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RAYTHEON **Technical Report**

PT-1846

FIRST ANNUAL REPORT

THERMIONIC CATHODE EVALUATION STUDY

MICROWAVE AND POWER TUBE DIVISION

MICROWAVE TUBE OPERATION, WALTHAM, MASS. 02154

RAYTHEON COMPANY
Microwave and Power Tube Division
Waltham, Massachusetts

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FIRST ANNUAL REPORT
THERMIONIC CATHODE EVALUATION STUDY

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January 1, 1967 - March 31, 1968

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ABSTRACT

Raytheon's Materials and Techniques Group has been conducting a study of the dc life capabilities of three different cathode types for the Jet Propulsion Laboratory.

A life test diode has been designed and tested for conformance with the required cathode current densities as specified for this study.

A 48-position life test station was designed, constructed and tested for use in this program.

One hundred twenty-six test diodes with pore-type dispenser, standard barium strontium oxide, and coated particle cathodes were fabricated for use in this study.

Sixteen diodes using pore-type dispenser cathodes have completed at least 4700 hours of life burning satisfactorily at temperatures ranging from 950°C to 1100°C with cathode current from 0.2 A/cm^2 to 1.6 A/cm^2.

Sixteen diodes using standard barium strontium oxide cathodes have completed life burning in times ranging from 1371 to 3439 hours. The diodes are showing cathode emission slump at current densities above 0.15 A/cm^2 and temperatures ranging from 800°C to 850°C and cathode currents from 0.075 A/cm^2 to 0.6 A/cm^2.

The coated-particle cathodes show the capability of being operated up to 0.55 A/cm^2 at 900°C. Further tests with higher current levels above 0.55 A/cm^2 show unexpected inhibited emission in comparison to pulsed emission; this discrepancy is under investigation.

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1.0 INTRODUCTION

The Materials and Techniques Group of Raytheon's Microwave 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.

This first annual report is a summation of the work completed during the period of January 1, 1967 to December 31, 1967 and the fourth interim period of January 1 to March 31, 1968.

The life capabilities and thermionic properties of the following electron tube cathode types are being evaluated during the period of this study.

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

A life test vehicle has been designed and tested for conformance with the required cathode current densities as specified for this study.

The diode test vehicle is a glass test structure using plane parallel geometry with a viewing port in the anode for determination of cathode temperature.

A total of 126 diodes containing the three cathode types were constructed, exhausted, and tested for use in this program.

Thirty-two diodes using pore-type dispenser and standard barium-strontium oxide cathodes have been selected for life burning.

A 48-position life test station was designed , constructed and tested for use in this program.

The thirty-two diodes have been on life burning for periods ranging from 1371 to 4796 hours.

Difficulty has been experienced in drawing over 0.3 A/cm^2 from the coated particle cathode at temperatures below 850°C.

2.0 THERMIONIC CATHODES

The three different thermionic cathodes used in this study have been designed and manufactured and are being used in test diodes under the varying current loading conditions required for this study.

2.1 Pore Type Dispenser Cathode

Fifty pore-type dispenser cathodes were built for use in this study. The pore-type dispenser cathode consists of an emission pellet 0.100 ±0.001 inch in diameter and 0.045 ±0.001 inch thick. This emitter is a porous tungsten pellet impregnated with a molten mixture of barium oxide, strontium oxide and aluminum oxide. Its thermionic emission mechanism consists of a monolayer of barium metal on oxygen on the tungsten face of the cathode.

Barium metal is generated by chemical reaction of the mixture of oxides with tungsten metal in the pores of the cathode. Barium is continually being generated and diffuses through the pores of the tungsten body to the surface of the cathode, replenishing the evaporating barium on the surface.

This pore-type dispenser cathode generally operates at 1100°C and has a work function of 1.9 - 2.1 electron volts. The cathode has capabilities of operating up to 50 amperes/cm^2 under vaying conditions of operation, i.e., pulse or dc operation. Emission failure occurs when the tungsten emitting surface is devoid of barium atoms. The emission failure is generally sudden and catastrophic.

The tungsten pellet is machined from a slug of copper impregnated tungsten which has a controlled porosity of 20 - 22%. The tungsten slug is carefully manufactured by controlled hydraulic pressing and sintering of pure tungsten power capable of passing through a 325-mesh sieve. Following the high temperature sintering, the tungsten slug is impregnated with molten OFHC copper at high temperature in a hydrogen atmosphere.

After machining, the copper in the tungsten pellet is removed by vacuum distillation and the porosity of the body is determined from the loss of weight of copper.

The porous tungsten pellet is polished with fine emery paper to a diameter of 0.100 ±.001 inch. It is then inserted into a molybdenum sleeve, 0.103 inch inside diameter and 0.230 inch long, and is peened into the shoulder of the sleeve.

The mixture of barium, calcium and aluminum oxides is now loaded on the emitting face of the cathode and is melted and absorbed into the pores of the porous tungsten body by high temperature heating in dry hydrogen.

After impregnation, the cathode is cleaned by polishing off the excess mixture. The cathodes are stored in vacuum until used.

2.2 Standard Barium-Strontium Oxide Cathode

The standard barium-strontium oxide cathode (better known as the oxide cathode) consists of a metallic body, machined from 0.1% zirconium metal in pure nickel, upon whose face is sprayed a layer of barium and strontium carbonates.

The metallic body of the cathode consists of a 0.1% Zr-Ni sleeve with an inside diameter of 0.093 ±.001 inch and an outside diameter of 0.0124 ±.001 inch. One end of the sleeve is closed, thus forming the emitting surface of the cathode (thickness = 0.045 inch).

The oxide coating used is a standard Raytheon mixture known as C51-3, which consists of a weighted mixture of Baker's RM No. 3, nitrocellulose, butyl acetate and butye alcohol. Baker's RM No. 3 is a standard 50 - 50 molar ratio of barium and strontium carbonates which has been used by the vacuum tube industry for over 25 years.

This mixture is sprayed upon the face of the cathode to give a thickness of 0.002 to 0.0025 inch and a coating density of one gram/cm^3.

Approximately 100 cathode bodies were machined to dimension and chemically cleaned by existing Raytheon Company standards. Fifty of these cathodes were sprayed with the standard oxide mixture and were stored in vacuum until used.

The oxide cathode normally operates in the temperature range of 750°C - 900°C and has a work function of 1.0 - 1.2 electron volts. The cathode is generally used for cathode loadings from 0.03 - 0.20 amperes/cm^2 under dc operating conditions.

2.3 Coated Particle Cathode

The third cathode involved in this study is the coated particle cathode as described in the Bell System Technical Journal, December 1967, pp 2375 - 2404.

The cathode at present is being manufactured by Raytheon Company and is being tested and used in several Raytheon vacuum tube devices.

The cathode coating differs from the conventional barium-strontium carbonate coating in that each particle is covered with a thin layer of mond nickel. Total weight of the nickel amounts to 1% ± 0.3% of the total weight of coating.

A fluid-bed process is used to coat the alkaline earth carbonate particles. A mixture of nickel carbonyl and hydrogen is bubbled through a suspension of the particles in amyl acetate at a temperature of 120°C. Nickel carbonyl decomposes to nickel and carbon monoxide, with the nickel deposited on the individual particles of the coating mixture.

When the coating process has been completed, nitrocellulose is added to the admixture of coated particles and amyl acetate to make a spray mixture.

50 cathodes made from 0.1% Zr-Ni were sprayed with the coated particle coating to the same specifications as mentioned in Section 2.2 (T = 0.002 - 0.0025 inch, D = 1 gm/cm^3).

The coated particle cathode operates in the range of 750°C - 850°C and has a work function of 1.2 - 1.4 electron volts. It is claimed that this cathode will operate up to 1 amp/cm^2 for long periods of time.

Theoretically, the system should withstand higher current density loading because of the continuous nickel path through the body of the coating which provides higher electrical conductivity.

3.0 THE DIODE TEST VEHICLE

3.1 Description

The diode test vehicle employed in this study is an adaptation of a quality control vehicle presently used for cathode material testing by the Materials and Techniques Group.

Construction of the diode is shown in Figure 1.

The diode is a plane-parallel type with a large, flat, winged anode, 1 inch square, and a small disc-type cathode which is the top surface of a hollow cylinder.

The proposed diode is constructed of metals compatible for each type of cathode. Both the stem and the glass envelope are made from Corning No. 772 nonex type hard glass. The dimensions of the sealed-in vehicle are 1.5 inch diameter by 4.25 inch height. The sealed-in glass vehicle is mounted in an octal bakelite base of 1.3 inch diameter.

The cathode is heated to desired temperature by radiation from a heater incerted into the cathode sleeve. Cathode temperature is monitored and controlled by visual observation through a hole in the anode, or by optical or infrared pyrometry. A swing type movable flap is closed over the hole in the anode to limit barium evaporation to the top of the glass envelope during the life burning cycle of the diode. The anode is of heavy construction to lessen overheating of the anode during test and life burning.

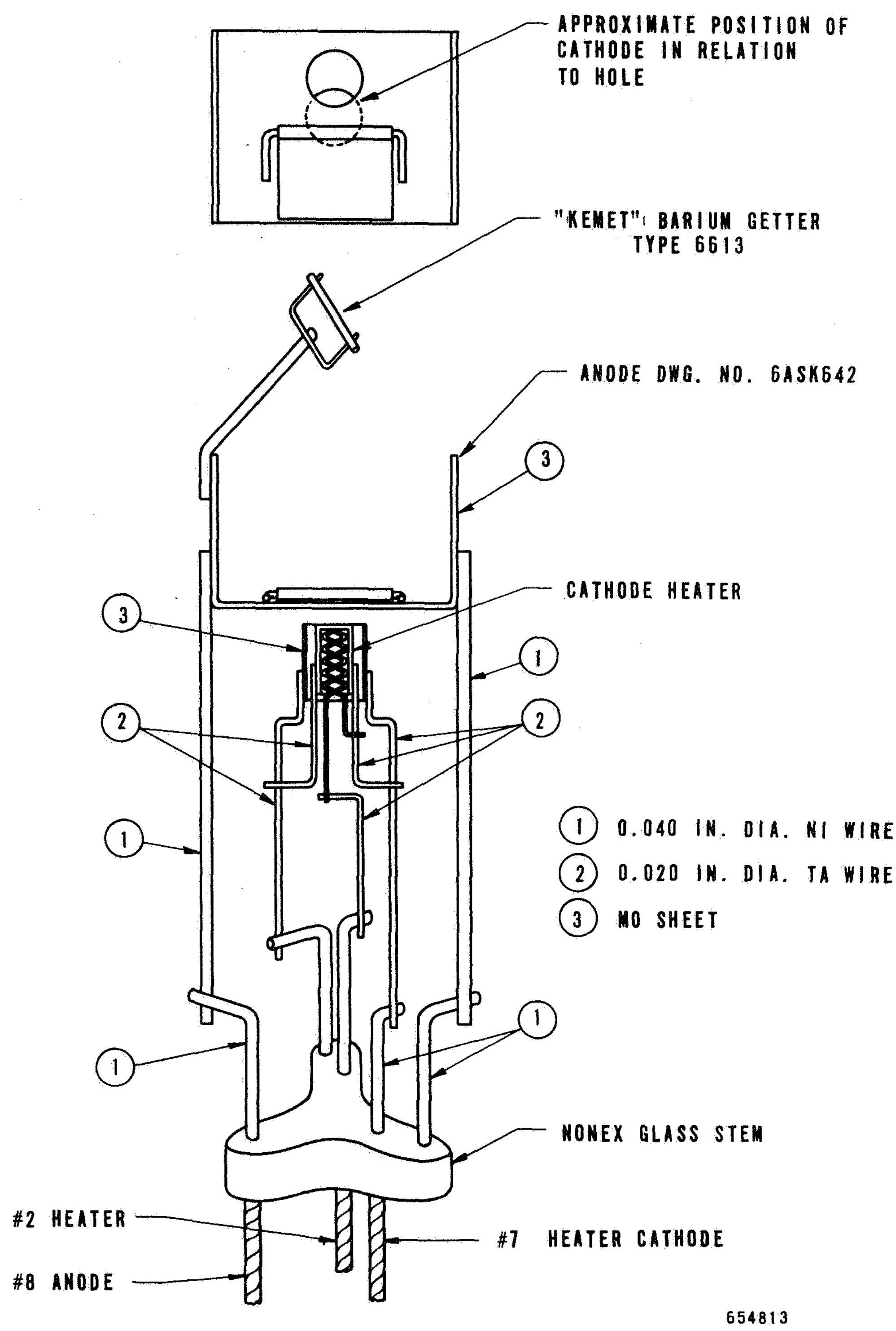


Figure 1. Diode Assembly for Thermionic Cathode Evaluation Study

The maximum dissipation of heat within the vehicle is 8 - 10 watts anode power and 10 watts heater power.

3.2 Construction

A total of 132 diodes were constructed during the first year of this study.

Thirty-six diodes using pore type dispenser cathodes were constructed for initial tests (12) and life testing (24). These diodes used the materials shown in Figure 1. All the metal parts were fabricated and chemically cleaned by the cathode section of the Materials and Techniques Group.

Cathode-to-anode spacing was held at 0.015 inch to allow the diodes to operate at a maximum wattage dissipation at 8 - 10 watts on the anode. The most extreme test condition required for the pore type dispenser cathode is $E_P = 100$ V and $i_p = 0.080$ mA.

Forty-eight diodes were constructed with the standard barium-strontium oxide cathode, of which 12 were used for initial testing and 36 diodes were used for selection of vehicles for life testing.

The test diodes, built for T_1 and T_2 test conditions were spaced 0.025 inch from cathode to anode. The diodes for T_3 and T_4 test specifications were spaced 0.015 inch from cathode to anode. Forty-eight diodes using coated particle cathodes were constructed for initial test (12), life testing (24) and investigative testing (12). In all cases, the cathode-to-anode spacing was 0.015 inch.

The diodes for the oxide and coated particle cathodes used materials different from those shown in Figure 1. All the metal parts within these diodes were Grade A nickel alloy. The parts were fabricated and chemically cleaned by existing standards by the laboratory.

The construction of the diodes was performed in an air conditioned and humidity controlled room.

