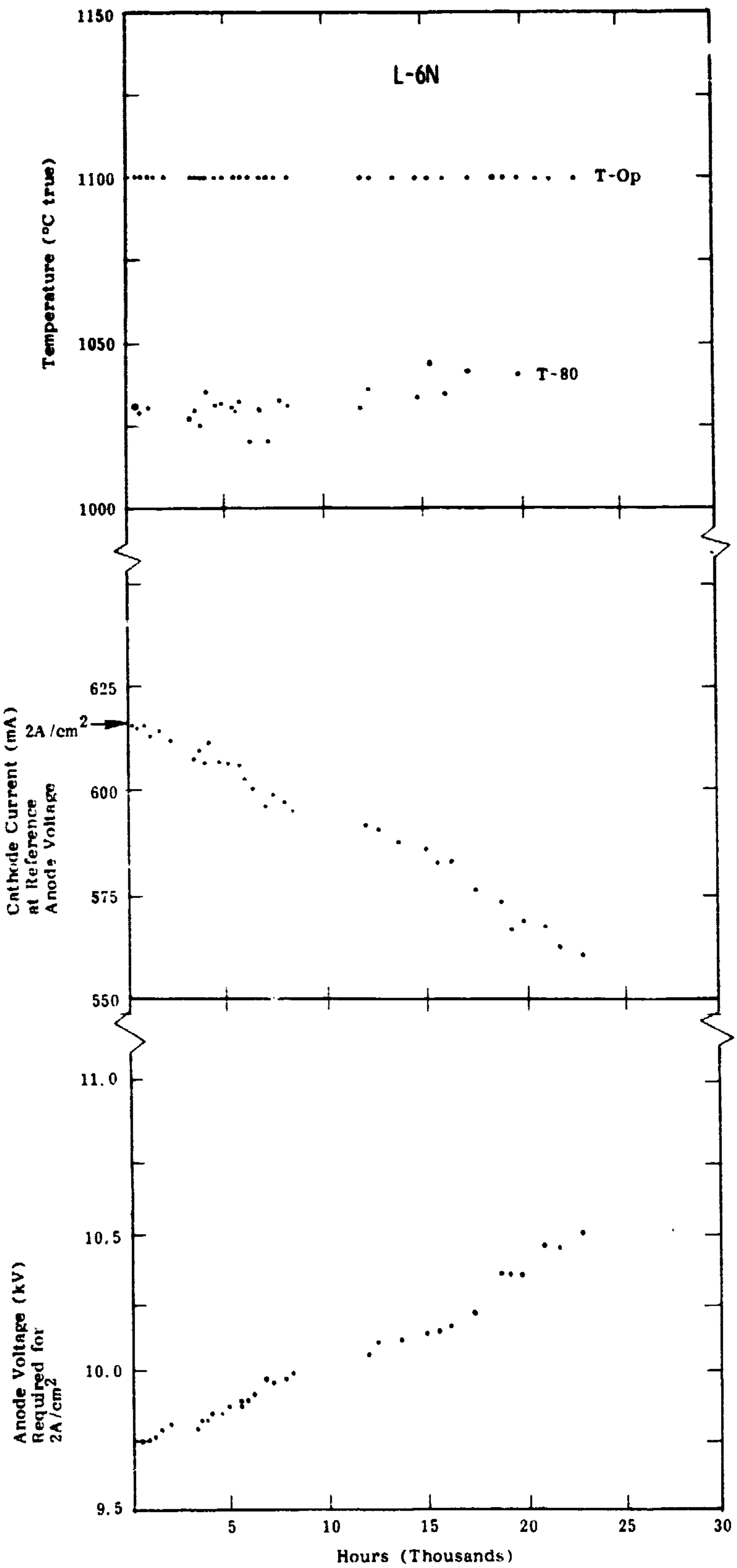

Figure 20 - Life Test Data for Unit L-6N

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5.4.4 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,C00 hours of life, with cathode emission at 90.6% of its initial value, unit L-6N was removed from test to allow testing to begin on another unit.

5.5 Philips Type M Life Test Units

Four units containing Philips Type M cathodes are on test at $2A/cm^2$ and $1010^{\circ}C$ true cathode temperature. Of these four, the longest running unit has accumulated over 52,000 hours of operating time. Figures 21 through 24 contain the graphed data for these four Type M units. As can be seen from the data, T-80 temperatures were relatively stable early in life, and began to rise after 15,000 to 20,000 hours. Cathode current for these Type M units, in contrast to all other units tested to date, was steady or increasing for approximately the first 15,000 hours: emission actually improved from beginning of life 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 30,000 hours at $2A/cm^2$; individual units may be expected to operate satisfactorily well beyond the 30,000 hour mark. Incorporating this Type M cathode into a microwave tube would appear to be a successful endeavor based on this data; however, use of this type of dispenser cathode may require use of a power supply that is capable of adjusting for tube perveance changes in both negative and positive directions.

5.5.1 M-1. Unit M-1 is the longest running of the Type M units on test with more than 52,000 hours accumulated. Data for this unit is presented in Figure 21. 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 $1050^{\circ}C$ true. However, it was decided that operation at $1010^{\circ}C$ provided adequate margin for stable operation. Subsequently, this and all other Type M units have been operating at $1010^{\circ}C$ true. Data show a steady T-80 temperature for about the first 20,000 hours; cathode emission actually increased from start of life to a peak value of almost 104% of initial value at around 22,000 hours and then gradually declined back down to its present level of 98.6% of initial emission at 52,000 hours. Unit M-1 continues to operate satisfactorily.

5.5.2 M-3. Unit M-3, with more than 30,000 hours accumulated so far, has shown behavior typical of these Type M units. T-80 temperature has held steady until about 20,000 hours. Cathode emission, after having risen more than 1% above its initial value during the first 6,000 hours of life, held steady up to about 27,000 hours before it began to decline, but is still above its initial emission level at present. Unit M-3 continues to run satisfactorily on test.

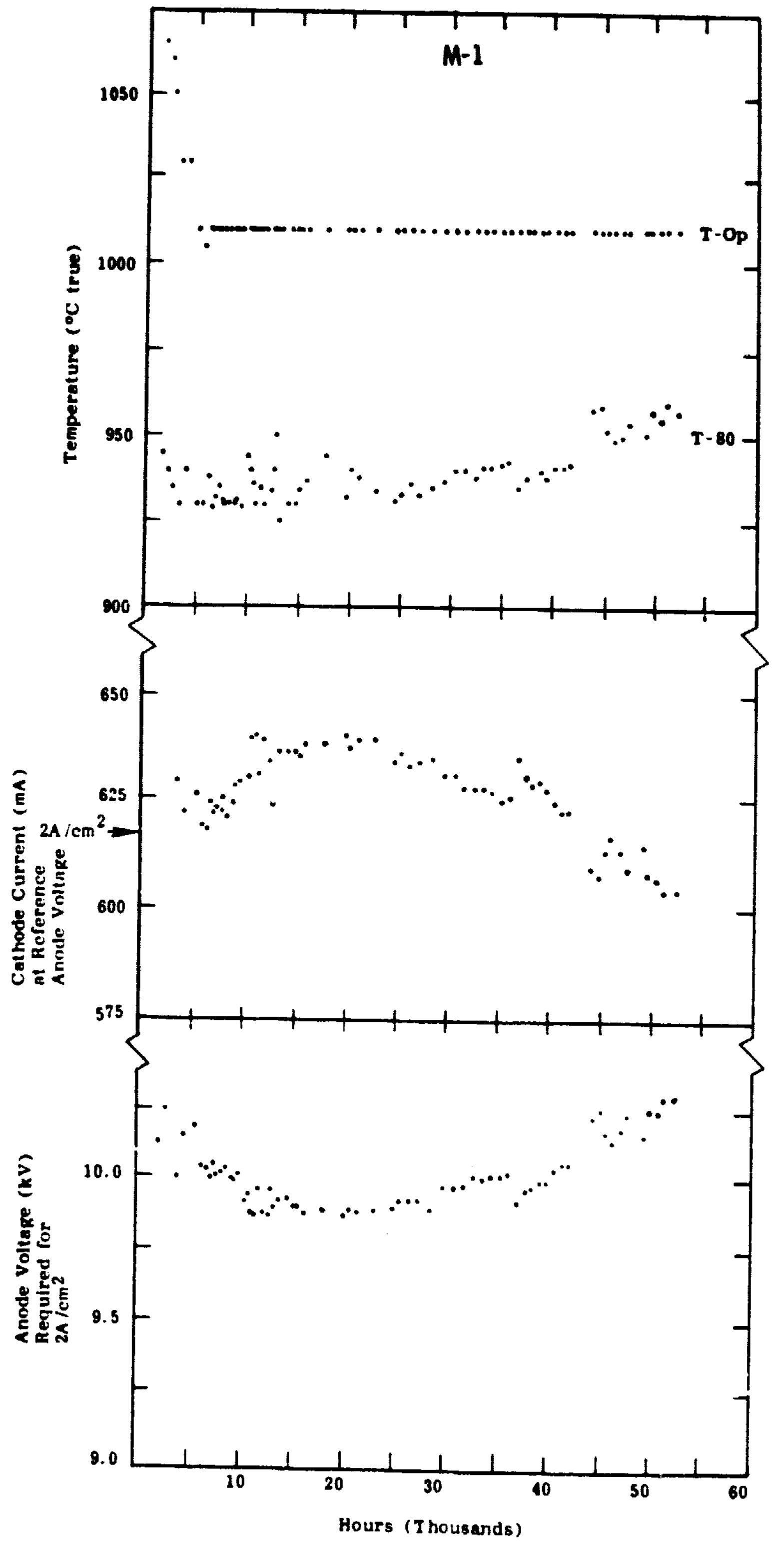

Figure 21 - Life Test Data for Unit M-1

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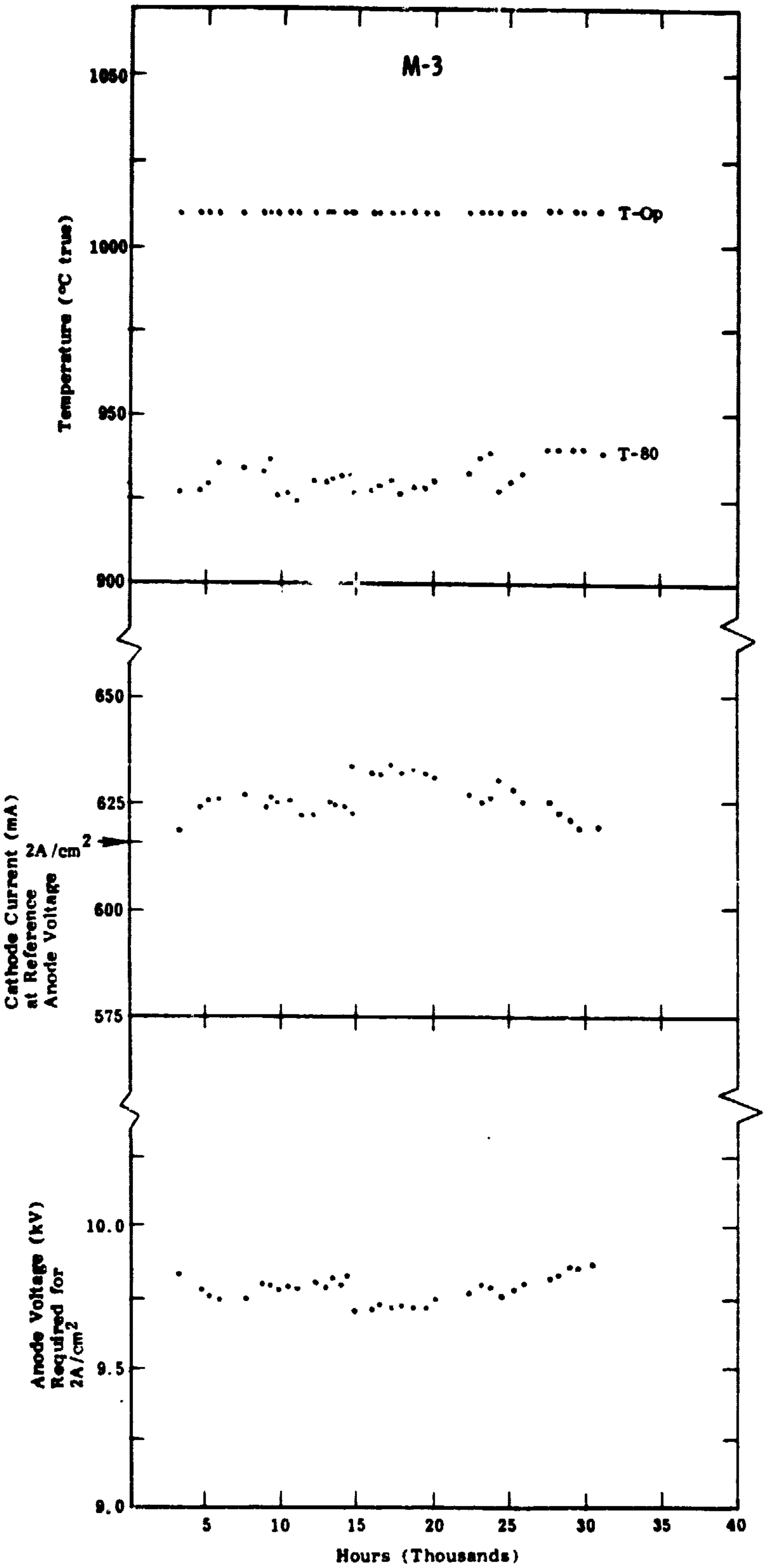

Figure 22 - Life Test Data for Unit M-3

ab46067

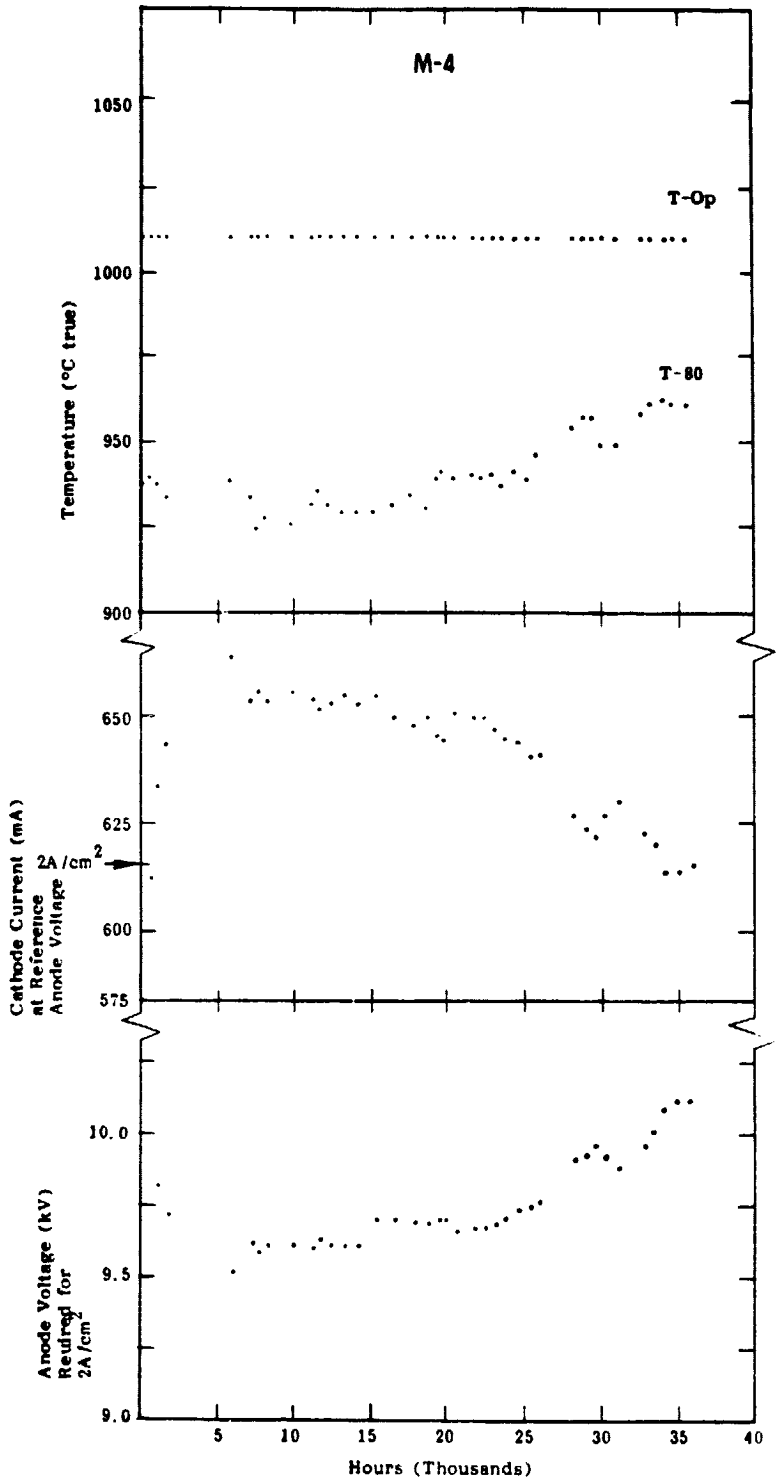

Figure 23 - Life Test Data for Unit M-4

ab46066A

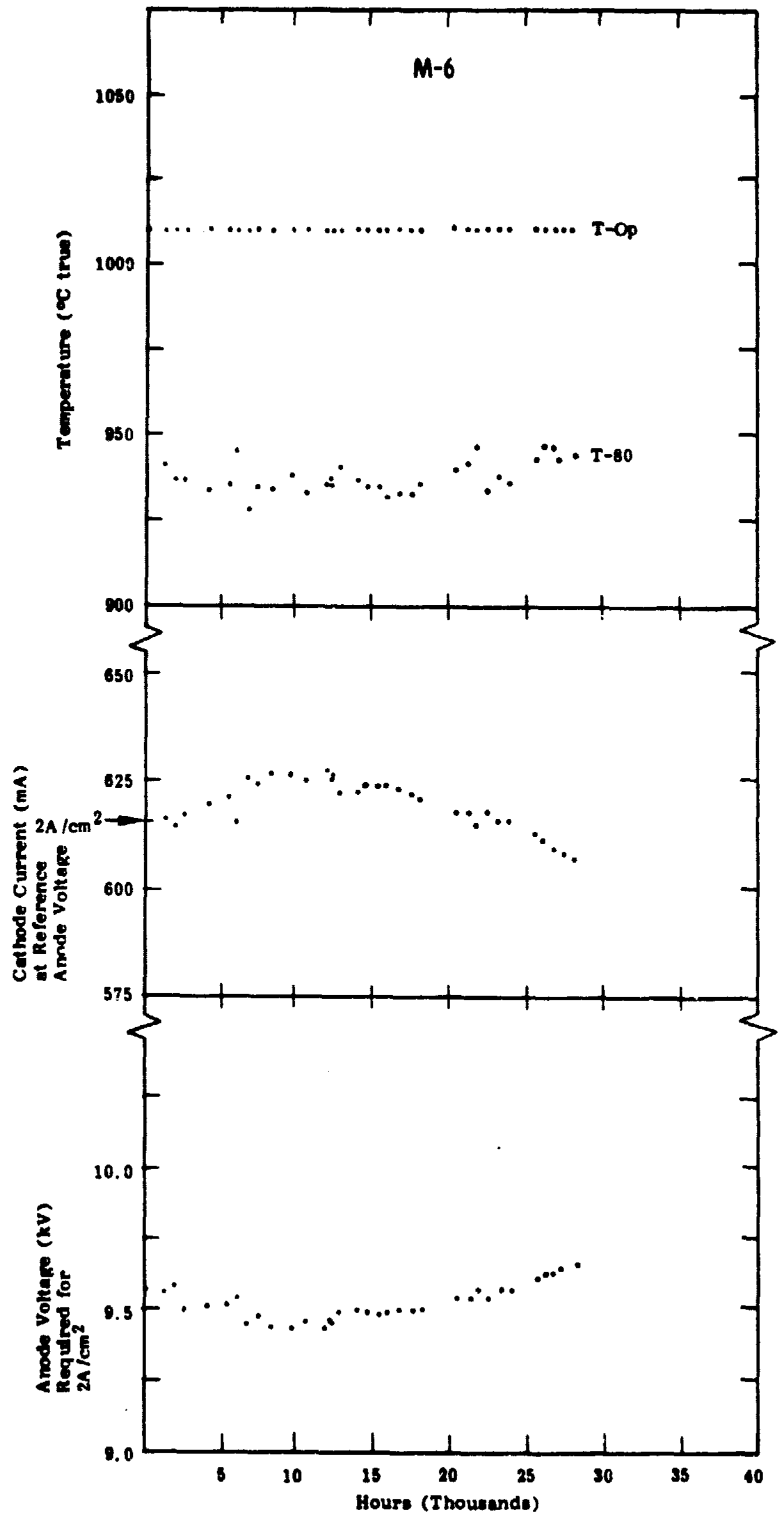

Figure 24 - Life Test Data for Unit M-6

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5.5.3 M-4. With 36,000 hours of life accumulated, unit M-4 has exhibited behavior similar to M-1 above. Data show a steady T-80 temperature to about 20,000 hours before it began to rise. Cathode emission increased steeply for the first 7,000 hours of life to a peak value of 106% of initial emission, and then leveled out for about 7,000 hours before it began to decline. The unit is still running satisfactorily at 36,000 hours of life with cathode emission at 99.5% of its initial value.

