RAYTHEON

Technical Report

PT-1735

THERMIONIC CATHODE EVALUATION STUDY

INTERIM REPORT NO. 3

MICROWAVE AND POWER TUBE DIVISION

MICROWAVE TUBE OPERATION, WALTHAM, MASS. 02154

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THERMIONIC CATHODE EVALUATION STUDY

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ABSTRACT

During this third interim period of thermionic-cathode evaluation, diodes using pore-dispenser cathodes have completed 2500 hours of life burning and are operating satisfactorily at cathode temperatures of 950°C to 1100°C and at cathode currents from 0.2 A/cm^2 to 1.6 A/cm^2.

Eight diodes using oxide-coated cathodes have completed 1240 hours of life burning and have shown a slump in emission of 5% to 25% at cathode temperatures of 825°C and 850°C and at cathode current levels from 0.225 A/cm^2 to 0.60 A/cm^2.

Eight diodes using oxide cathodes with anode-to-cathode spacing of 0.025 in. have been built, exhausted and pretested for life burning operation of the T1 and T2 life-test conditions of 0.075 A/cm^2 to 0.300 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.

Further study has shown the coated-particle cathode capable of pulsed operation up to 1.5 A/cm^2 peak current with a 3% duty cycle.

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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 two years of life testing.

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

The progress of work and life burning results during the third interim period of this study are described in this report.

Section 2.0 describes the electrical testing and selection of diodes using coated-particle and oxide-coated cathodes for life burning. Data is also presented to show the behavior of these two cathodes under pulsed operation conditions.

Section 3.0 of this report describes further testing of coated-particle cathodes, with changes in exhaust processing and cathode alloys. The purpose of these tests is to improve the emission capabilities of coated-particle cathodes.

The construction, exahust processing, and electrical selection of oxide-coated cathodes in diodes with 0.025 in. cathode-to-anode spacing is described. The diodes are for use under T1 and T2 electrical test conditions.

Section 4.0 describes the life-test procedure and testing of diodes up to date. Sixteen diodes using pore-dispenser cathodes have completed at least 2500 hours of life burning with cathode temperatures ranging from 950°C to 1100°C with plate currents ranging from 0.2 to 1.6 A/cm^2.

Eight diodes using oxide-coated cathodes have completed at least 1242 hours of life burning at cathode temperatures of 825°C and 8[illegible]°C and with plate currents ranging from 0.225 A/cm^2 to 0.60 A/cm^2.

2.0 ELECTRICAL TESTING AND SELECTION OF TEST DIODES FOR LIFE BURNING

In the third interim period of this study, the diodes constructed with oxide-coated and coated-particle cathodes were burned at 850°C cathode temperature and with 50 V dc applied to the anode during the aging cycle to stabilize their thermionic-emission levels.

After the aging period, the cathodes were tested for compliance with the JPL specifications noted in Figure 1 and Table 1. After the diodes were tested for zero field-current, they were tested for dip temperature according to the schematic diagram shown in Figure 2.

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

The heater voltage is then turned off to allow the change in emission characteristic to be recorded. When the anode current reaches 50% of its initial level, the heater voltage is turned on again. The curve that is obtained by this method is used to determine dip temperature. The temperature-limited portion of the curve is extrapolated back to the initial current level on the Y-axis, where the point of intercept on the X-axis is taken as the dip temperature.