The welds in the diode were performed by resistance welding as shown in Figure 2. A stream of helium gas was blown on the weld during the operation to minimize oxidation of the weld joint.

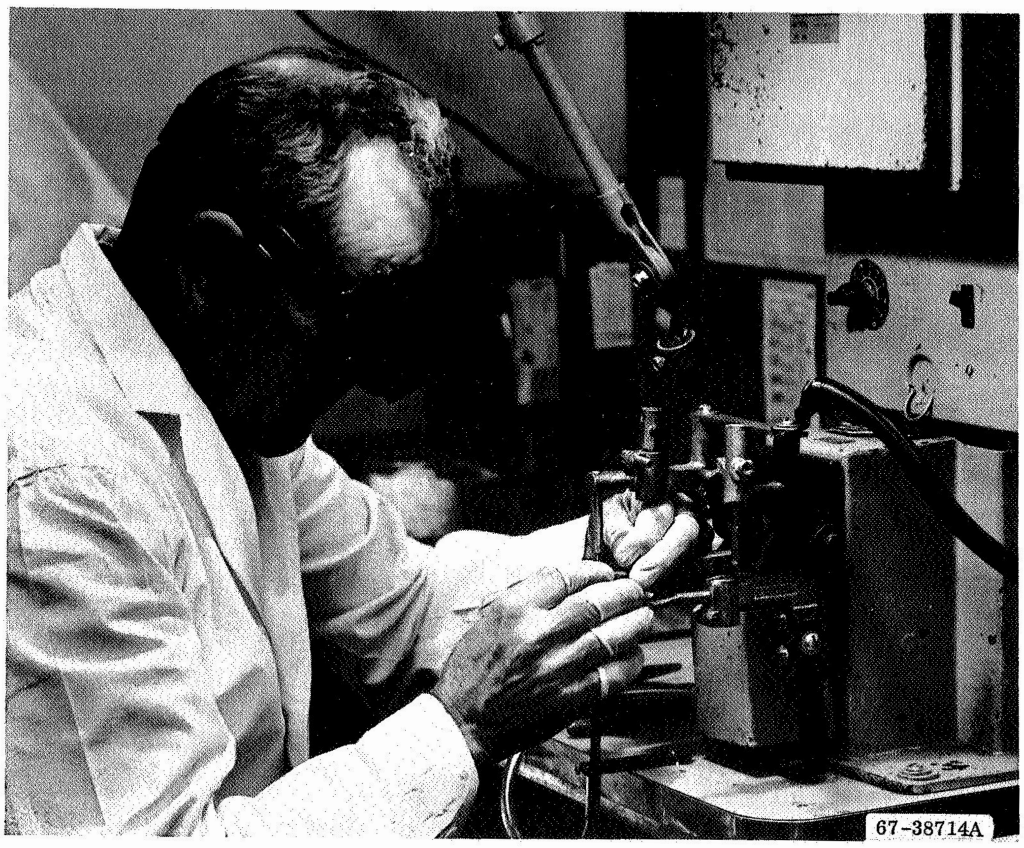


Figure 2   Resistance Welding of Diode Test Vehicle

4.0 EXHAUST PROCEDURES

4.1 Exhaust System

Exhaust processing of all the diode test vehicles was performed on the exhaust system shown in Figure 3. The system is located in a limited access area of the Material and Techniques Group and is under the supervision of the personnel who designed and built the unit originally. The unit has an overall length of 6 feet and width of 3 feet. It is capable of maintaining a vacuum of 10^{-9} torr and is equipped with an electric oven for bakeout of 6 vacuum diodes simultaneously. Each of the 6 exhaust ports has its own 8-litre VacIon pump and vacuum shut-off valve. The system is backed by a K3 Kinney compound pump for rough vacuum pumping and by an oil diffusion pump (200 l/sec) and nitrogen cold trap for medium vacuum range pumping (10^{-3}-10^{-6} torr).

Each glass vehicle is sealed to a glass port which is attached to a stainless-steel, vacuum-tight flange. Each tube has its own vacuum pumping system and cannot contaminate the other tubes during the bakeout and exhaust processing step.

Initial loading, vacuum pumping, and 16-hour bakeout at 450°C are outlined in detail in Table I.

At this point, the load of tubes should be in the 10^{-9} torr vacuum range and the glass parts should be relatively free of gas and water vapor.

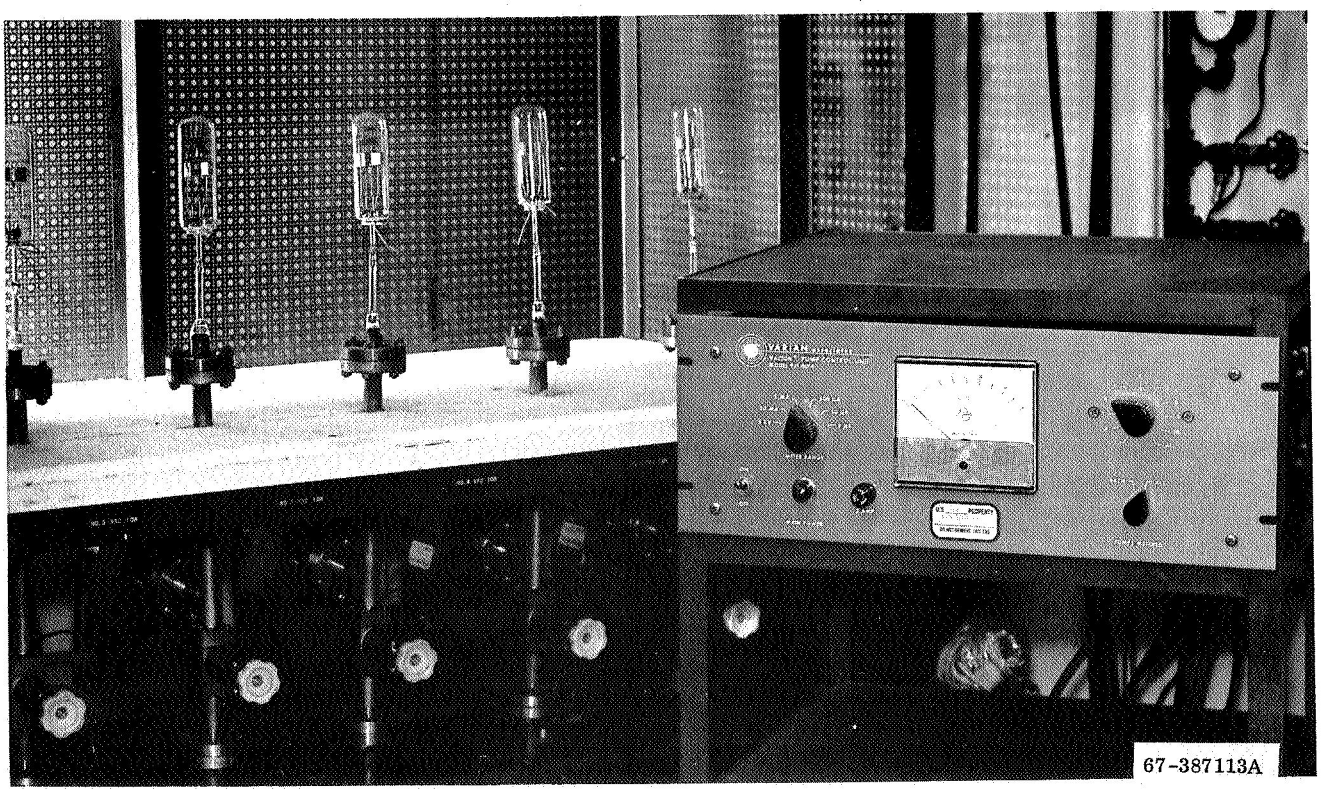


Figure 3 Exhaust System for Diode Test Vehicle
(Cathode Laboratory)

TABLE I

Exhaust Unit Operation Through Bakeout

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

4.2 Exhaust Processing of Pore-Type Dispenser Cathodes

The pore-type dispenser cathodes were exhaust-processed according to the schedule shown in Table II.

TABLE II

Exhaust Processing of Pore-Type Dispenser Cathodes

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

Cathode temperature was read during the exhaust cycle by means of an optical Pyrometer (Leeds Northrup Cat. No. 8622c) aimed through the anode hole.

The main point of interest during the exhaust cycle is the degassing of the cathode and auxiliary metal parts of the tube. Chemical generation of barium metal starts in the cathode pores, and the surface of the cathode shows the presence of barium metal at the tube seal-off step.

In all, 36 diodes were exhaust processed during this period of the study by the aforementioned exhaust schedule. Twelve diodes were used for initial evaluation of the test structure, and 24 diodes were processed for final life test selection. One diode was lost because of an air leak, leaving 23 diodes for life test evaluation.

4.3 Exhaust Processing of the Barium-Strontium Oxide Cathode

Forty-eight test diodes using the standard oxide cathode were exhaust processed during this period. Of these, 12 diodes were used for initial evaluation of the test structure. Twenty-four diodes using 0.015 inch cathode-to-anode spacing were exhaust processed with a yield of 21 acceptable diodes for life testing, and 12 diodes with 0.025 inch cathode-to-anode spacing were acceptable for life test evaluation.

The procedure for exhaust processing is shown in Table III.

TABLE III

Exhaust Processing of Barium Strontium Oxide Cathodes

a.	After bakeout, the vacuum on each diode should be on the 10^{-9} torr scale.
b.	Degas Getter.
c.	Outgas anode at 900°C for 1 minute.
d.	Heat cathode to 1050°C keeping pressure below 1×10^{-4} torr (approximately 10 minutes).
e.	Hold 5 minutes at 1050°C.
f.	Drop cathode temperature to 950°C and hold 10 minutes.
g.	Turn off heater.
h.	Repeat steps (b) - (g) for other 5 diodes.
i.	Seal off 6 diodes. Vacuum on each tube should be on the 10^{-9} torr scale.
j.	Flash Getter.
k.	Attach bakelite bases to tubes.

The chemical reactions occurring during the exhaust process of this cathode are entirely different from those of the pore-type dispenser cathode.

In addition to accomplishing the degassing of auxiliary metal parts of the diode, other gaseous end products are produced by the chemical reactions for producing barium metal in the cathode system.

The initial step in cathode processing is the conversion of the cathode coating to the oxides.

$$\text{No. 1 - } \left.\begin{matrix} BaCO_3 \\ SrCO_3 \end{matrix}\right\rangle \longrightarrow \left.\begin{matrix} BaO \\ SrO \end{matrix}\right\rangle + 2\ CO_2 \uparrow$$

This is accomplished by heating the cathode as rapidly as possible to an elevated temperature (1050°C) and pumping off the carbon dioxide gas through the vacuum pumping system.

The second step in the processing of the cathode is the generation of barium metal within the oxide coating body.

When the cathode is heated, minute quantities of reducing impurities (i.e., zirconium) will diffuse to the surface of the cathode at the interface of the nickel body and the oxide coating. Zirconium metal will react chemically with either the alkaline earth carbonates or alkaline earth oxide; the reaction is dependant on the state of decomposition of the cathode coating.

If the reducing impurity sees a carbonate, the reaction will be as follows, in the case of barium carbonate:

$$\text{No. 2 - } BaCO_3 + M \longrightarrow BaO + MO + CO \uparrow$$

If the reducing impurity sees an oxide, the reaction will be as follows in the case of barium oxide:

$$\text{No. 3 - } BaO + M \qquad BaO + MO + Ba$$

In summarizing the barium generating reactions, the alkaline earth carbonates should be reduced to the oxides as rapidly as possible to prevent the deleterious reactions from taking place (Reaction No. 2).

During the lifetime operation of the oxide cathode, we have a system generating barium continuously. The reducing impurity diffuses to the nickel cathode surface, reacts with barium oxide, produces free barium metal, and eventually evaporates from the coating to the nearest cool surface.

The current loading capabilities of the oxide cathode are dependent upon the number of barium atoms present within the oxide coating. The concentration of barium within the coating will decrease during the lifetime of the tube and will eventually deplete itself. The current capabilities of the oxide cathode will show a gradual decay and eventual failure during the lifetime operation of the cathode.

4.4 Exhaust Processing of the Coated Particle Cathode

Forty-eight test diodes using the coated particle cathode were exhaust processed during this first year of study. Twelve diodes were used for initial evaluation of the test structure. Thirty-six diodes for life test evaluation were exhausted with a yield of 32 diodes for test. The procedure for exhaust processing is shown in Table IV.

Chemical reactions during this exhaust processing are the same as in the case of the barium-strontium oxide cathode. The cathode is processed very slowly to 850°C to convert the alkaline earth carbonate to the oxides and to minimize the oxidation of the nickel particles in the body of the coating. The barium producing mechanism is the same as in the case of the oxide cathode.

Both types of cathode should generate the same amount of barium metal and have approximately the same life capabilities and the same failure mechanism.

The only chemical mechanism present that will reduce the free barium supply is the oxidation of the nickel member of the coating during cathode processing and the subsequent reduction of the nickel oxide by the free barium present in the coating to form barium oxide.

TABLE IV

Exhaust Processing of Coated Particle Cathodes

a.	After bakeout, the vacuum on each diode should be on the 10^{-9} torr scale.
b.	Degas Getter.
c.	Outgas anode at 900°C for 1 minute.
d.	Heat cathode slowly to 850°C keeping pressure below 5×10^{-6} torr (approximately 90 minutes).
e.	Raise cathode temperature to 1050°C rapidly and hold for 20 minutes.
f.	Draw 50 miliamperes of current to anode and hold for 3 minutes.
g.	Drop cathode temperature to 950°C.
h.	Repeat step (f).
i.	Drop cathode temperature to 850°C.
j.	Repeat step (f).
k.	Turn off heater.
l.	Repeat steps (b) - (k) for other 5 diodes.
m.	Seal off 6 diodes. Vacuum on each tube should be on the 10^{-9} torr scale.
n.	Flash Getter.
o.	Attach bakelite bases to tubes.

5.0 ELECTRICAL TESTING AND SELECTION OF TEST DIODES FOR LIFE BURNING

5.1 Electrical Test Procedures

The selection of test diodes was made in accordance with the required method of selection as shown in Figure 4 and Table V.

The method of selection was to match the required zero field current level with the lowest possible temperature for each condition shown in Table V.