5.5.4 M-6. Data for this unit, similar to that of the other Type M cathodes, has shown a steady T-80 temperature until about 20,000 hours. Cathode emission increased for the first 10,000 hours to 102% of initial emission, then slowly declined to its present level of 98.7% of initial. Unit M-6 continues to run satisfactorily on test.

5.6 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 of $4A/cm^2$. The Philips Company had discontinued manufacturing cathodes in this country since the first Type M units went on test in this program. Therefore, it became necessary to look for other sources of good Type M cathodes. Two manufacturers in the U.S., 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 we mentioned in an earlier section of this report, the area of the emitter surface of the $4A/cm^2$ cathodes is half that of the $2A/cm^2$ cathodes - thus, the same cathode current of 616 mA can be drawn from these new cathodes, but the current loading per cm^2 of emitter area is doubled. Figures 25 through 30 show the graphed data of these life test units.

5.6.1 Spectra-Mat Type M Cathodes. Three of these units, SP-2, SP-3 and SP-4, are running on test at $4A/cm^2$ loading. The longest running of these, Unit SP-2, has accumulated 18,300 hours of life so far. Figures 25 through 27 show the date on these three units. In general, these units show a steady or slight increase in cathode emission for the first 3,000 to 5,000 hours before beginning to fall off. This early behavior was expected for the Type M cathodes; the earlier than expected fall off may be attributable to the higher loading when compared to the Philips Type M's at $2A/cm^2$. Total hours running time (and emission levels) for units SP-2, SP-3 and SP-4 are 18,300 (97.9%), 16,800 (97.7%) and 15,950 (96.1%), respectively.

5.6.2 Semicon Type M Cathodes. Three of these units are running on test at $4A/cm^2$: SM-1, SM-2 and SM-3. Figures 28 through 30 show the collected data for these units. Behavior of the Semicon cathodes with time is similar to that of the Spectra-Mat cathodes, where an early in life steady or slight increase in activity can be seen. However, these Semicon units appear to be slightly more active, as can be seen by their lower T-80 temperatures. Total hours (and emission levels) for units SM-1, SM-2 and SM-3 are 17,800 (99%), 14,800 (99.4%) and 11,800 (98.1%), respectively.

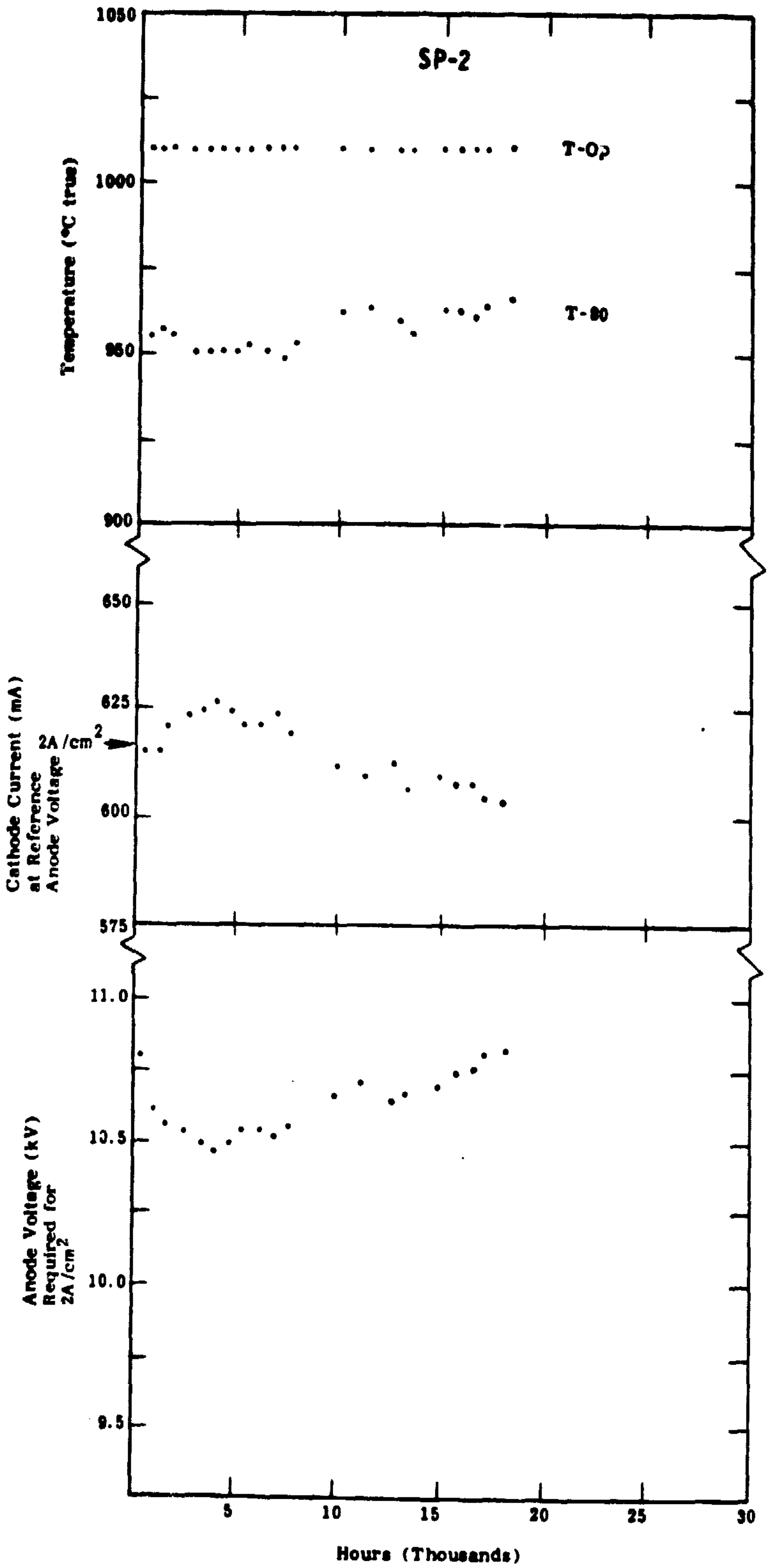

Figure 25 - Life Test Data for Unit SP-2

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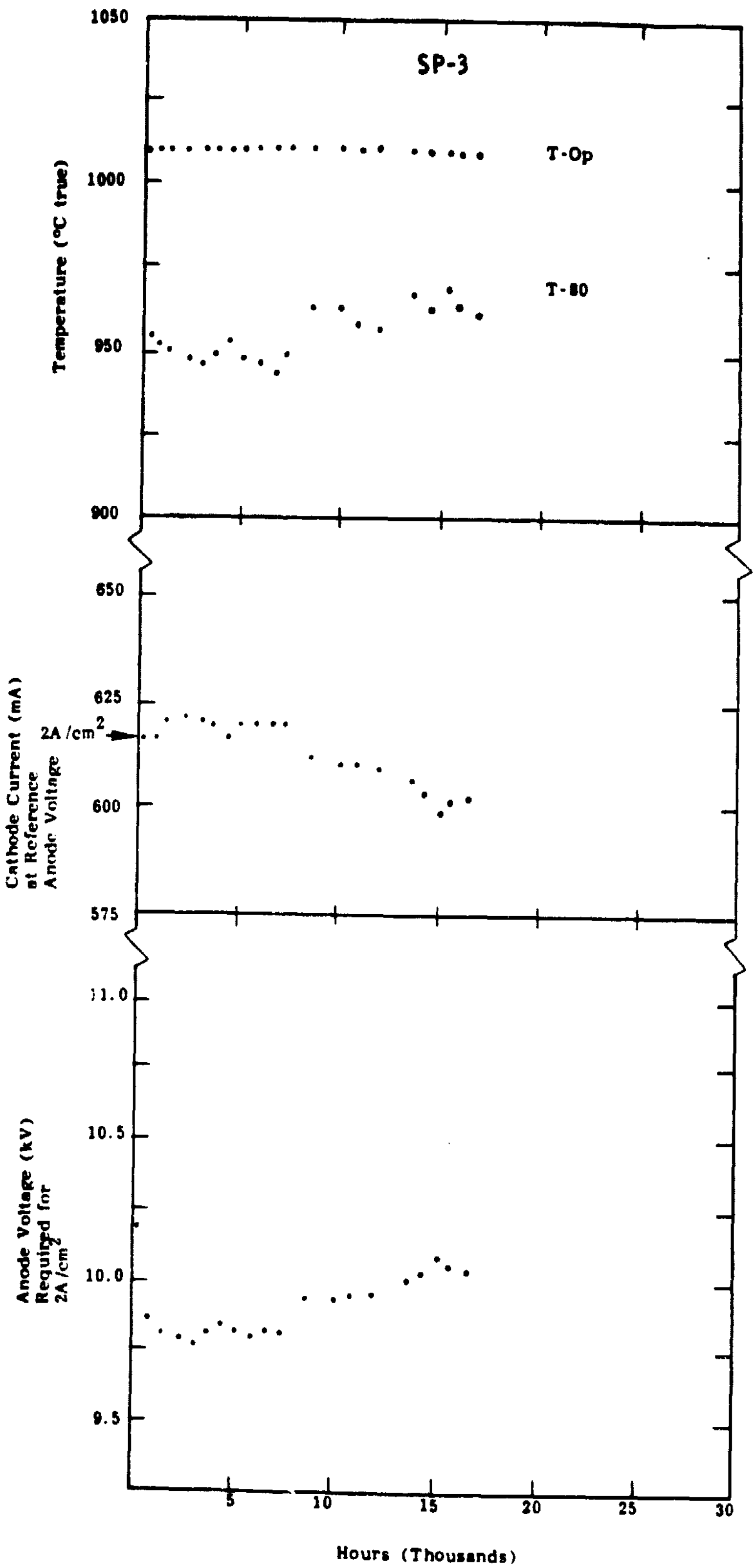

Figure 26 - Life Test Data for Unit SP-3

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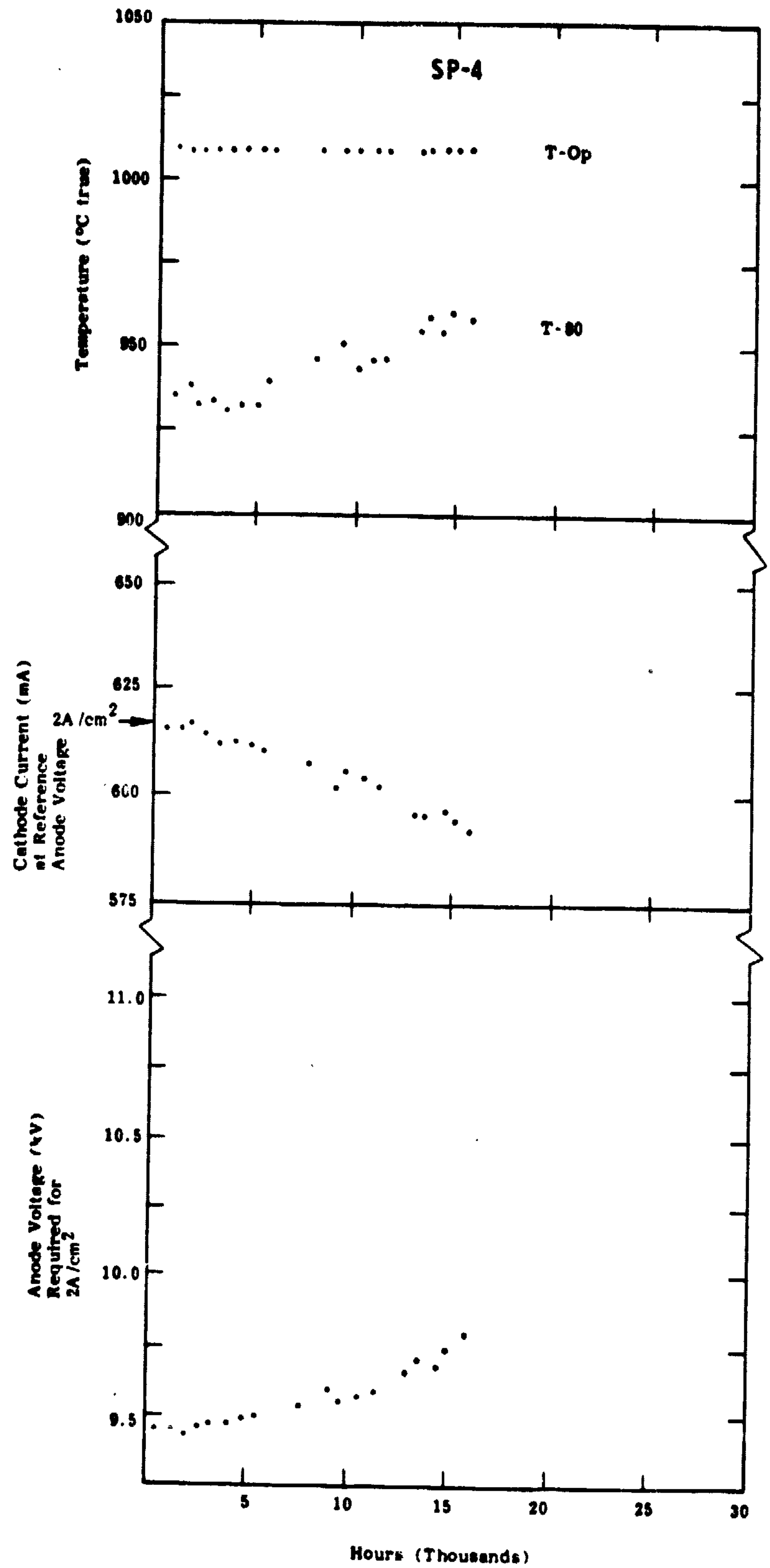

Figure 27 – Life Test Data for Unit SP-4

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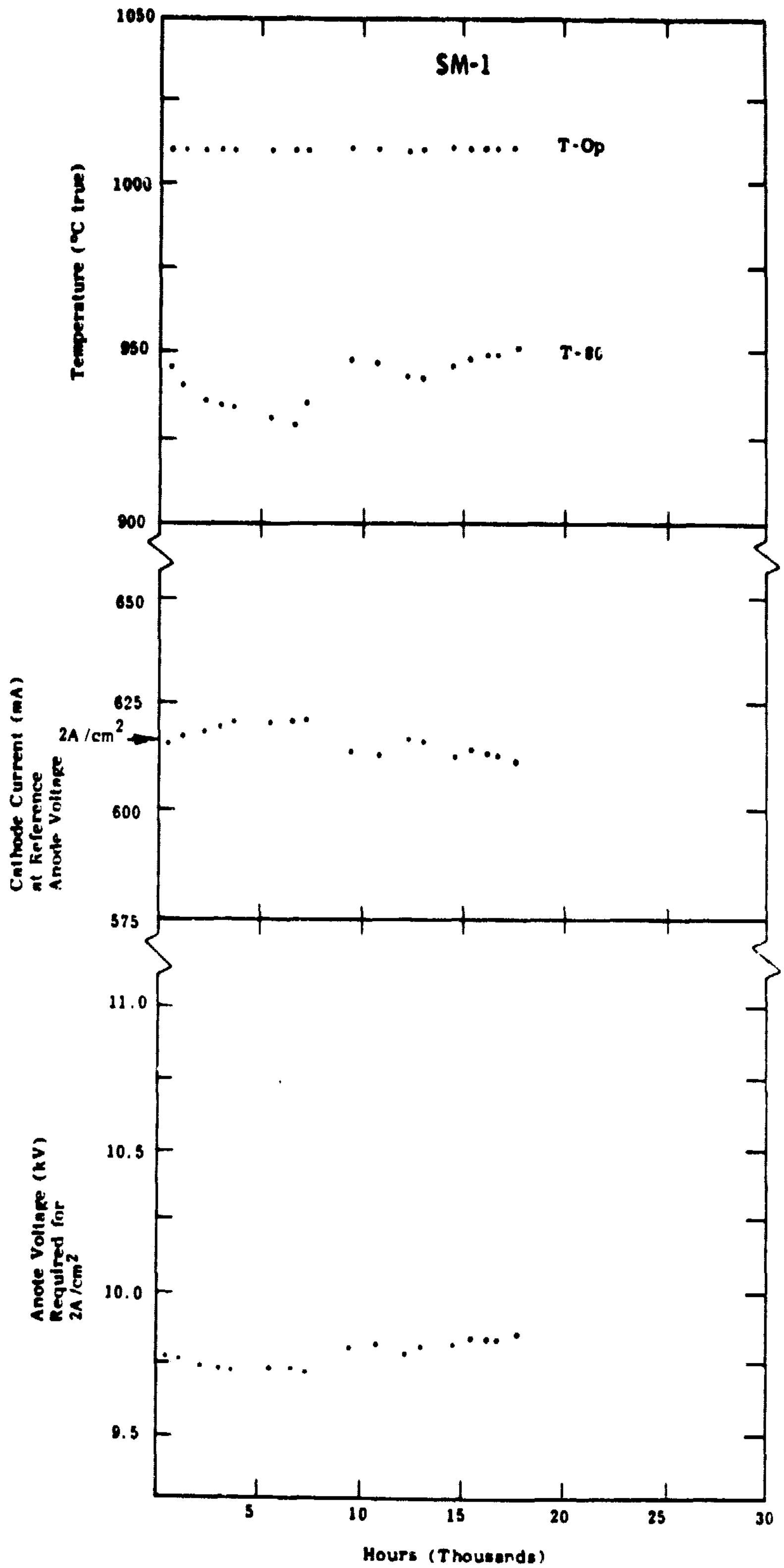