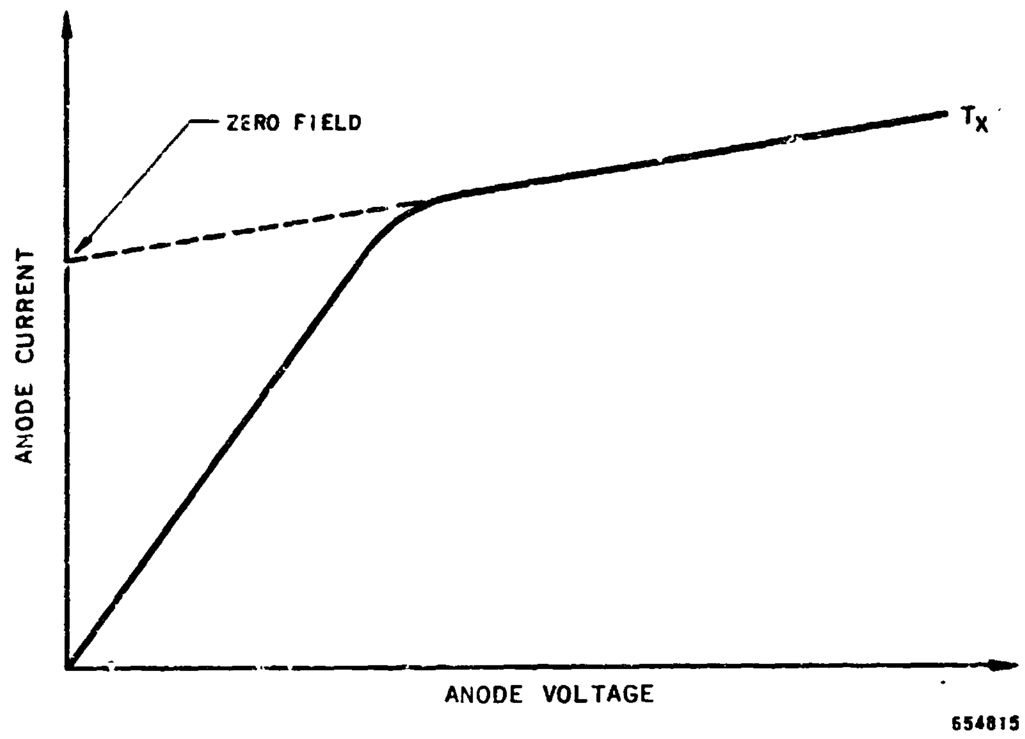
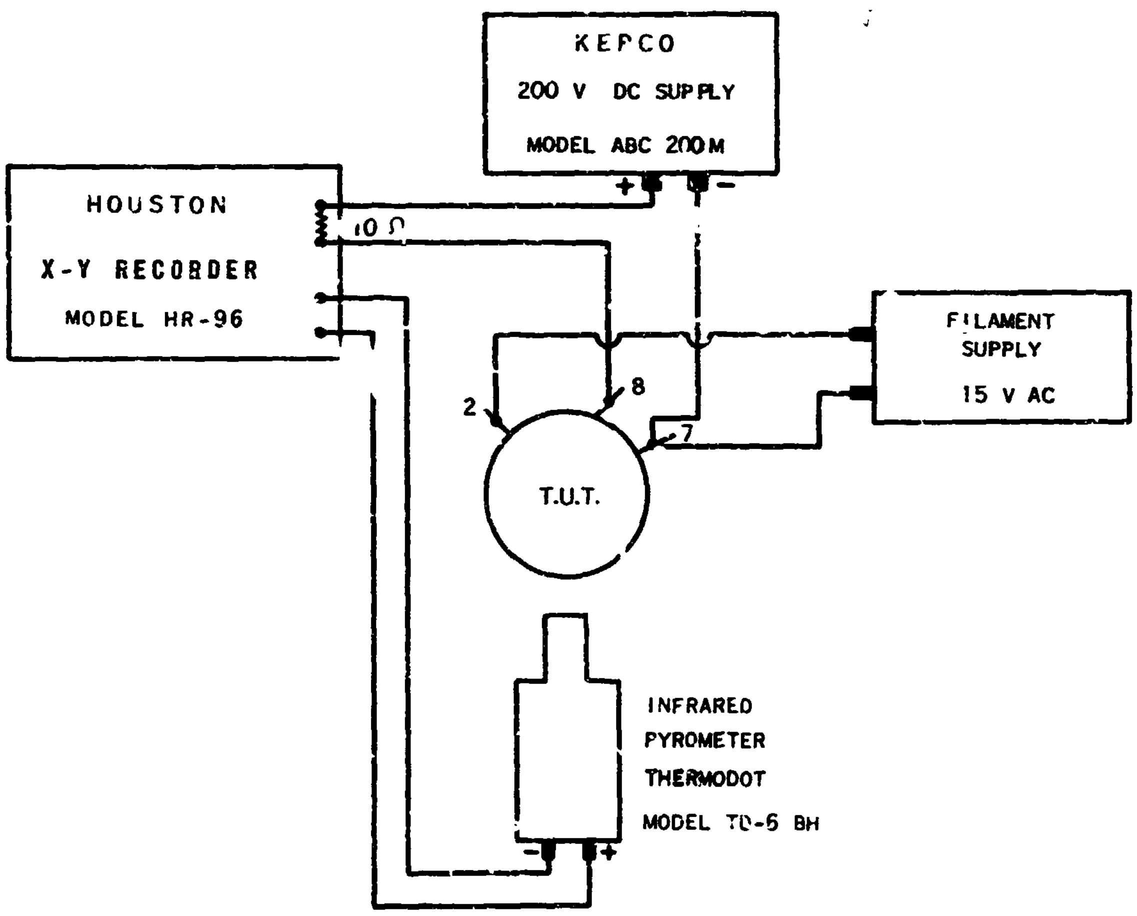


Figure 1. Current Density Level (JPL Specification)



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

Figure 2. Dip Test of Diode Vehicles

TABLE 1

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

2.1 Coated-Particle Cathodes

The four loads of diodes with coated-particle cathodes (Exhaust Nos. 5, 6, 7, 8), whose construction and processing were described in the Second Interim Report were burned in accordance with the procedures described previously in this report. The burning times are as follows: load 5-117 hours, load 6-190 hours, load 7-100 hours, load 8-143 hours.

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 2 in the forementioned time periods.

TABLE 2

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 blueish 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 2. 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 cathode. Figure 3 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 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 T1 (0.275 A/cm^2) and T2 (0.55 A/cm^2) operating conditions as specified in Table 1.

The dip-test results for diode no. C-7 is shown in Figure 4. This shows a dip temperature of 770°C for a plate-current level of 0.275 A/cm^2 at 850°C (T1) and of 877°C for a plate current level of 0.55 A/cm^2 at 900°C (T2).

Further measurements of other diodes showed the dip temperatures to be between 770-830°C at 0.275 A/cm^2 (T1) and between 870-900°C at 0.55 A/cm^2 (T2).

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.