The diodes were tested for zero field current levels in the electrical test rack shown in Figure 5.

The diodes were mounted on the rack with the anode flap open. After the cathodes were heated, the temperature of each diode was adjusted to the desired level by means of a 4-ohm variable resister in each heater circuit. The anode flap was then closed and the cathode current was recorded from 0 to 150 volts dc in 25 volt steps. The zero field plot was extrapolated from these collected data. The activation status of the cathode was checked using the Bell Telephone Laboratory's "dip test" method as described in the IRE transactions PGED, Jan. 1958, "Dip Testing, a New Method for Measuring Cathode Activity," Page 43.

The test circuit is shown in Figure 6 for dip testing of cathode activity.

The diode was set into a socket with the anode flap in the open position. Cathode temperature was monitored by means of an optical pyrometer. Then, the infrared pyrometer was pointed at the cathode surface and was calibrated and set to read the optical temperature of the

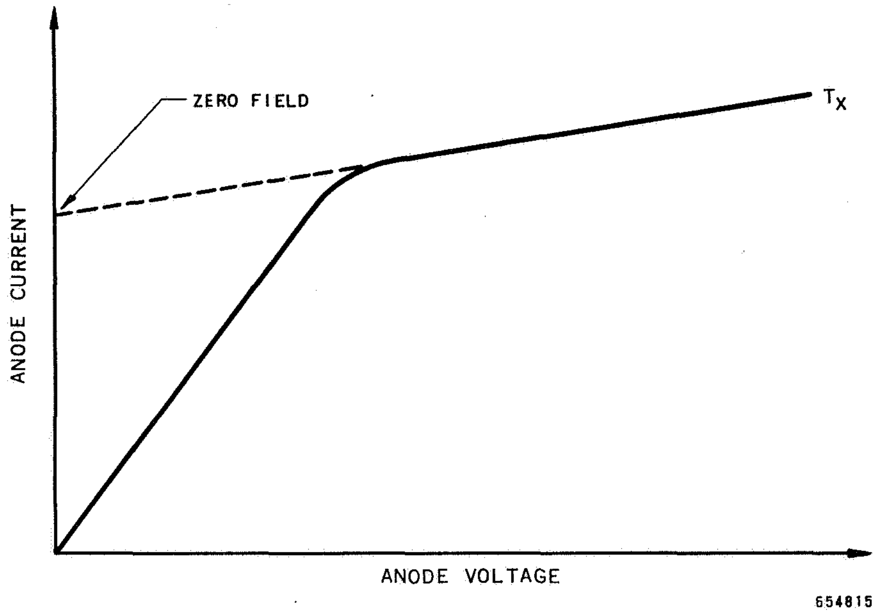


Figure 4 Current Density Level (JPL Specification)

TABLE V
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

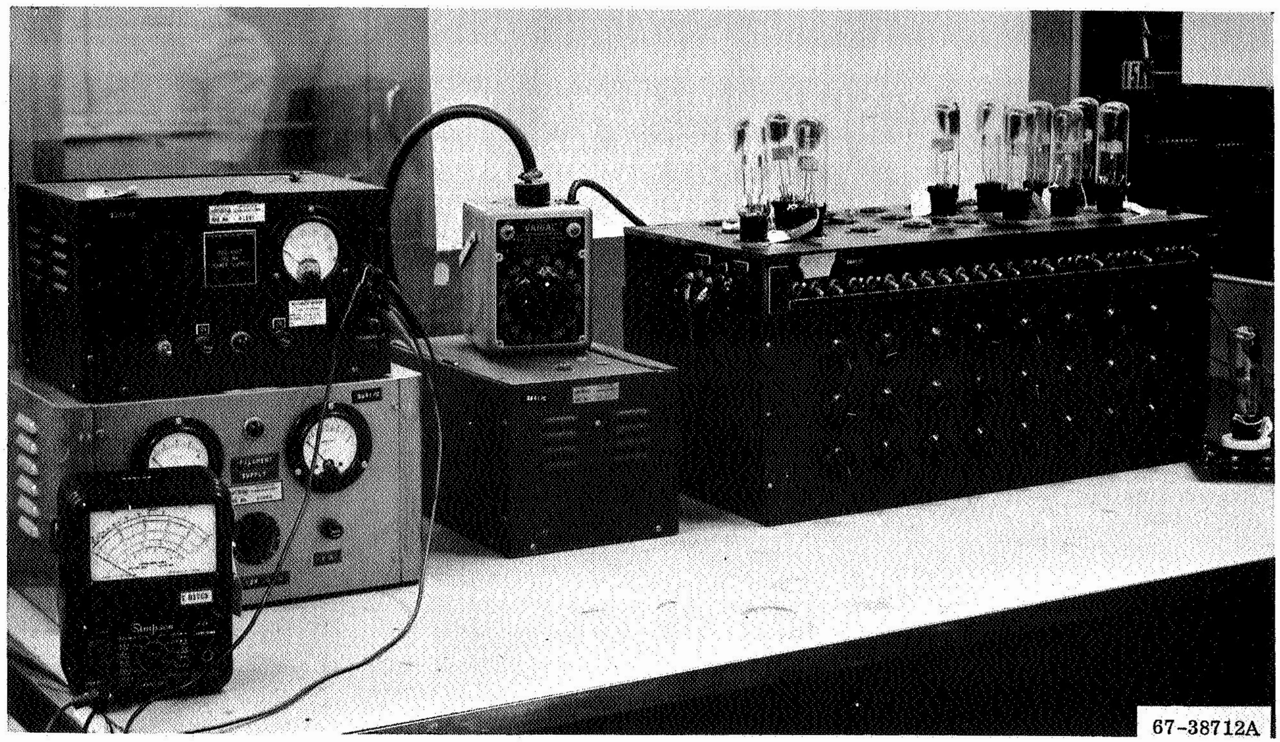
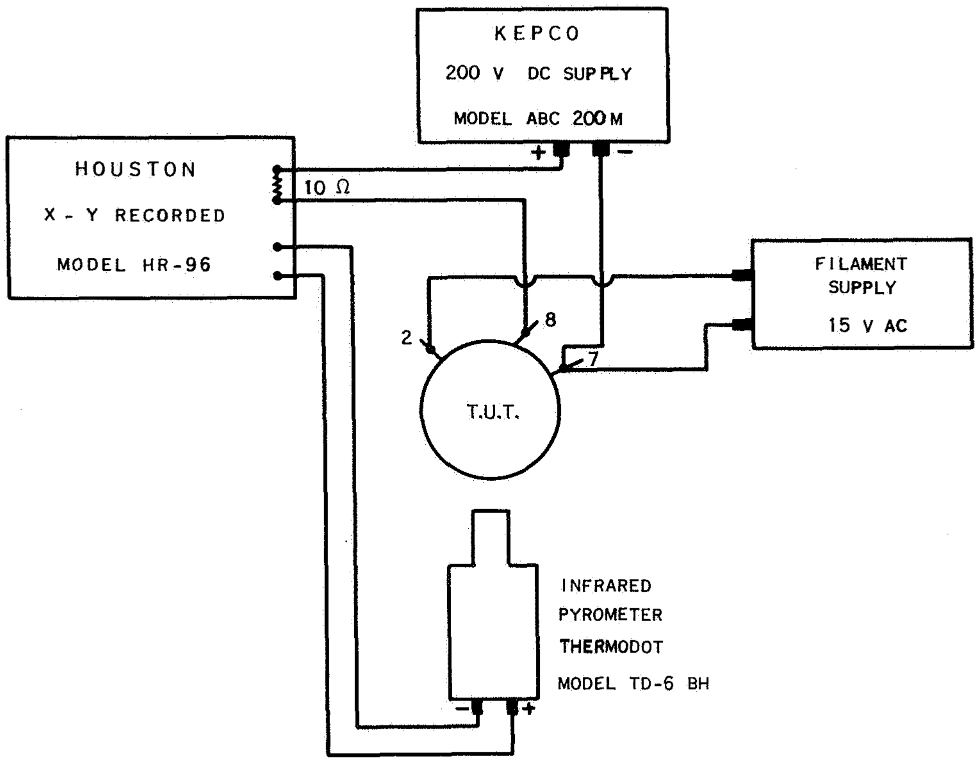


Figure 5 Diode Electrical Test Rack (Cathode Laboratory)



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

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Figure 6 Dip Test of Diode Vehicles

cathode from the prescribed temperature to room temperature in the X-axis of a recorder. The anode current was set on the Y-axis to read from the desired current level to 0 current.

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

Diodes which successfully achieved the zero field current levels and showed sufficient dip temperature were used for life test evaluation of the three cathode types.

5.2 Pore Type Dispenser Cathodes

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

The diodes were first tested for zero field current density for two diodes using pore type dispenser cathodes. The current level for tube M-3 is shown on the left side of the graph and for tube M-4 on the right side of the graph. Figure 7 shows the plot of zero field current.

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 V, Electrical Test Procedure). The 2 tubes had a zero field current level of $0.4/cm^2$ at 900°C (0.020 A x 20 $= 0.2$ A/cm^2). However, a subsequent dip test showed the two tubes to be operating in the temperature-limited emission region.

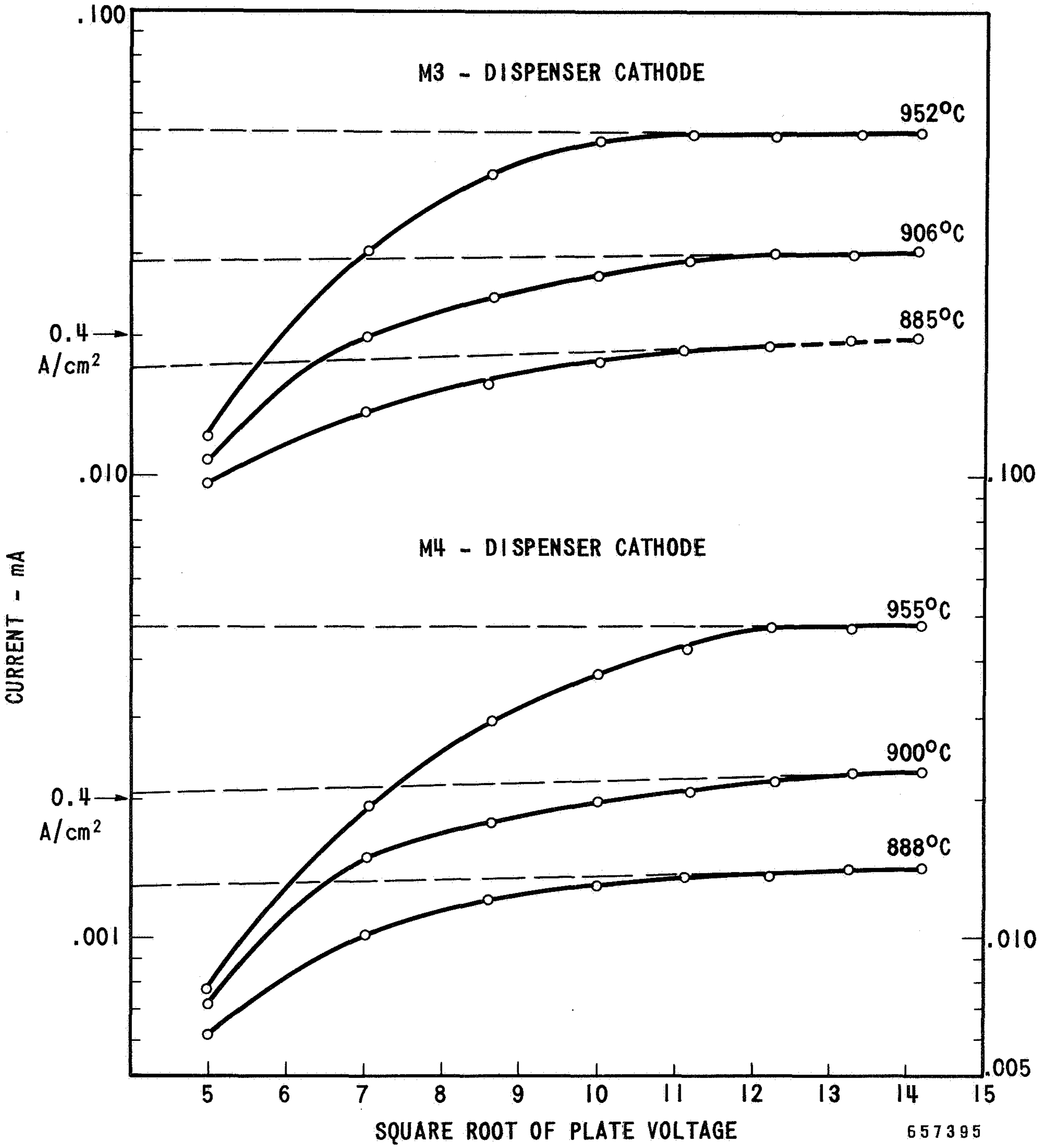


FIGURE 7 Zero Field Current Density

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 VI 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 amp/cm^2.

Final temperatures selected were 950°C at T_1, 985°C at T_2, 1035°C at T_3 and 1100°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 8, 9, 10 and 11.