Figure 28 - Life Test Data for Unit SM-1

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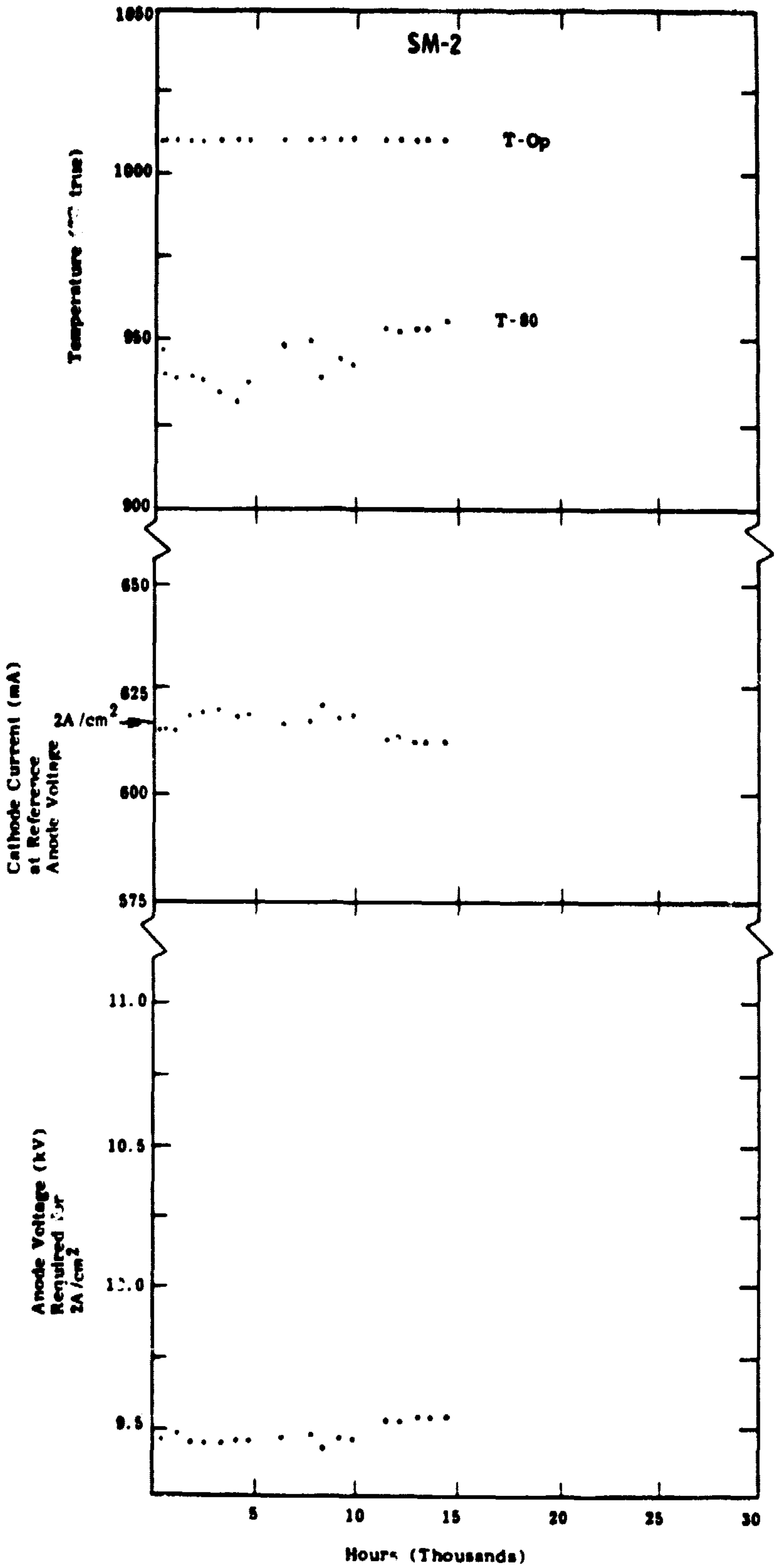

Figure 29 - Life Test Data for Unit SM-2

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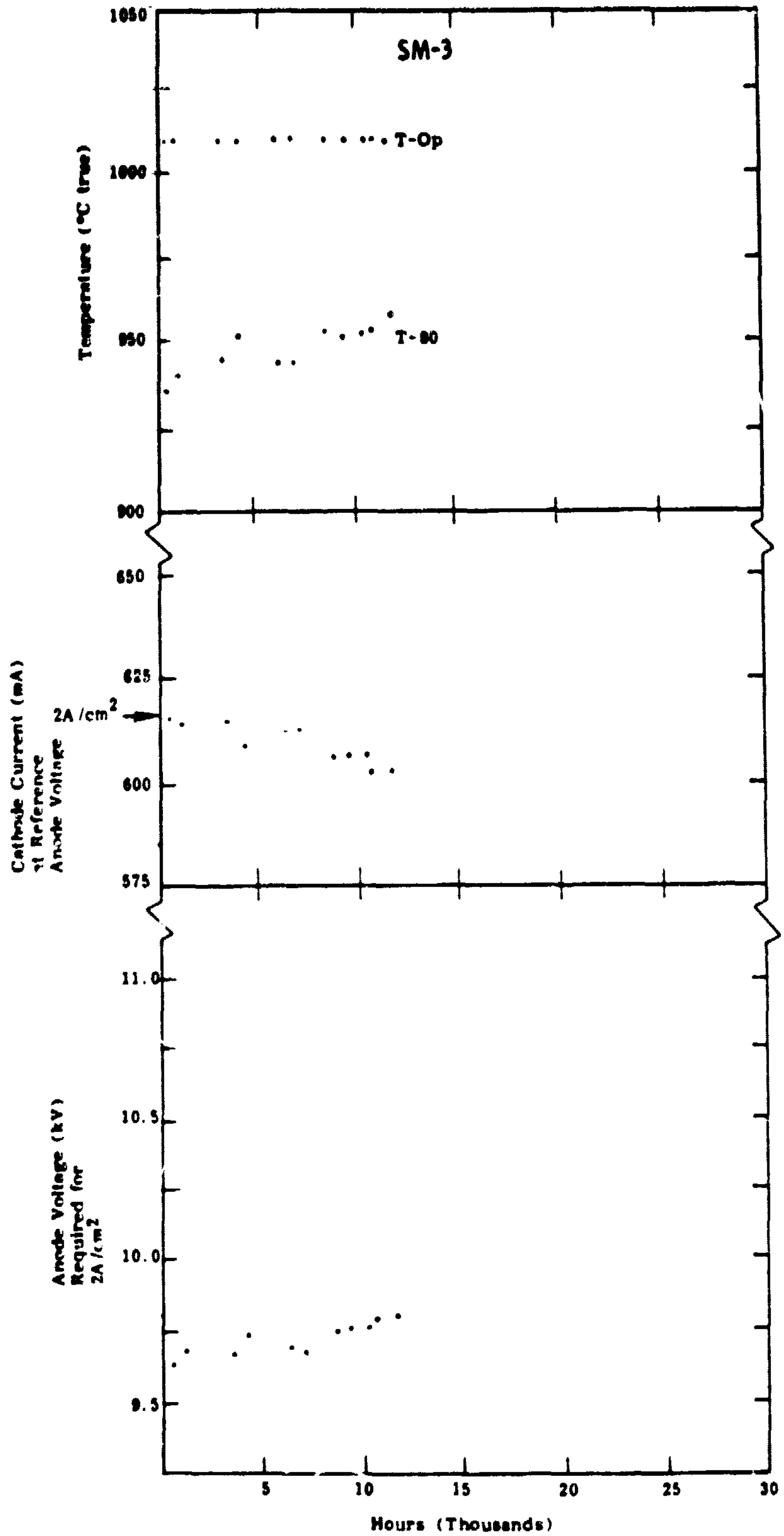

Figure 30 - Life Test Data for Unit SM-3

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6.0 CONCLUSIONS AND RECOMMENDATIONS

The life test results to date for the cathode types tested show the following:

1. The GE Tungstate cathodes were not suitable for long-lived application at $2A/cm^2$.

2. The Semicon (Type S) cathodes exhibited a moderately rapid degradation in emission at $2A/cm^2$ loading and at 1060°C true, resulting in marginal suitability for operation in a microwave power tube to 20,000 hours.

3. 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 is to be expected during life which could affect device performance.

4. The Litton impregnated cathodes show 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.

5. The Philips (Type M) cathodes tested show great promise for this application. Operating at 1010°C true, these units show early improvement of emission characteristics, unlike all other cathode types tested to date.

6. Data on the Spectra-Mat and Semicon Type M cathodes show that, at 1010°C true temperature, these cathodes can indeed sustain $4A/cm^2$ emission density. Data is not yet adequate to conclude anything further at the present time.

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. The importance of this comparative aspect cannot be over-emphasized. The resulting information should prove to be of considerable importance to space missions in the future.

7.0 APPENDICES

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.* During this life test period, six Type M cathodes, designated for testing at $4A/cm^2$, were processed for life testing. Three of these cathodes were manufactured by Spectra-Mat, Inc.; three were manufactured by Semicon Associates, Inc. Each activation schedule used was arrived at by discussion between Watkins-Johnson Company and the individual cathode manufacturer to assure that each cathode received the optimum processing available. The schedules used for these new cathodes are presented in this section.

*References 14, 15 and 16.

WATKINS-JOHNSON COMPANY COMMON EXHAUST 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 x 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 x 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 x 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.

<u>Spectra-Mat Type M Cathode Activation Continuation:</u>

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.)

APPENDIX II

CATHODE SELECTION FOR LIFE

Refer to a previous interim report* for a discussion of this topic.

*Reference 16.

APPENDIX III

COMMENTS ON THIS LIFE TEST PERIOD

During the latter part of the last interim report period, several modifications were made to the life test station to increase reliability and total "on time" (see Reference 17, Appendix III). One of these changes, elimination of the high potential between focusing solenoid coil and outer case, has decreased the down time due to solenoid malfunction from 20% of total unit running time for the last report period to 3.7% during this report period. Another change worth noting is the increase in temperature set point for the life test's main cooling unit. This report period has seen 1.5% of total unit running time lost to cooling system malfunction compared to a loss of 9.7% in the previous report period for the same length of time. It appears that the modifications have had a positive effect; efforts continue toward the goal of attaining maximum utilization of the life test stations.

Concerning equipment calibration, during this report period it was noticed that our two optical pyrometers, both maintained in calibration, disagreed with one another by almost $10^{\circ}C$. The pyrometer manufacturer called our attention to an adjustment on the indicating meter that would occasionally require checking during the useful calibration period. To our knowledge, this adjustment had not been done previously. We feel this may account for some scatter and short-term false trends that can be seen in the data plots for this life test (see also pertinent comments on optical pyrometry in Section 4.0 of this report). Since the latter half of 1982, pains have been taken to check meter adjustment before every monthly check; this will continue as long as the optical pyrometer is used in this life test to maximize precision of the optical measurements. Additionally, an automatic pyrometer will be looked at for use on this program; use of such a pyrometer could eliminate operator error as a factor in the optical measurements, and may prove to have the long-term accuracy that is required for this life test.

APPENDIX IV

DIP TEST DATA

As was mentioned previously in this report, dip testing has been a fairly recent addition to the regularly scheduled data gathering techniques employed in this life test. The dip test measurement, described in detail in Section 4.0 of this report, is scheduled to be taken on a new unit several times during the first 10,000 hours of operation, and then at 5,000 hour intervals. The dip test measurement can be used to compare individual units, but is more widely used in monitoring an individual unit's behavior over time. Dip tests have been taken on all presently running units; measurements will continue to be taken according to the predetermined schedule. The following tables show dip test data taken on all units to date. Additionally, actual dip test plots of the earliest and latest dip tests on each unit follows the tables.

DIP TEST SUMMARY

$2A/cm^2$

Unit	Hours	Dip Time (Sec)
L-5N	29,624	3.3
P-4	44,900	1.9
M-1	37,083	4.1
	42,713	3.6
	52,619	2.2
M-3	15,250	5.2
	20,738	5.3
	30,695	4.2
M-4	20,977	3.7
	26,601	3.1
	35,995	1.9
M-6	13,166	4.3
	18,703	4.8
	28,727	3.5
SP-2	765	9.5
	2,711	9.5
	3,459	9.8
	8,362	9.0
	10,684	8.4
	18,352	7.4
SP-3	468	11.0
	2,462	11.2
	3,210	11.2
	9,481	9.0
	16,870	8.7

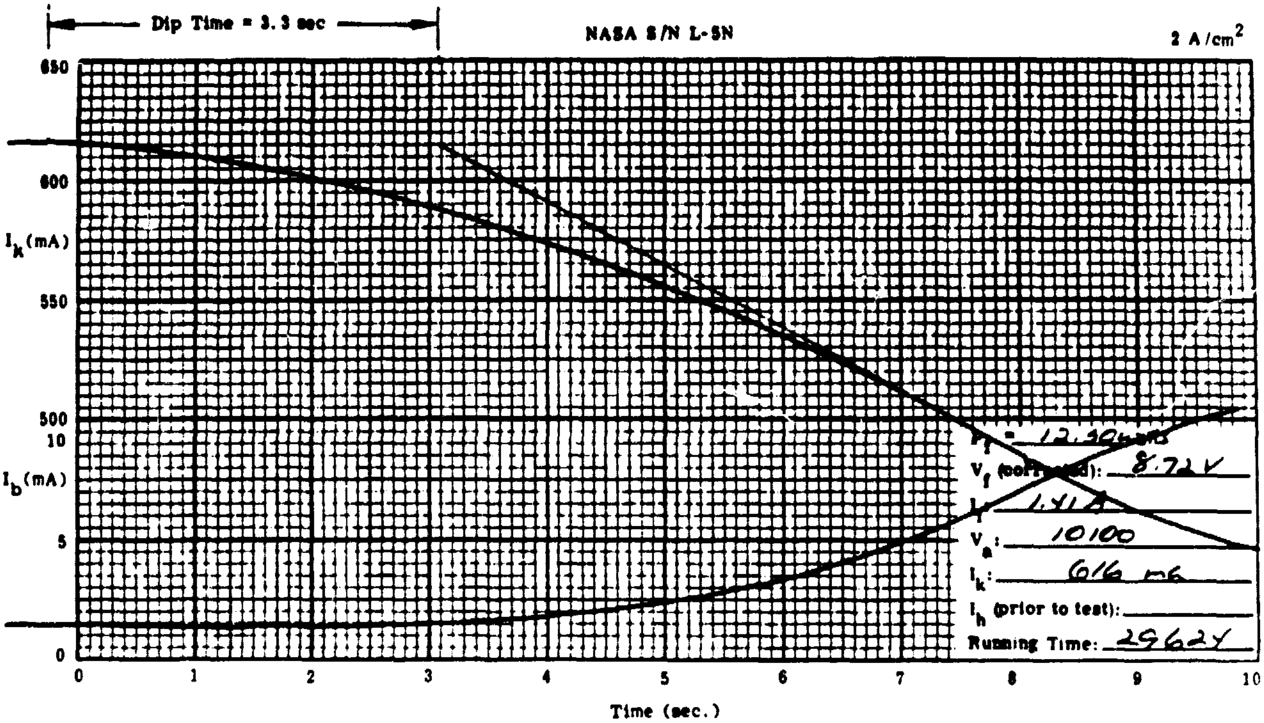
Unit	Hours	Dip Time (Sec)
SP-4	577	13.0
	1,325	12.0
	2,011	12.7
	4,812	11.6
	6,156	10.7
	8,476	9.8
	16,004	8.3
SM-1	147	11.5
	2,335	12.5
	3,083	12.6
	7,986	11.7
	10,239	10.6
	17,907	10.0
SM-2	542	11.8
	1,302	11.9
	4,102	12.0
	7,182	10.3
	14,800	9.0
SM-3	601	11.7
	1,944	10.8
	5,158	9.6
	11,888	8.4

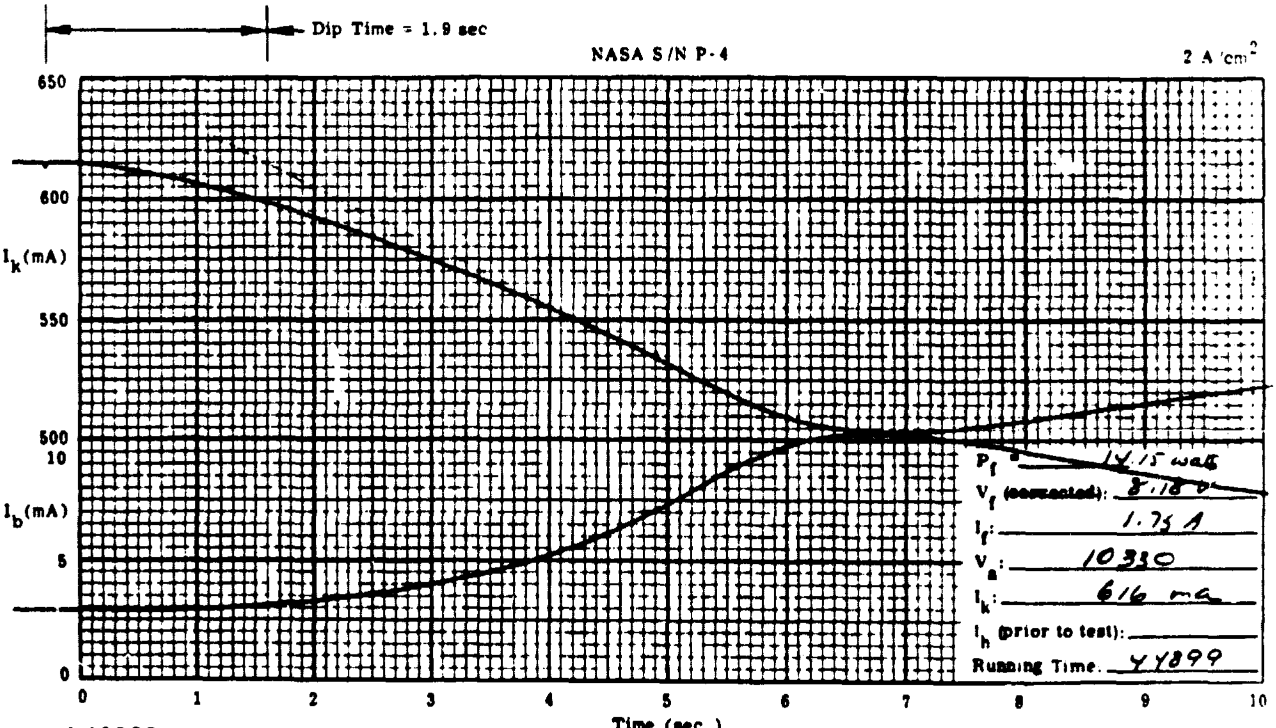
DIP TEST SUMMARY (Continued)

