RAYTHEON

Technical Report

PT-1615

THERMIONIC CATHODE EVALUATION STUDY

INTERIM REPORT NO.2

MICROWAVE AND POWER TUBE DIVISION

MICROWAVE TUBE OPERATION, WALTHAM, MASS. 02154

RAYTHEON COMPANY
Microwave and Power Tube Division
Waltham, Massachusetts

INTERIM REPORT NO. 2
THERMIONIC CATHODE EVALUATION STUDY

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NOTICE

ABSTRACT

During this second interim period, the diodes for pore-type dispenser, coated particle, and barium strontinum cathodes were fabricated and exhausted for use in this study of the life capability of three different thermionic cathode types.

The diodes with pore-type dispenser cathodes have completed at least 576 hours of life burning and are operating satisfactorily at cathode temperature from 950°-1100°C and at cathode current from 0.2A/cm^2 to 1.6A/cm^2.

The diodes using coated particle cathodes have been tested up to 0.275A/cm^2 at 850°C and appear satisfactory. Further tests above 850°C have been unsuccessful due to unexpected inhibited emission.

The diodes using barium strontium oxide cathodes are at the preaging and testing stage, and appear likely to meet the maximum operating condition of 0.60 A/cm^2 at approximately 850°C cathode temperature.

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1.0 INTRODUCTION

The Material and Techniques Group of Raytheon's Microwave and Power Tube Operation is performing a study of the life capabilities of three different types of thermionic emitters for the Jet Propulsion Laboratory, California Institute of Technology.

The life capabilities of the following electron tube cathode types are to be evaluated for a period of 2 years of life testing.

a. Pore-Type Dispenser Cathode
b. Coated Particle Cathode
c. Standard Barium Strontium Oxide Cathode.

This report describes progress in the work accomplished during the second interim period of this study. Section 2.0 describes the building of the cathodes, and assembly and exhaust of the test diodes. The exhaust schedules for each cathode type, and their corresponding exhaust pressures, are described in detail.

The electrical testing and selection of these diodes by zero field emission and dip tests are described in Section 3.0.

Difficulty has been experienced in the performance of the coated particle cathode. The test diodes show cathode temperature saturation above 0.275 A/cm^2 at 850°C.

Section 4.0 describes the life test procedure and testing of diodes. Test diodes with pore-type dispenser cathodes are at 576 hours of life burning and look satisfactory up to 1.6 A/cm^2 at 1100°C.

2.0 CONSTRUCTION AND EXHAUST PROCESSING OF TEST DIODES

During this second interim period, construction of all test diodes was completed and these tube were exhausted in accordance with the specifications as noted in Interim Report No. 1, Thermionic Cathode Evaluation Study (PT-1490). Figure 1 shows the diode assembly used for all these three different cathode types.

2.1 Pore-Type Dispenser Cathode

The pore-type dispenser cathode (shown in Figures 2 and 3) is a porous tungsten structure of 20-22% porosity impregnated with a molten mixture of barium oxide, calcium oxide and aluminum oxide. The emission pellet is ∝ 0.100 in. in diameter and 0.045 in. thick, with an emitting area of 0.05 sq cm.

Twenty-four test diodes of this type were constructed, with assembly being carried out in an air-conditioned and humidity-controlled room.

Auxiliary metal parts were made of molybdenum tantalum and/or nickel, and all parts were constructed and cleaned in accordance with the specifications in PT-1490. Welds in the diodes were performed by resistance welding with a stream of helium gas blowing on the weld during the operation.

Cathode-to-anode spacing, in all cases, was held to 0.015 ± 0.001 in. to allow the diodes to operate with a maximum of 8 - 10 watts anode dissipation under the most extreme test conditions required for this study (E_p = 100V, I_p = 0.080 mA or 1.6 A/cm^2).

After the glass envelopes were sealed to the diode assemblies, the vehicles were sealed onto the exhaust parts of the exhaust system shown in Figure 4.