TABLE VI

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

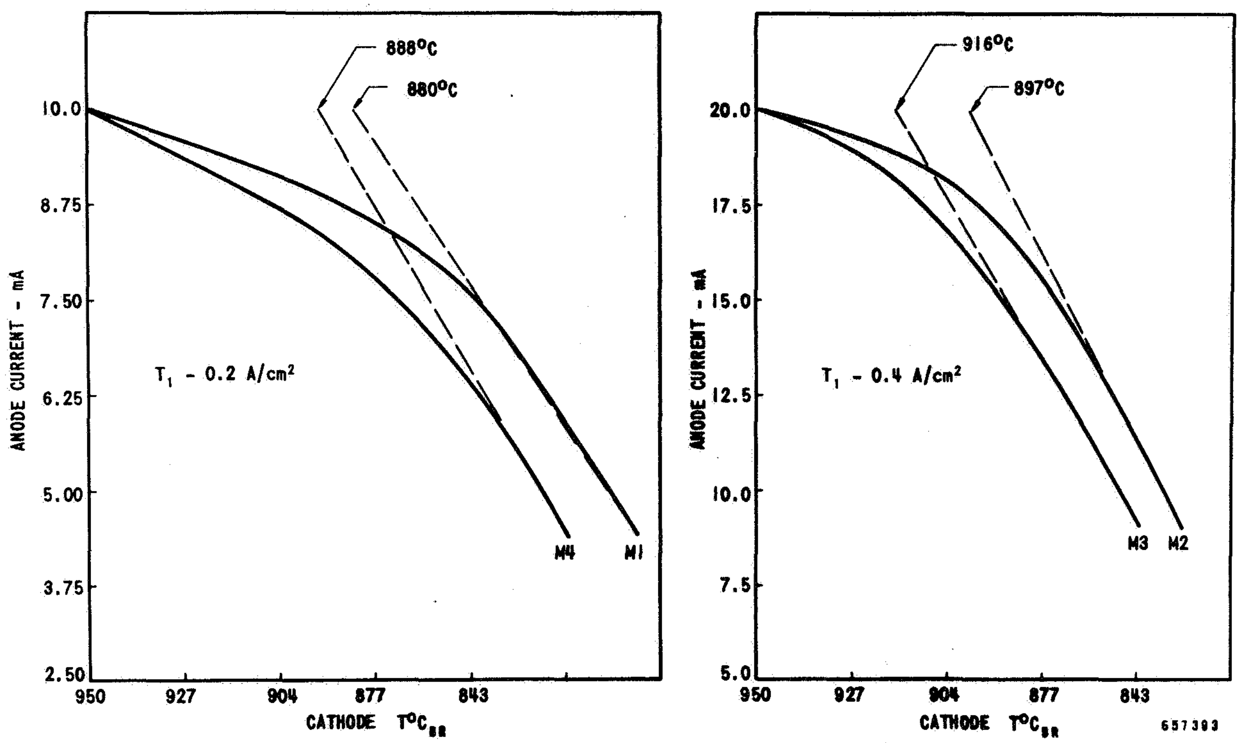


Figure 8 Pore-Type Dispenser Cathode Dip Test

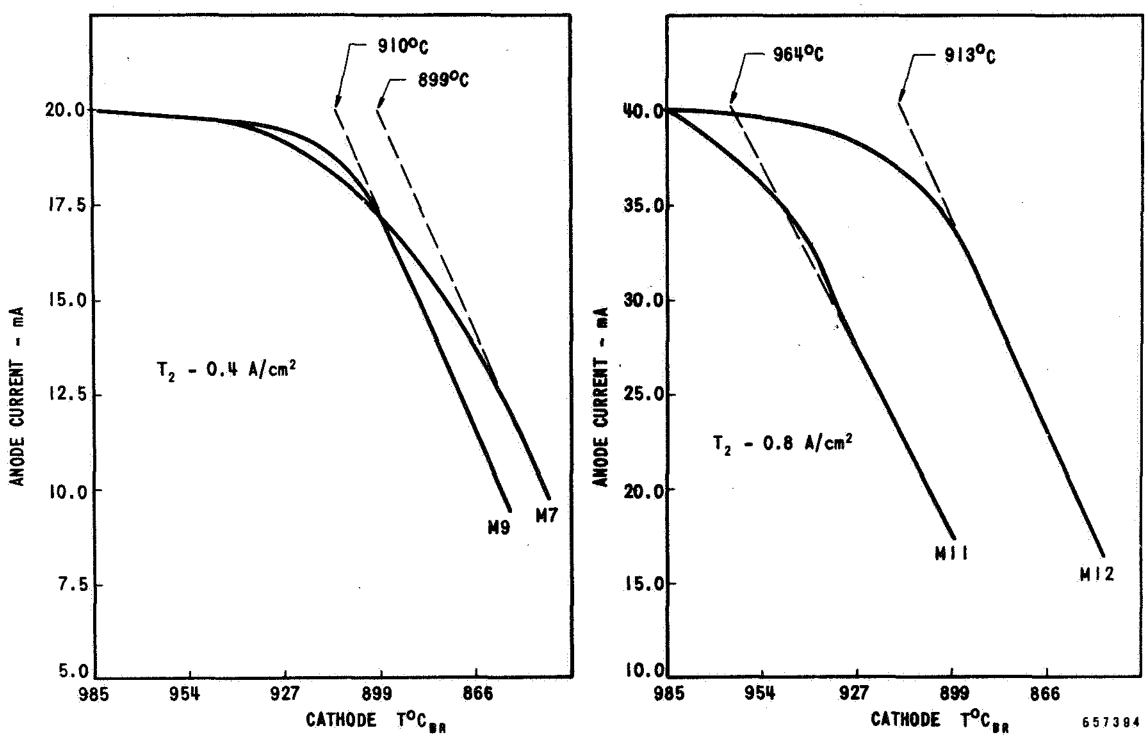


Figure 9 Pore-Type Dispenser Cathode Dip Test

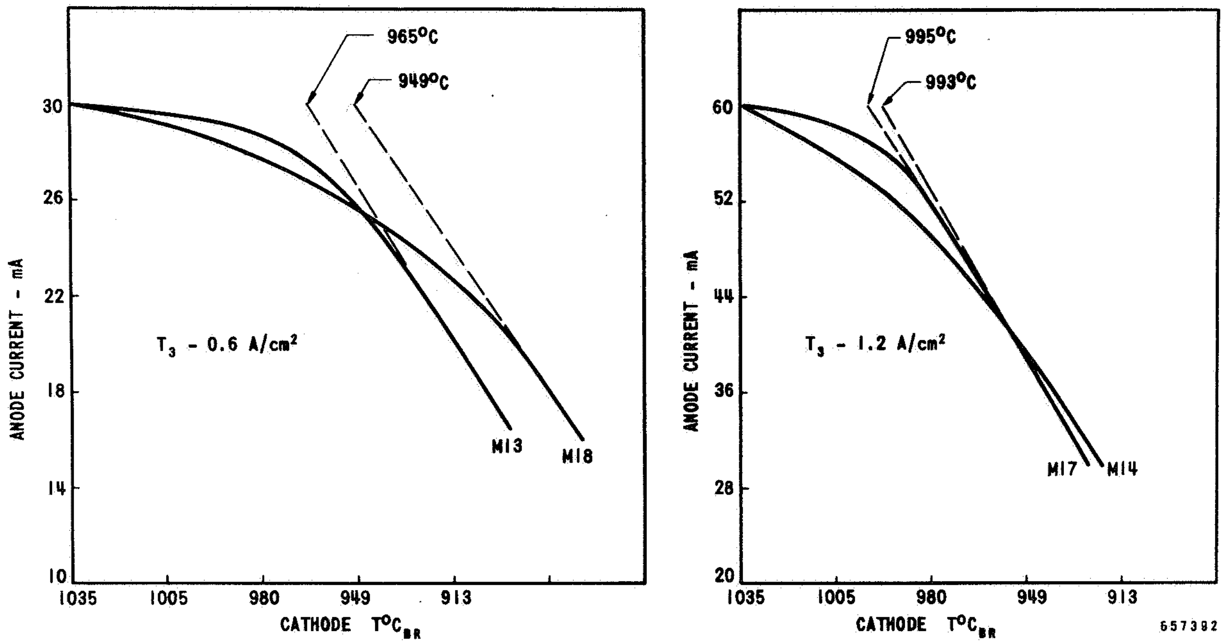


Figure 10 Pore-Type Dispenser Cathode Dip Test

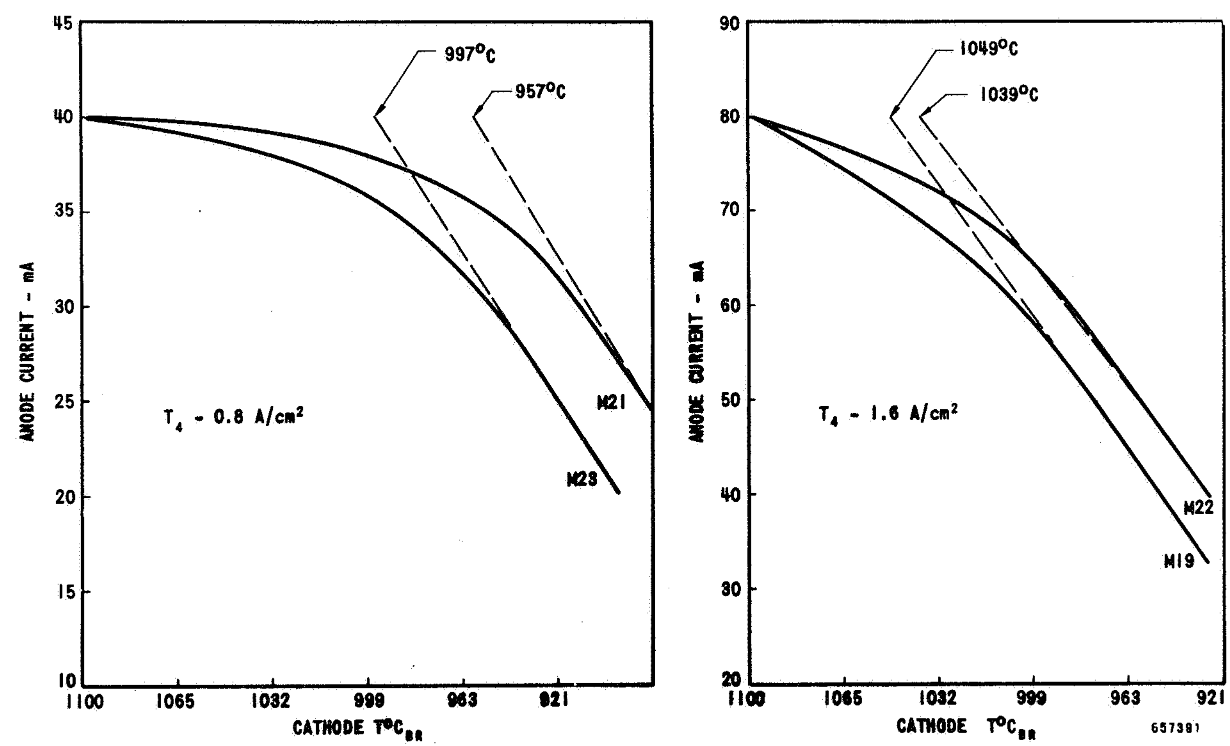


Figure 11 Pore-Type Dispenser Cathode Dip Test

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.

5.3 Standard Barium-Strontium Oxide Cathodes

The test diodes using the standard oxide cathode with 0.015 inch cathode-to-anode spacing were numbered O1 through O24 for identification.

The diodes were preaged on the electrical test rack (Figure 5) up to 150 hours at 50 volts E_p with the cathode temperature at 850°C.

The diodes started out at very low plate current levels (0 - 5 ms) and gradually built up to the levels shown for a representative sample of 10 diodes in Table VII.

It was also observed that, when testing diodes with oxide cathodes at voltages higher than 100 V dc, the anode current had a runaway tendency toward higher levels. When the diodes showed rapid increases in current levels, a greenish ion glow was observed at the cathode surface. When the voltage was changed to lower levels, the cathode current showed an increase and then a gradual decrease to the levels as shown in Table VII.

It was impossible to obtain good zero-field-emission plots for oxide cathodes because of their failure to saturate at higher dc voltage levels.

TABLE VII

Oxide-Coated Cathodes
Emission Measurements
At 850°C Cathode Temperature

Tube No.	25V	50V	75V	100V
O 1	25	32	37	41
O 2	21	26	26	26
O 4	15	36	50	56
O 7	25	57	98	150
O 8	24	55	92	136
O10	12	31	45	60
O11	15	35	52	62
O12	22	50	61	77
O13	11	25	36	47
O14	10	25	37	50

The estimated zero-field current levels at 850°C cathode temperature are 0.5 A/cm^2 to 0.7 A/cm^2. (Cathode current in mA x 12.7 = A/cm^2.

Because of the difficulty in obtaining satisfactory zero-field emission data, the test diodes were selected by dip testing.

Figure 12 shows the dip-temperature for four diodes selected for operation at the T_4 condition of 0.3 and 0.6 A/cm^2 at 850°C.

Figure 13 shows the dip-temperature for four diodes selected for operation at the T_3 condition of 0.225 A/cm^2 and 0.45 A/cm^2 at 825°C.

The test diodes using the standard oxide cathode with 0.025 inch cathode-to-anode spacing were numbered O30 - O42.

The cathode-to-anode spacing for the diodes needed to meet the low current requirements under T_1 and T_2 conditions had to be increased from 0.015 inch to 0.025 inch because of the unacceptable low plate voltage drop across the diode.

It is desirable to keep the anode voltage above 10 volts dc (at least at 20 volts) to prevent the undesirable 10.0 volt effect.

Eight diodes were selected for life testing under the requirement for oxide cathodes at the T_1 and T_2 conditions.

The dip temperatures for diodes under T_2 conditions are shown in Figure 14 and for T_1 conditions in Figure 15.