$4A/cm^2$

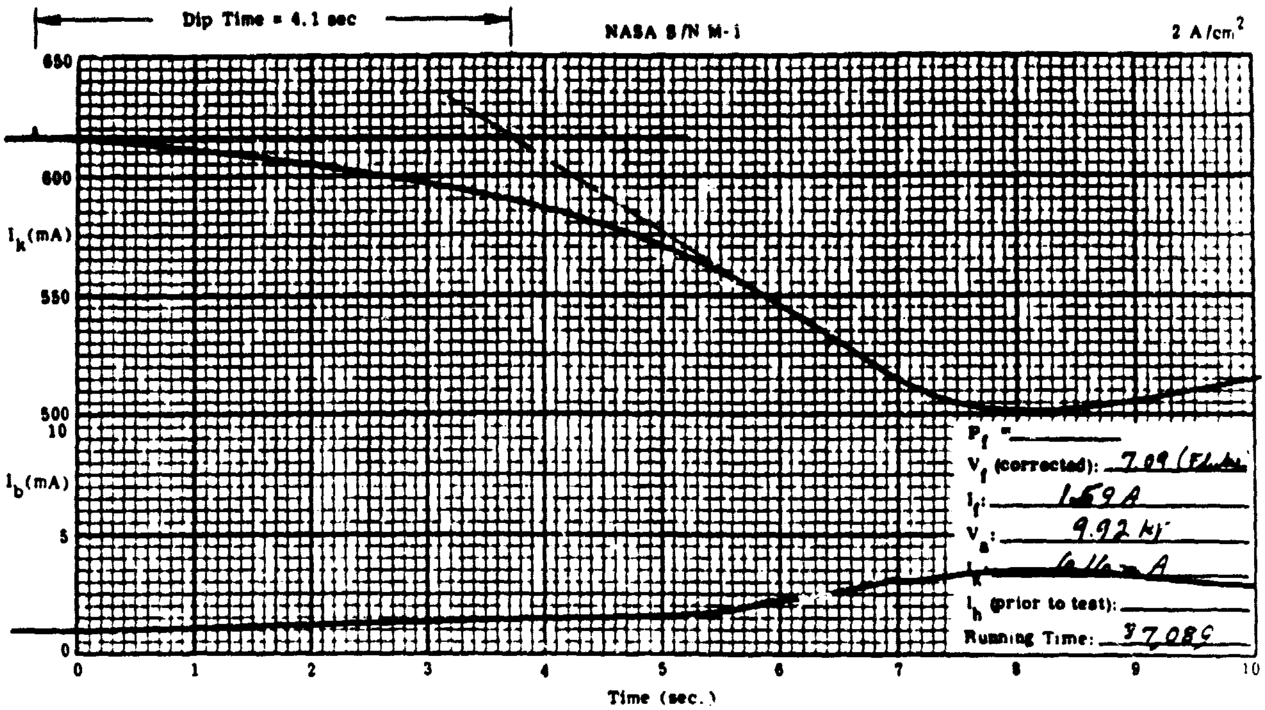
Unit	Hours	Dip Time (Sec)
SP-2	746	2.8
	2,642	3.2
	3,455	3.4
	8,266	3.4
	9,922	2.5
	18,343	2.6
SP-3	446	3.5
	2,392	4.5
	3,206	4.5
	8,713	2.0
	16,811	2.8
SP-4	507	5.8
	1,322	5.5
	2,010	5.4
	4,793	4.8
	6,059	5.1
	7,715	3.6
	15,995	2.8

Unit	Hours	Dip Time (Sec)
SM-1	147	4.2
	2,267	4.8
	3,079	4.8
	7,890	4.3
	10,482	3.3
	17,899	3.4
SM-2	294	4.5
	539	4.4
	1,301	4.4
	4,084	5.1
	7,425	3.8
	14,792	3.1
SM-3	577	5.1
	1,848	4.3
	4,969	3.6
	11,879	3.1

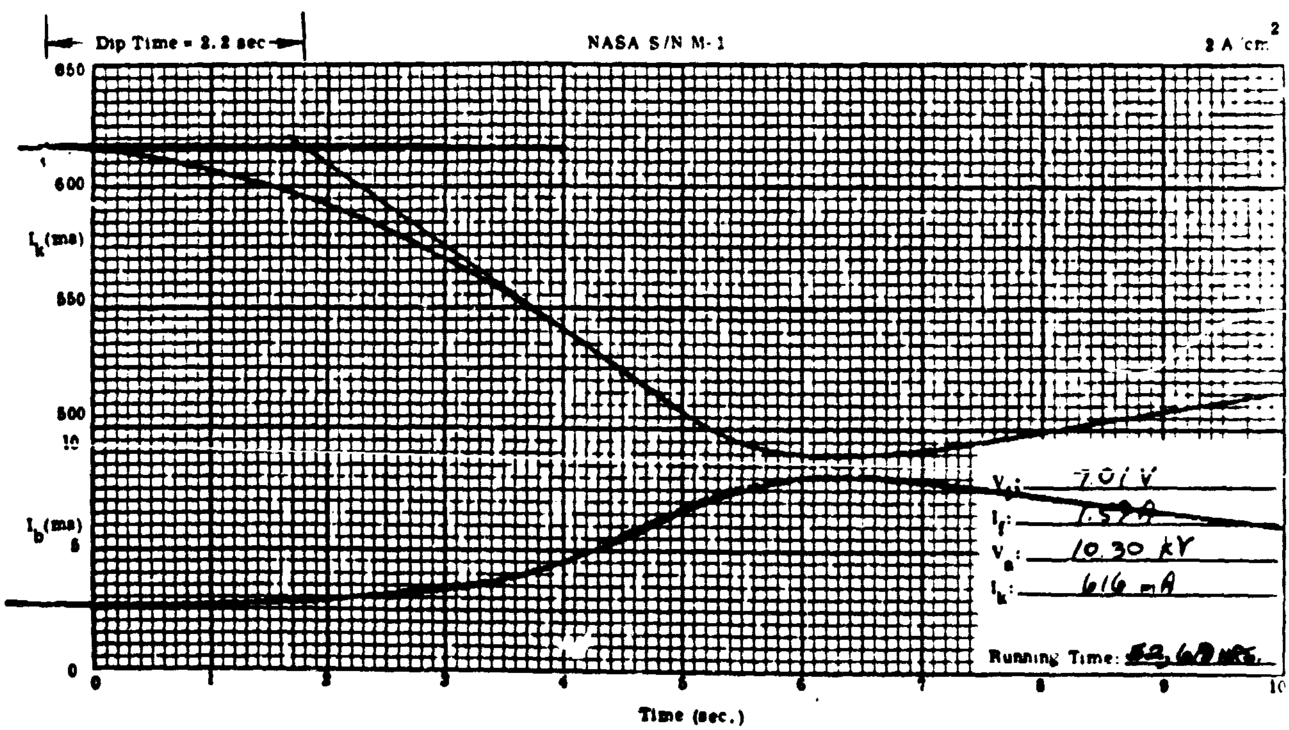

Dip Time = 3.3 sec
NASA S/N L-5N
2 A/cm²
650
600
I_k(mA)
550
500
10
I_b(mA)
5
0
0 1 2 3 4 5 6 7 8 9 10
Time (sec.)
P_f = 12.30 watts
V_f (corrected): 8.72 V
I_f: 1.41 A
V_a: 10100
I_k: 616 ma
I_h (prior to test):
Running Time: 29624


Dip Time = 1.9 sec
NASA S/N P-4
2 A/cm²
650
600
I_k(mA)
550
500
10
I_b(mA)
5
0
0 1 2 3 4 5 6 7 8 9 10
Time (sec.)
P_f = 14.15 watts
V_f (corrected): 8.18 V
I_f: 1.73 A
V_a: 10330
I_k: 616 ma
I_h (prior to test):
Running Time: 44899

ab46039

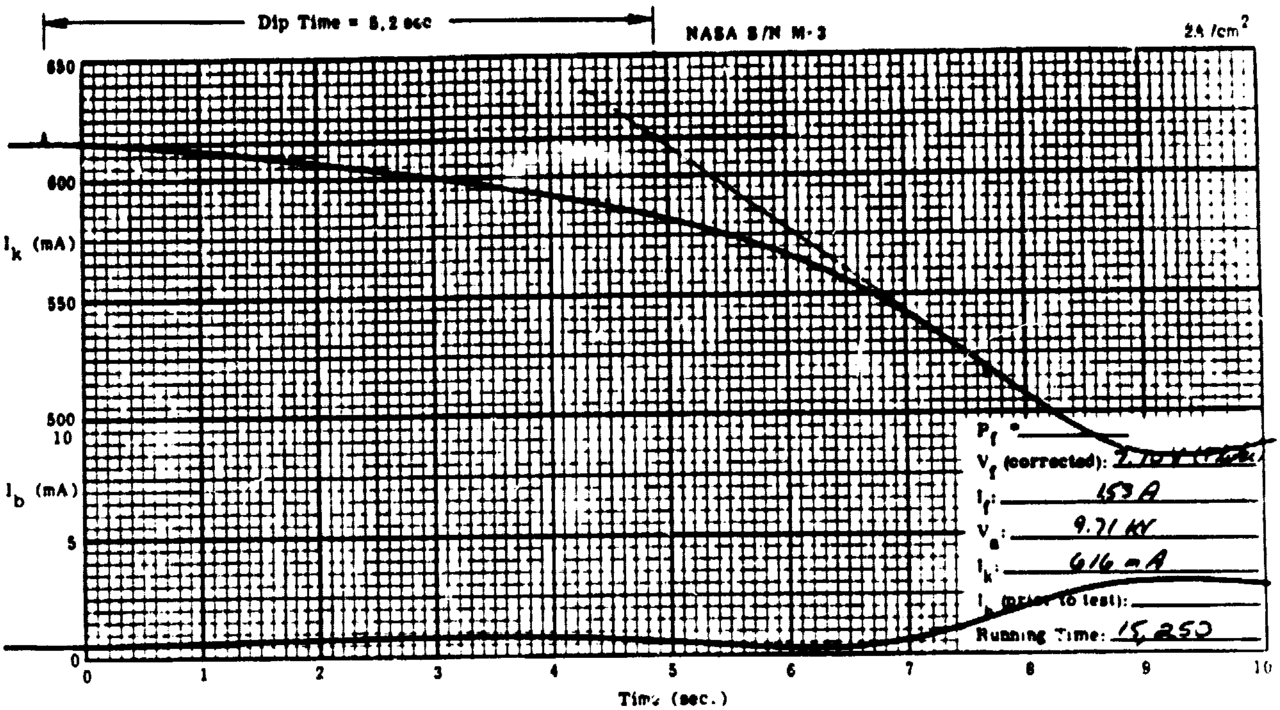


Dip Time = 4.1 sec
NASA S/N M-1
2 A/cm²
650
600
I_k(mA)
550
500
10
I_b(mA)
5
0
P_f =
V_f (corrected): 7.09 (Fluke)
I_f: 1.59 A
V_a: 9.92 kV
I_k: 616 mA
I_h (prior to test):
Running Time: 37089
0 1 2 3 4 5 6 7 8 9 10
Time (sec.)

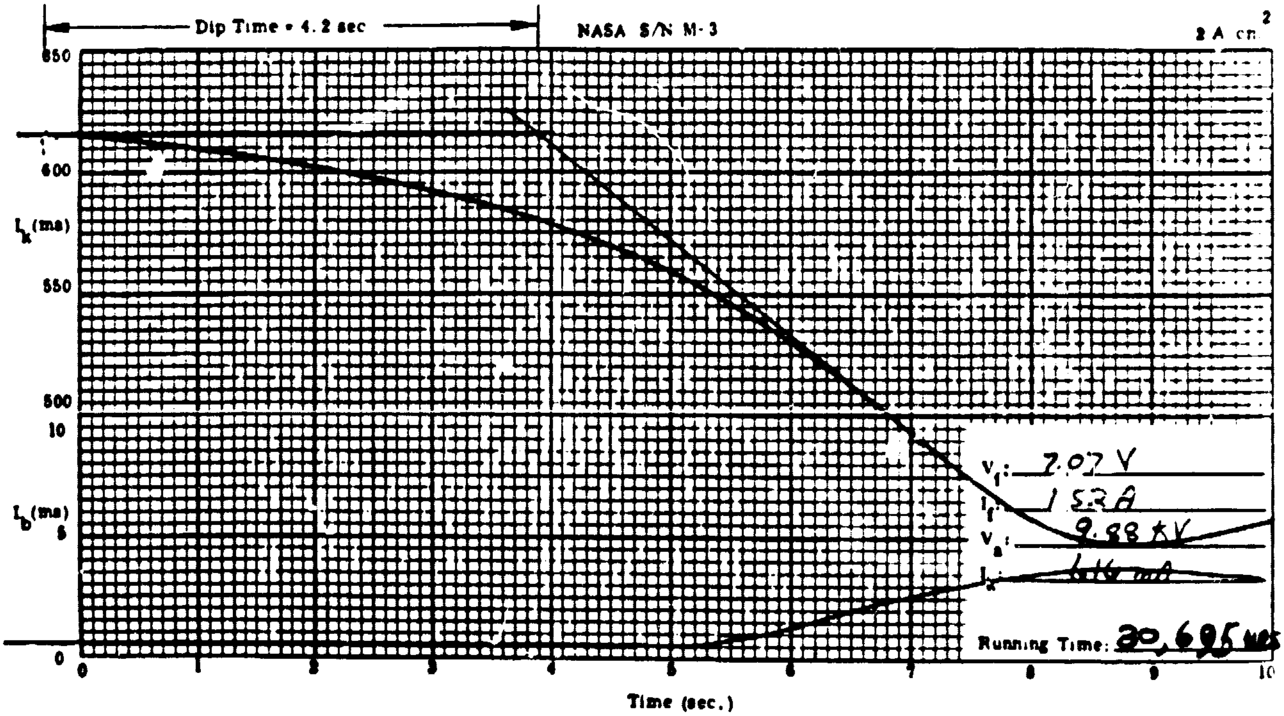


Dip Time = 2.2 sec
NASA S/N M-1
2 A/cm²
650
600
I_k(ma)
550
500
10
I_b(ma)
5
0
V_f: 7.01 V
I_f: 1.59 A
V_a: 10.30 kV
I_k: 616 mA
Running Time:
0 1 2 3 4 5 6 7 8 9 10
Time (sec.)

ab46040

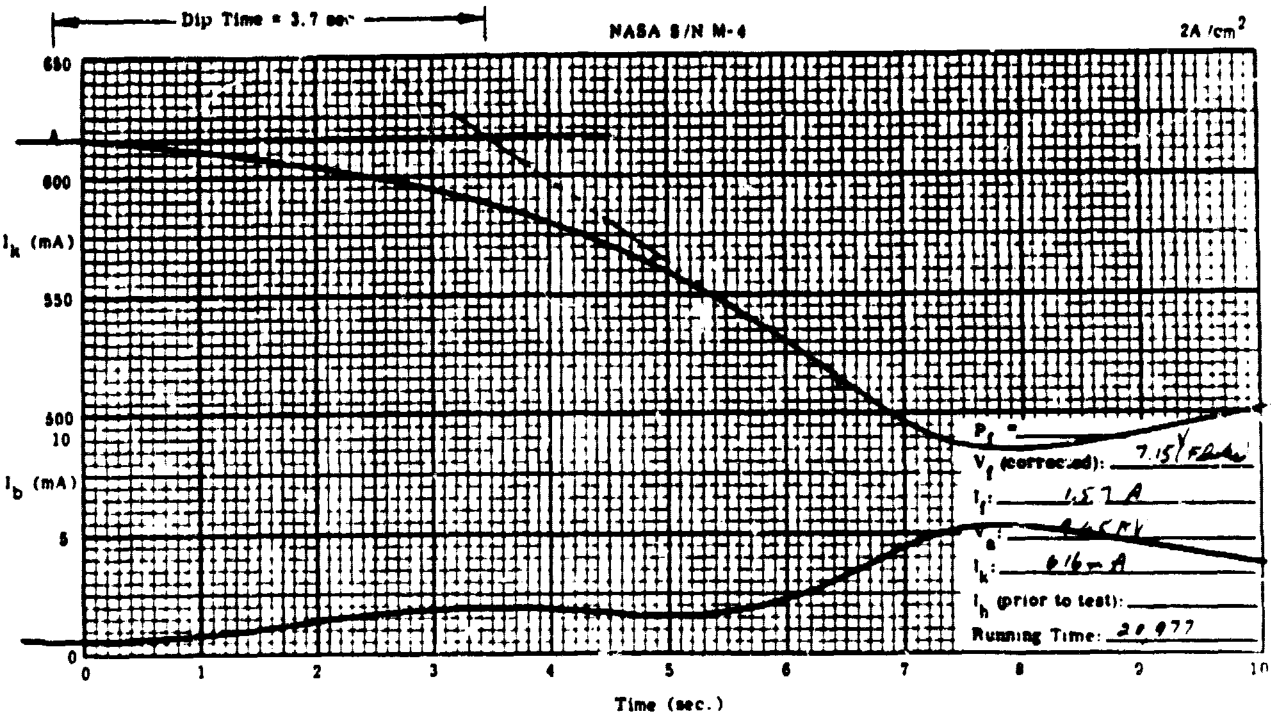


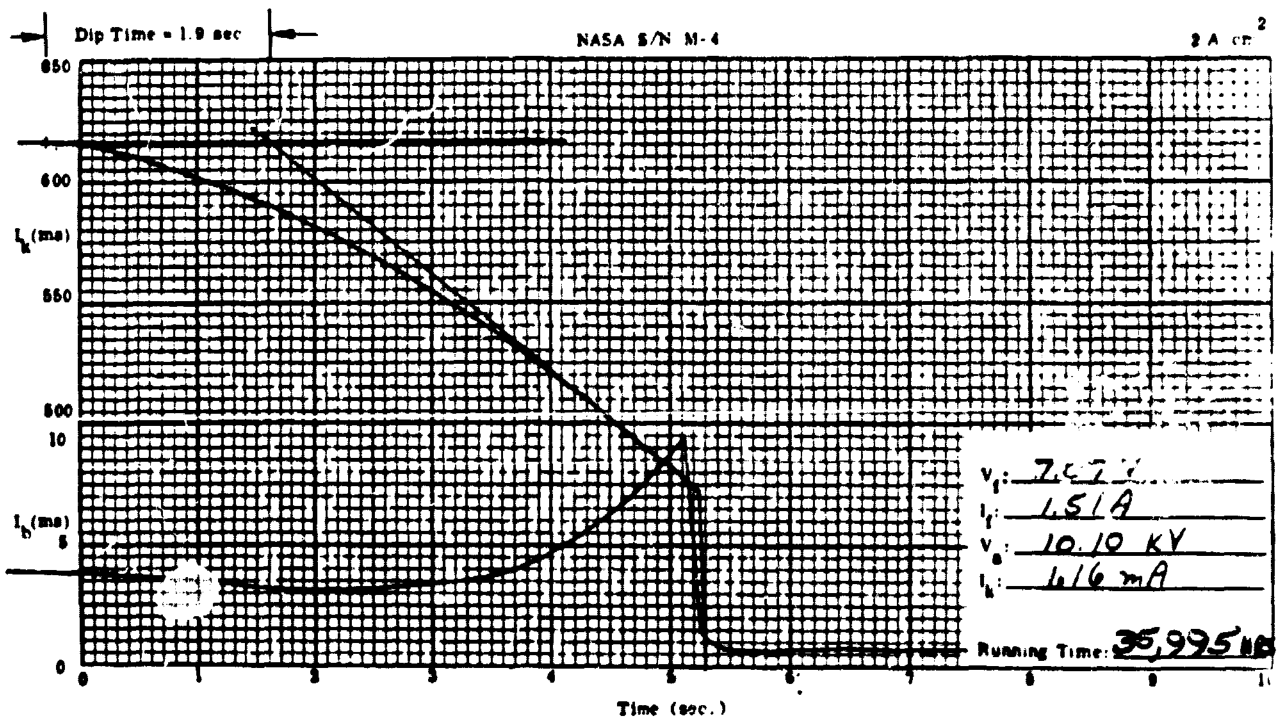
Dip Time = 8.2 sec
NASA S/N M-3
2A/cm²
650
600
I_k (mA)
550
500
10
I_b (mA)
5
0
0 1 2 3 4 5 6 7 8 9 10
Time (sec.)
P_f:
V_f (corrected):
I_f: 153 A
V_a: 9.71 kV
I_k: 616 mA
I_b (prior to test):
Running Time: 15,250