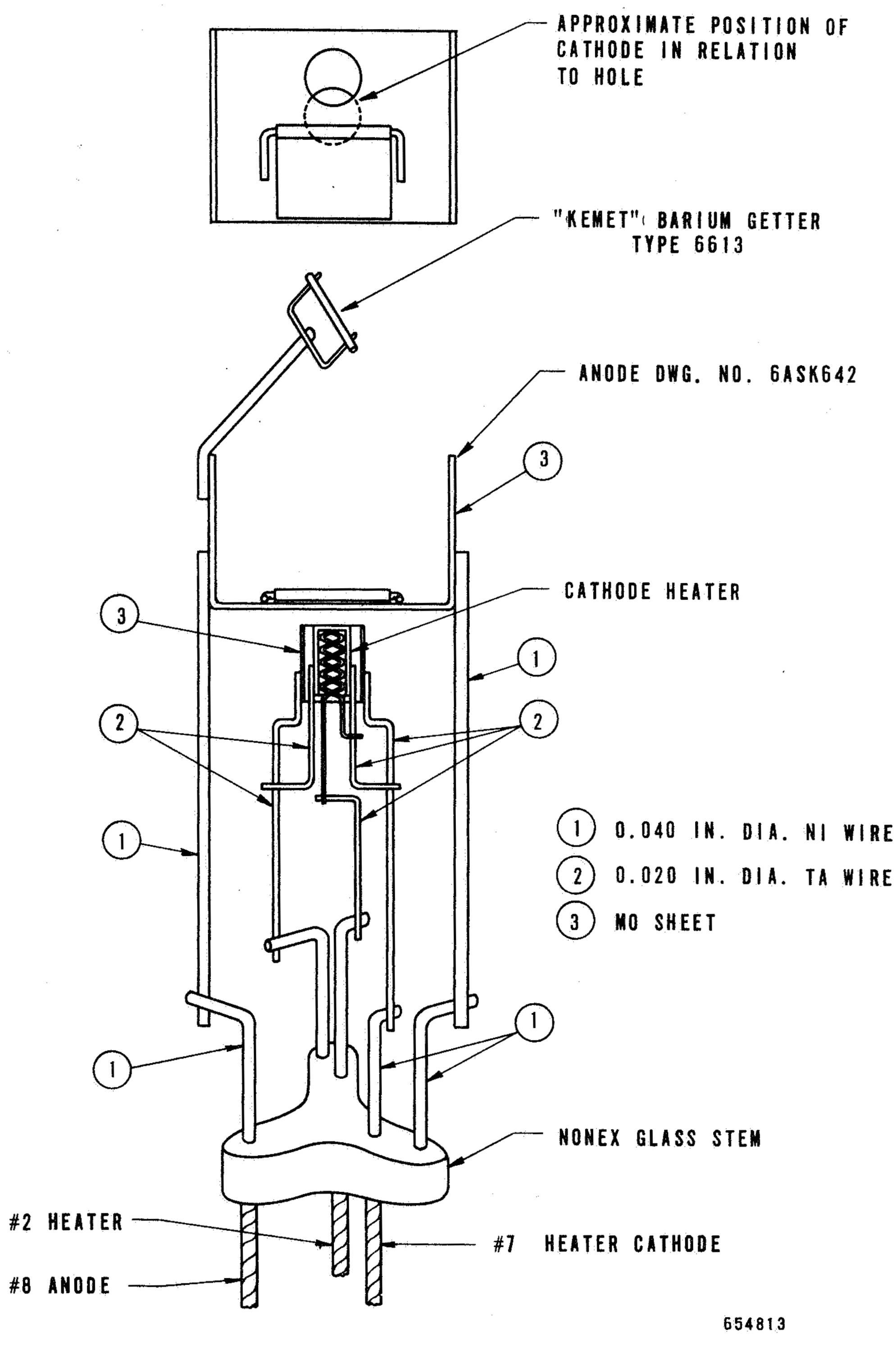


Figure 1. Diode Assembly for Thermionic Cathode Evaluation Study

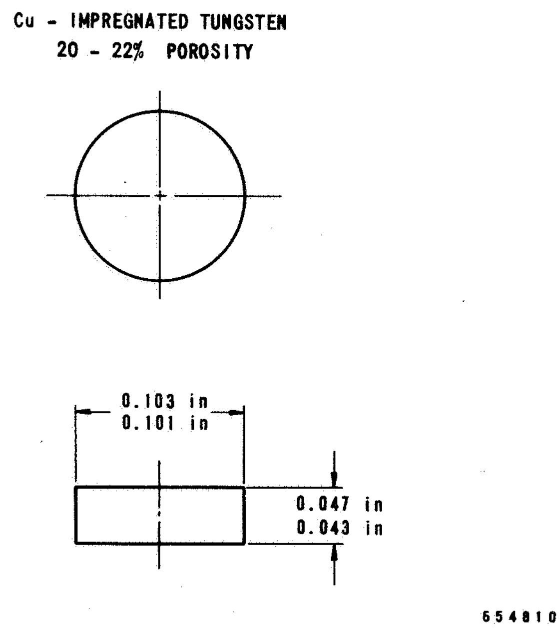


Figure 2. Emission Pellet

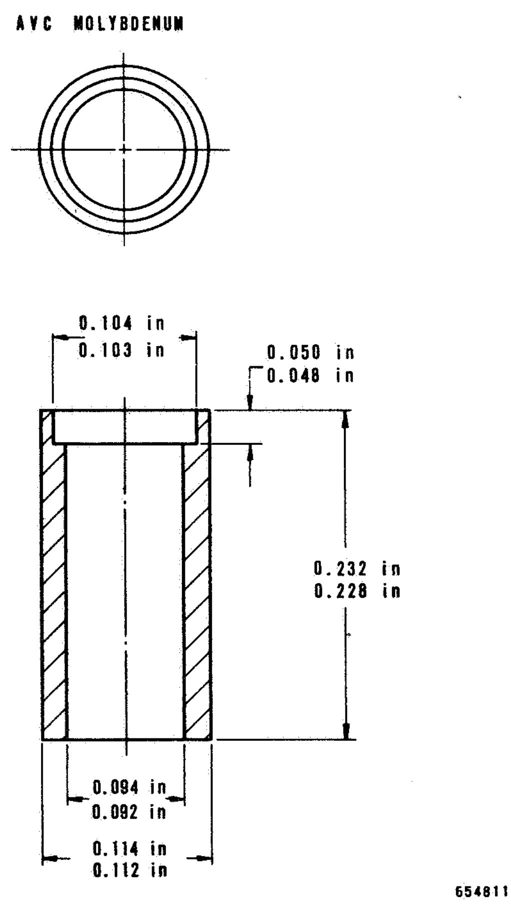


Figure 3. Sleeve for Emission Pellet

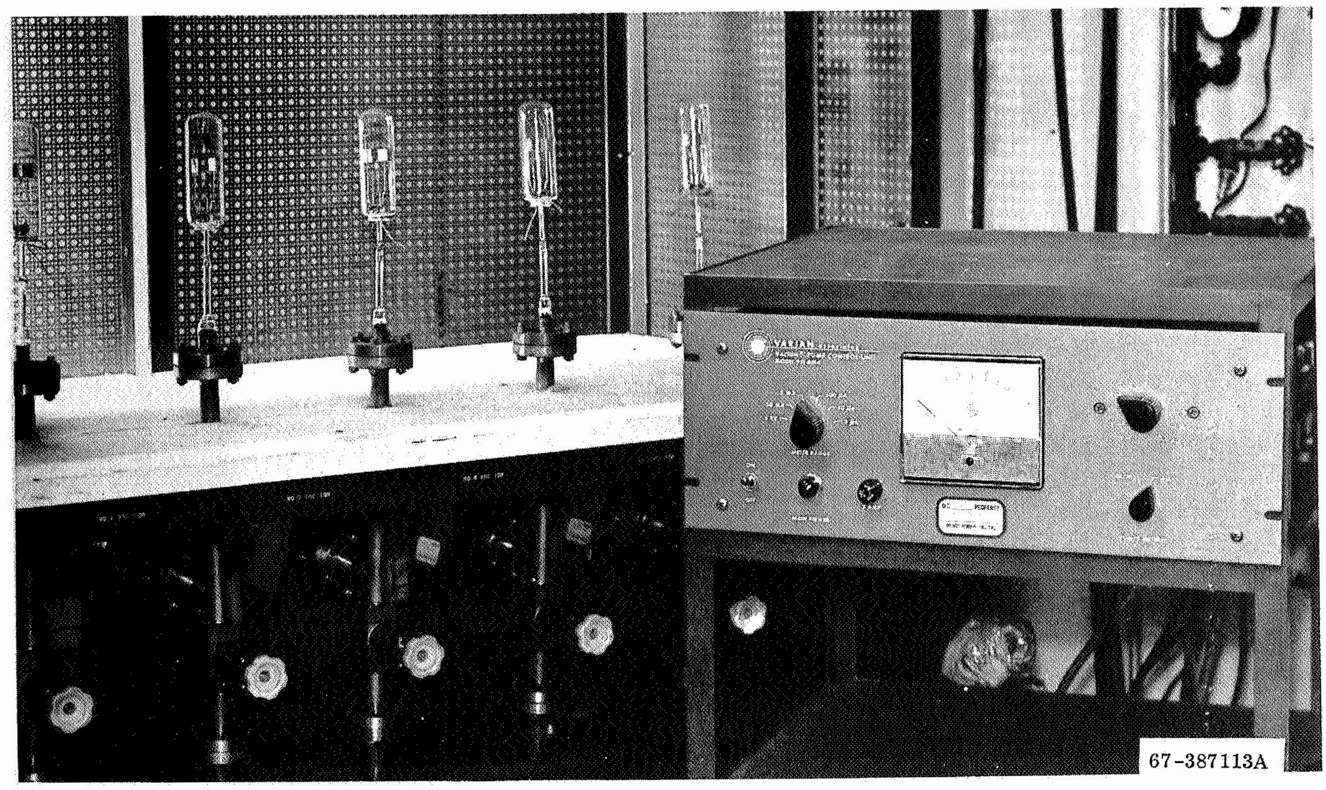


Figure 4. Exhaust System for Diode Test Vehicle (Cathode Laboratory)

In all, 4 loads of 6 diodes each using pore-type dispenser cathodes were exhausted in accordance with the procedures noted in Tables I and II.

TABLE I

Exhaust Unit Operation Through Bakeout

1. Open vacuum valve leading to 6 exhaust positions. (Vac-Ion pumps are off).
2. Close valves leading to roughing and oil diffusion pump systems.
3. Open bleeder valve, cut off glass exhaust tubes and seal-on 6 glass diodes.
4. Close bleeder valve and open vacuum valve to roughing pump. Run until vacuum is at 5 microns pressure.
5. Fill liquid nitrogen cold trap, close roughing pump valve and open valve to oil diffusion pump system.
6. Pump for 2 hours or until vacuum is less than 5×10^{-6} torr.
7. Turn on Vac-Ion pumps and pump until Vac-Ion pumps read less than 5×10^{-5} torr.
8. Close off oil diffusion system and valve off each individual Vac-Ion system.
9. Pump until the 6 systems are at 1×10^{-6} torr.
10. Lower electric oven and heat gradually to 450°C not allowing the vacuum to exceed 5×10^{-5} (2-hour period).
11. Bake out diode at 450°C for 16 hours.
12. Shut off oven and cool for 2-hour period. Vacuum should be on the 10^{-9} torr range.

TABLE II

Exhaust Processing
Pore-Type Dispenser Cathodes

1. After bakeout, the vacuum on each diode should be on the 10^{-9} torr scale.
2. Slowly heat cathode to 1100°C holding vacuum below 5×10^{-5}.
3. Hold cathode at 1100°C for 30 minutes.
4. After 15 minutes of cathode heating at 1100°C, heat anode to 900°C for 1 minute by rf heating.
5. Degas Getter.
6. Turn off heater.
7. Repeat steps 2 - 6 for other 5 tubes.
8. Seal-off 6 diodes. Vacuum on each tube should be on the 10^{-9} torr scale.
9. Flash Getters.
10. Attach bakelite base to tubes.

Table III presents the minimum and maximum pressures for each load of diodes at various steps during the bakeout and exhaust process.

After tip-off, the getters were flashed and bases were added to the tube.

Initial heating and electrical testing showed that, of the 24 diodes exhausted, one was an air leaker (leak at stem load).

In all, 23 diodes were ready for electrical test and final selection for life burning at the emission densities specified for this study (16 diodes needed).