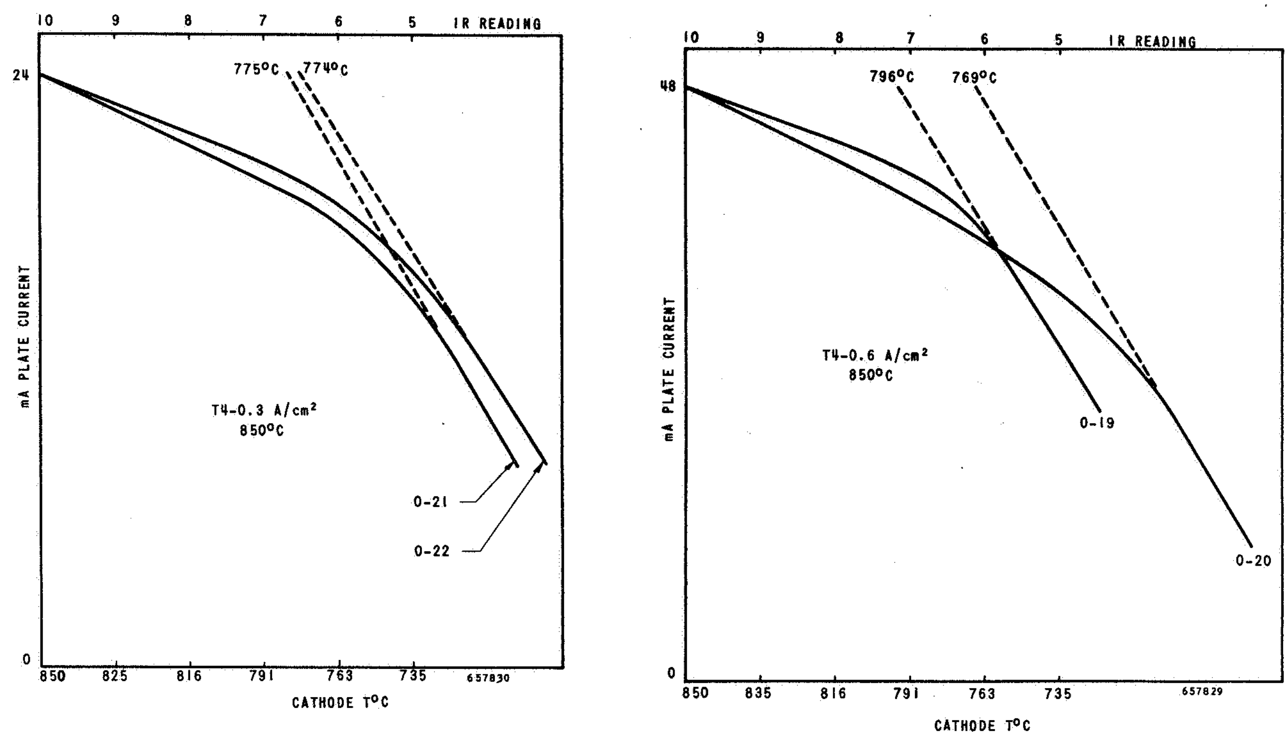


Figure 12 Diodes O-19/20/21/22 - Oxide-Coated Cathode Dip Test

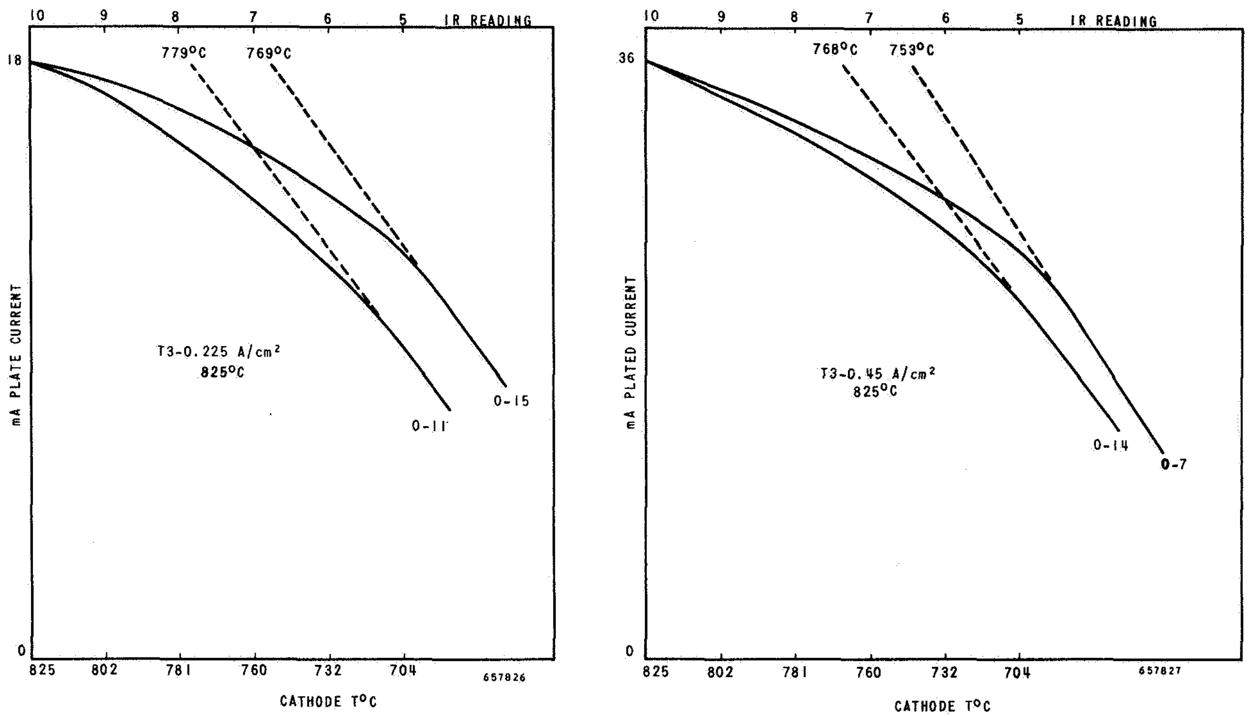


Figure 13 Diodes O-7/11/14/15 - Oxide-Coated Cathode Dip Test

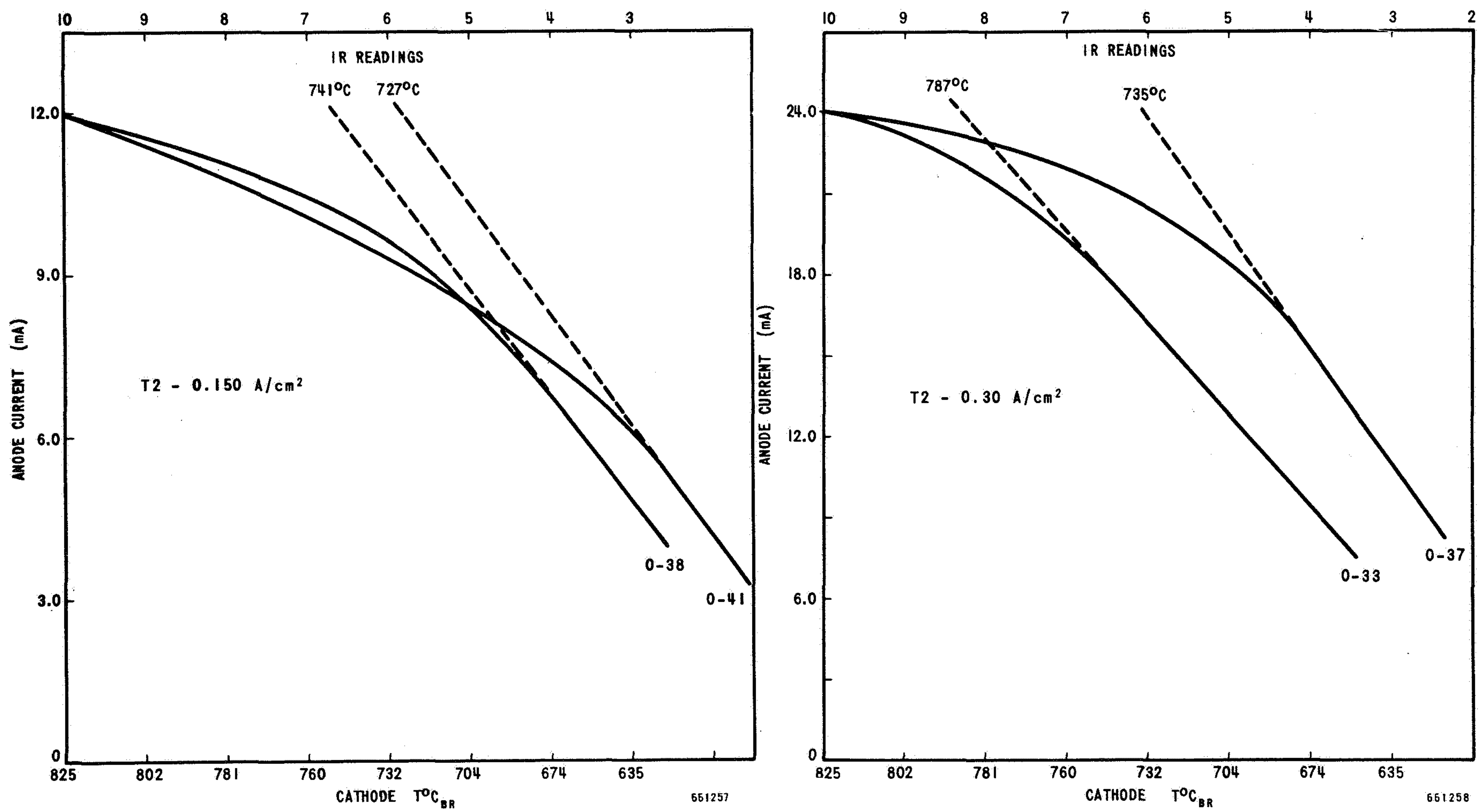


Figure 14 Diodes 0-38/41/33/37 - Oxide Coated Cathode Dip Test

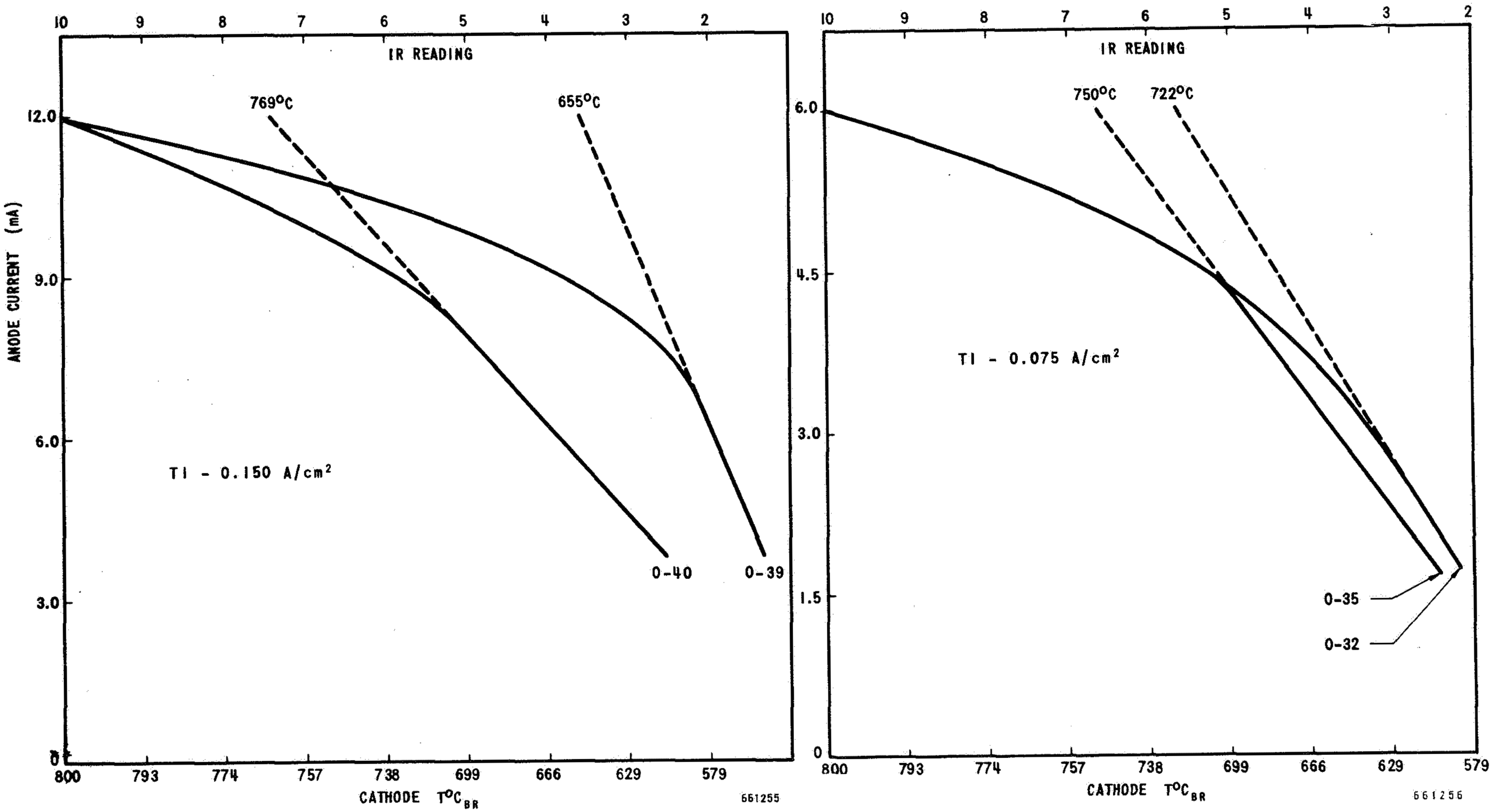


Figure 15 Diodes 0-32/35/39/40 - Oxide-Coated Cathode Dip Test

At this point, the diodes using the standard barium-strontium oxide cathode were considered to be ready for life burning.

5.4 Coated Particle Cathodes

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

The diodes were preaged on the electrical test rack (Figure 5) up to 150 hours at 50 volts E_p with the cathode temperature at 850°C.

The diodes, at the initial stages of burning, showed very low plate currents (0 - 5 mA) and gradually built up to the levels shown in Table VIII in the forementioned time periods.

TABLE VIII

Coated Particle Cathodes
Emission Measurements
At 850°C Cathode Temperature

Tube No.	25V	50V	75V	100V
C 2	25	53	75	90
C 3	33	39	40	43
C 4	29	41	43	43
C 7	30	57	68	72
C 8	17	37	58	63
C 9	11	27	42	53
C10	24	43	48	50
C14	18	39	54	58
C15	12	27	42	64
C16	20	41	80	gassing

Note: Readings are in milliamperes of anode current.

It was observed, while testing the diodes, that voltages applied to the anode higher than 100 V dc would cause the diode to show runaway current levels.