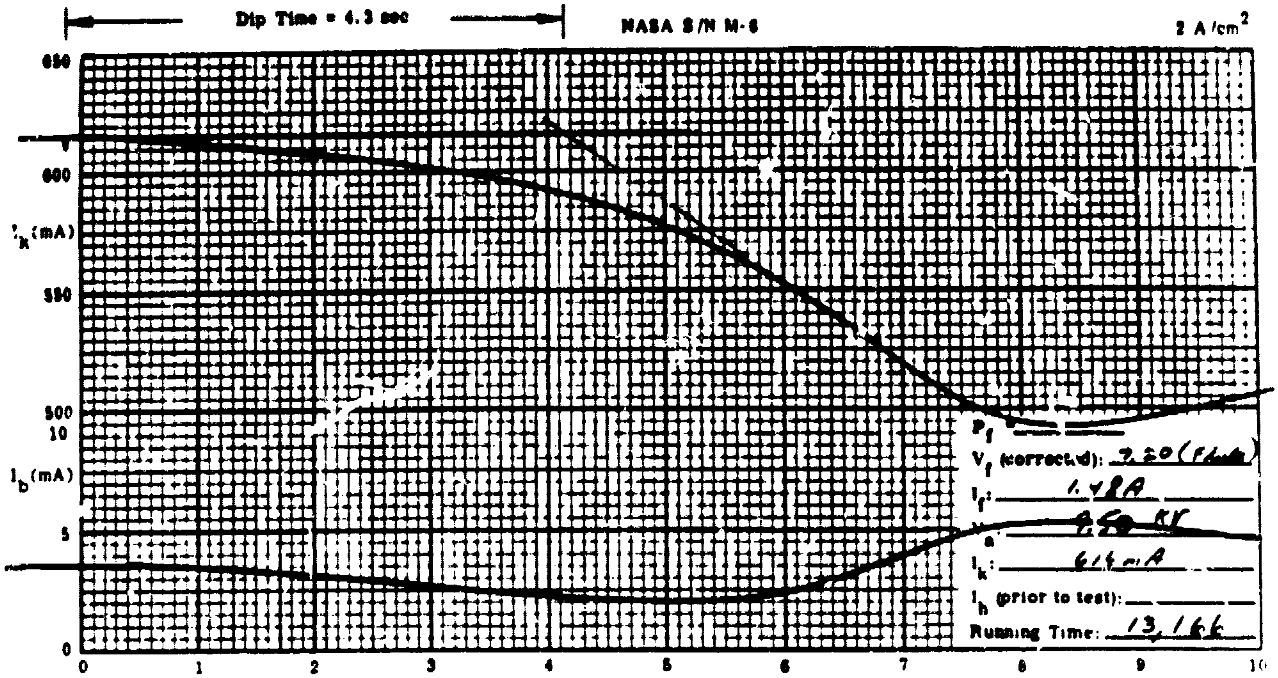
Dip Time = 4.2 sec
NASA S/N M-3
2 A/cm²
650
600
I_k(ma)
550
500
10
I_b(ma)
5
0
0 1 2 3 4 5 6 7 8 9 10
Time (sec.)
V_f: 7.07 V
I_f: 152 A
V_a: 9.88 kV
I_k: 616 mA
Running Time: 20,695 hrs

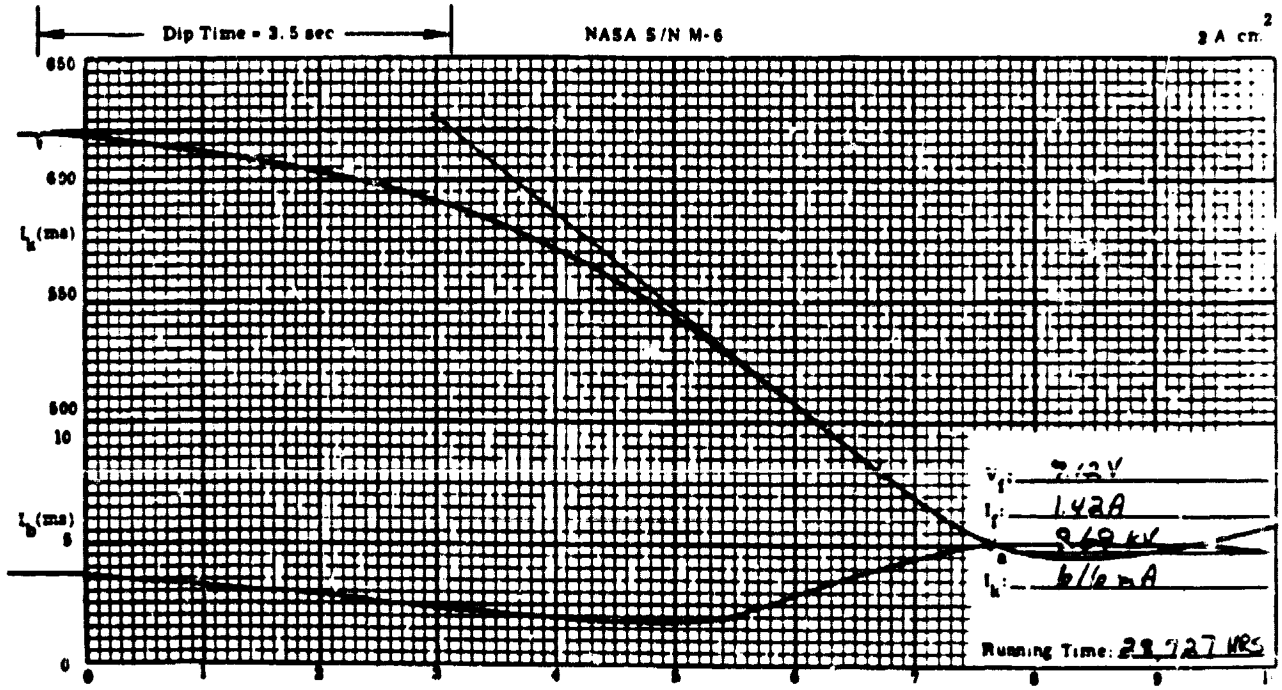
ab46041


Dip Time = 3.7 sec
NASA S/N M-4
2A /cm²
650
600
I_k (mA)
550
500
10
I_b (mA)
5
0
P_f =
V_f (corrected):
I_f:
V_a:
I_k:
I_h (prior to test):
Running Time:
0 1 2 3 4 5 6 7 8 9 10
Time (sec.)

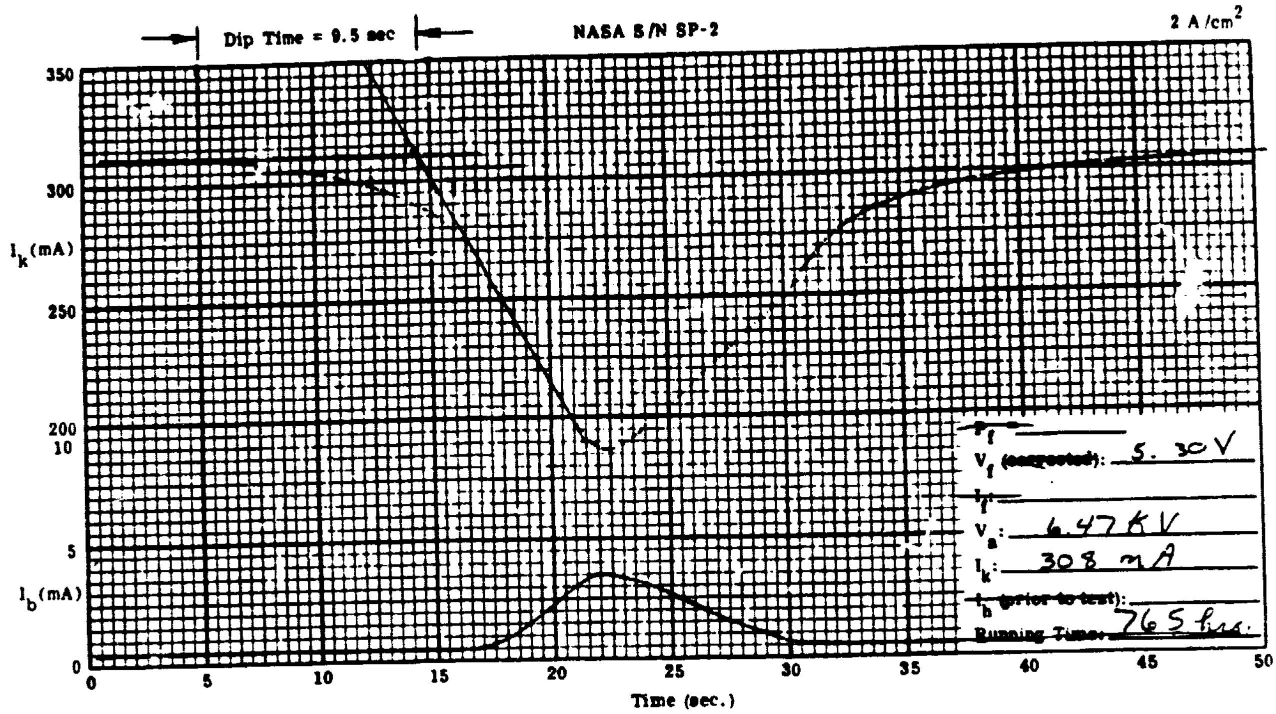

Dip Time = 1.9 sec
NASA S/N M-4
2 A cm²
650
600
I_k(ma)
550
500
10
I_b(ma)
5
0
V_f:
I_f: 1.51A
V_a: 10.10 KV
I_k: 616 mA
Running Time: 35,995
0 1 2 3 4 5 6 7 8 9 10
Time (sec.)

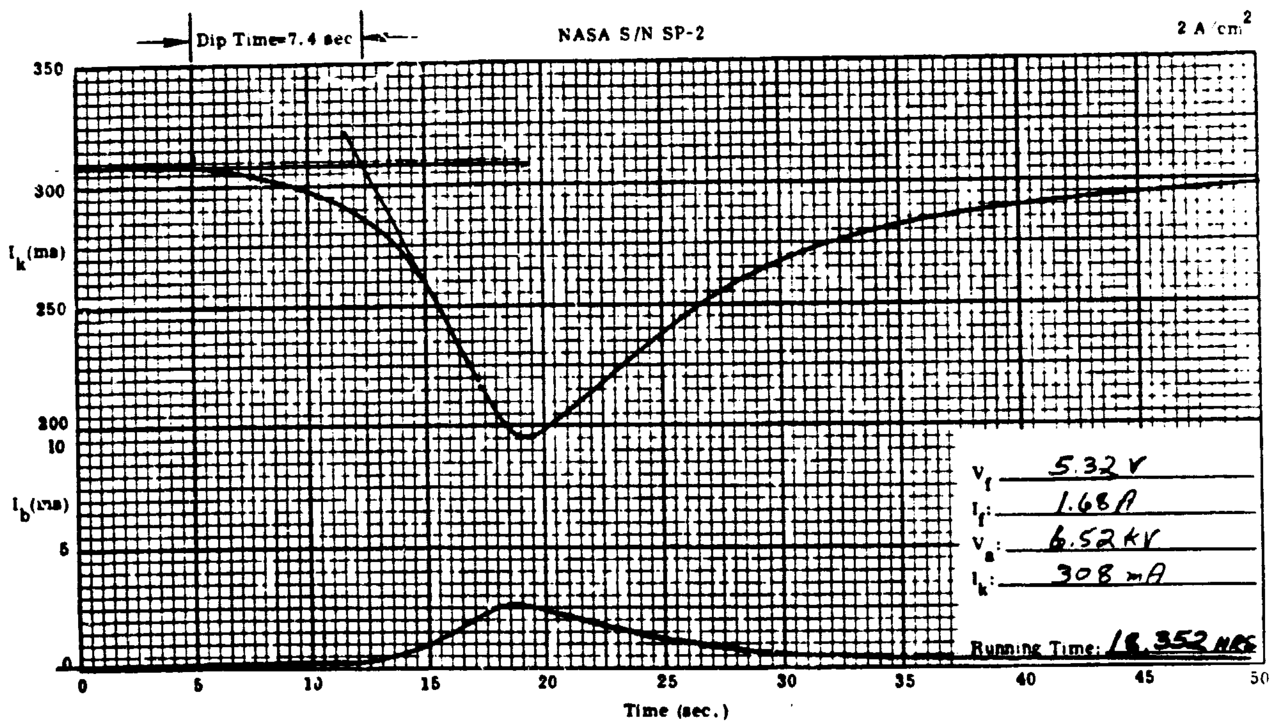
ab46042A


Dip Time = 4.3 sec
NASA S/N M-6
2 A/cm²
650
600
I_k(mA)
550
500
10
I_b(mA)
5
0
0 1 2 3 4 5 6 7 8 9 10
Time (sec.)
P_f:
V_f (corrected): 7.20 (Fluke)
I_f: 1.48A
V_a: 9.50 KV
I_k: 614 mA
I_h (prior to test):
Running Time: 13,166

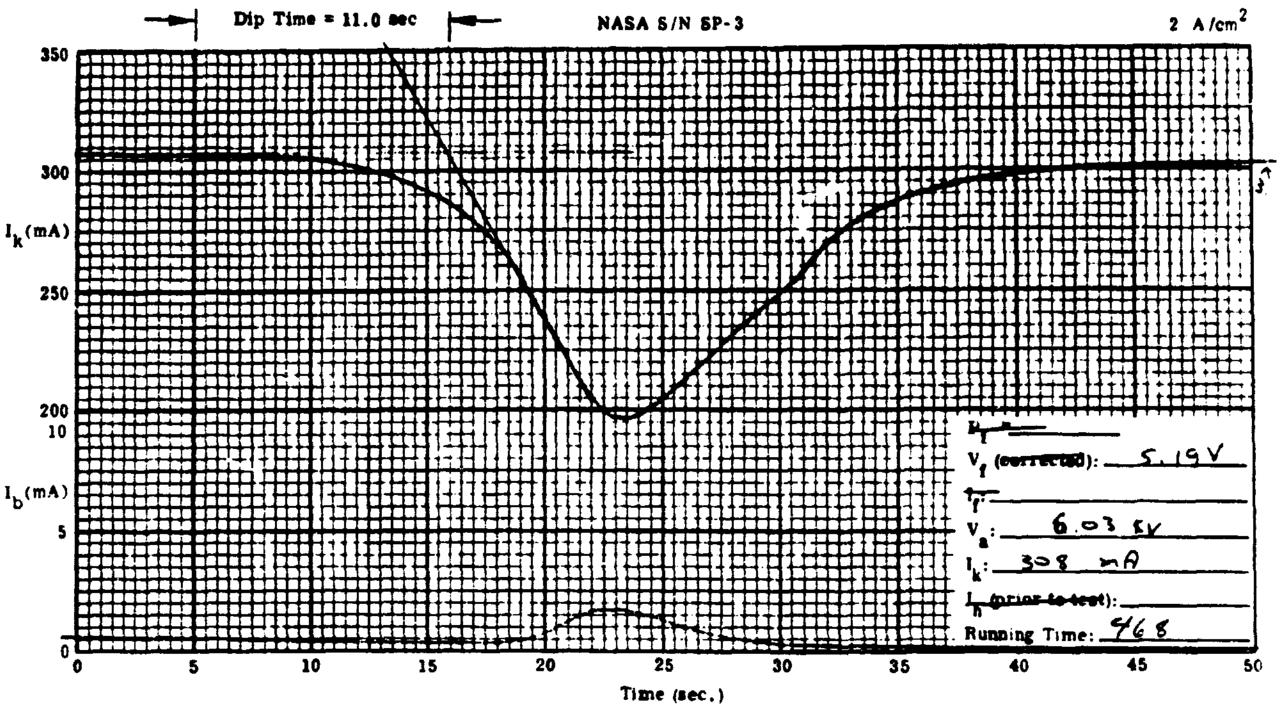

Dip Time = 3.5 sec
NASA S/N M-6
2 A cm²
650
600
I_k(ma)
550
500
10
I_b(ma)
5
0
0 1 2 3 4 5 6 7 8 9 1
Time (sec.)
V_f: 7.13V
I_f: 1.42A
V_a: 9.49 KV
I_k: 616 mA
Running Time: 29,727 HRS

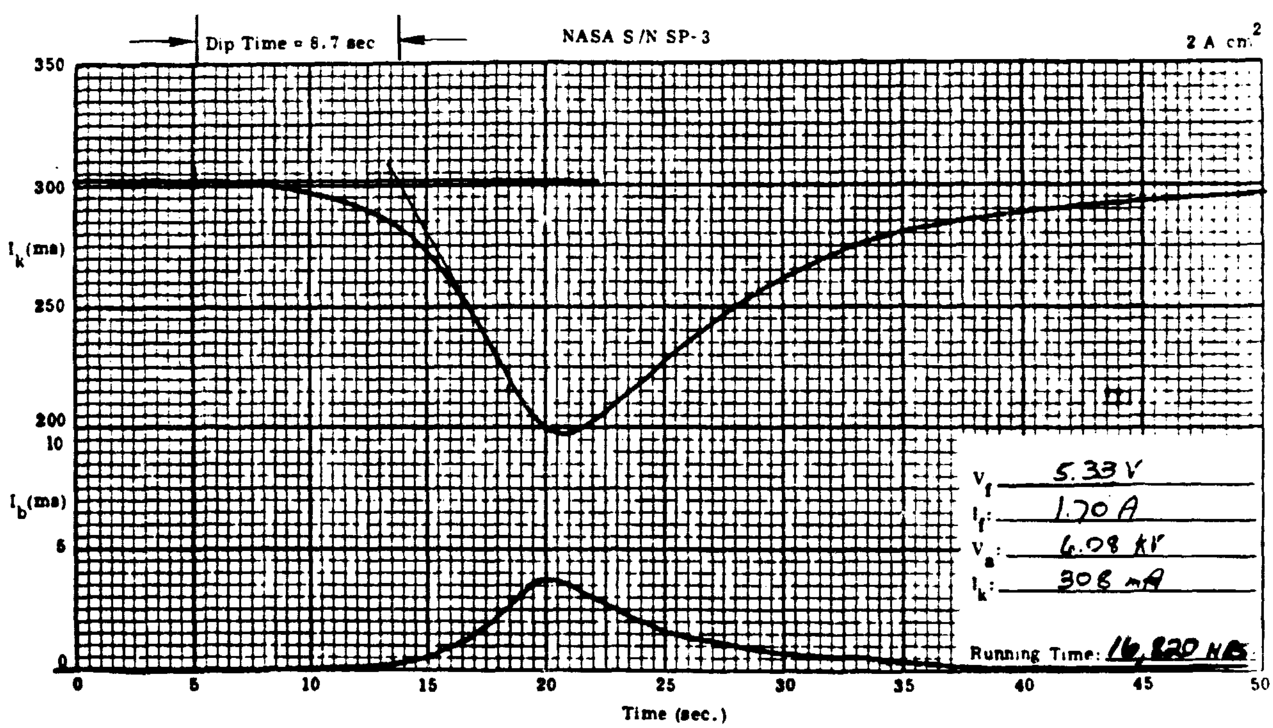
ab46043


Dip Time = 9.5 sec
NASA S/N SP-2
2 A/cm^2
350
300
I_k(mA)
250
200
10
5
I_b(mA)
0
V_f (corrected): 5.30 V
V_a: 6.47 KV
I_k: 308 mA
I_b (prior to test):
Running Time: 765 hrs.
0 5 10 15 20 25 30 35 40 45 50
Time (sec.)