TABLE III

Pressures at Exhaust
Pore-Type Dispenser Cathodes

Step	Load No. 1	Load No. 2	Load No. 3	Load No. 4
Pressure at start	2×10^{-7} 2×10^{-8}	2×10^{-7} 5×10^{-8}	1×10^{-8} 3×10^{-8}	2×10^{-8} 2×10^{-9}
Start of bakeout 100°C	2×10^{-5} 3×10^{-5}	2×10^{-6} 2×10^{-6}	6×10^{-7} 2×10^{-7}	3×10^{-7} 7×10^{-7}
Oven @ 450°C (2 hours 100-450°C)	8×10^{-6} 2×10^{-5}	1×10^{-6} 1×10^{-7}	1×10^{-6} 1×10^{-6}	1×10^{-6} 7×10^{-7}
Oven @ 450°C 16 hours - bakeout	2×10^{-7} 3×10^{-7}	1×10^{-7} 2×10^{-7}	1×10^{-7} 2×10^{-7}	1×10^{-7} 2×10^{-7}
Cool oven 2 hours pressure@	1×10^{-7} 6×10^{-9}	2×10^{-8} 7×10^{-9}	2×10^{-8} 7×10^{-9}	1×10^{-8} 5×10^{-9}
Time to heat cathode to 1100°C pressure $<5 \times 10^{-5}$	13 - 31 minutes	30 - 34 minutes	18 - 33 minutes	41 - 55 minutes
Cathode at 1100°C 30 minutes	4×10^{-6} 2×10^{-7}	2×10^{-6} 4×10^{-7}	2×10^{-6} 2×10^{-7}	1×10^{-7} 3×10^{-7}
Degas anode @ 800°C - 1 minute highest pressure	2×10^{-5} 3×10^{-5}	2×10^{-5} 3×10^{-5}	3×10^{-5} 4×10^{-5}	2×10^{-5} 4×10^{-5}
Pressure at tipoff	1×10^{-8} 2×10^{-8}	2×10^{-8} 3×10^{-8}	1×10^{-8} 8×10^{-9}	1×10^{-8} 8×10^{-9}

Pressure ranges indicated in torrs

2.2 Coated Particle Cathodes

The coated particle cathodes used in this study is a barium strontium oxide cathode, with each particle of oxide coating covered with a thin layer of nickel metal. The cathode is described in the publication, "Bell Laboratories Record" dated December 1965 (as improved and revised by the Raytheon Company).

The cathode was prepared by spraying the coated particle mix onto a 0.1% zr - ni cathode (Figure 5), to a coating density of 1.0 ± 0.1 gms/cc and a thickness of 0.002 ± 0.005 in. The emitting surface of the cathode is 0.125 in. in diameter, with an emitting area of 0.0794 sq cm.

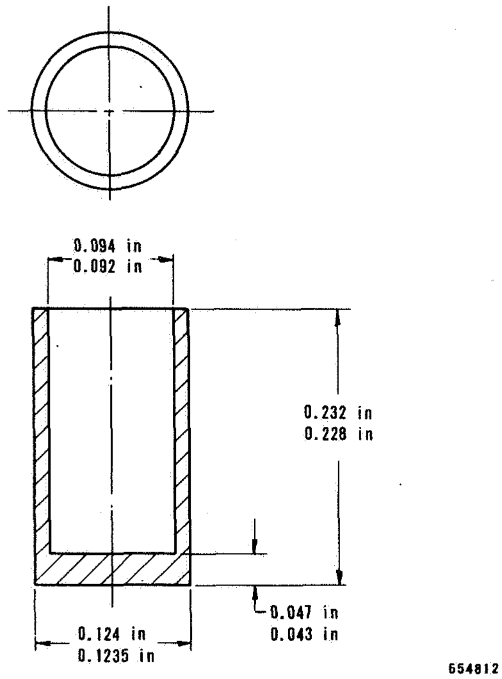
Twenty-two test diodes were constructed, with all metal parts of the diode being made from grade A nickel alloy. All parts were constructed and cleaned as noted in PT-1490.

The diodes were assembled in the manner previously described for pore-type diodes, with cathode-to-anode spacing held to 0.015 ± 0.001 in.

Four loads of diodes using coated particle cathodes were exhausted by the method shown in Tables I and IV. The number of tubes in each load of diodes was 6, 6, 5, and 5. Pressure ranges for each load of diodes during exhaust are shown in Table V.

Initial heating and electrical testing showed 2 diodes to be defective (poor getter flash, air leaker at stem wire. The 20 remaining diodes were used for electrical test and selection for life burning (16 diodes needed).

0.1% ZIRCONIUM - NICKEL



NOTE: USE ONLY NUJOL AS LUBRICANT FOR MACHINING

Figure 5. Emission Cathode

TABLE IV

Exhaust Processing

Coated Particle Cathodes

1.	After bakeout, the vacuum on each diode should be on the 10^{-9} torr scale.
2.	Degas Getter.
3.	Outgas anode at 900°C for 1 minute.
4.	Heat cathode slowly to 850°C keeping pressure below 5 x 10^{-6} torr (approximately 90 minutes).
5.	Raise cathode temperature to 1050°C rapidly and hold for 20 minutes.
6.	Draw 50 milliamperes of current to anode and hold for 3 minutes.
7.	Drop cathode temperature to 950°C.
8.	Repeat step (6).
9.	Drop cathode temperature to 850°C.
10.	Repeat step (6).
11.	Turn off heater.
12.	Repeat steps (2) - (11) for other 5 diodes.
13.	Seal off 6 diodes. Vacuum on each tube should be on the 10^{-9} torr scale.
14.	Flash Getter.
15.	Attach bakelite bases to tubes.

TABLE V

Pressures at Exhaust

Coated Particle Cathodes

Step	Load No. 5	Load No. 6	Load No. 7	Load No. 8
Pressure at start	1×10^{-6} 1×10^{-7}	1×10^{-6} 3×10^{-6}	1×10^{-7} 4×10^{-8}	3×10^{-6} 7×10^{-6}
Start of bakeout 100°C	1×10^{-5} 6×10^{-6}	5×10^{-6} 9×10^{-6}	1×10^{-6} 4×10^{-7}	1×10^{-5} 2×10^{-5}
Oven @ 450°C (2 hours 100-450°C)	2×10^{-6} 3×10^{-6}	1×10^{-6} 1×10^{-6}	1×10^{-6} 7×10^{-7}	3×10^{-6} 3×10^{-6}
Oven @ 450°C 16 hours-bakeout	1×10^{-7} 2×10^{-7}	2×10^{-7} 8×10^{-8}	1×10^{-7} 2×10^{-7}	1×10^{-7} 2×10^{-7}
Cool oven 2 hours pressure @	2×10^{-8} 9×10^{-8}	3×10^{-8} 9×10^{-8}	1×10^{-8} 5×10^{-8}	3×10^{-8} 5×10^{-9}
Outgas anode @ 800°C - 1 minute highest pressure	2×10^{-5} 4×10^{-5}	1×10^{-5} 2×10^{-5}	2×10^{-5} 3×10^{-5}	1×10^{-5} 2×10^{-5}
Time to heat cathode to 850°C pressure $<5 \times 10^{-6}$	116-118 minutes	124 minutes	125 minutes	81 minutes
Cathode at 850°C 10 minutes	1×10^{-7} 2×10^{-7}	1×10^{-7} 2×10^{-7}	2×10^{-7} 3×10^{-7}	6×10^{-8} 7×10^{-8}
Cathode at 1050°C 20 minutes	1×10^{-7} 2×10^{-7}	2×10^{-7} 1×10^{-8}	2×10^{-7} 8×10^{-8}	1×10^{-7} 2×10^{-7}
Pressure at tipoff	2×10^{-8} 9×10^{-9}	4×10^{-9} 5×10^{-9}	1×10^{-8} 8×10^{-8}	1×10^{-8} 2×10^{-8}

Pressure ranges indicated in torrs

2.3 Barium Strontium Oxide Cathode

The barium strontium oxide cathode consists of the same metallic body as used with the coated particle cathode, upon whose emitting face is sprayed a layer of barium strontium carbonates.

As before, the spray density is 1.0 ± 0.1 gms/cc and the coating thickness is 0.002 ± 0.0005 in. The emitting surface of the cathode is 0.125 in. in diameter and its area ia 0.0794 sq cm.

The diodes, parts and assembly, are the same as used with the coated particle cathodes.

Four loads of diodes (6, 6, 5, and 4) using barium strontium oxide cathodes were baked out and exhausted by the procedure noted in Table I and VI. Pressure ranges for each load of diodes during the exhaust cycle are shown in Table VII, on the next page.

TABLE VI

Exhaust Processing

Barium Strontium Oxide Cathodes

1.	After bakeout, the vacuum on each diode should be on the 10^{-9} torr scale.
2.	Degas Getter.
3.	Outgas anode at 900°C for 1 minute.
4.	Heat cathode to 1050°C keeping pressure below 1 x 10^{-4} torr (approximately 10 minutes).
5.	Hold 5 minutes at 1050°C.
6.	Drop cathode temperature to 950°C and hold 10 minutes.
7.	Turn off heater.
8.	Repeat steps (2) - (7) for other 5 diodes.
9.	Seal off 6 diodes. Vacuum on each tube should be on the 10^{-9} torr scale.
10.	Flash Getter.
11.	Attach bakelite bases to tubes.