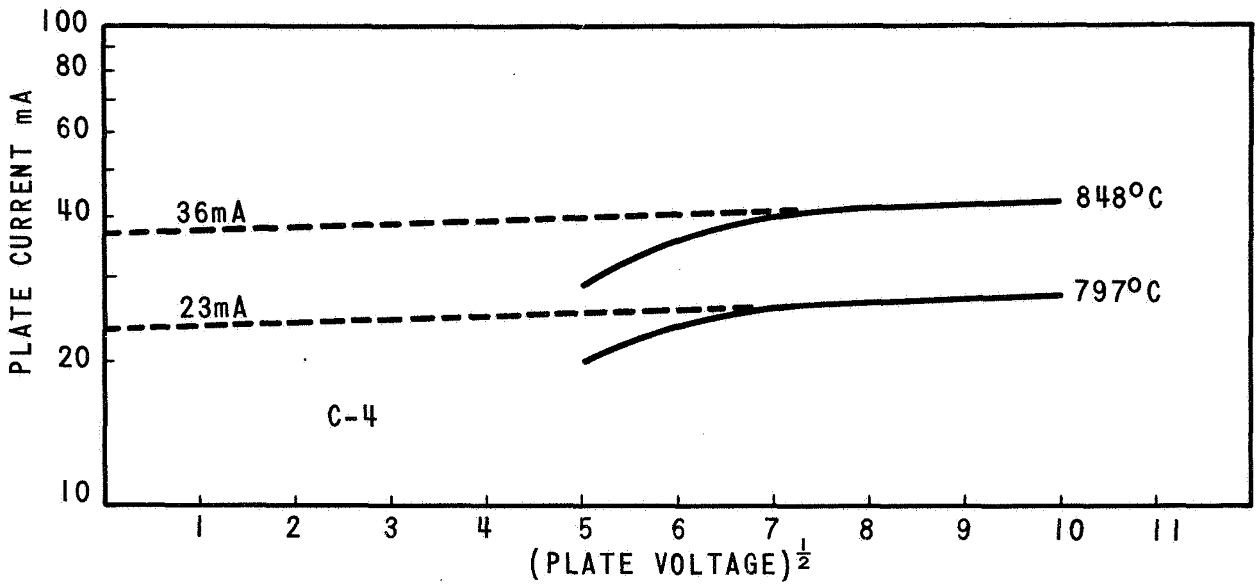
When the diodes showed rapid increases in current levels, a bluish ion glow was observed at the cathode surface. At this point of testing, when the cathode voltage was dropped to lower levels, the cathode current would be higher than shown in Table II. If the cathode was left at lower voltage, the current would decay to its original levels very gradually in a period of 10 - 30 minutes.

For this reason, it was impossible to obtain good zero field-emission plots for coated-particle cathodes. Figure 16 shows the zero field-current density plots for diodes C4, C7, at cathode temperatures of approximately 850°C and 800°C. The point to be noted is the small, unexpected change in zero-field current for a change of 50°C in cathode temperature. The estimated zero field-currents at 805°C are ranging from 0.3 to 0.5 A/cm^2 and at 850°C from 0.5 to 0.7 A/cm^2 in measurable diodes.

The diodes with coated-particle cathodes were next tested for dip temperature under T_1 (0.275 A/cm^2) and T_2 (0.55 A/cm^2) operating conditions as specified in Table V.

The dip-test results for diode no. C-7 are shown in Figure 17. This shows a dip temperature of 770°C for a plate-current level of 0.275 A/cm^2 at 850°C (T_1) and of 877°C for a plate current level of 0.55 A/cm^2 at 900°C (T_2).

Further measurements of other diodes showed the dip temperatures to be between 770 and 830°C at 0.275 A/cm^2 (T_1) and between 870 and 900°C at 0.55 A/cm^2 (T_2).



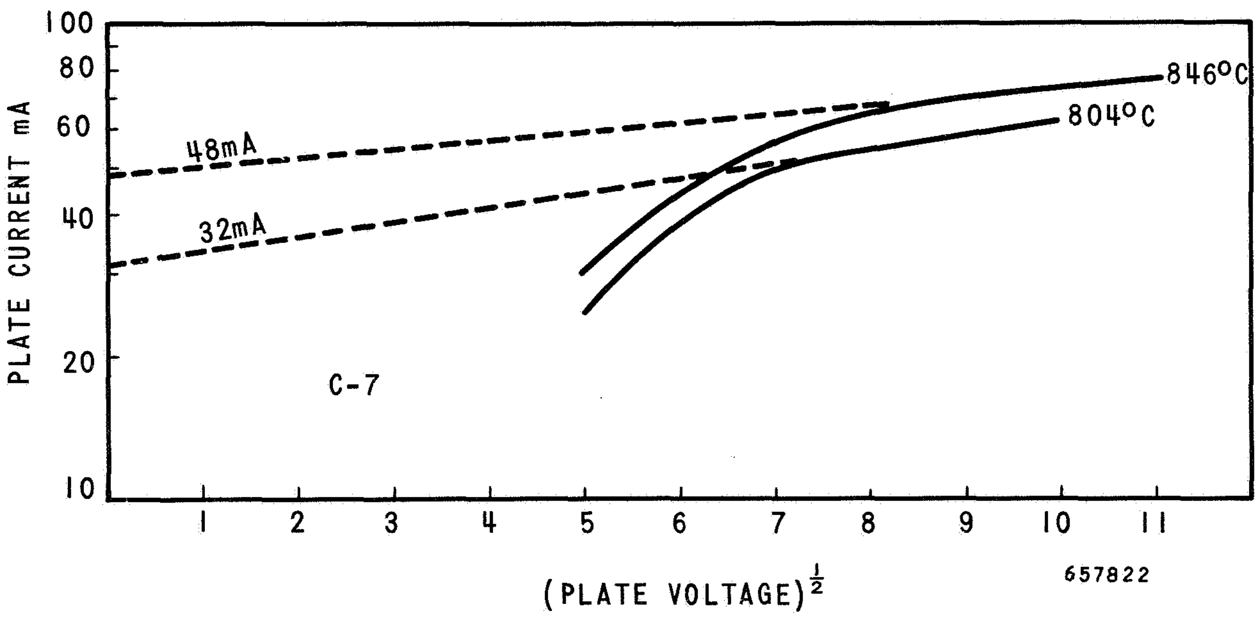


Figure 16 Diodes C-4/7 - Zero Field-Current Density Coated-Particle Cathodes

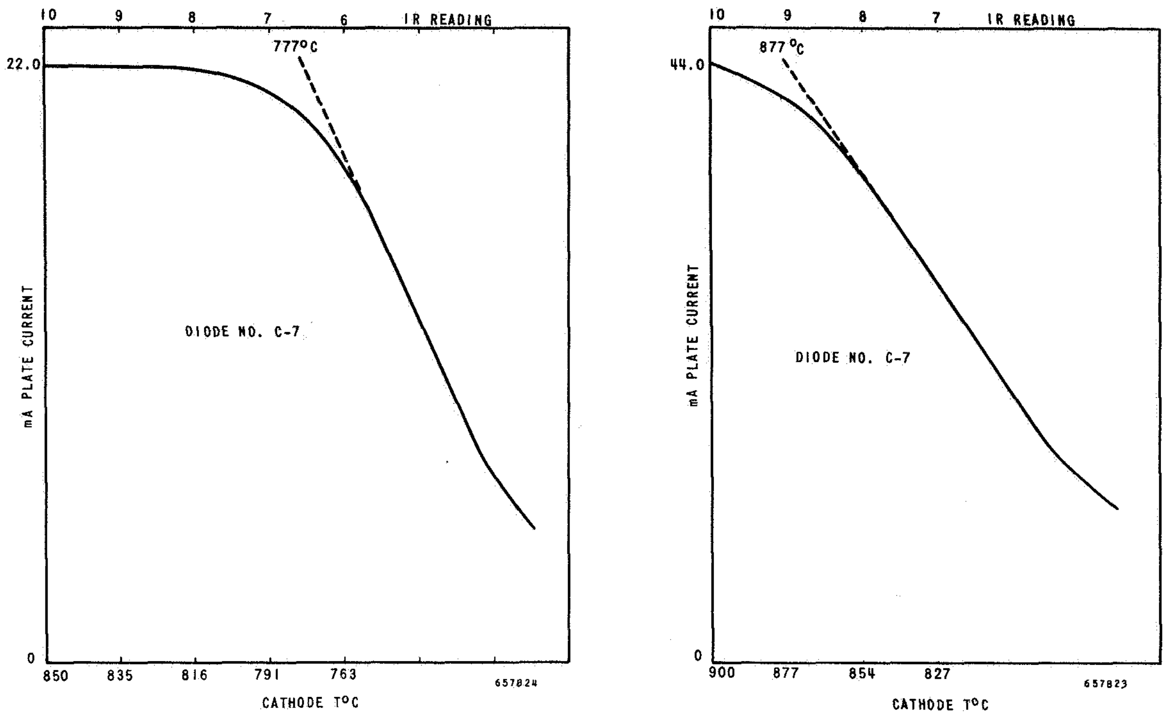


Figure 17 Diode C-7 - Coated-Particle Cathode Dip Test

Dip-temperature measurement at current levels from 0.55 A/cm^2 to 0.83 A/cm^2 at 900°C did not show any space-charge region or measureable dip temperature.

A peculiar change in dip-temperature measurement is noted in Figure 18. Diode No. C-4 was originally measured at 850°C cathode temperature for dip-temperature at 0.275 A/cm^2 and showed the dip-temperature to be 850°C. The cathode temperature was then raised to 900°C and the dip-temperature was determined to be 866°C (Dip No. 1). Then the diode was measured at 0.83 A/cm^2 and the dip-temperature was at 900°C. The test was repeated at 0.275 A/cm^2 and the dip-temperature was lowered to 766°C (Dip No. 2). The diode, on aging 10 minutes at 22 mA, showed a dip-temperature rise to 844°C (Dip No. 3). This condition is repeatable on the same diode and all other diodes at either 850°C or 900°C at 0.275 A/cm^2.

The reason for this change in dip temperature is believed to be caused by temporary electrolytic activation of the cathode.

An analysis of the presented data shows the coated-particle cathode, under the conditions of construction and test, to be capable of meeting the T_1 test conditions (0.275 A/cm^2) at 850°C and the T_2 test conditions (0.55 A/cm^2) at 900°C. Electrical testing at higher current densities at 900°C does not show any appreciable measurement of a dip-temperature.

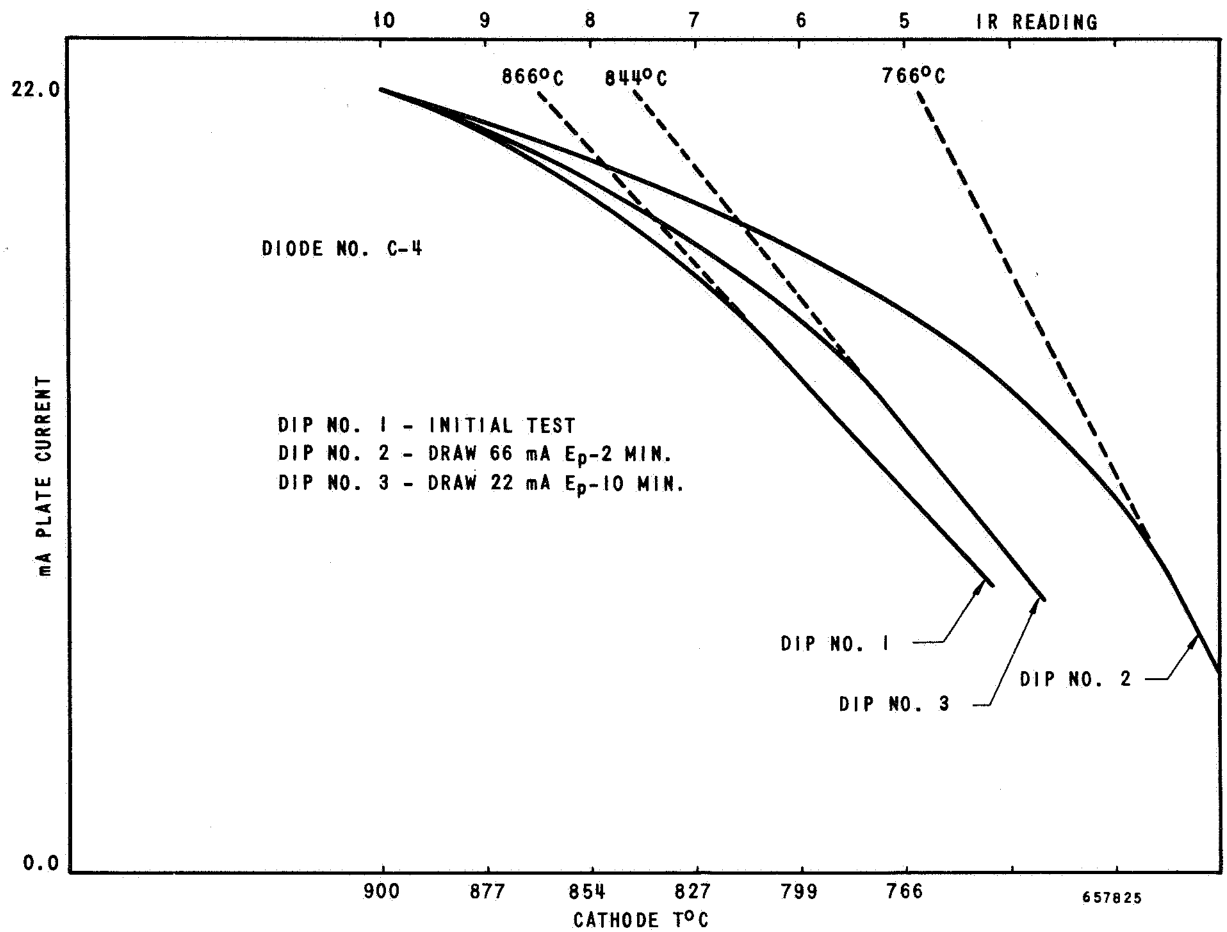


Figure 18 Diode C-4 - Coated-Particle Cathode Dip Test

5.5 Pulse Testing of Oxide and Coated Particle Cathodes

Because of the difficulty experienced with coated-particle and oxide cathodes in obtaining high current densities (1.0 A/cm^2) a series of tests was conducted to compare the dc and the pulsed-voltage behavior of the two cathodes under investigation.

Figure 19 shows the comparison of two oxide cathodes (O-4, 0-12) and two coated-particle cathodes (C-2, C-17) tested under dc and pulsed voltage conditions.

The four diodes under dc operating conditions show deviations from space charge at low current levels.

The same tubes, under pulsed (3% duty cycle, 0.5 ms pulse) show a straight line with a slope equal to 1.23 - 1.30.

An examination of the oscilloscope trace of the square wave form of the pulse does not show any deterioration of the peak pulse line.