Dip Time=7.4 sec
NASA S/N SP-2
2 A/cm^2
350
300
I_k(ma)
250
200
10
I_b(ma)
5
0
V_f: 5.32 V
I_f: 1.68 A
V_a: 6.52 kV
I_k: 308 mA
Running Time: 18,352 HRS
0 5 10 15 20 25 30 35 40 45 50
Time (sec.)

ab46044





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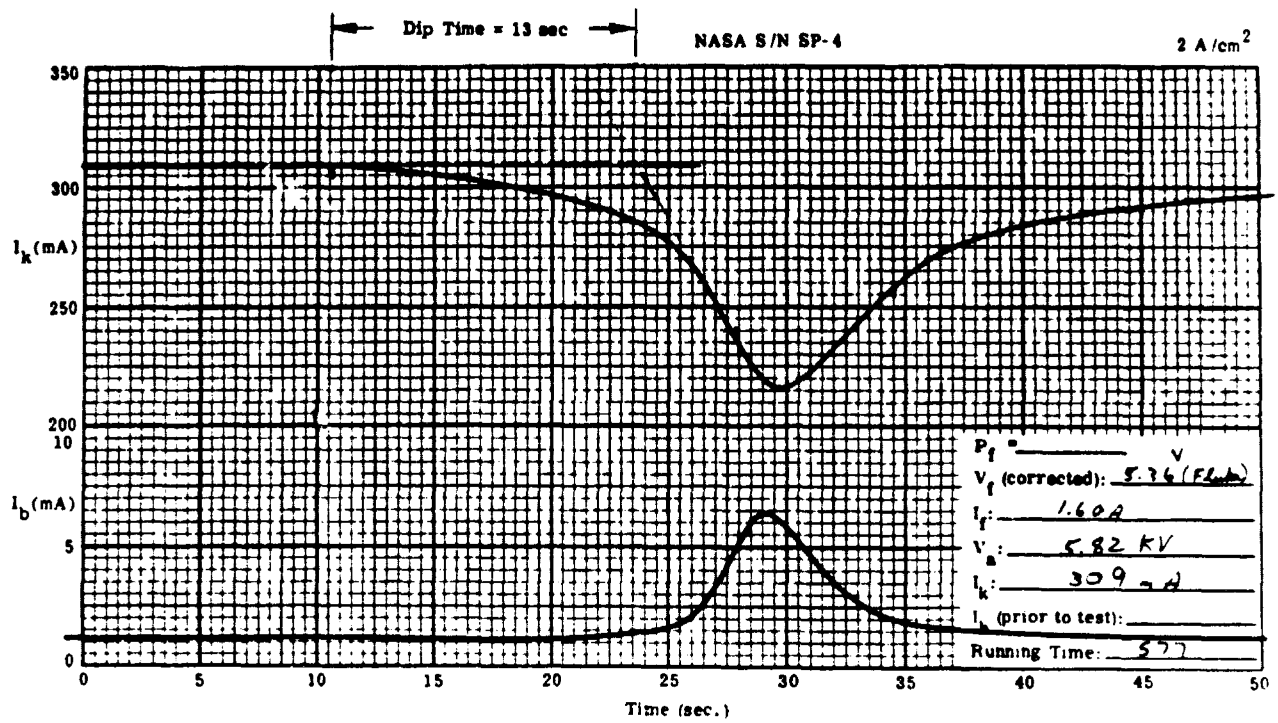

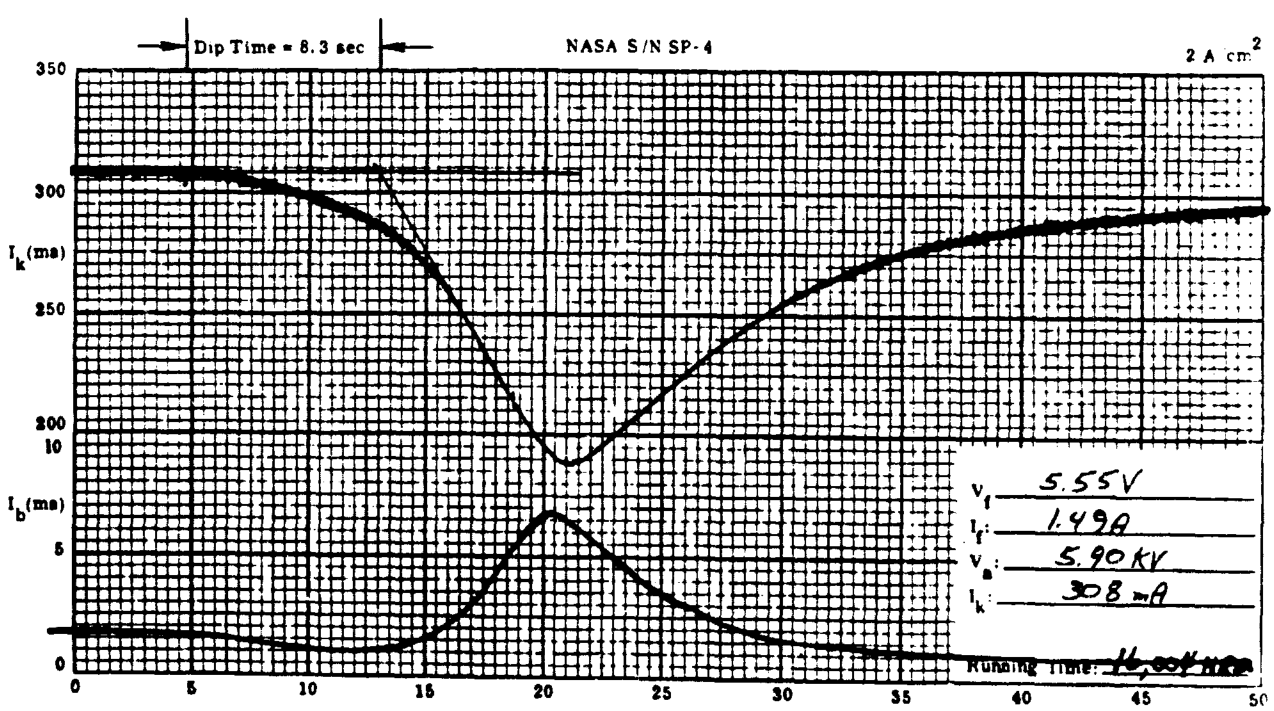

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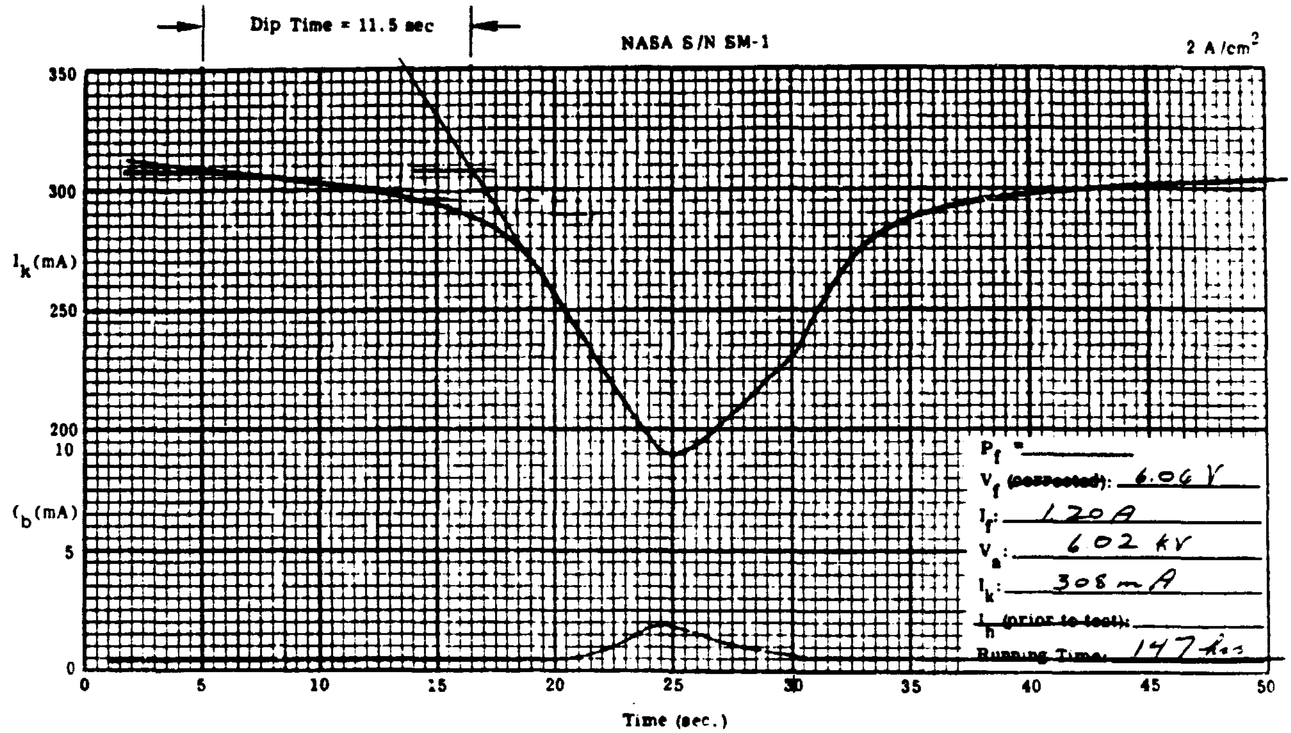

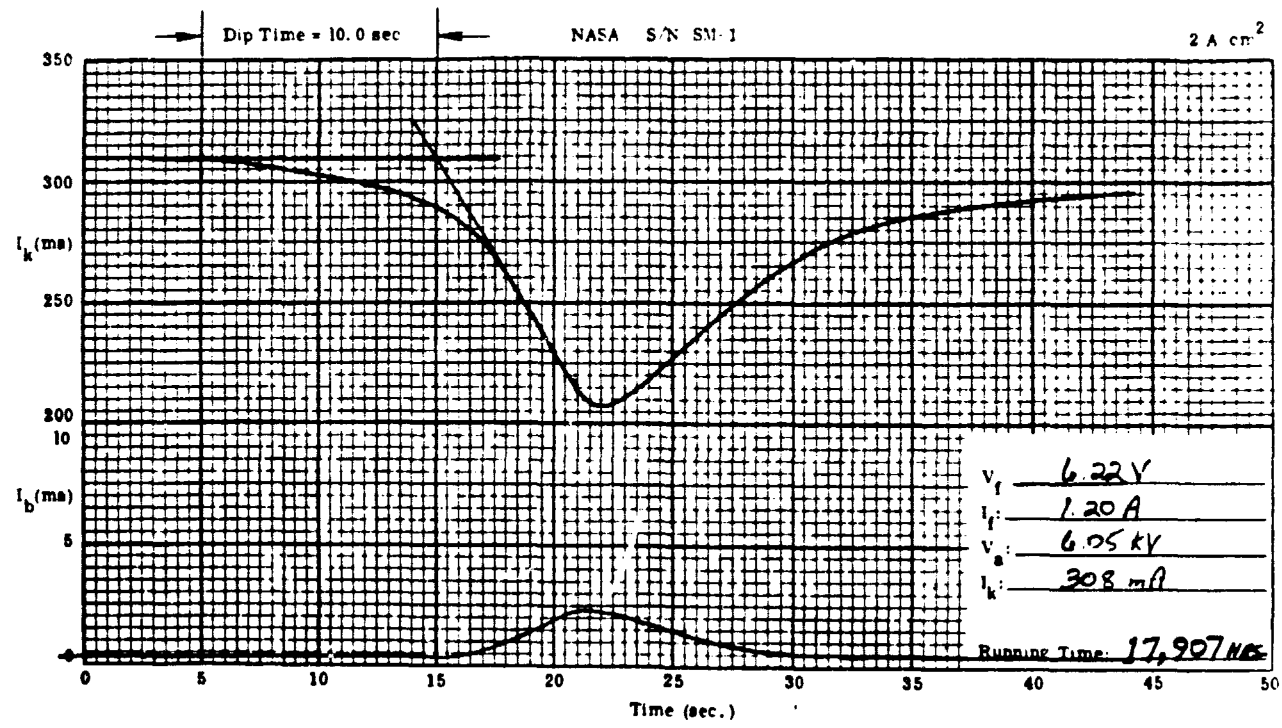

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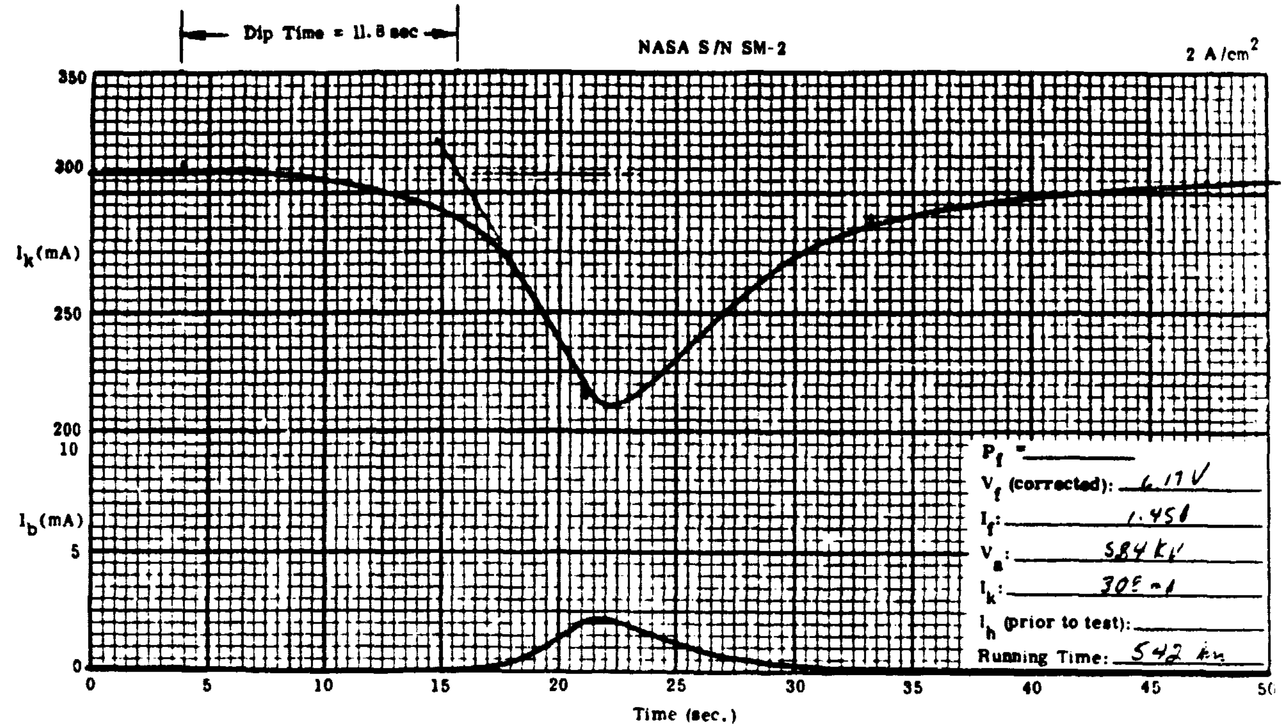

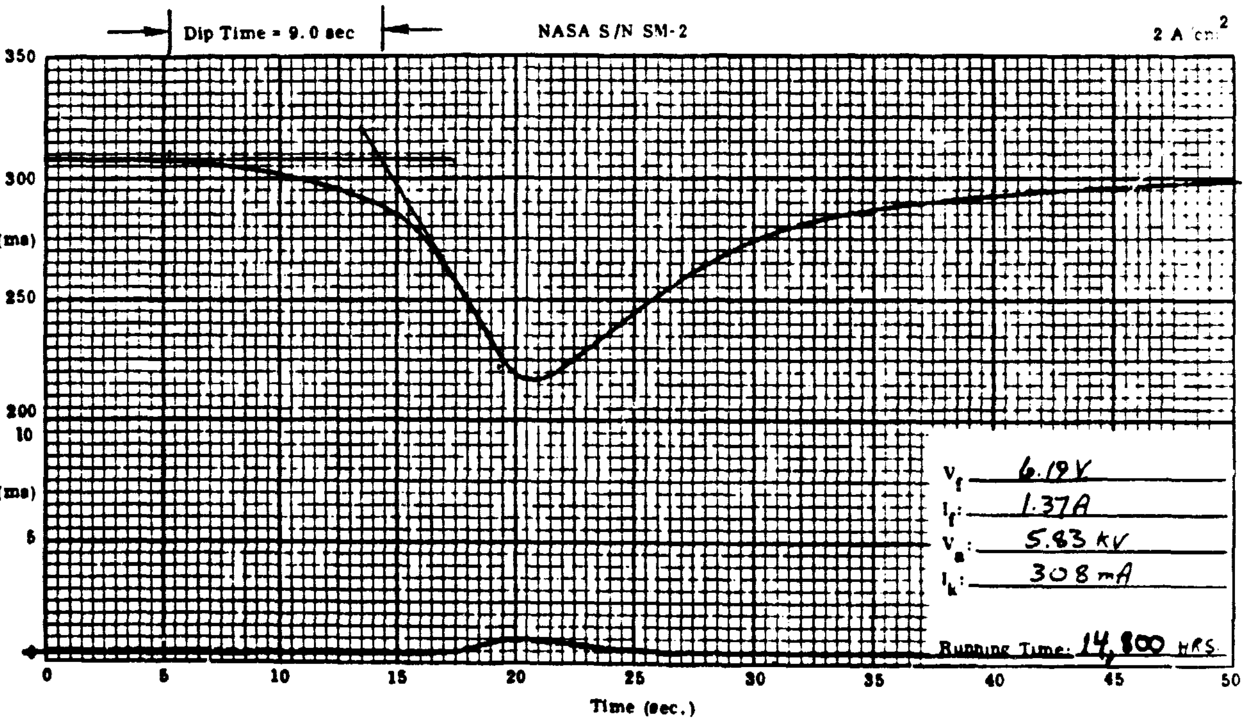

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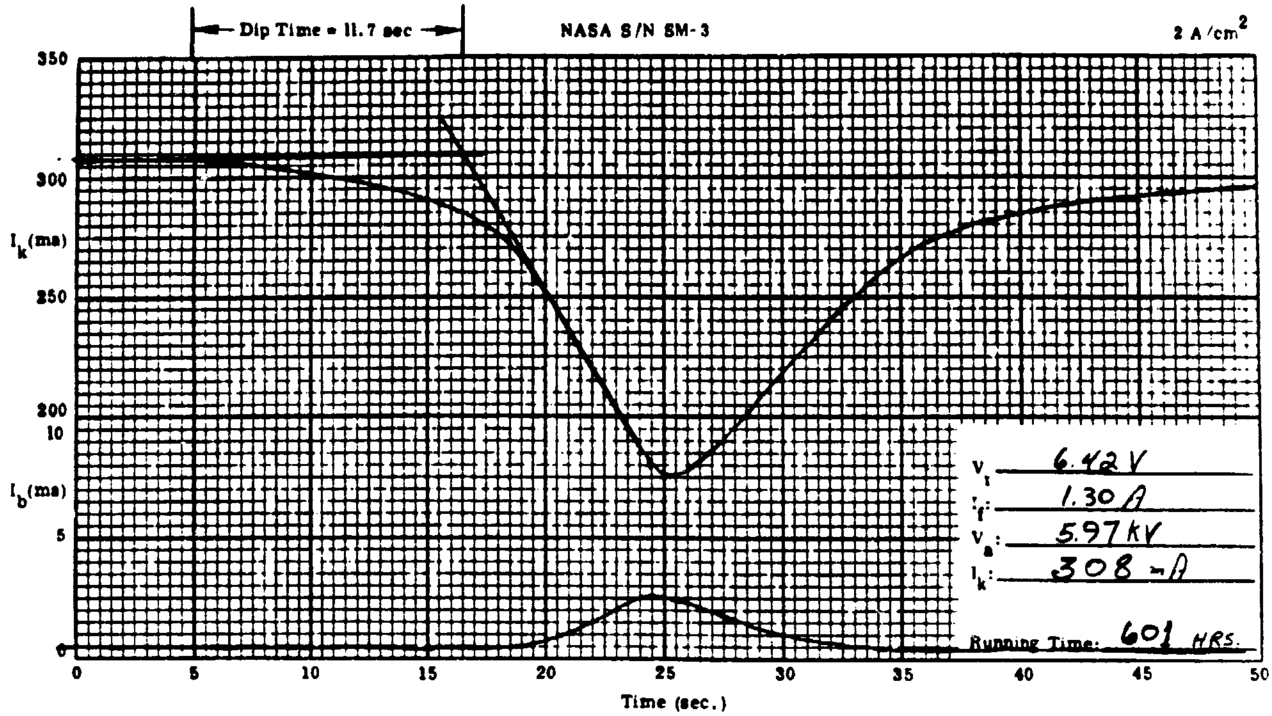