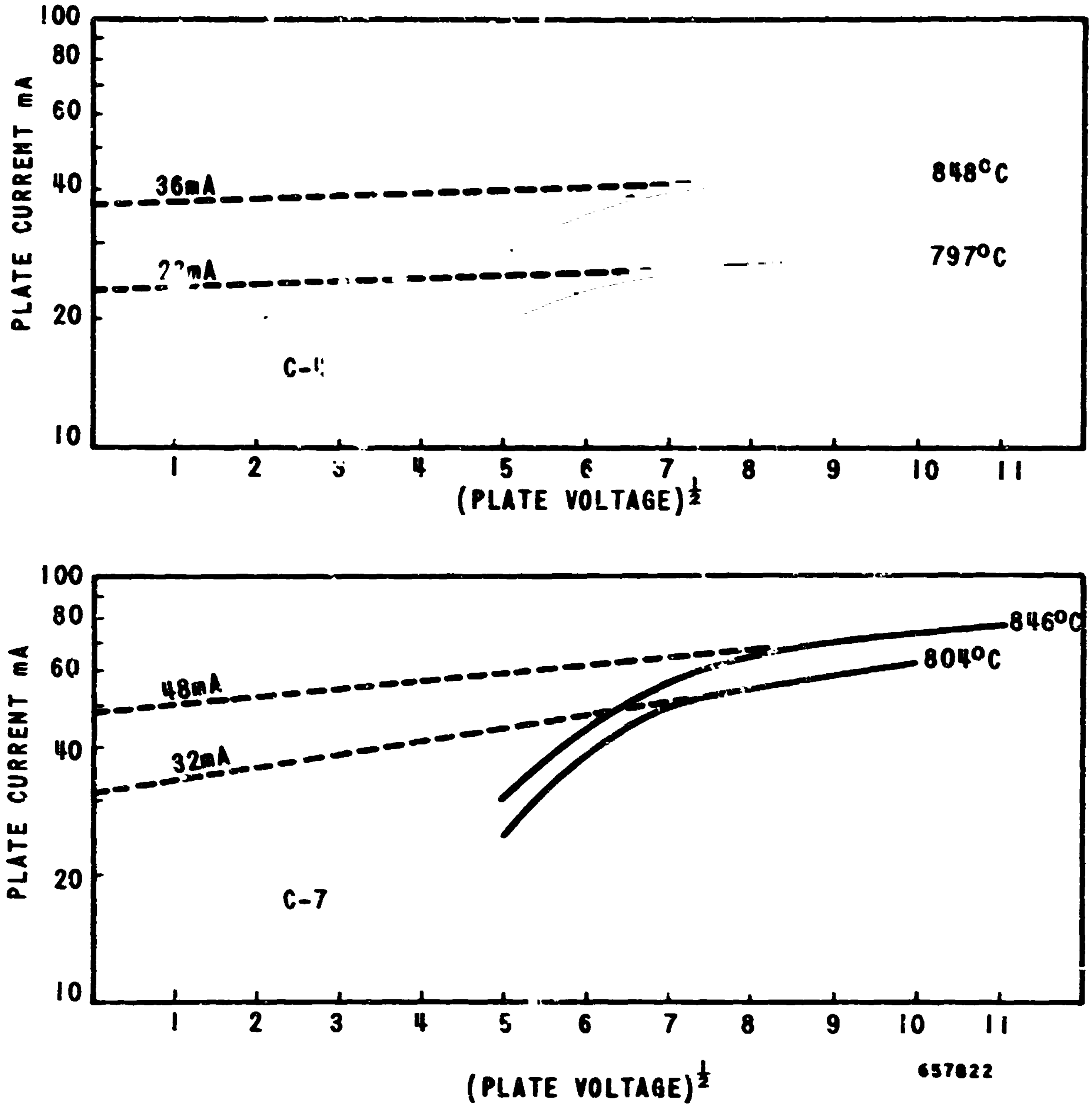


Figure 3 Diodes C-4/7 - Zero Field-Current Density Coa*ted-Particle Cathodes

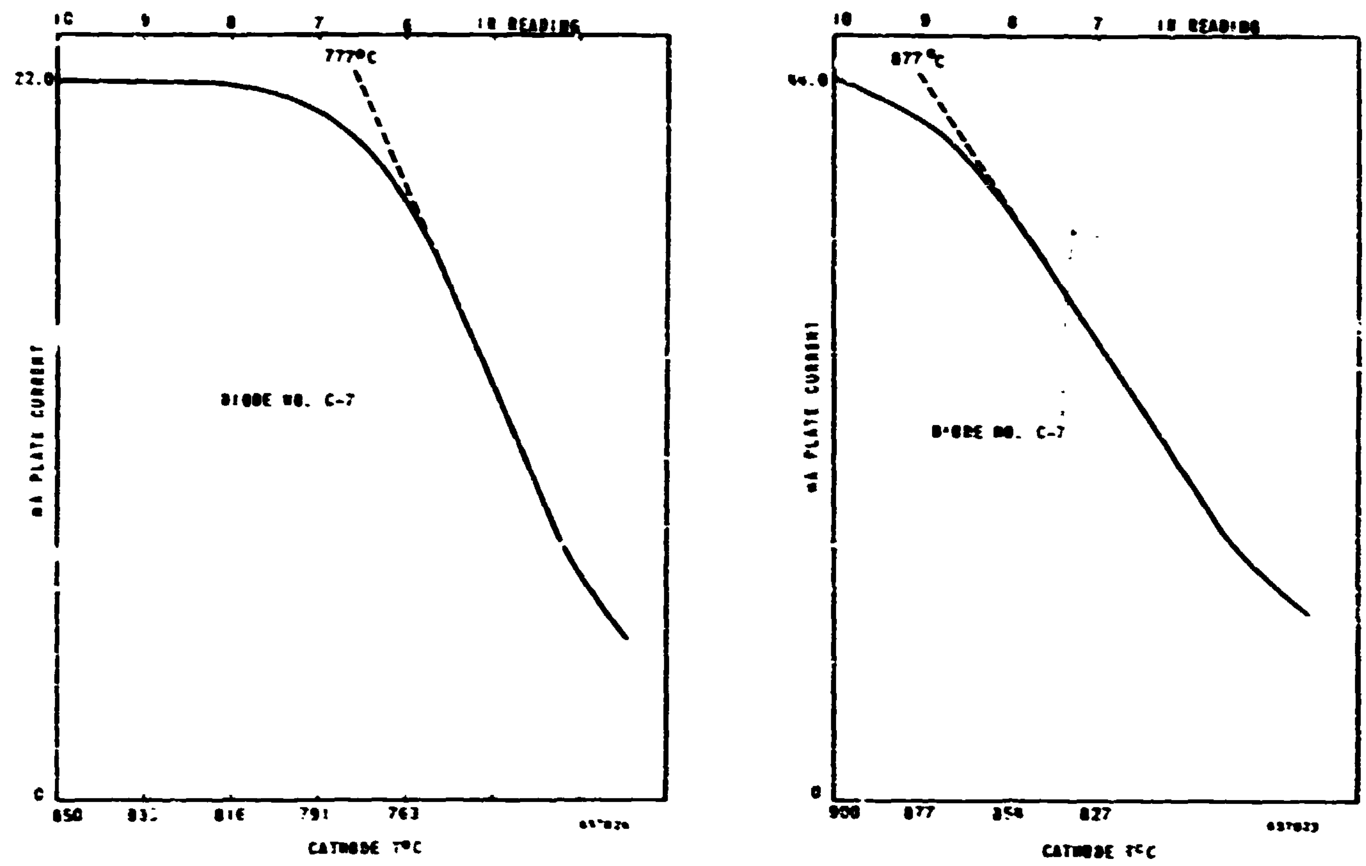


Figure 4 Diode C-7 - Coated-Particle Cathode Dip Test

A peculiar change in dip-temperature measurements is noted in Figure 5. 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 reasons for this change in dip temperatures 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 T1 test conditions (0.275 A/cm^2) at 850°C and the T2 test conditions (0.55 A/cm^2) at 900°C. Electrical testing at higher current densities at 900°C does not shown any appreciable measurement of a dip-temperature.