TABLE VII

Pressure at Exhaust
Barium Strontium Oxide Cathode

Step	Load No. 9	Load No. 10	Load No. 11	Load No. 12
Pressure at start	2×10^{-6} 2×10^{-7}	2×10^{-7} 5×10^{-7}	5×10^{-7} 1×10^{-8}	1×10^{-7} 5×10^{-7}
Start of bakeout 100°C	4×10^{-6} 5×10^{-6}	8×10^{-7} 9×10^{-7}	4×10^{-7} 7×10^{-7}	4×10^{-6} 4×10^{-7}
Oven @ 450°C (2 hours 100-450°C)	1×10^{-6} 8×10^{-6}	3×10^{-6} 4×10^{-6}	2×10^{-7} 7×10^{-7}	1×10^{-7} 5×10^{-7}
Oven @ 450°C 16 hours - bakeout	1×10^{-7} 2×10^{-7}	1×10^{-7} 1×10^{-7}	2×10^{-7} 8×10^{-8}	3×10^{-7} 9×10^{-8}
Cool oven 2 hours pressure @	8×10^{-8} 8×10^{-9}	6×10^{-8} 4×10^{-9}	2×10^{-7} 2×10^{-8}	2×10^{-8} 6×10^{-8}
Outgas anode @ 800°C - 1 minute highest pressure	2×10^{-5} 3×10^{-5}	2×10^{-5} 4×10^{-5}	2×10^{-5} 4×10^{-5}	3×10^{-5} 4×10^{-5}
Time to heat cathode 1050°C pressure $<1 \times 10^{-4}$	18 - 27 minutes	12 - 34 minutes	11 - 18 minutes	12 - 22 minutes
Cathode at 1050°C 5 minutes	1×10^{-7} 8×10^{-7}	7×10^{-7} 8×10^{-8}	4×10^{-7} 9×10^{-8}	2×10^{-7} 6×10^{-7}
Cathode at 950°C 10 minutes	1×10^{-7} 4×10^{-8}	1×10^{-7} 8×10^{-8}	2×10^{-7} 8×10^{-8}	3×10^{-7} 9×10^{-8}
Pressure at tipoff	2×10^{-8} 3×10^{-9}	3×10^{-9} 7×10^{-9}	2×10^{-8} 6×10^{-8}	1×10^{-8} 8×10^{-8}

Time in minutes or hours
Pressure ranges indicated in torrs

Initial heating and electrical testing showed all 21 diodes to be satisfactory for life burning selection (16 diodes needed).

3.0 ELECTRICAL TESTING AND SELECTION OF TEST DIODES FOR LIFE BURNING

All test diodes constructed and exhausted are being aged at temperatures compatible for the particular type of cathode used. Plate voltage (50V dc) is applied to the diodes during the aging cycle to stabilize their thermionic emission levels.

After this period of aging, the cathodes are being tested for compliance with the JPL specifications noted in Figure 6 and Table VIII. If the diode shows proper zero field current level at the lowest possible cathode temperature for the required electrical test specification (Table VIII), it is then tested for dip temperature according to the schematic diagram shown in Figure 7.

TABLE VIII

Electrical Test Procedures (JPL Specification)

	Diode Selection			Life-Test Operation			
	Req'd Units	Life Test Temp	Zero Field Current Dens ma/sq cm	Req'd Units	Current Density ma/sq cm	Req'd Units	Current Density ma/sq cm
Oxide Cathodes	4	T_1	250	2	75	2	150
	4	T_2	500	2	150	2	300
	4	T_3	750	2	225	2	450
	4	T_4	1000	2	300	2	600
CP Cathodes	4	T_1	345	2	138	2	275
	4	T_2	690	2	275	2	550
	4	T_3	1035	2	415	2	830
	4	T_4	1380	2	550	2	1100
Dispenser Cathodes	4	T_1	400	2	200	2	400
	4	T_2	800	2	400	2	800
	4	T_3	1200	2	600	2	1200
	4	T_4	1600	2	800	2	1600

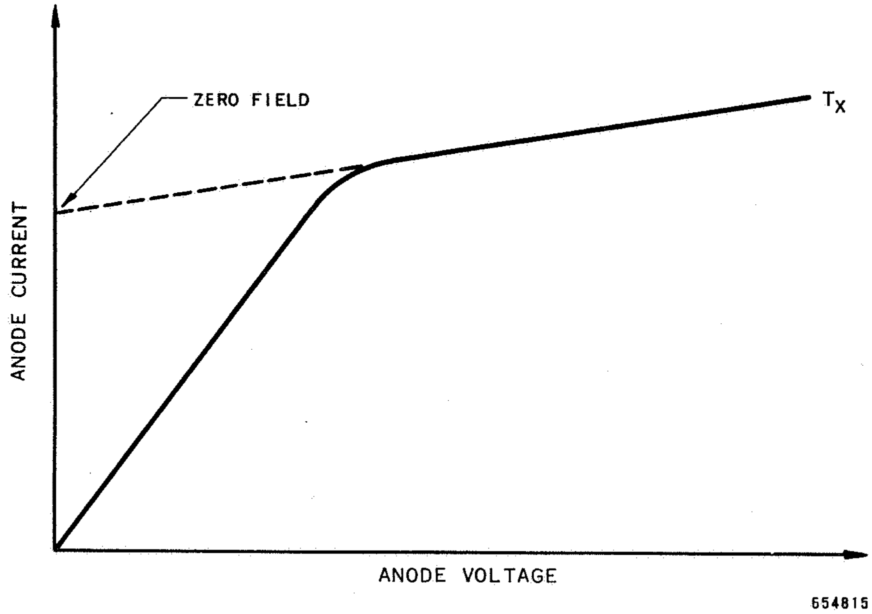
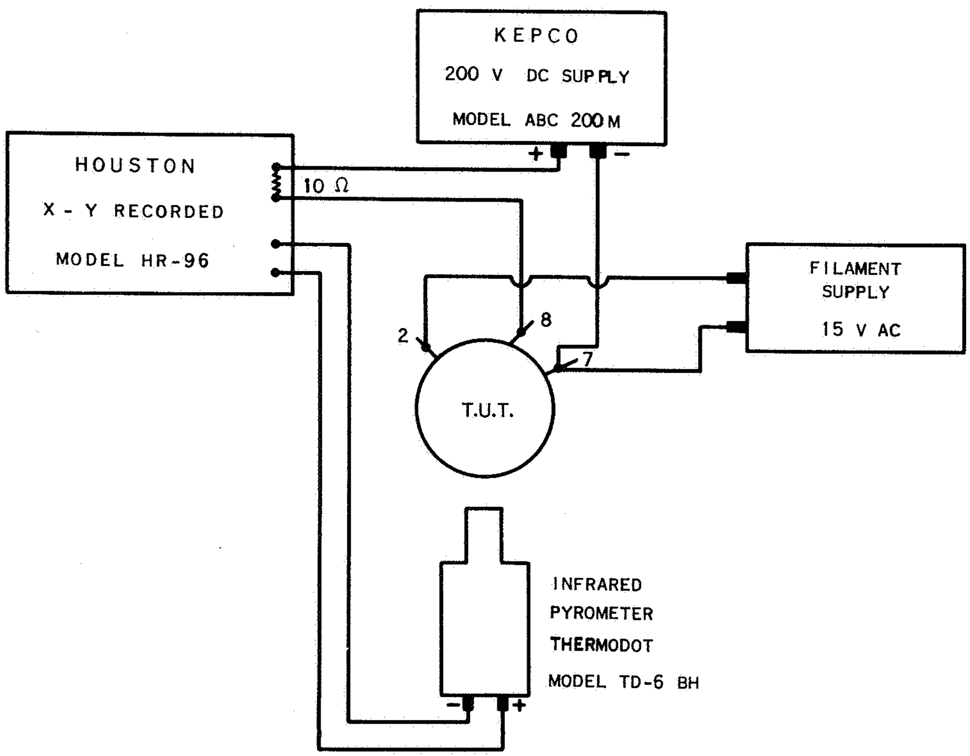


Figure 6 Current Density Level (JPL Specification)



T.U.T. - TUBE UNDER TEST
PIN 2 - HEATER
PIN 7 - HEATER, CATHODE
PIN 8 - ANODE

Figure 7 Dip Test of Diode Vehicles

In testing for dip temperature, the diode is set into the electrical socket with the anode flap in the open position. Cathode brightness temperature (in °C) is read and set using an optical pyrometer. The infrared pyrometer then is focused on the cathode surface and is calibrated and set to read the brightness temperature of the cathode surface, from the prescribed temperature to room temperature, on the X-axis or abscissa of the XY Houston recorder. Anode voltage on the diode is set to read the anode current on the Y-axis or ordinate, from the desired current level in milliamperes to zero current.