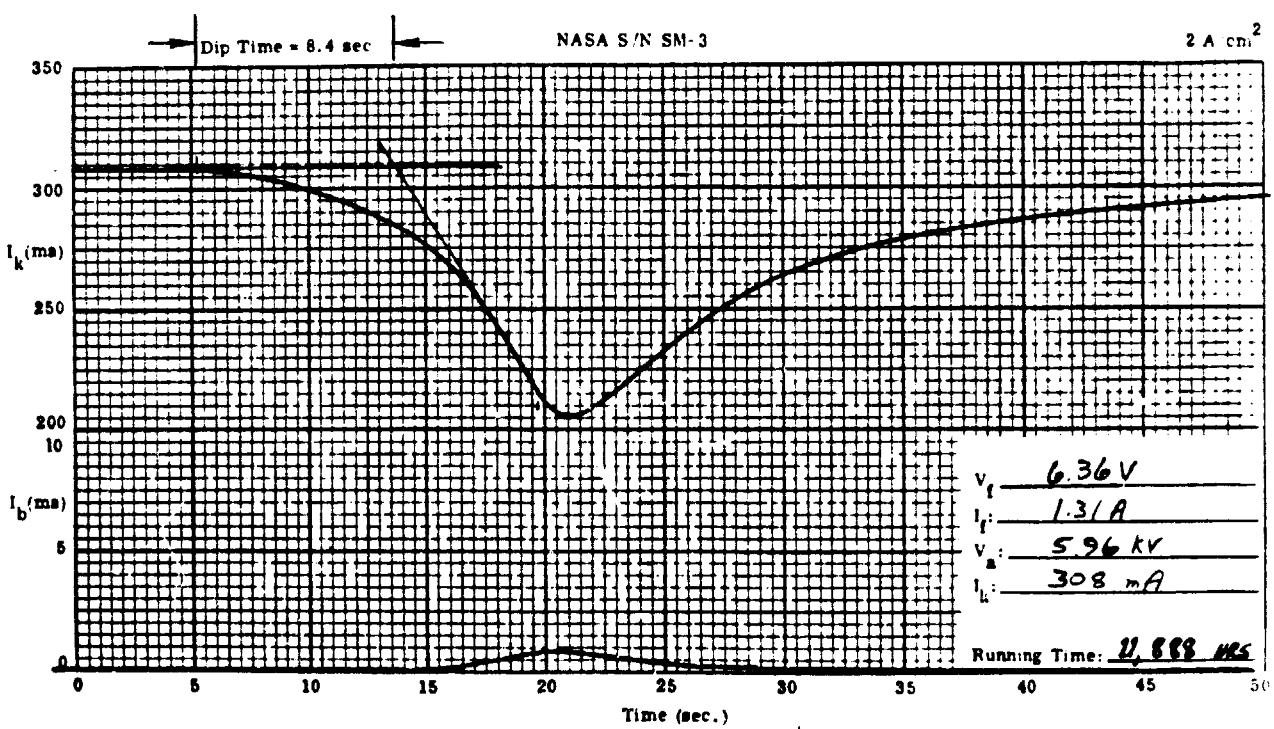

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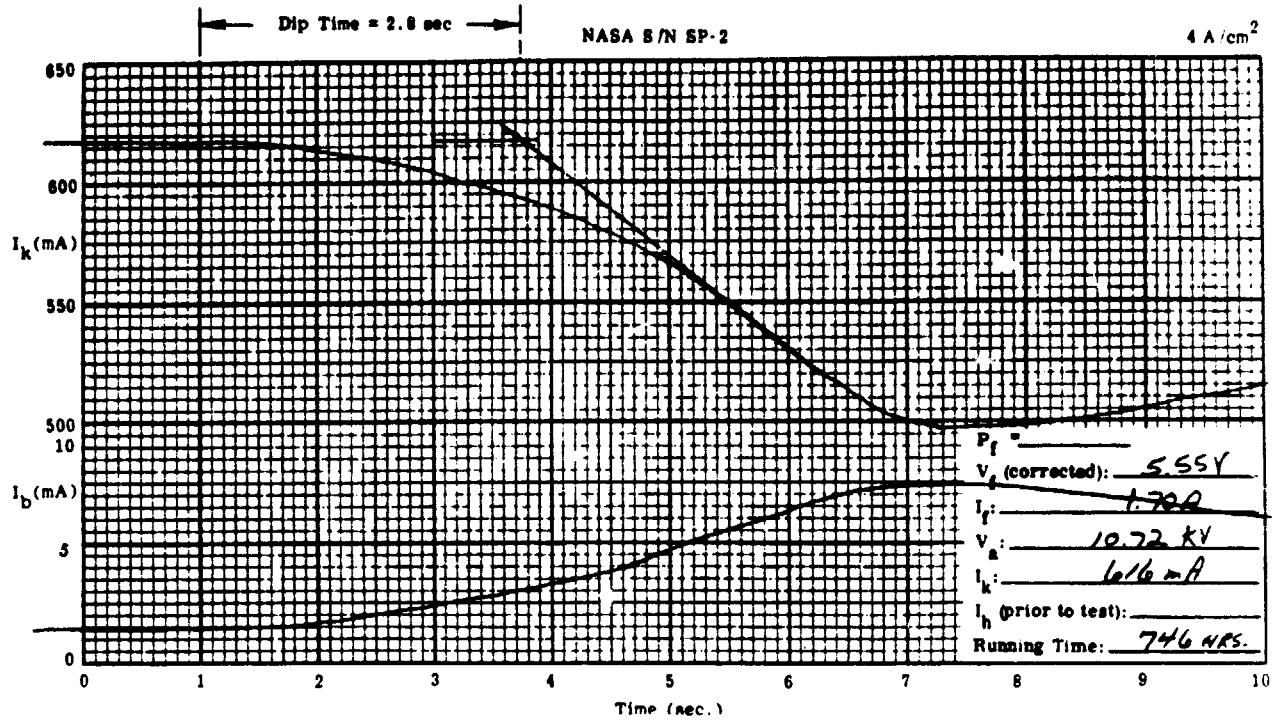

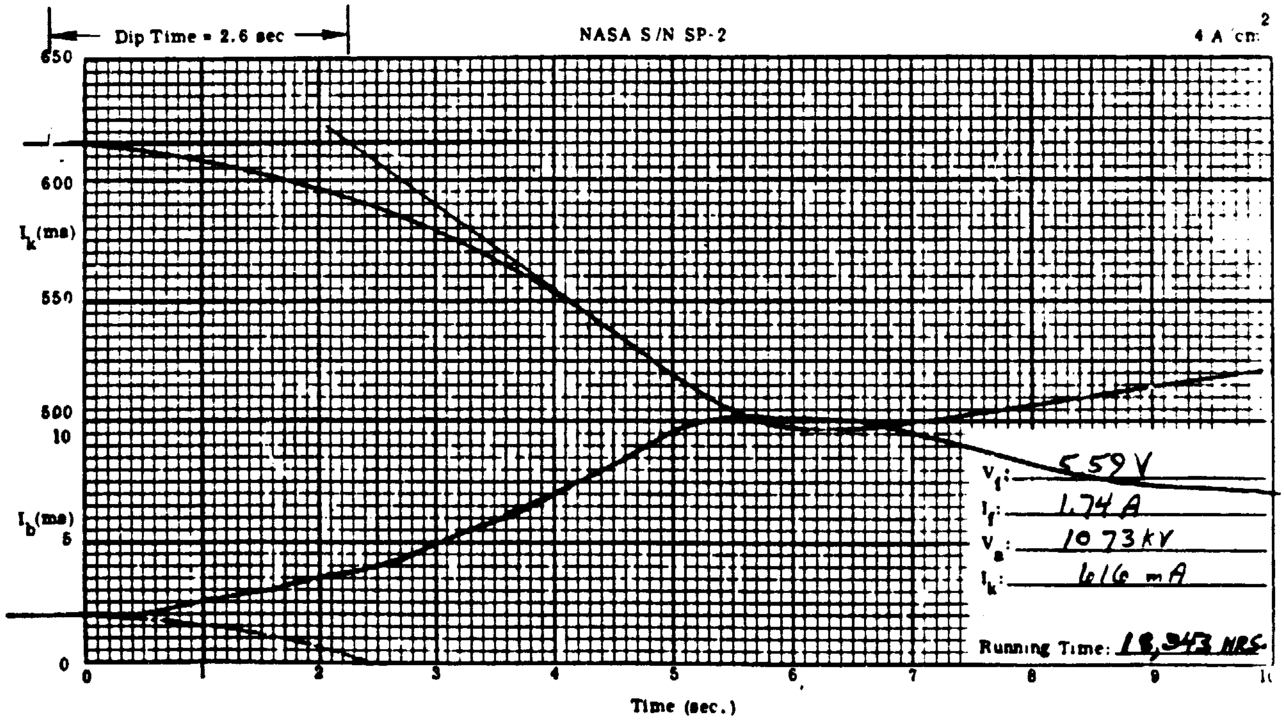

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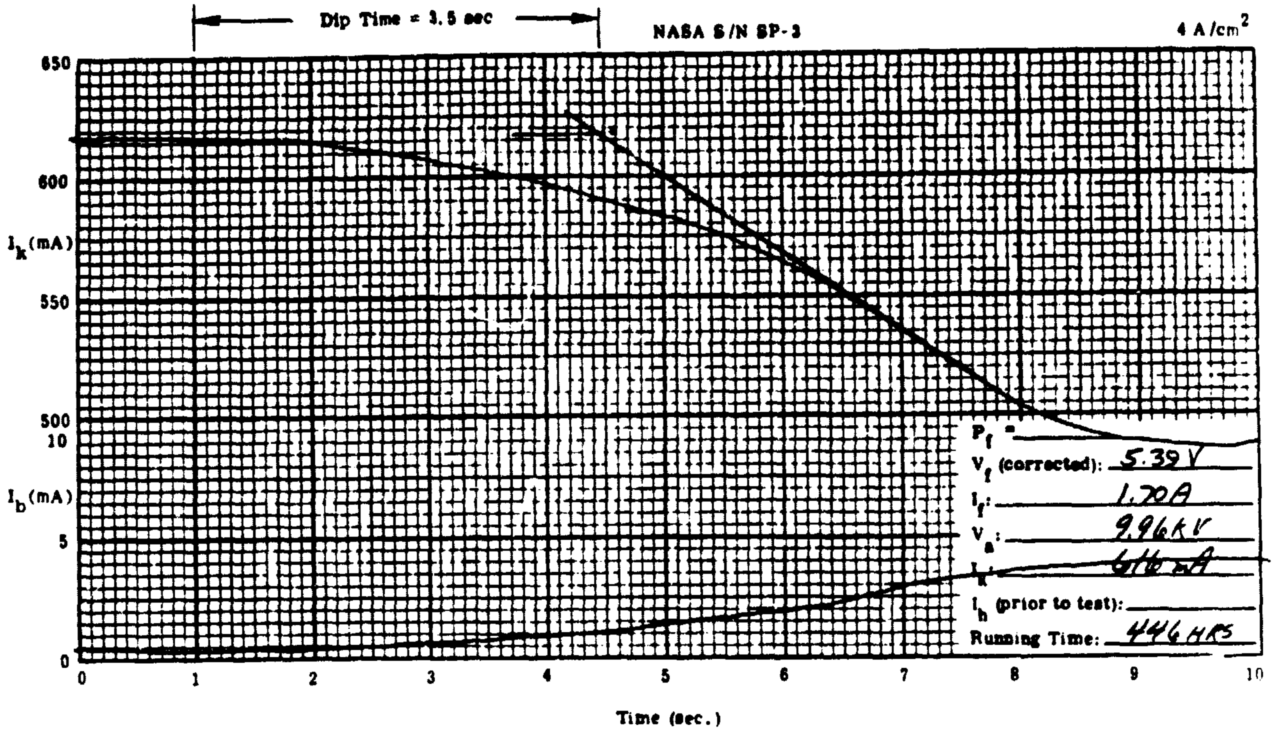

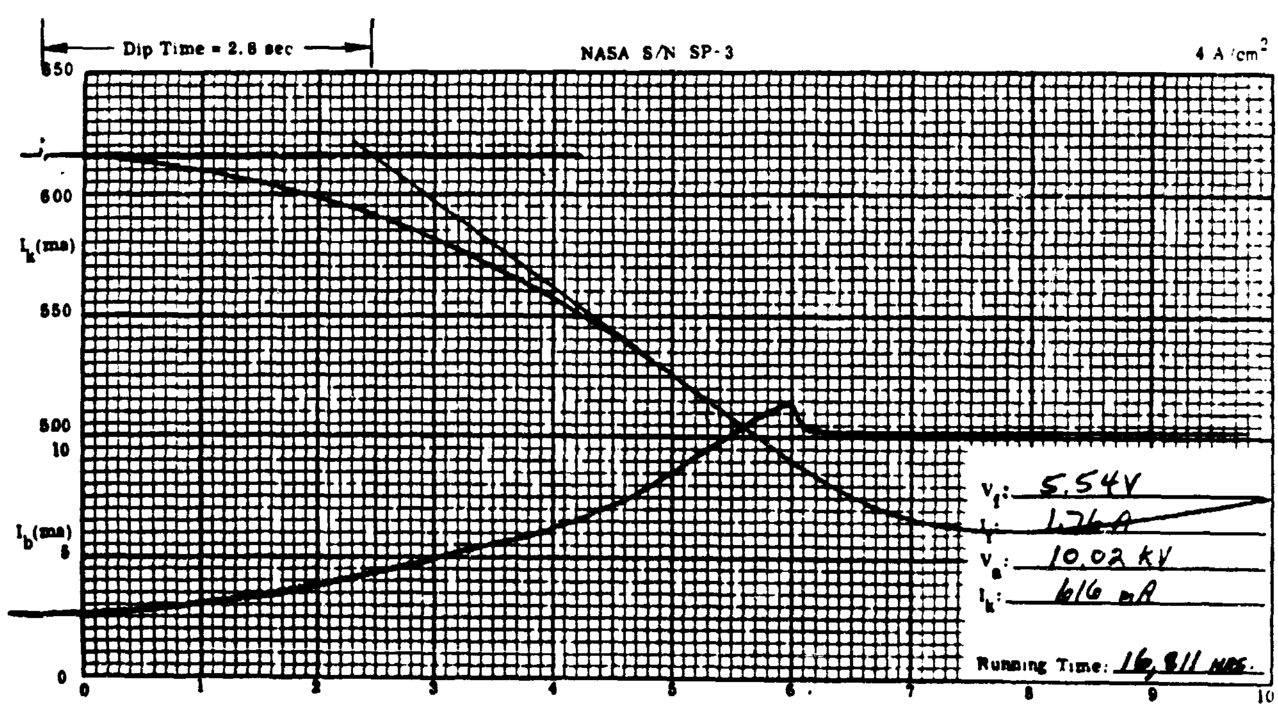

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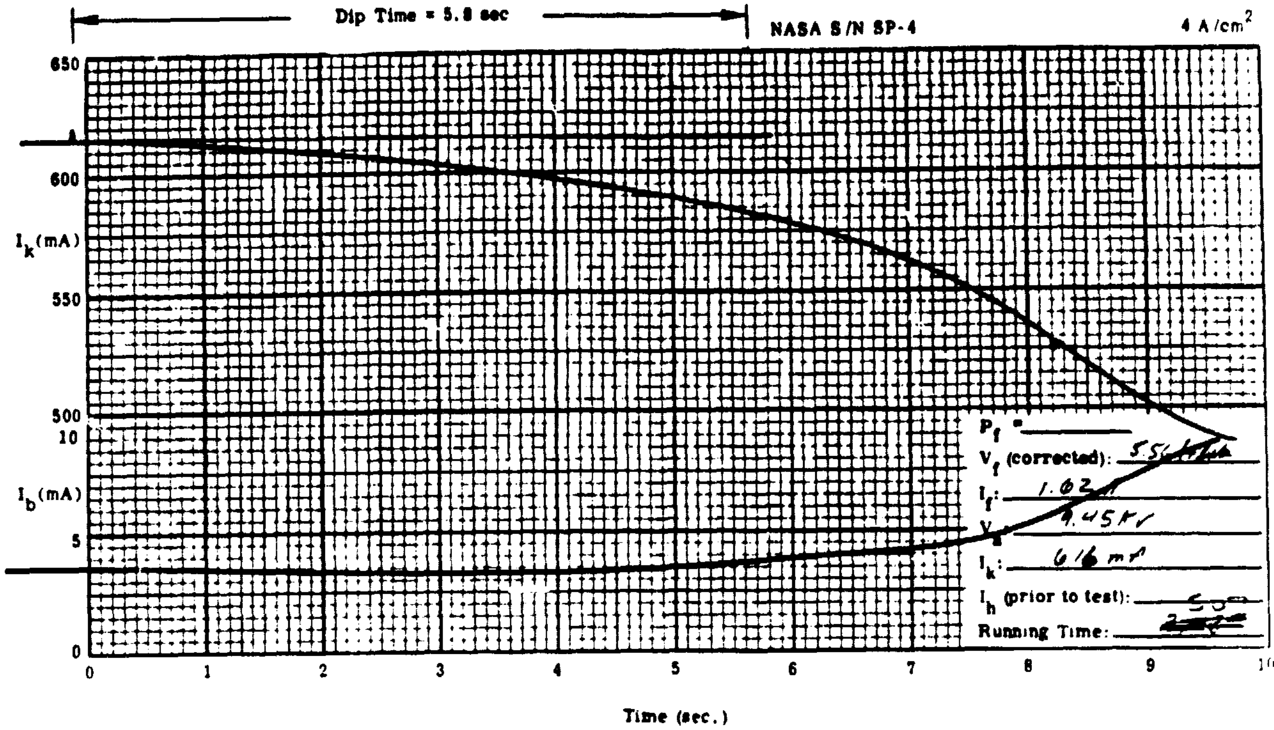