It should be noted that the four diodes show the same behavior under pulsed conditions with a deviation from space charge with increased pulse length is not known at this time.

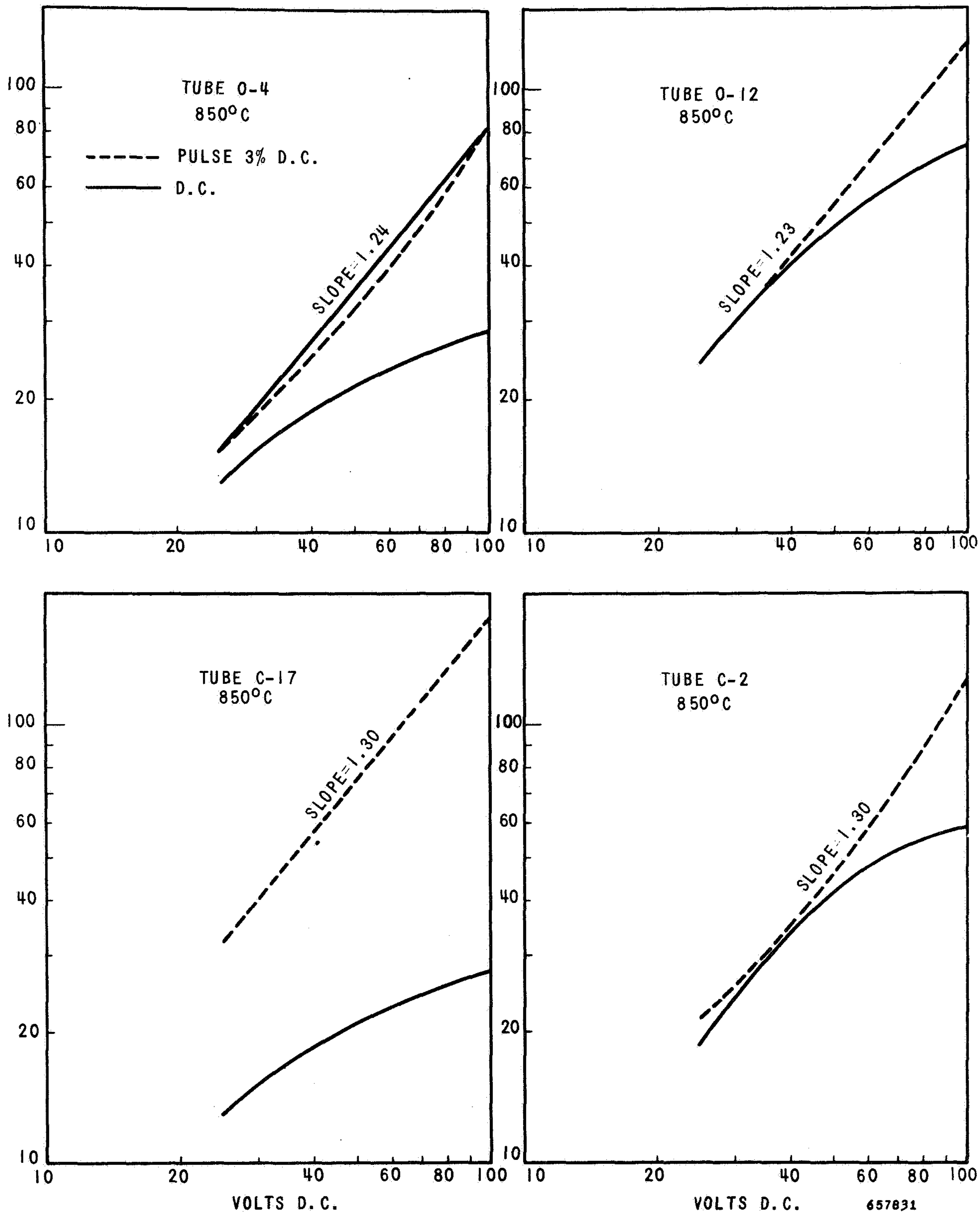


Figure 19 Test Diodes - Dc Conditions Compared to Pulsed Conditions (0.3 ms pulse, 100 pps)

6.0 LIFE BURNING AND TESTING OF DIODES

6.1 Life Test Equipment

To meet the life test requirement for this thermionic cathode study, a life test rack was designed by Raytheon personnel and was constructed by the Cober Electronics Company of Stanford, Connecticut.

The life test equipment was delivered to the Materials and Techniques Group on May 31, 1967. A photograph of the equipment is shown in Figure 20.

The cathode life test rack, Cober Model No. 1369, has 48 test positions with each position having its own controls. Sockets are 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 test position has a 4-ohm, 50 watt rheostat to adjust filament current for 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 module for adjustment of plate voltage which feeds from two Technipower solid-state model L-100.0 - 6.0 M regulated power supplies.

The constant voltage setting on each socket is monitored by a calibrated 7-1/2 inch square tautband meter, Weston Model 1971. It has a sensitivity of 20,000 ohms per volt with internal multipliers permitting two ranges, 0 to 100 V dc and 0 - 250 V dc.

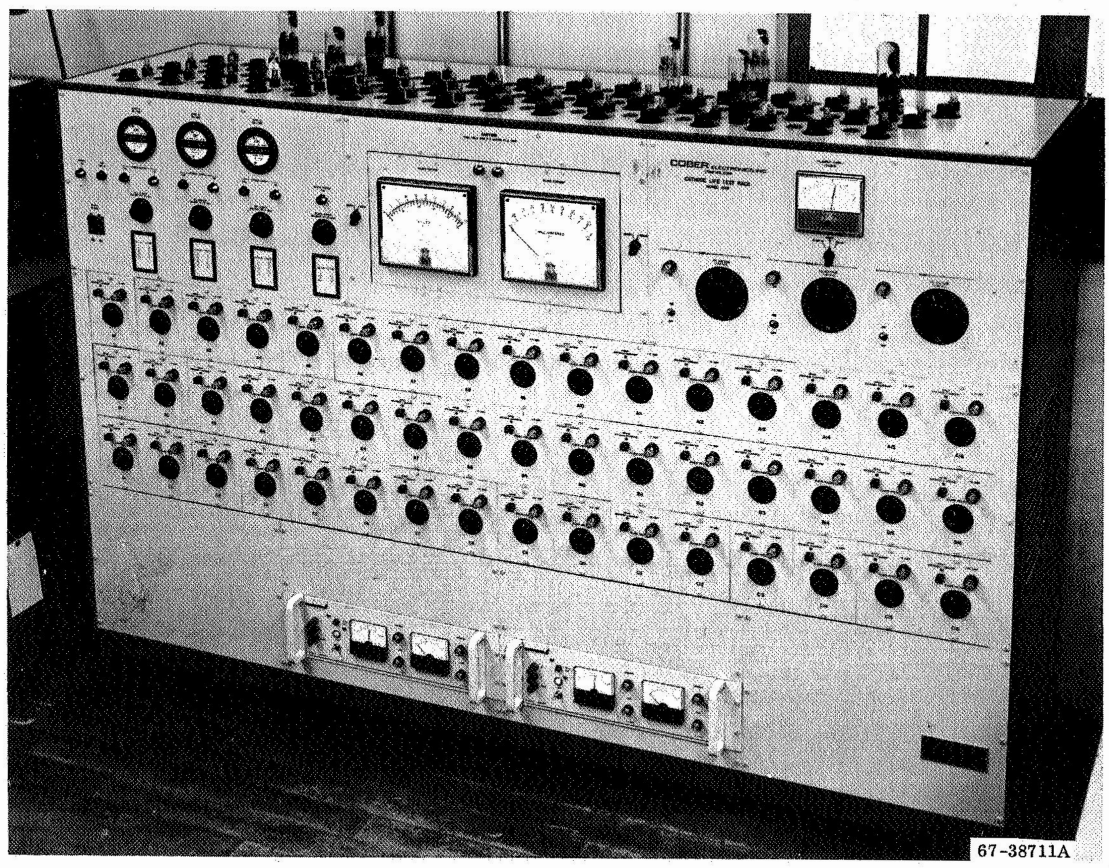


Figure 20 Life Burning Equipment

The life test rack was installed in a limited recess area in the cathode development section of the Materials and Techniques Group.

The equipment has been in operation since June 5, 1967, and the first life test tubes were set up on the rack on August 24, 1967.

The interim period between the two mentioned dates was used for pretesting diode samples and evaluating the reliability of the equipment.

6.2 Life Test Procedure

The test diodes are placed in groups of four into the same bank of sockets according to the required "T" specifications and cathode type.

The life test rack is turned on and the plate voltage supplies are set at 110 V dc. The filaments are raised to a predetermined voltage and each diode is calibrated for cathode temperature by means of the adjustable 4-ohm rheostats. The temperature is monitored by an optical pyrometer thru the open anode flap.

The anode flap is then closed and the individual anode voltage modules are adjusted to give the constant plate voltage necessary to draw the required cathode current as specified in Figure 5.

At each inteval of life testing, the cathode current is recorded at the predetermined anode voltage. The current is also read at ±20% of the specified voltage of the test diode.

The diodes are removed from the life test rack and are read for dip temperature according to the procedure attained in Section 5.1, Electrical Test Procedures. The cathode current is also determined for 95% of the operating temperature from the dip temperature curve tracing.

The diodes are replaced in the life test rack and are recalibrated for cathode temperature and anode voltage.

6.3 Pore-Type Dispenser Cathodes

The test diodes with pore-type dispenser cathodes under T_1 and T_2 and T_3 conditions were placed on life burning on August 24, 1967, and have completed 4796 hours as of the end of this fourth interim period of cathode study.

The life test results are summarized in Tables IX (T_1), X (T_2), XI (T_3).

The test diodes under T_4 conditions were placed on life burning on August 31, 1967, and have completed 4729 hours.

The life test results are shown in Table XII (T_4).

TABLE IX

Life-Test Results
Pore-Dispenser Cathodes

Test	Diode	Hours	I_p	I_p - 20%V	I_p + 20%V	Dip T°C	I_p @ 95% T
T_1 - 950°C	M1			(32V)	(46V)		
0.2A/cm^2	E_p = 39 V	0	10.0	8.4	12.0	880	8.70
	E_f = 9.0 V	757	10.0	8.2	12.7	895	8.30
		1464	11.0	9.0	13.2	920	7.50
		2176	11.0	8.9	13.0	881	8.13
		2688	11.0	8.9	13.2	891	8.00
		3479	11.0	9.0	13.4	906	8.13
		4106	11.0	9.0	13.2	895	7.90
		4796	11.0	9.0	13.2	886	8.69
				(22V)	(32V)		
	M4	0	10.0	8.3	12.5	888	8.81
	E_p = 26 V	757	10.0	8.4	13.0	895	8.60
	E_f = 9.0 V	1464	10.5	8.4	13.0	922	7.00
		2176	10.2	8.6	12.6	881	8.44
		2688	10.0	8.4	12.2	906	8.25
		3479	10.0	8.4	12.1	896	8.13
		4106	9.9	8.2	11.8	901	8.80
		4796	10.0	8.2	11.9	904	7.98
T_1 - 950°C	M2			(39V)	(59V)		
	E_p = 49 V	0	20.0	15.1	27.3	916	19.3
	E_f = 9.0 V	757	21.0	15.8	26.4	895	18.0
0.4A/cm^2		1464	21.4	16.2	26.8	911	17.0
		2176	20.4	15.8	24.8	859	17.6
		2688	21.2	16.1	25.9	896	17.5
		3479	21.0	16.0	25.5	896	17.6
		4106	20.9	16.0	25.4	916	17.9
		4796	21.0	16.2	25.4	896	17.8
				(28V)	(42V)		
	M3	0	20.0	16.5	27.0	897	15.0
	E_p = 35 V	757	21.5	16.4	27.0	891	18.0
	E_f = 9.0 V	1464	22.0	17.0	27.2	921	16.2
		2176	21.2	16.5	25.8	877	17.0
		2688	20.7	16.2	25.2	907	16.6
		3479	21.0	16.4	25.8	901	16.6
		4106	21.5	16.5	26.0	904	16.3
		4796	21.0	16.5	25.8	872	18.5

TABLE X

Life-Test Results
Pore-Dispenser Cathodes

Test	Diode	Hours	I_p	I_p - 20%V	I_p + 20%V	Dip T°C	I_p @ 95% T
T_2 - 985°C				(28V)	(42V)		
0.4A/cm^2	M7	0	20.0	16.8	27.5	899	19.3
	E_p = 34.5 V	757	20.0	15.4	25.0	958	16.4
	E_f = 9.0 V	1464	20.8	16.4	26.4	946	16.6
		2176	20.9	16.5	26.2	968	16.4
		2688	20.0	15.8	24.4	957	16.6
		3479	20.8	16.4	25.8	970	16.8
		4106	22.8	18.0	28.4	954	16.8
		4796	23.3	18.5	29.6	954	16.8
				(30V)	(50V)		
	M9	0	20.0	14.6	28.5	910	18.8
	E_p = 40 V	757	21.2	15.0	27.8	938	17.5
	E_f = 9.0 V	1464	22.2	16.0	29.5	927	16.6
		2176	22.0	15.9	29.1	941	16.6
		2688	22.5	15.9	29.1	938	17.7
		3479	22.5	16.0	29.2	936	18.1
		4106	22.8	16.0	29.4	941	18.8
		4796	22.4	16.0	29.2	938	17.8
				(54V)	(76V)		
T_2 - 985°C	M11	0	40.0	32.0	49.5	964	28.0
0.8A/cm^2	E_p = 65 V	757	35.9	29.0	42.3	966	33.0
	E_f = 9.0 V	1464	35.0	28.8	41.9	976	31.8
		2176	37.5	30.8	45.8	959	33.0
		2688	27.5	30.8	45.8	979	30.3
		3479	37.2	30.5	44.2	963	29.7
		4106	37.0	30.4	43.6	985	27.5
		4796	37.0	30.2	43.6	985	31.3
				(44V)	(64V)		
	M12	0	40.0	31.0	50.0	913	38.0
	E_p = 54 V	757	39.0	30.0	49.5	938	36.0
	E_f = 9.0 V	1464	37.3	29.2	45.5	960	31.9
		2176	36.0	28.3	42.8	951	32.5
		2688	37.0	29.2	45.0	957	32.0
		3479	36.8	28.9	44.4	954	32.5
		4106	35.8	28.2	42.8	985	23.8
		4796	35.0	27.9	42.4	985	31.8