After the diode has been properly set and calibrated for cathode brightness temperature and anode current, the heater voltage is turned off to allow the changes in characteristics to be recorded. When anode current reaches 50% of its initial level, the heater voltage is turned on again. The curve that is obtained by this method is then used to determine dip temperature. The temperature-limited portion of the curve is extrapolated back to the initial anode current level on the Y-axis, where the point of intercept on the X-axis is taken as the dip temperature.

This method of thermionic emission evaluation provides a measure of the length of the space charge region of the cathode in terms of temperature.

Diodes which successfully pass the zero field current and dip tests are used for life burning evaluation of the three cathode types.

3.1 Pore-Type Dispenser Cathodes

The test diodes using pore-type dispenser cathodes were numbered for identification: M1 through M24.

They were first tested for zero field current in accordance with the desired specification. Figure 8 shows a plot of zero field current density for two diodes using pore-type dispenser cathodes. The current level for tube M-3 is shown on the Y-axis on the left and for tube M-4 in the right side of the graph.

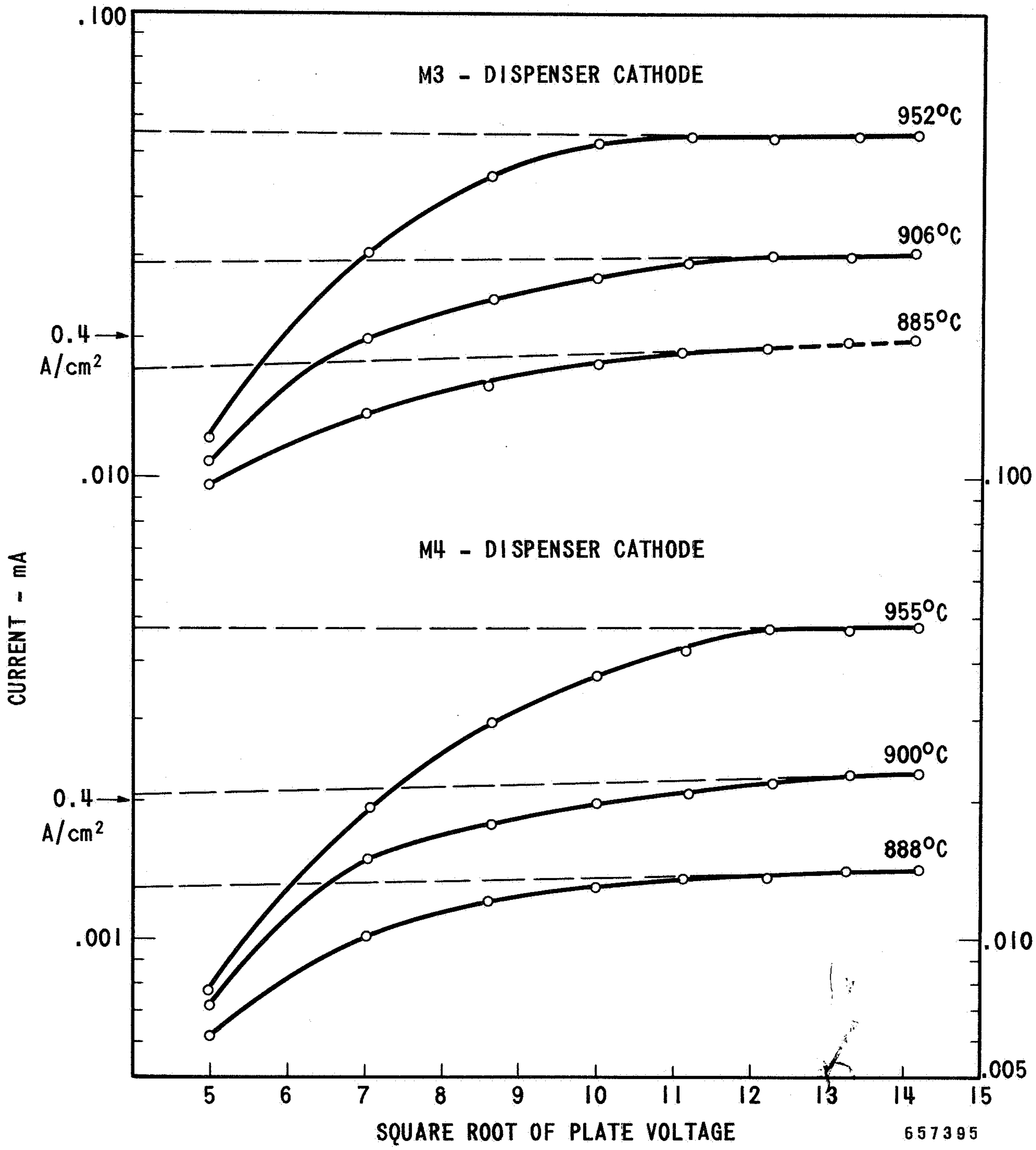


FIGURE 8 Zero Field Current Density

The square root of the voltage ($\sqrt{E_p}$) is plotted against the milliamperes of plate current for the diodes M3 and M4 at three different cathode temperatures. It should be noted that the lowest $\sqrt{E_p}$ shown is 3 volts, at which point the zero field current was determined. The error in zero field current level is less than 2% at $\sqrt{E_p}$ = 3 volts.

For these two diodes, 900°C was determined to be the proper temperature for operation of the diodes under the T_1 condition for pore-type dispenser cathodes (Table VIII, Electrical Test Procedure). The 2 tubes had a zero field current level of ~ 0.4 A/cm^2 at 900°C (0.020 mA x 20 = 0.4 A/cm^2). However, a subsequent dip test showed the two tubes to be operating in the temperature-limited emission region. It was also found that the prescribed zero field current levels for T_2, T_3 and T_4 diode operation were too low for pore-type dispenser cathodes. The diodes were all temperature-limited under these conditions and showed no drop in dip temperature from the operating temperature.

After a conference with the JPL representative, it was decided to raise the zero field current levels at each test condition to give a dip temperature approximately 50°C lower than the operating temperature. Table IX shows the selected zero field current levels and temperatures used for test and evaluation of pore-type dispenser cathodes.

The tubes tested at T_4 did not show current saturation at 1100°C at the highest anode voltage (200V) that could be used on the diode. Above this voltage, the diodes showed overheating of the anode with the cathode current running far above normal current ratings. It is estimated that at 1100°C the zero field current should be in the range of 2.5 amps/cm^2.

Final temperatures selected were 950°C at T_1, 985°C at T_2, 1035°C at T_3 and 100°C at T_4.

The dip temperatures were determined for each tube at the four T_1 temperatures and eight operating current levels. The results for the dip temperatures are plotted in Figures 9, 10, 11, and 12.

TABLE IX

Zero Field Current Levels
Pore-Type Dispenser Cathodes

Test	Tube No.	AMPS/cm^2	T°C$_{BR}$
T_1 - 950°C	M 1	0.90	950
	M 4	0.96	949
	M 2	1.00	952
	M 3	1.10	955
T_2 - 985°C	M 7	1.32	988
	M 9	1.22	989
	M11	1.26	988
	M12	1.40	984
T_3 - 1025°C	M13	1.70	1029
	M18	1.60	1025
	M14	1.60	1029
	M17	1.70	1026
T_4 - 1050°C	M21	1.90	1049
	M23	1.80	1054
	M19	1.90	1049
	M22	1.80	1053