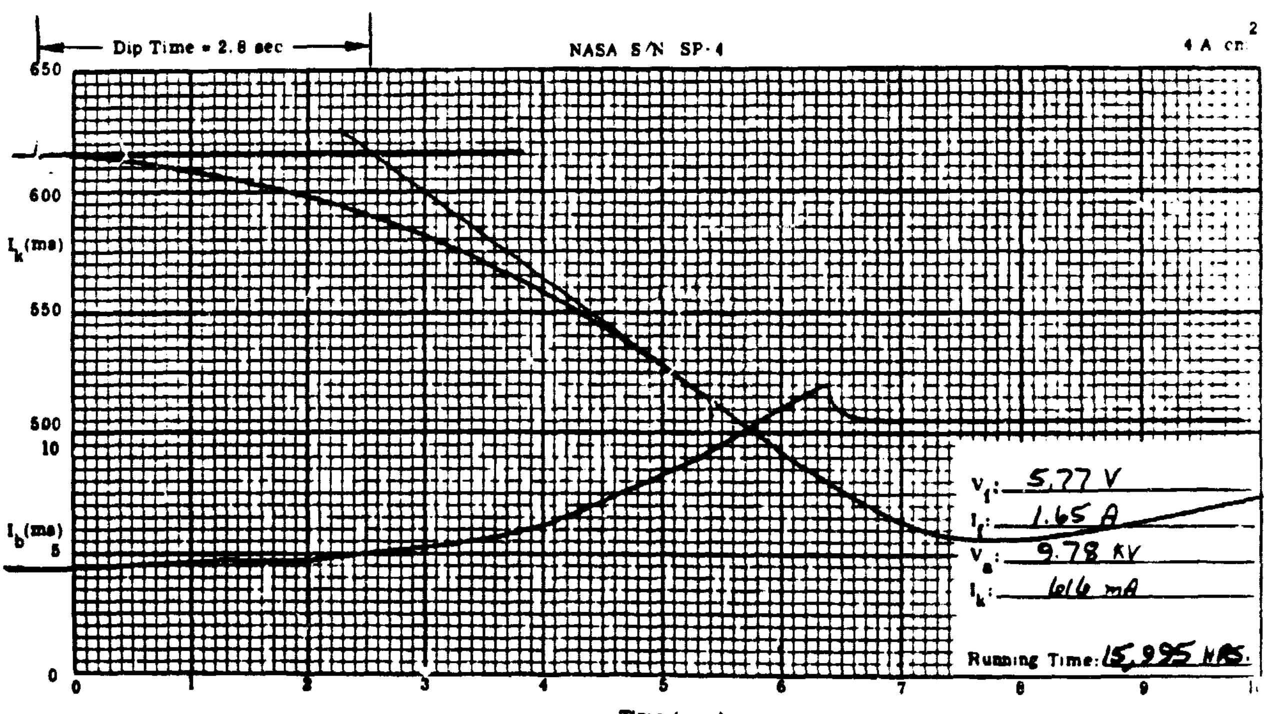

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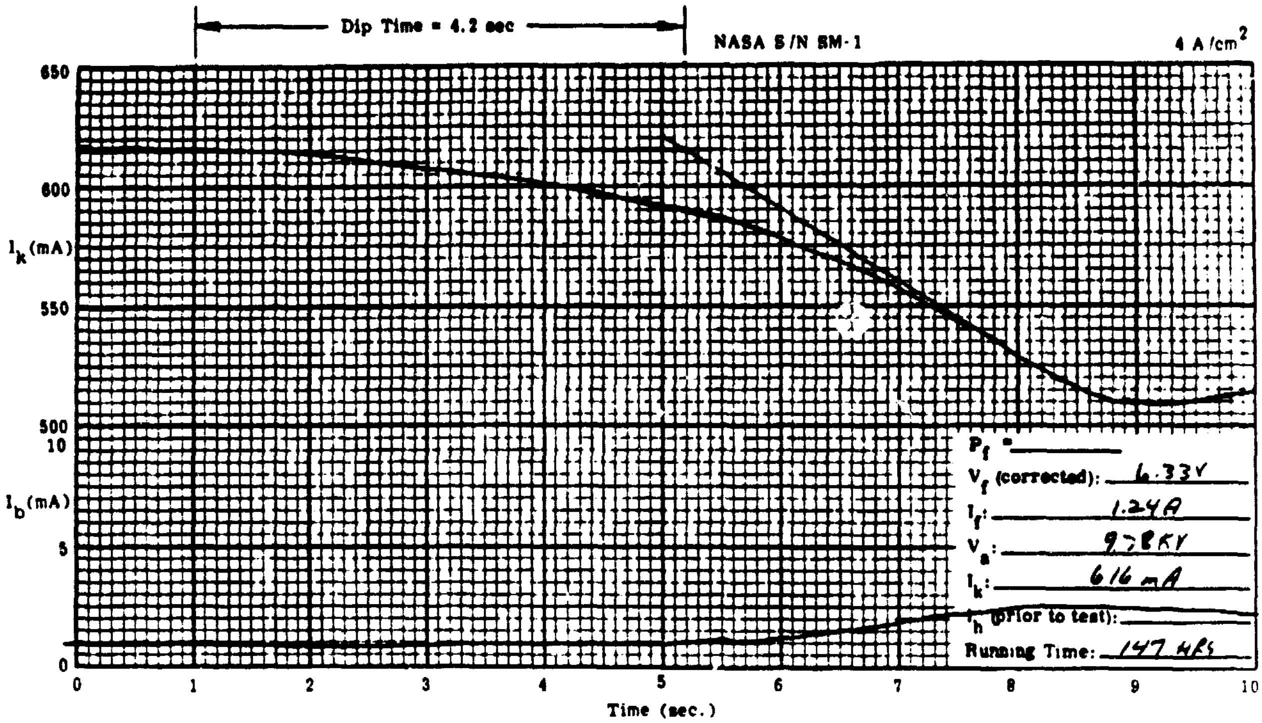
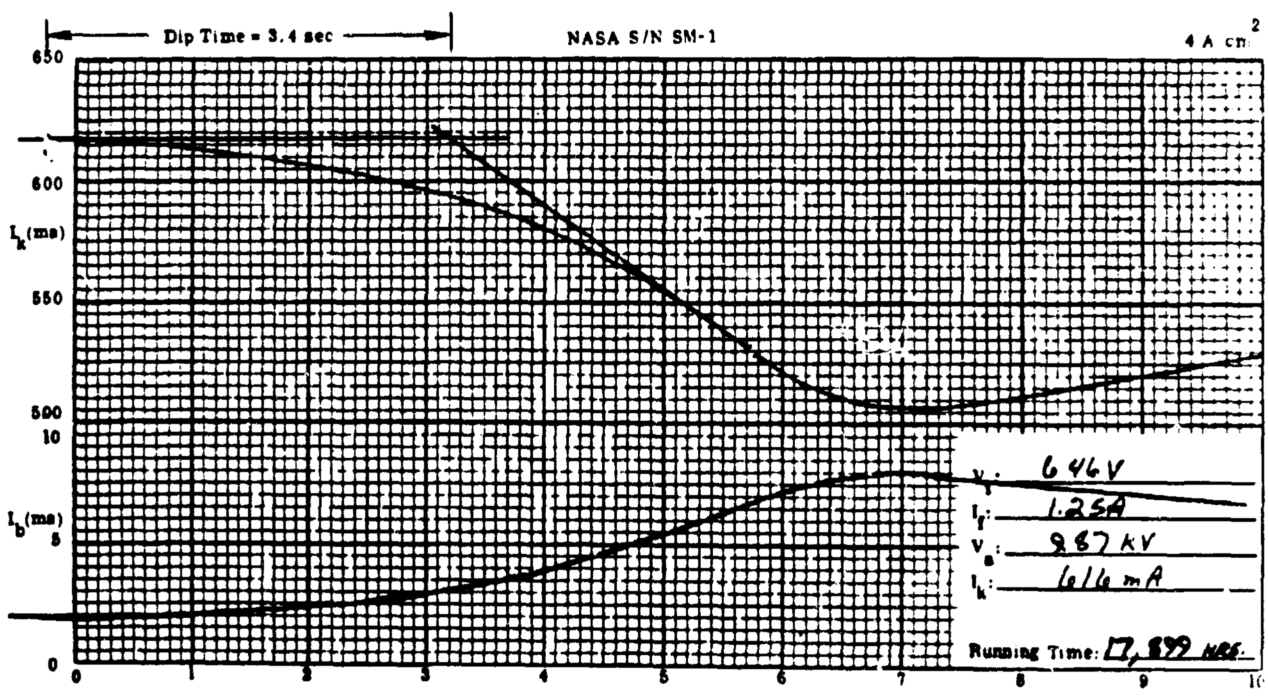
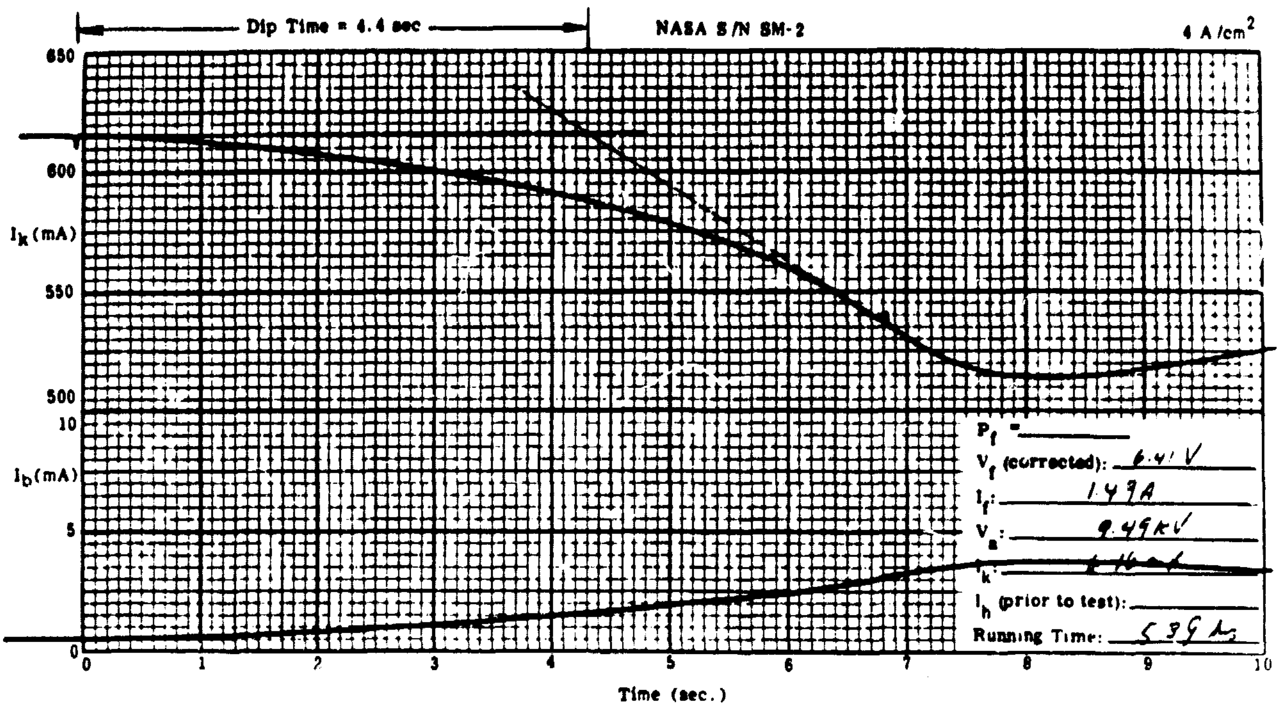
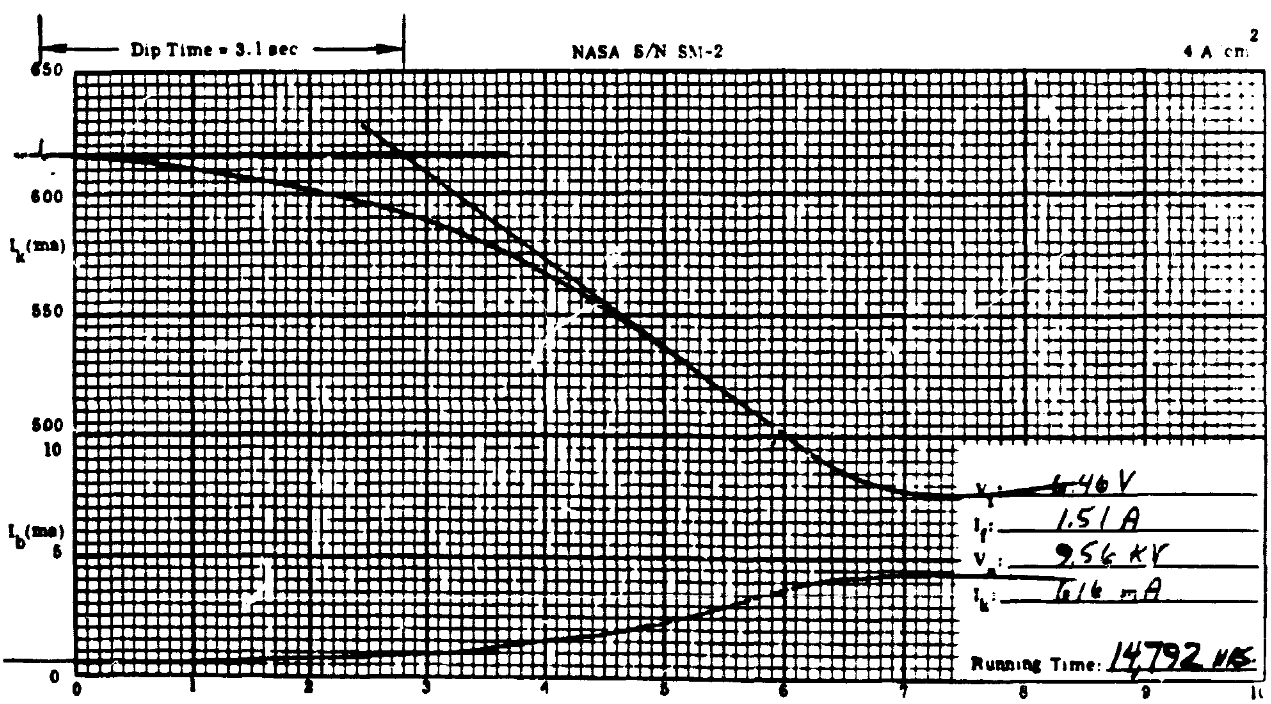




ab46051

PAGE 18





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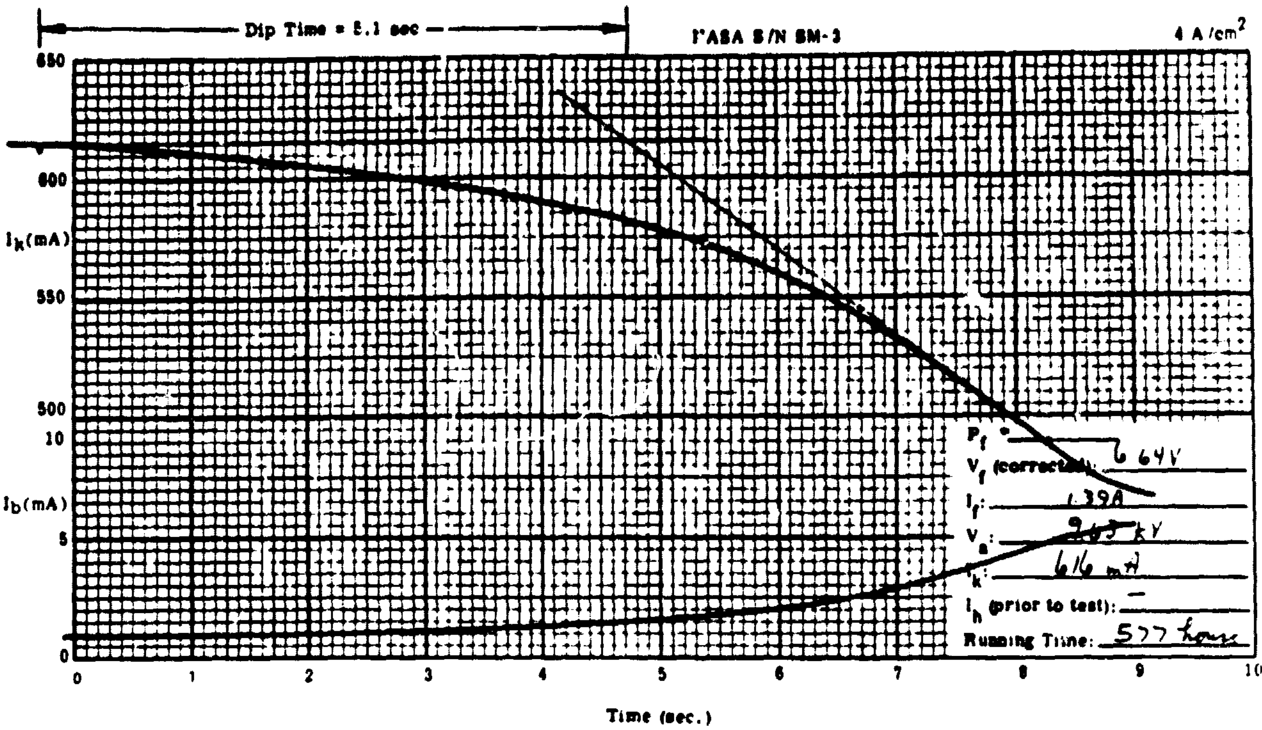

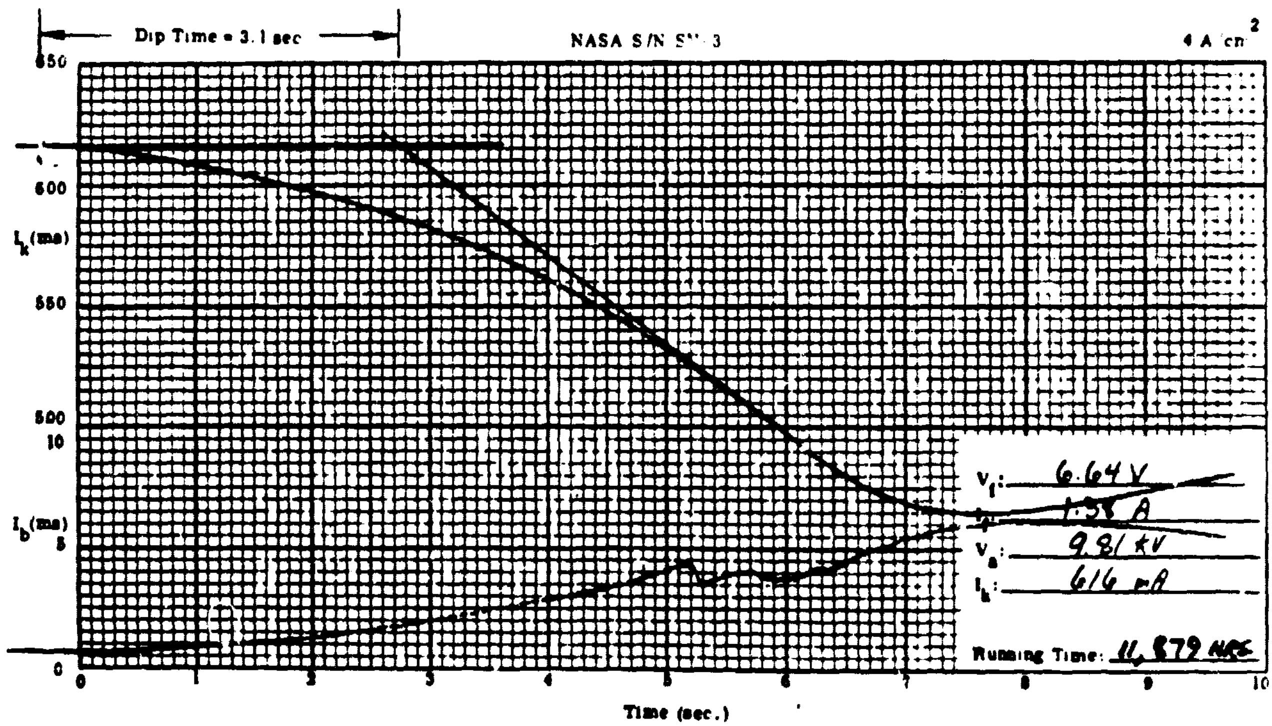

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APPENDIX V

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