TABLE XI

Life-Test Results
Pore-Dispenser Cathodes

Test	Diode	Hours	I_p	I_p - 20%V	I_p + 20%V	Dip T°C	I_p @ 95% T
				(36V)	(54V)		
T_3 - 1035°C	M13	0	30.0	22.5	38.5	965	29.2
0.6A/cm^2	E_p = 45 V	757	29.8	22.2	38.0	935	28.4
	E_f = 11.0V	1464	30.0	22.4	37.8	965	26.2
		2176	30.0	22.8	36.5	965	26.2
		2688	30.0	23.9	39.8	961	26.4
		3479	31.6	24.0	40.7	961	26.0
		4106	32.0	24.3	40.8	974	25.0
		4796	31.0	24.3	40.5	967	27.4
				(39V)	(59V)		
	M18	0	30.0	21.5	38.0	949	29.2
	E_p = 48.5V	757	27.0	20.8	34.2	983	26.4
	E_f = 11.0V	1464	27.8	20.9	33.7	977	27.0
		2176	28.5	22.0	35.5	985	24.8
		2688	30.0	23.0	37.8	1003	25.6
		3479	31.2	24.0	39.9	974	25.4
		4106	31.5	24.2	39.8	1002	23.6
		4796	31.7	24.5	40.0	1005	24.2
				(72V)	(108V)		
T_3-1035°C	M17	0	60.0	45.0	78.5	993	55.5
1.2A/cm^2	E_p = 90V	757	54.0	40.8	68.0	997	53.6
	E_f = 11.0V	1464	57.5	42.9	70.0	1008	52.0
		2176	59.7	46.2	74.0	985	54.8
		2688	61.2	47.8	77.4	1020	51.6
		3479	62.9	48.7	77.7	1029	50.4
		4106	62.5	45.0	72.9	1035	51.2
		4796	62.9	49.2	76.8	1017	52.0
				(78V)	(118V)		
	M14	0	60.0	44.5	69.0	995	56.0
	E_p = 98 V	757	52.9	39.3	67.2	969	57.4
	E_f = 11.0V	1464	53.0	38.9	66.7	974	56.0
		2176	54.2	40.7	69.9	998	53.2
		2688	54.9	41.2	70.2	977	55.2
		3479	59.7	44.9	76.0	993	53.6
		4106	60.4	45.8	77.0	987	53.6
		4796	61.7	46.4	78.0	974	55.4

TABLE XII

Life-Test Results
Pore-Dispenser Cathodes

Test	Diode	Hours	I_p	I_p - 20%V	I_p + 20%V	Dip T°C	I_p @ 95% T
				(43V)	(81V)		
T_4-1100°C	M21	0	40.0	23.0	52.0	957	37.6
0.8A/cm^2	E_p = 67 V	576	39.2	22.8	49.9	995	34.0
	E_f = 11.0V	1297	42.6	26.0	54.0	1024	34.9
		2009	45.0	27.4	57.4	1021	32.5
		2521	46.4	28.8	59.5	1055	34.6
		3372	46.3	28.0	58.9	1025	33.0
		4039	47.0	28.5	59.4	1053	36.5
		4729	48.0	29.4	60.8	1032	36.0
				(49V)	(87V)		
	M23	0	40.0	24.0	51.0	997	38.0
	E_p = 73 V	576	40.8	25.9	47.0	1045	31.0
	E_f = 11.0V	1297	42.0	27.3	51.4	1072	27.5
		2009	42.5	28.0	51.2	1066	29.8
		2521	37.2	23.9	45.8	1079	31.0
		3312	31.9	20.8	38.8	1086	30.5
		4039	33.5	21.9	41.0	1100	30.3
		4729	34.8	22.9	42.3	1089	34.9
				(89V)	(132V)		
T_4-1100°C	M19	0	80.0	61.0	94.0	1049	77.0
1.6A/cm^2	E_p = 110V	576	80.2	61.3	100.0	1039	75.0
	E_f = 11.0V	1297	80.0	62.4	98.0	1053	65.0
		2009	79.2	62.8	98.5	1066	65.0
		2521	84.5	67.0	104.0	1075	61.0
		2713	HEATER BURNOUT				
				(84V)	(128V)		
	M22	0	80.0	59.0	100.0	1039	73.0
	E_p = 106V	576	85.0	66.5	110.0	1033	73.0
	E_f = 11.0V	1297	87.0	68.3	110.0	1065	59.0
		2009	87.1	71.3	110.0	1051	66.0
		2521	86.5	71.7	110.0	1072	61.0
		3312	86.0	72.0	110	1069	62.5
		4039	87.0	74.4	100	1058	59.6
		4729	88.3	74.4	110	1100	65.0

To date, one diode failed as a heater burnout at 2713 hours under T_4 conditions at 1100°C and 1.6 A/cm^2.

Two diodes under T_2 conditions at 985°C and 0.8 A/cm^2 have shown a slump of 8% and 12% in cathode current.

One diode under T_4 conditions at 1100°C and 0.8 A/cm^2 has shown a slump of 15% in cathode current.

In summary, it can be said that the pore type dispenser cathodes have operated satisfactorily upto 4700 hours of life burning from 950°C to 1100°C with the cathode current varying from 0.2 A/cm^2 to 1.6 A/cm^2.

6.4 Standard Barium Strontium Oxide Cathodes

The test diodes, using oxide cathodes under T_3 and T_4 conditions, were placed on life burning on October 25, 1967, and have completed 3439 hours up to this point.

The life test results are summarized in Tables XIII (T_3), XIV (T_4). The test diodes using oxide cathodes under T_1 and T_2 conditions, were placed on life burning on January 31, 1967, and have completed 1371 hours of life burning.

The life test results are summarized in Table XV, (T_1, T_2).

In general, all the cathodes operating above 0.15 A/cm^2 are showing varying conditions of slumping cathode emission, though no diodes have shown complete emission failure.

TABLE XIII

Life-Test Results
Oxide-Coated Cathodes

Test	Diode	Hours	I_p	I_p - 20%V	I_p + 20%V	Dip T°C	I_p @ 95% T
				(27V)	(41V)		
T_3-825°C	O-7	0	36.0	28.0	45.5	783	33.5
0.45A/cm^2	E_p = 34 V	91	34.0	27.0	45.0	771	31.5
	E_f = 8.0 V	734	31.0	27.4	36.2	745	33.3
		1246	31.0	25.0	36.2	825	27.0
		2038	24.9	21.0	28.0	825	29.0
		2762	27.0	21.6	33.7	825	27.5
		3439	20.0	17.0	22.4	825	32.8
				(54V)	(80V)		
	O-14	0	36.0	28.0	44.5	768	31.7
	E_p = 67 V	91	34.9	27.2	42.5	793	32.3
	E_f = 8.0 V	734	31.0	24.2	39.0	798	28.1
		1246	30.5	24.0	39.0	816	24.0
		2038	35.0	27.0	46.9	788	31.2
		2762	34.7	26.9	46.4	797	31.1
		3439	35.4	27.0	46.2	825	29.3
T_3-825°C	O-11			(24V)	(37V)		
0.225A/cm^2	E_p = 31 V	0	18.0	14.0	22.2	779	16.4
	E_f = 8.0 V	91	18.0	13.2	22.0	787	15.8
		734	14.3	11.2	16.9	818	14.1
		1246	13.8	10.8	15.8	825	14.0
		2083	12.2	10.0	14.2	825	11.3
		2762	11.0	9.3	12.4	825	11.8
		3439	11.0	9.0	12.4	825	11.6
				(22V)	(34V)		
	O-15	0	18.0	13.9	23.5	769	16.6
	E_p = 28 V	91	18.0	13.4	22.4	775	16.4
	E_f = 8.0 V	734	14.0	11.0	16.3	798	16.2
		1246	15.5	12.0	18.2	825	14.3
		2038	12.2	12.0	18.7	825	11.3
		2762	14.6	11.5	18.3	825	12.1
		3439	14.2	11.3	18.0	825	13.5

TABLE XIV

Life-Test Results
Oxide-Coated Cathodes

Test	Diode	Hours	I_p	I_p -20%V (46V)	I_p +20%V (70V)	Dip T °C	I_p At 95% T
T_4-850°C	O-19	0	48.0	35.0	59.3	796	42.0
0.6A/cm^2	E_p=57.5V	120	44.0	34.5	55.3	807	38.6
	E_f=8.0V	752	38.2	31.0	46.8	841	35.1
		1264	41.8	34.6	51.5	832	33.9
		2038	38.8	30.0	57.0	841	37.2
		2762	36.4	28.9	60.0	850	35.1
		3439	41.9	31.4	64.5	850	36.0
				(60V)	(80V)		
	O-20	0	48.0	36.8	60.0	769	42.6
	E_p=70V	120	45.9	36.0	54.2		37.9
	E_f=8.0V	752	51.0	36.0	63.8	839	40.2
		1264	46.8	35.2	63.2	835	33.9
		2038	44.9	34.0	59.4	831	34.2
		2762	43.0	32.9	56.9	833	39.0
		3439	41.4	32.0	55.3	850	37.5
				(32V)	(46V)		
T_4-850°C	O-21	0	24.0	18.2	29.0	774	21.6
0.3A/cm^2	E_p=39V	120	23.0	18.6	27.0	842	18.0
	E_f=8.0V	752	19.8	15.5	27.0	836	21.0
		1264	17.2	15.2	25.0	842	17.3
		2038	16.0	13.0	23.5	850	19.8
		2762	15.0	12.4	23.0	850	19.0
		3439	15.0	12.2	19.8	850	18.3
				(37V)	(55V)		
	O-22	0	24.0	19.7	28.0	775	18.2
	E_p=46V	120	24.8	21.4	27.5	845	13.5
	E_f=8.0V	752	23.9	20.0	34.0	847	16.3
		1264	19.5	20.2	33.2	850	17.3
		2038	17.0	13.9	32.8	850	15.9
		2762	15.3	12.8	26.0	850	15.8
		3439	15.8	13.1	21.2	850	19.3

TABLE XV

Life Burning - Oxide-Coated Cathodes

Test	Diode	Hours	Ip (ma)	Volts	Ip + 20% V	Dip T°C	Ip @ 95%T
T_1-800°C 0.075A/cm^2	O-32	0	6.0	19.5	4.7 - 7.9	722	4.13
		18	6.0		4.7 - 7.9	644	5.35
		694	5.8		4.5 - 7.0	659	5.60
		1371	6.0		4.9 - 7.4	666	5.14
	O-35	0	8.0	18.5	7.1 - 9.7	750	4.13
		18	8.0		7.2 - 9.7	744	5.25
		694	7.4		7.2 - 8.5	748	5.55
		1371	7.8		7.2 - 8.9	740	5.14
T_1-800°C 0.15A/cm^2	O-39	0	12.0	36.0	9.0 - 15.1	655	10.9
		18	12.0		8.9 - 15.0	607	11.0
		694	11.1		8.3 - 13.8	651	10.9
		1371	11.8		8.9 - 14.3	680	10.5
	O-40	0	12.0	29.0	9.6 - 14.7	769	9.3
		18	12.2		9.6 - 14.6	679	9.9
		694	11.6		9.3 - 13.7	660	10.4
		1371	12.0		9.9 - 14.1	703	10.1
T_2-825°C 0.15A/cm^2	O-38	0	12.0	29.0	9.3 - 15.2	741	11.0
		18	12.0		9.3 - 15.2	758	11.1
		694	10.0		8.0 - 12.1	785	10.9
		1371	11.0		8.9 - 13.0	804	10.2
	O-41	0	12.0	34.0	9.1 - 14.7	727	10.8
		18	12.0		9.2 - 14.8	726	10.7
		694	11.1		8.6 - 13.6	740	10.8
		1371	12.0		9.3 - 14.9	758	10.8
T_2-825°C 0.30A/cm^2	O-33	0	24.0	45.0	19.0 - 30.4	787	21.0
		18	24.2		18.8 - 30.2	791	21.8
		694	19.4		15.8 - 23.6	825	17.3
		1371	20.9		16.2 - 25.4	825	20.8
	O-37	0	24.0	56.0	19.1 - 30.7	735	22.6
		18	24.8		19.2 - 30.4	760	21.3
		694	19.6		15.7 - 22.8	788	21.7
		1371	21.0		17.0 - 24.7	825	18.0

7.0 CONCLUSIONS AND RECOMMENDATIONS

The Raytheon Materials and Techniques Group, in conducting a study of the life capabilities of three different types of thermionic emitters, can conclude the following results from nine months of life burning under the specified conditions noted in Table V.

A. The pore-type dispenser cathode (impregnated tungsten) is suitable for dc operation for at least 4700 hours for current ranges of 0.2 A/cm^2 to 1.6 A/cm^2 at temperatures ranging from 950°C to 1100°C. The only detrimental feature of the cathode is the high evaporation rate of barium metal from the cathode surface during high temperature life burning.

B. The standard barium-strontium oxide cathodes are showing erratic emission slump at current densities higher than 0.15 A/cm^2 during the life burning cycle. Approximately 50% of the diodes at the high current densities are running without large emission changes up to 3439 hours.

C. The coated particle cathodes show the capability of being operated dc up to 0.55 A/cm^2 at 900°C. Up to the present time, we have not been able to sustain 1.0 A/cm^2 at temperatures in the range of 800°C under dc voltage conditions. Diodes with coated particle cathodes show good results with pulsed voltage conditions.

It is recommended that the following work be attempted to clarify our understanding of the operational parameters of the standard barium-strontium oxide and coated particle cathodes.

A. Improve diode construction by using class 100 clean room conditions. The purpose of this change is to insure diode parts cleanliness, and thus eliminate possible causes of cathode poisoning.

B. Repeat diode tests using more active cathodes than the 0.1% Zi-Ni cathode now being used. The purpose of this change is to correct the erratic emission slump noted with the standard barium-strontium oxide cathodes.

C. Conduct a study of the behavior of coated-particle cathodes under dc and pulsed voltage conditions.

D. Investigate the possible role of anode effects on cathode poisoning.