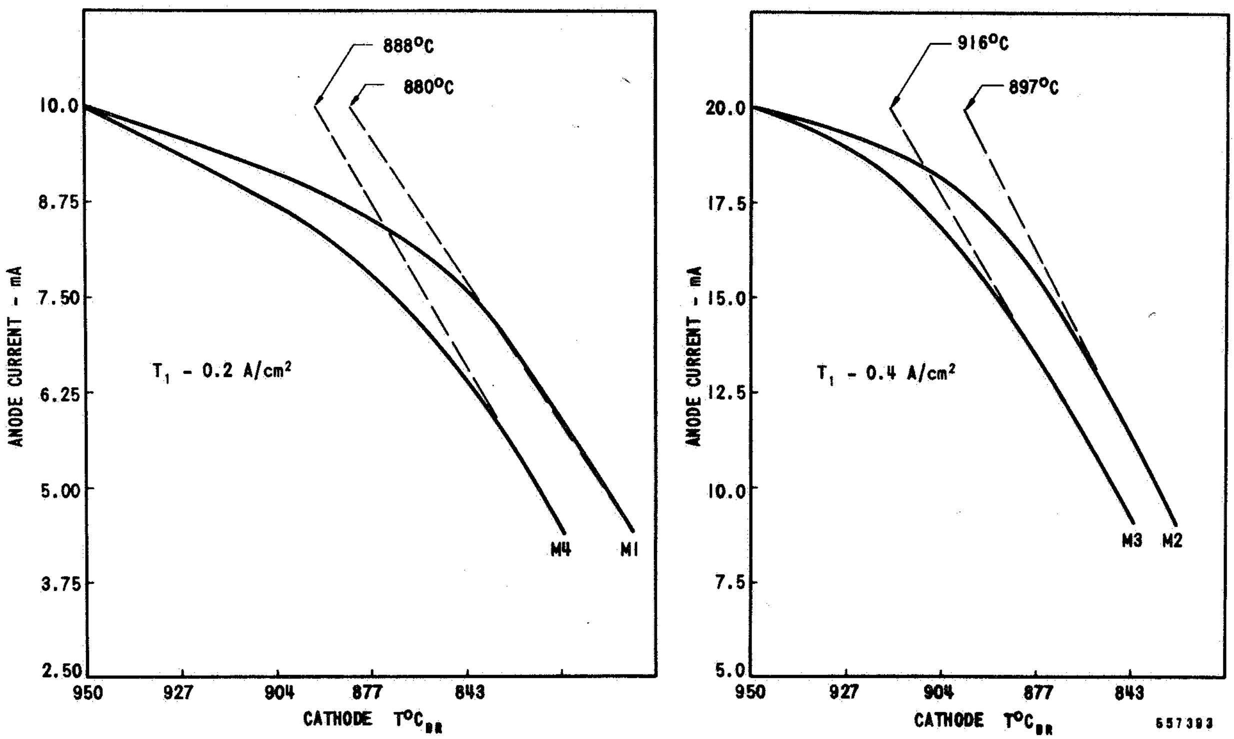


Figure 9 Pore-Type Dispenser Cathode Dip Test

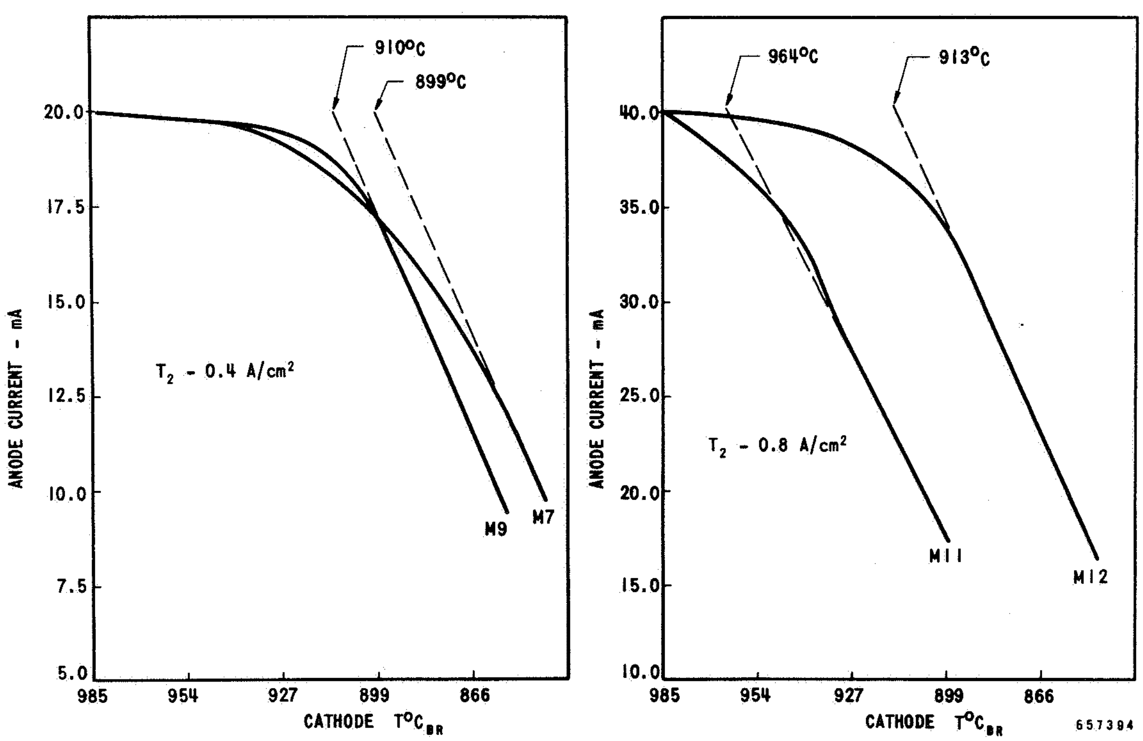


Figure 10 Pore-Type Dispenser Cathode Dip Test

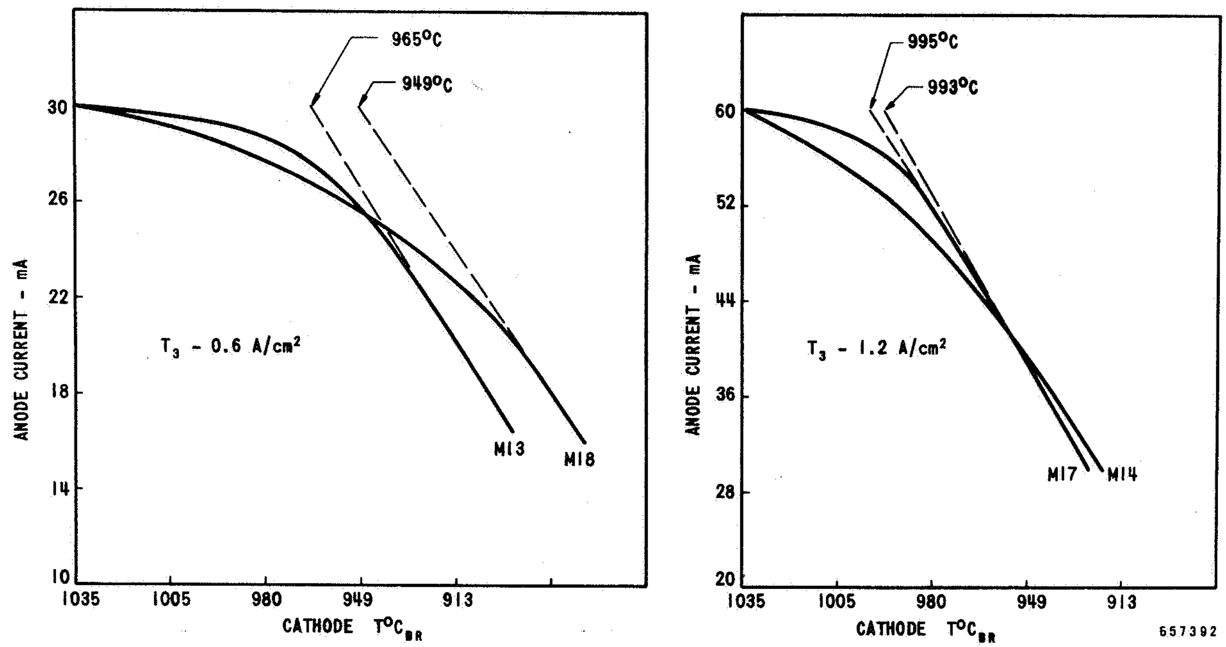


Figure 11 Pore-Type Dispenser Cathode Dip Test

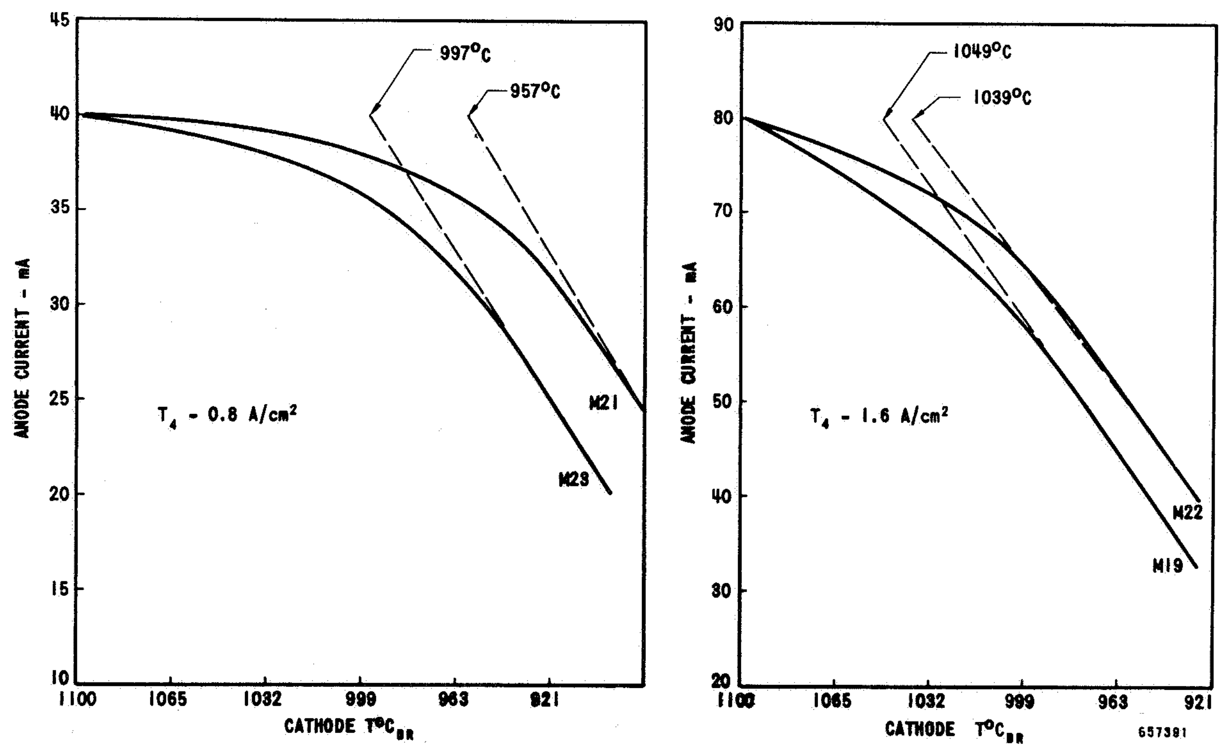


Figure 12 Pore-Type Dispenser Cathode Dip Test

An analysis of the results showed the dip temperatures to be 50 - 103°C lower than the operating temperature at the lower current operating levels with the four different temperature conditions.

At the higher current density levels with the four temperature conditions, the dip temperatures were 21 - 72°C lower than the operating conditions.

At this point, the diodes with the pore-type dispenser cathodes were considered to be ready for life burning.

3.2 Coated Particle Cathodes

The diodes using coated particle cathodes were numbered for identification: C1 through C24.

At the close of the second interim period of this study, the test diodes were still at the aging stage for evaluation of zero field current and dip temperature. Final life test selection has not been made.

The zero field currents at 805°C are ranging from 0.5 to 0.64 amps/cm^2 and at 850°C from 0.57 to 0.76 amps/cm^2. The T_1 current density requirements are being met at 850°C. This has been determined from dip temperature measurements. With the diodes set at 850°C and drawing 0.275 amps/cm^2, the dip temperature has been determined to be between 770 - 800°C. The diodes are being aged further and tested for T_2 current density requirements at elevated temperature above 850°C.

The increase in average zero field current from 0.57 A/cm^2 at 805°C to 0.67 A/cm^2 at 850°C is considered to be anomalously small in comparison with the coated particle cathode behavior observed in specific tube applications at Raytheon. A resolution of this issue will be attempted by a consideration of the following factors:

1. CW vs pulsed operation of the diode;
2. Activity level of the Ni (i. e., comparison of high and low percentage of reducing impurities; and
3. Diode processing to minimize residual gases.

3.3 Barium Strontium Oxide Cathodes

The diodes using barium strontium oxide cathodes were numbered for identification: O1 through O24.

These test diodes are at the aging and evaluation stage for zero field current and dip temperatures.

At present, it appears that the diodes will meet the maximum T_4 operating condition of 0.60 $amps/cm^2$ at ~ 850°C.

Not all the diodes has been aged at the conclusion of this second interim period and the zero field current levels and dip temperatures have not been determined.

4.0 LIFE BURNING AND TESTING OF TEST DIODES

Currently, test diodes using pore-type dispenser cathodes are at life burning on the test rack constructed for this study.