2.2 Oxide-Coated Cathodes

The four loads of diodes with oxide cathode (Exhaust Nos. 9, 10, 11, 12) - whose construction and processing were described in the Second Interim Report - were burned in the same manner as described for the coated-particle cathodes (850°C cathode temperature - E_p = 50 V). The burning times were: load 9-105 hours, load 10-146 hours, load 11-84 hours, load 12-98 hours.

The diodes started out at a very low plate-current level (0-5 mA) and gradually built up to the levels shown for a representative sample of 10 diodes in Table 3.

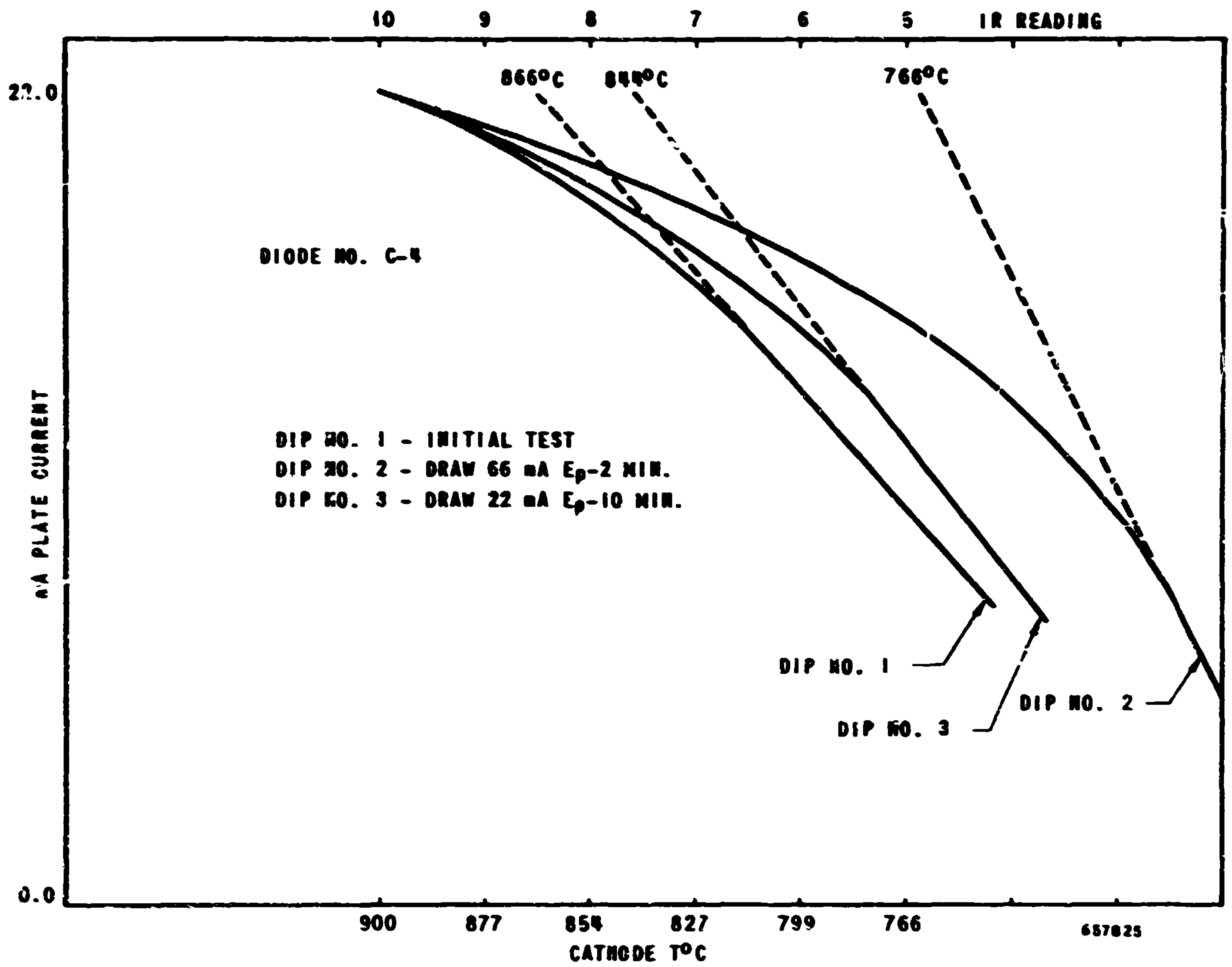


Figure 5 Diode C-4 - Coated-Particle Cathode Dip Test

TABLE 3

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

It was also observed that when testing diodes with oxide cathodes at voltages higher than 100 V dc, the anode current had a runaway tendence 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 of Table 3.

It was also impossible to obtain good zero field-emission plots for oxide cathodes.

The estimated zero field-current under the test conditions is 0.5 A/cm^2 to 0.7 A/cm^2 at 850°C.

Because of the changes noted in dip-temperatures with high current drain (Figure 5), the diodes with oxide-coated cathodes were only tested at the required operating points.

Figure 6 shows the dip-temperature for four diodes selected for operation at the T4 conditions of 0.3 and 0.6 A/cm^2 at 850°C.

Figure 7 shows the dip-temperatures for four diodes selected for operation at the T3 conditions of 0.225 A/cm^2 and 0.45 A/cm^2 at 825°C.

It should be noted that the diodes do not show a very sharp break from the space-charge region to the temperature-limited region as one would like to see in a dip-temperature measurement.

Difficulty was experienced in selecting diodes for the T1 and T2 conditions because of plate voltage requirements under 25 volts dc. An examination of Table 3 shows that a voltage of less than 25V is required to draw 6 to 12 milliamperes of current required for the T1 and T2 conditions for oxide cathodes with a diode spacing of 0.015 inch.

New diodes were constructed using oxide cathodes with a 0.025 in. spacing. The diodes are described in Section 3.0.

2.3 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 were conducted to compare the dc and the pulsed-voltage behavior of the two cathodes under investigation.

Figure 8 shows the comparison of two oxide cathodes (O-4, O-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.

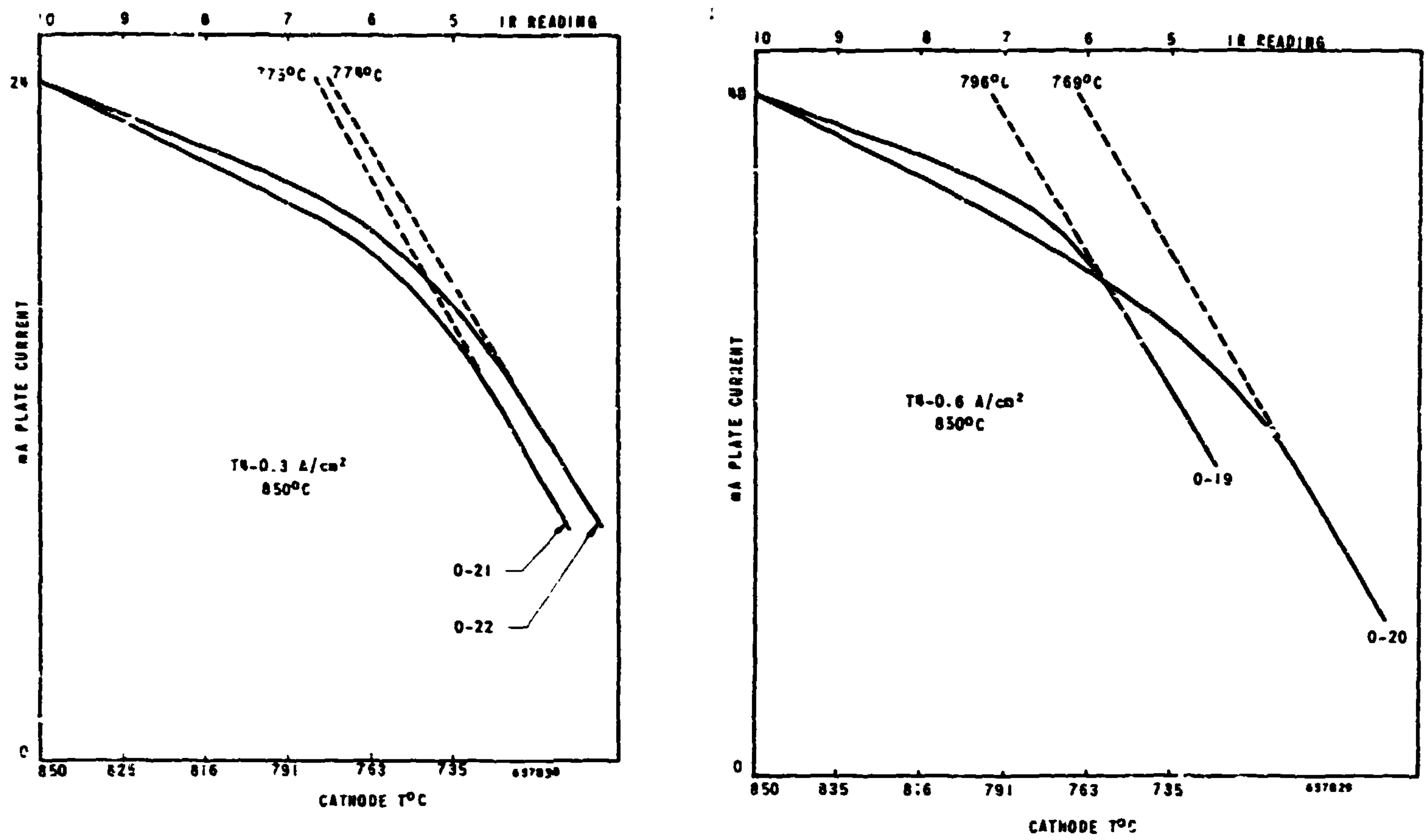


Figure 6 Diodes O-19/20/21/22 - Oxide-Coated Cathode Dip Test

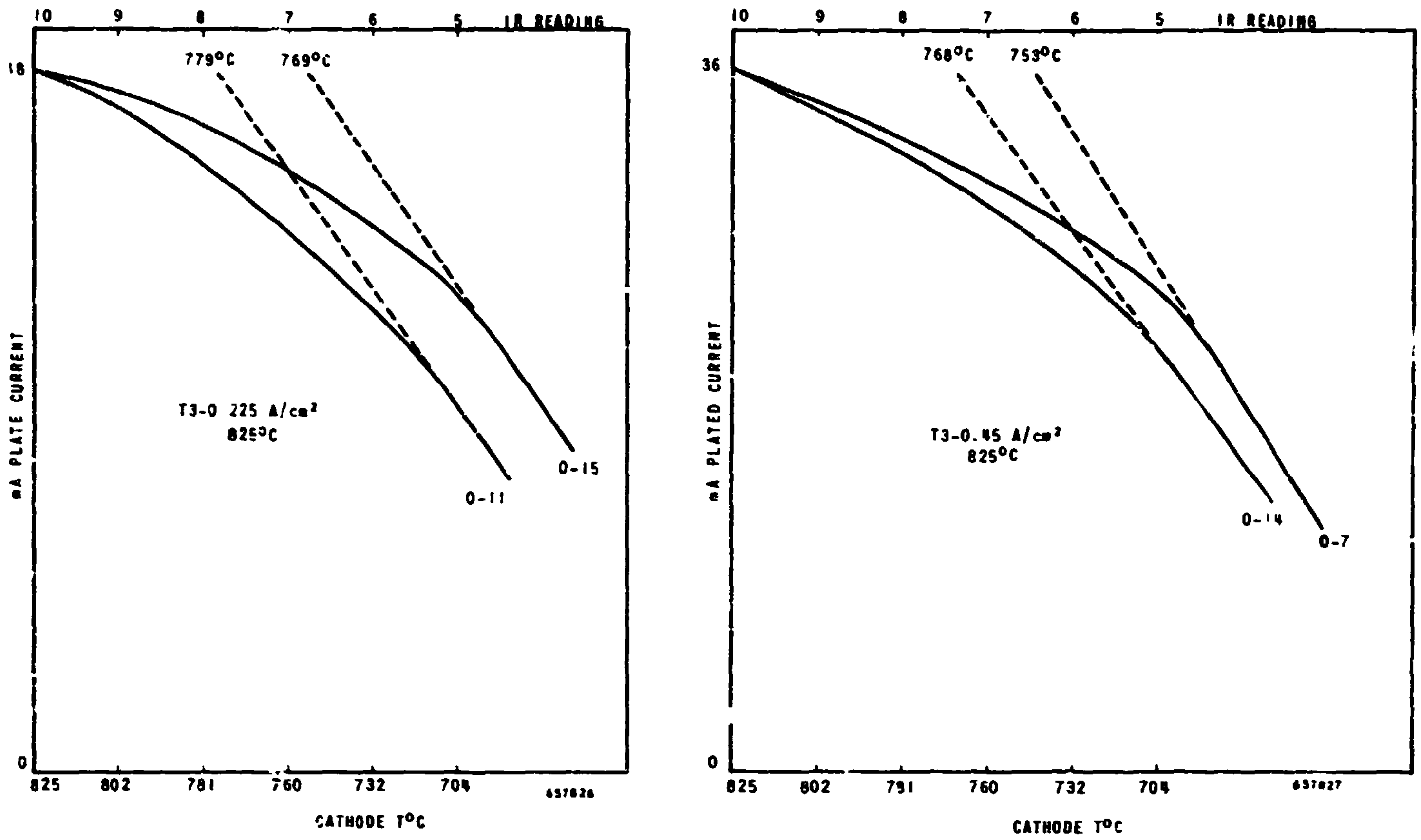


Figure 7 Diodes O-7/11/14/15 - Oxide-Coated Cathode Dip Test

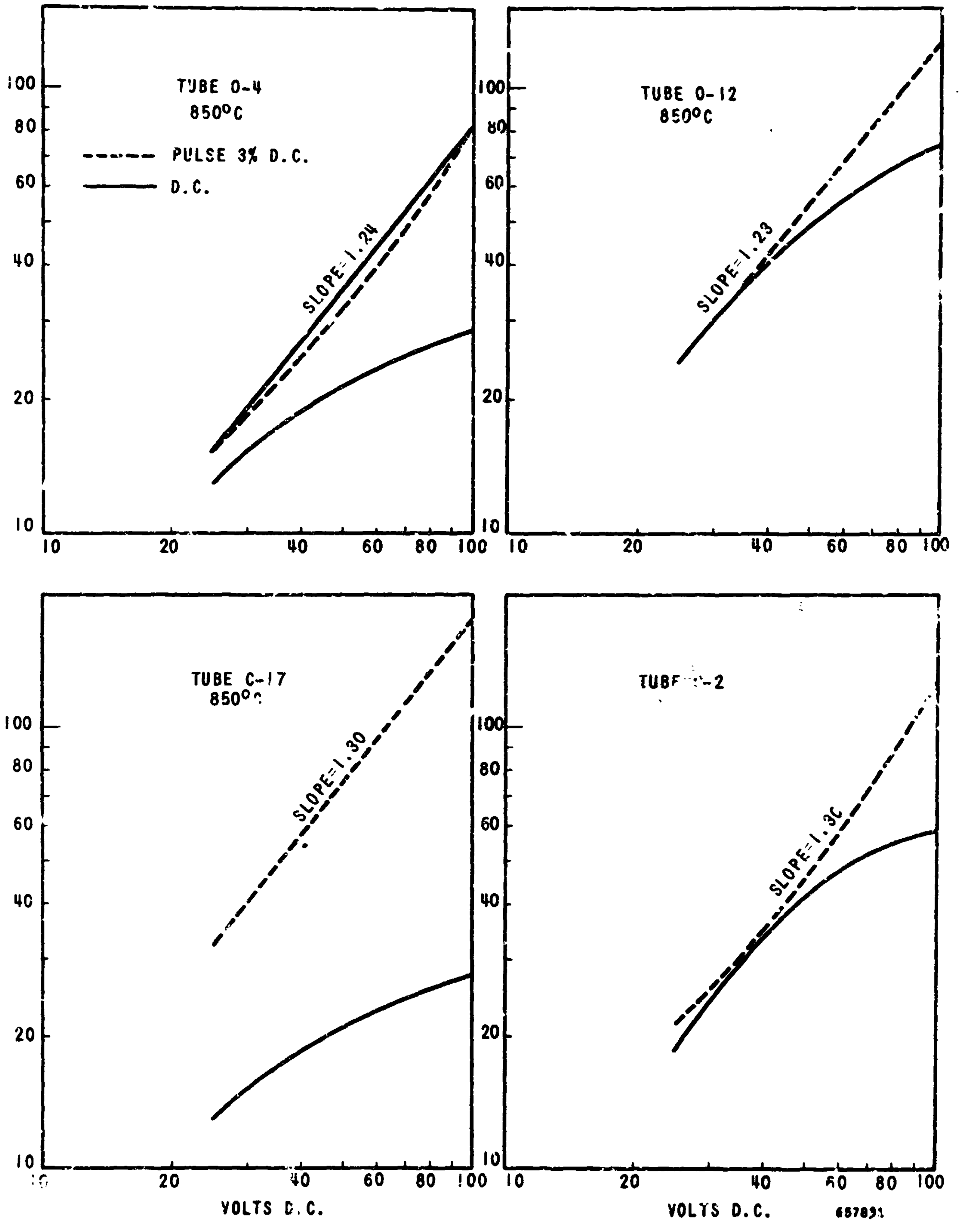


Figure 8 Test Diodes - Dc Conditions Compared to Pulsed Conditions
(0. 3 ms pulse, 100 pps)

The same tubes, under pulsed conditions (5% dc, 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 and dc test conditions, with a deviation in the theoretical slope of 1.5 to 1.23. The reasons for this deviation are not known at the present time.

Also, the point of cathode emission deviation from space charge with increased pulse length is not known at this time.