This cathode life test rack, designed by Raytheon personnel and constructed by the Cober Electronics Company of Stanford, Connecticut, is designated a Cober Model No. 1369. It has 48 test positions with each position having its own heater and plate voltage control. The equipment is divided into 3 banks of 16 sockets each. Each bank has its own regulated filament supply which can deliver 24 volts at 20 amperes ac to each bank. Each socket has a 4-ohm 50-watt rheostat to adjust filament current for individual control of cathode temperature. The cathode temperature can be varied up to 100°C on each bank over the 800°C - 1100°C range setting on the particular bank.

A variable constant plate voltage is supplied to each socket in the range of 25 to 200 V dc. Each socket has its own transistorized module for adjustment of plate voltage which feeds from two Technipower solid-state model L-100, 0 - 6.0 M regulated power supplies.

4.1 Pore-Type Dispenser Cathode

At the end of the second interim period of this study, the diodes at the T_1, T_2 and T_3 specifications had completed 757 hours of life burning. The test diodes at the T_4 specification had completed 576 hours of life burning. Test results are shown in Tables X through XVII.

The diodes were placed in the sockets on two different banks on the test rack and set at 9.0V E_f and 11.0 E_f, respectively. Each diode was set at its proper temperature using optical temperature control. The plate voltage power supplies were set at 110 volts dc an and each diode was adjusted to a constant anode voltage to draw the specified cathode current for the test diode. Initial dip temperatures were previously noted in Figures 9 through 12.

TABLE X

Life Test Results
Pore-Type Dispenser Cathodes
T_1 = 950°C 0.20 amps/cm^2

Diode	Hours	T°C	I_p	I_p - 32V	I_p-46V	D_{IP}T°C	I_p@ 904°C
M1	0	950	10.0	8.4	12.0	880	8.70
E_p = 39V	16	948	10.0	8.2	12.2	880	8.65
E_f = 9.0V	92	950	10.0	7.9	12.1	880	8.65
	184	949	10.2	8.1	12.2	874	8.80
	305	948	10.2	7.8	11.9	901	8.75
	423	950	10.2	8.2	11.7	885	8.80
	592	950	10.0	8.2	12.4	---	----
	757	950	10.0	8.2	12.7	895	8.3
				I_p - 22V	I_1-32V		
M4	0	950	10.0	8.3	12.5	888	8.80
E_p = 26.0V	16	952	10.0	8.3	12.7	901	8.76
E_f = 9.0V	92	951	10.0	8.2	12.6	911	8.35
	184	950	9.9	8.3	12.5	895	8.65
	305	949	10.0	8.2	12.7	913	8.65
	423	950	9.9	8.2	12.6	885	8.75
	592	950	10.0	8.4	13.0	---	----
	757	950	10.0	8.4	13.0	895	8.60

TABLE XI

Life Test Results

Pore-Type Dispenser Cathodes

T_1 = 950°C 0.40 amps/cm^2

Diode	Hours	T°C	I_p	I_p-39V	I_p-59V	D_{Ip} T°C	I_p @ 904°C
M2	0	950	20.0	15.1	27.3	916	19.3
E_p = 49V	16	950	20.0	15.2	27.3	880	18.5
E_f = 9.0V	92	950	19.7	14.9	26.8	880	18.5
	184	950	20.1	15.3	27.1	904	17.6
	305	950	19.9	14.9	27.1	885	18.8
	423	952	20.8	15.7	27.0	890	18.0
	592	952	21.0	15.8	26.3	---	----
	757	950	21.0	15.8	26.4	895	18.0
				I_p-28V	I_p-42V		
M3	0	950	20.0	16.5	27.0	897	15.0
E_p = 35V	16	951	20.4	16.7	26.8	901	15.3
E_f = 9.0V	92	950	20.2	15.6	27.2	912	15.8
	184	950	20.5	16.0	27.3	886	18.9
	305	949	20.5	15.7	27.3	885	18.3
	423	952	20.3	16.5	27.0	895	17.5
	592	950	21.5	16.4	26.9	---	----
	757	953	21.5	16.4	27.0	891	18.0