3.0 CONSTRUCTION AND EXHAUST PROCESSING OF TEST DIODES

Six further exhaust processing tests, using oxide and coated-particle cathodes, were conducted during the third interim period of this cathode study.

The purpose of the tests was to study the effect of exhaust-processing changes and cathode alloys on the thermionic-emission levels of oxide and coated-particle cathodes. Also, ten diodes using oxide cathodes with a spacing increase to 0.025 in. were processed for compliance with the T1 and T2 specifications for oxide cathodes.

3.1 Coated-Particle Cathodes

Diodes were constructed according to Figure 1 of the Second Interim Report. The exhaust schedule was changed from the previous method (Second Interim Report) to the schedule in Table 4.

TABLE 4

Exhaust Processing - Coated-Particle Cathodes

1.	Seal in diodes on exhaust system, using an oil-diffusion pump with liquid-nitrogen cold trap.
2.	Pump diodes to 5×10^{-5} Torr pressure.
3.	Bake out diodes at 450°C for 90 minutes.
4.	Cool to room temperature.
5.	Measure vacuum pressure ($< 5 \times 10^{-6}$ Torr).
6.	Heat cathodes rapidly to 1050°C (one minute).
7.	Hold cathodes at 1050°C for five minutes.
8.	Decrease cathode temperature to 950°C and hold for 10 minutes.
9.	Heat anode to 800°C for one minute during Step 8.
10.	Measure vacuum pressure ($< 5 \times 10^{-6}$ Torr).
11.	Seal off diodes.
12.	Flash getter.
13.	Attach bakelite bases to diodes.

The total exhaust heating time for this schedule is twenty minutes in comparison to the previous schedule of 81 to 125 minutes of cathode heating.

Four lots of diodes were exhausted to test the effects of this exhaust schedule with changes in cathode alloys as shown in Table 5.

TABLE 5

Exhaust Processing Schedule

Load No.	No. of Diodes	Cathode	Processing
13	5	Coated-particle with Z_r - Ni	Table IV
14	6	Oxide cathode with 220 alloy	Table IV
15	6	Coated-particle with 220 alloy	Table IV
16	5	Coated-particle with 220 alloy	Second Interim Report

In the case of exhaust load no. 13, the diodes showed faster activation for the coated-particle cathode with the faster exhaust schedule. The diodes were aged at E_b = 50 V with the cathode temperature at 850°C. The maximum space-charge level for the diodes was reached after 24 hours. The levels are the same as reported in Table 2 of this report. The diodes also showed increasing plate currents, with a bluish ion glow at voltages over 100 volts dc. The diodes were aged to 287 hours without noticeable charges in plate current from the 24-hour readings.

Exhaust load no. 14, using oxide cathodes with 220 alloy nickel and the faster processing schedule, did not show any improvement in emission levels, as reported in Table 3. The diodes activated faster than was previously noted for oxide cathodes using the slower exhaust schedule. The diodes activated in 24 hours in comparison to the previous times of 98 to 146 hours.

Load no. 15, using coated-particle cathodes with 220 alloy nickel and the faster exhaust schedule, showed peeling of the cathode coating after the exhaust processing. The cause was attributed to lack of cathode surface roughness. The 220 alloy cathodes were prepared without surface honing with aluminum oxide.

Exhaust load no. 16, using honed 220 alloy cathode coated-particle coating and the slower exhaust schedule (Second Interim Report) showed the same results as previously reported with load no. 13.

In summarizing the results from the four tests (Exhaust loads 13-16), it can be said that the change in cathode alloy and exhaust processing with the coated-particle or oxide cathodes results in faster activation of the diode. An improvement in thermionic emission levels was not noted in these tests. The characteristic bluish glow with coated-particle cathodes and greenish glow with oxide cathodes was noted in both cases.

3.2 Oxide-Coated Cathodes

Ten diodes using oxide cathodes with 0.1% Zr-Ni were constructed with a change in anode-to-cathode spacing from 0.015 in. to 0.025 in.

The diodes (exhaust loads 17 and 18) were exhausted in compliance with the slow schedule as reported in the Second Interim Report.

The initial test results from aging are shown in Table 6 after 100 hours of burning.

The cathodes were aged at 800°C cathode temperature with E_p = 50 V. The diodes will be dip tested and placed on life burning during the next interim period in compliance with the conditions listed in Table 1 for T1 and T2 conditions for oxide-coated cathodes.

TABLE 6

Oxide-Coated Cathode - 0.025 in. Spacing
Emission Measurements
At 800°C Cathode Temperature

Tube No.	25V	50V	75V	100V
O-32	5.4	11.9	16.0	19.0
O-33	8.0	19.9	30.0	36.8
O-35	7.2	14.7	18.1	20.8
O-36	9.2	18.1	23.0	26.2
O-37	6.0	16.2	26.0	34.4
O-38	7.0	18.9	34.0	48.0
O-39	7.0	19.5	29.9	36.7
O-40	6.0	15.4	27.9	39.2
O-41	8.0	18.0	26.9	31.0
O-42	8.2	20.0	34.9	40.9

4.0 LIFE BURNING AND TESTING OF DIODES

Currently, twenty-four test diodes are on life burning in the test rack constructed for this study.

Sixteen diodes using pore-dispenser cathodes and eight diodes using oxide-coated cathodes are being tested for life and emission stability.

The cathode life-test rack, designed by Raytheon personnel and constructed by the Cober Electronics Company of Stamford, Connecticut, is designated as Cober Model No. 1369. It has 48 test positions with each position having its own heater-voltage and plate-voltage contro. The equipment is divided into three banks of 16 sockets each. Each bank has its own regulated filament supply which can deliver 24 volts at 20 amperes ac. 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 800-1100°C range setting on the particular bank.

A regulated plate voltage is supplied to each socket, and may be adjusted over the range of 20-200V dc. Each socket has its own transistorized module for adjustment of plate voltage, which is obtained from two Technipower, solid-state, Model L-100, 0-6.0 A, regulated power supplies.

4.1 Pore-Dispenser Cathodes

At the end of this third interim period of study, the diodes operating at the T1, T2 and T3 specifications had completed 2688 hours of life burning. The diodes operating under the T4 conditions had completed 2521 hours of life burning. The test results are shown in Tables 7 through 10.