TABLE XII

Life Test Results

Pore-Type Dispenser Cathodes

T_2 = 985°C 0.40 amps/cm^2

Diode	Hours	T°C	I_p	I_p-28V	I_p-42V	D_{IP}T°C	I_p @ 936°C
M7	0	985	20.0	16.8	27.5	899	19.3
E_p = 34.5V	16	986	20.0	15.6	26.5	957	17.5
E_f = 9.0V	92	985	20.3	16.5	26.8	970	16.5
	184	985	19.7	15.2	24.5	971	17.0
	305	981	20.0	15.5	25.9	954	17.4
	423	985	20.0	15.8	25.9	954	18.1
	592	984	19.9	15.1	24.5	---	----
	757	985	20.0	15.4	25.0	958	16.4
				I_p-30V	I_p-50V		
M9	0	985	20.0	14.6	28.5	910	18.8
E_p = 40V	16	983	20.3	14.3	29.5	941	16.0
E_f = 9.0V	92	985	20.3	14.3	28.8	945	15.1
	184	984	20.5	14.7	29.0	931	14.0
	305	987	20.2	15.0	28.2	932	18.0
	423	985	21.2	15.2	28.0	937	17.6
	592	984	21.2	15.0	27.9	---	----
	757	986	21.2	15.0	27.8	938	17.5

TABLE XIII

Life Test Results
Pore-Type Dispenser Cathodes
T_2 = 985°C 0.80 amps/cm^2

Diode	Hours	T°C	I_p	I_p-54V	I_p-76V	D_{IP} T°C	I_p@936°C
M11	0	985	40.0	32.0	49.5	964	28.0
E_p = 65V	16	987	40.0	32.0	48.0	975	33.0
E_f = 9.0V	92	986	38.2	30.7	45.8	982	31.0
	184	985	38.4	31.7	46.8	968	32.5
	305	985	36.0	28.5	42.2	967	33.5
	423	983	36.5	29.0	43.7	964	33.0
	592	984	36.3	29.0	43.8	---	----
	757	986	35.9	29.0	42.3	966	33.0
				I_p-44V	I_p-64V		
M12	0	985	40.0	31.0	50.0	913	38.0
E_p = 54V	16	985	40.5	31.3	50.7	943	30.0
E_f = 9.0V	92	984	40.0	31.0	50.0	940	35.0
	184	986	40.5	31.4	50.2	920	38.5
	305	983	39.0	30.3	48.5	932	37.0
	423	984	39.8	31.0	49.5	925	35.0
	592	985	38.7	29.3	48.0	---	----
	757	985	39.0	30.0	49.5	938	36.0

TABLE XIV

Life Test Results

Pore-Type Dispenser Cathodes

T_3 = 1035°C 0.60 amps/cm^2

Diode	Hours	T°C	I_p	I_p-36V	I_p-54V	D_{IP}T°C	I_p @ 1005°C
M13	0	1035	30.0	22.5	38.5	965	29.2
E_p = 45V	16	1037	30.8	22.9	39.0	952	29.0
E_f = 11.0V	92	1034	30.4	22.8	38.8	945	29.2
	184	1033	30.9	23.2	39.6	913	28.8
	305	1033	30.1	22.7	39.7	925	29.2
	423	1035	30.7	22.8	39.1	949	26.8
	592	1034	29.4	22.0	37.1	---	----
	757	1036	29.8	22.2	38.0	935	28.4
				I_p-39V	I_p-59V		
M18	0	1035	30.0	21.5	38.0	949	29.2
E_p = 48.5V	16	1036	28.0	2.18	37.0	980	28.8
E_f = 11.0V	92	1032	29.2	22.4	37.5	985	27.6
	184	1035	29.2	22.4	36.8	980	27.0
	305	1035	25.5	19.8	32.0	993	27.0
	423	1034	28.0	21.7	36.0	991	26.4
	592	1037	26.0	22.0	33.0	---	----
	757	1035	27.0	20.8	34.2	983	26.4

TABLE XV

Life Test Results

Pore-Type Dispenser Cathodes

T_3 = 1035°C 1.20 amps/cm^2

Diode	Hours	T°C	I_p	I_p-72V	I_p-108V	D_{IP}T°C	I_p@ 1005°C
M17	0	1035	60.0	45.0	78.5	993	55.5
E_p = 90V	16	1033	61.0	45.5	75.9	1020	52.5
E_f = 11.0V	92	1035	54.5	41.0	67.5	1007	51.5
	184	1036	58.5	43.5	75.0	1017	51.2
	305	1034	58.7	38.0	63.0	1002	50.8
	423	1033	57.4	43.0	71.0	1008	51.2
	592	1036	53.9	40.0	66.0	----	----
	757	1034	54.0	40.8	68.0	997	53.6
				I_p-78V	I_p-118V		
M14	0	1035	60.0	44.5	69.0	995	56.0
E_p = 98V	16	1035	61.4	45.0	78.5	975	56.0
E_f = 11.0V	92	1037	58.5	44.5	75.0	975	55.5
	184	1034	60.4	45.0	76.5	976	55.5
	305	1037	56.0	42.0	71.0	967	52.2
	423	1035	57.0	42.0	71.5	963	56.4
	592	1035	53.2	39.7	70.4	---	----
	757	1037	52.9	39.3	67.2	969	57.4

TABLE XVI

Life Test Results

Pore-Type Dispenser Cathodes

$T_4 = 1100°C$ 0.8 amps/cm^2

Diode	Hours	T°C	I_p	I_p-43V	I_p-81V	D_{IP} T°C	I_p @ 1045°C
M21	0	1100	40.0	23.0	52.0	957	37.6
E_p = 67V	18	1102	40.7	23.0	52.4	1005	37.0
E_f = 11.0V	118	1097	38.2	22.0	49.2	1002	35.0
	261	1099	38.6	22.0	49.0	976	33.5
	432	1104	37.9	21.8	48.0	----	----
	576	1102	39.2	22.8	49.9	995	34.0
				I_p-49V	I_p-87V		
M23	0	1100	40.0	24.0	51.0	997	38.0
E_p = 73V	18	1104	40.4	27.5	50.8	963	37.0
E_f = 11.0V	118	1100	38.2	23.4	48.4	976	33.2
	261	1102	40.0	24.5	50.0	1035	31.0
	432	1100	40.0	25.5	49.8	----	----
	576	1100	40.8	25.9	47.0	1045	31.0

TABLE XVII

Life Test Results
Pore-Type Dispenser Cathodes
T_4 = 1100°C 1.6 amps/cm^2

Diode	Hours	T°C	I_p	I_p-89V	I_p-132V	D_{IP}T°C	I_p @ 1045°C
M19	0	1100	80.0	61.0	94.0	1049	77.0
E_p = 110V	18	1104	83.0	72.4	108.0	1029	81.0
E_f = 11.0V	118	1105	77.7	59.0	98.0	1006	71.5
	261	1102	78.7	62.0	100.0	1037	66.0
	432	1100	79.0	62.0	98.5	----	----
	576	1104	80.2	61.3	100.0	1039	75.0
				I_p-84V	I_p-128V		
M22	0	1100	80.0	59.0	100.0	1039	73.0
E_p = 106V	18	1102	87.0	65.5	110.0	1042	77.0
E_f = 11.0V	118	1105	82.0	62.8	107.0	1052	66.5
	261	1100	83.0	64.5	110.0	1038	65.0
	432	1104	85.0	65.3	110.0	----	----
	576	1102	85.0	66.5	110.0	1030	73.0

After the diodes were set for operating parameters, they were burned for the time noted in Table X through XVII.

At the stated time intervals, the diodes were checked for cathode temperature and anode current at the predetermined constant plate voltages. Then, plate current can read at ± 20% of the prescribed plate voltage.

The diodes were tested for dip temperature at each interval of life burning. Cathode current at 95% of the operating temperature was determined from the curve tracing obtained by the dip test method.

After the electrical testing was completed, the diodes were replaced on the life burning rack, recalibrated, and allowed to run until the next test interval.

An analysis of the test data shows 4 diodes out of 16 to have changed 10% in the operating anode current at a constant voltage. One diode at T_2 - 0.8 A/cm^2, one diode at T_3 - 0.6 A/cm^2, and two diodes at T_3 - 1.2 A/cm^2 have shown this change in cathode current. At the present time, no significance or reason can be assigned to this change of 10% in anode current for 4 diodes. Further life burning and analysis of the test data is necessary before any conclusions can be drawn from the test results.

In summary, the diodes are operating satisfactorily up to this time in life burning.

5.0 PLANS FOR THE THIRD INTERIM PERIOD

The third interim period of this study, from October 1 to December 31, 1967, will include the following work schedule:

a. Continue life testing of pore-type dispenser cathodes.

b. Review and reevaluate test diodes using coated particle cathodes.

c. Preage and test diodes using barium strontium oxide cathodes.

d. Start life testing of barium strontium oxide cathodes.