TABLE 7

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
T1 - 950°C	M1			(32V)	(46V)		
0.2 A/cm²	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
				(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
T1 - 950°C	M2			(39V)	(59V)		
	E_p = 49 V	0	20.0	15.1	27.3	916	19.3
	E_f = 9.0V	757	21.0	15.8	26.4	895	18.0
0.4 A/cm²		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
				(28V)	(42V)		
	M3	0	20.0	16.5	27.0	397	15.0
	E_p = 35V	757	21.5	16.4	27.0	891	18.0
	E_f = 9.0V	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

TABLE 8

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
T2-985°C				(28V)	(42V)		
0.4A/cm^2	M7	0	20.0	16.8	27.5	899	19.3
	E_p=34.5V	757	20.0	15.4	25.0	958	16.4
	E_f= 9.0V	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
				(30V)	(50V)		
	M9	0	20.0	14.6	28.5	910	18.8
	E_p=40V	757	21.2	15.0	27.8	938	17.5
	E_f=9.0V	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
				(54V)	(76V)		
T2-985°C	M11	0	40.0	32.0	49.5	964	28.0
0.8A/cm^2	E_p=65V	757	35.9	29.0	42.3	966	33.0
	E_f=9.0V	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
				(44V)	(64V)		
	M12	0	40.0	31.0	50.0	913	38.0
	E_p=54V	757	39.0	30.0	49.5	9[illegible]	36.0
	E_f=9.0V	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

TABLE 9

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)		
T3-1035°C	M13	0	30.0	22.5	38.5	965	29.2
0.6A/cm^2	E_p=45V	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
				(39V)	(59V)		
	M18	0	30.0	21.5	38.0	949	29.2
	E_p=48.5V	757	27.0	20.9	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
				(72V)	(108V)		
T3-1035°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
				(78V)	(118V)		
	M14	0	60.0	44.5	69.0	995	56.0
	E_p= 98V	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

TABLE 10

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)		
T4-1100°C	M21	0	40.0	23.0	52.0	957	37.6
0.8A/cm^2	E_p=67V	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
				(49V)	(87V)		
	M23	0	40.0	24.0	51.0	997	38.0
	E_p=73V	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
				(89V)	(132V)		
T4-1100°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
				(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

The diodes are operating on two different banks of the test rack at $E_f = 9.0$ V and $E_f = 11.0$ V, respectively. The plate-voltage power supplies were set at 110 volts dc and each diode was adjusted to a constant anode voltage to draw the specified cathode current noted under the test specifications.

At the stated time intervals noted in Tables 7 through 10, the diodes are checked for cathode temperature and anode current at the predetermined constant plate voltages. Then, the plate current is read at ± 20% of the prescribed plate voltage.

The diodes are then tested for dip temperature at the same intervals of burning. Cathode current at 95% of the operating temperature is determined from the curve tracings obtained by the dip-test method.

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

It should be noted in Tables 7 through 10 that the cathode current is being reported in milliamperes. The cathode current density per square centimeter is 20 times the reported current (cathode area = 0.050 $cm^2 \times 20 = 1.0\ cm^2$).

An analysis of the test data shows the pore-dispenser cathode to be operating satisfactorily up to 2521 hours of life and at current densities ranging from 0.2 A/cm^2 to 1.6 A/cm^2 with the cathode temperatures ranging from 950°C to 1100°C.

The diodes under T1 conditions have not shown any slump in cathode current through 2688 hours of life burning. Three diodes have shown an average increase of 13°C in dip temperature, while one diode has shown a decrease of 18°C in dip temperature.

The diodes operating at T2 conditions have shown a drop of 7% in cathode current in the case of two diodes operating at 0.8 A/cm^2. The average increase in dip temperature is 36°C. The range of average dip temperature is -21°C and +22°C.

In the case of the diodes operating under T3 conditions, one diode operating at 1.2 A/cm^2 has shown a plate current decrease of 8.5%. The change in dip temperature is sporadic. Two tubes show an average decrease of 40°C in dip temperature, while the other two tubes show an average decrease of 10°C in dip temperature.

The diodes operating under T4 conditions have only shown an emission slump in one case (7.5%). The dip temperatures have increased 85°C in the case of two diodes and 29°C in the case of the other two diodes.

In summary, the sixteen diodes using pore-dispenser cathodes are operating satisfactorily up to this point in life burning.

4.2 Oxide-Coated Cathodes

At this point in life burning, the diodes using oxide-coated cathodes have completed at least 1246 hours of life burning under the T3 conditions at 825°C, and 1264 hours under the 4 conditions at 850°C.

The life-test results are shown in Tables 11 and 12.

An analysis of the results shows the plate-current levels to be dropping from 5% to 25% at this point in life.

The dip temperatures have shown increases almost to the operating temperatures after 700 to 1264 hours of operation.

The diodes will be continued on life burning and will be reported once a month in the Monthly Life Test Report.

TABLE 11

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)		
[illegible]-825°C	O-7	0	36.0	26.[illegible]	45.5	78[illegible]	33.5
0.45A/cm^2	E_p=34V	91	34.0	27.0	45.0	771	31.5
	E_f=8.0V	734	31.0	27.4	36.2	745	33.3
		1246	31.0	25.0	36.2	825	2[illegible].0
				(54V)	(80V)		
	O-14	0	36.0	26.0	44.5	768	31.7
	E_p=67V	91	34.9	27.2	42.5	793	32.3
	E_f=8.0V	734	31.0	24.2	39.0	798	28.1
		1246	30.5	24.0	39.0	816	24.0
T3-825°C	O-11			(24V)	(37V)		
0.225A/cm^2	E_p=31V	0	18.0	14.0	22.2	779	16.4
	E_f=8.0V	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
				(22V)	(34V)		
	O-15	0	18.0	13.9	23.5	769	16.6
	E_p=28V	91	18.0	13.4	22.4	775	16.4
	E_f=8.0V	734	14.0	11.0	16.3	798	16.2
		1246	15.5	12.0	18.2	825	14.3

TABLE 12

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
				(46V)	(70V)		
T4-850°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
				(60V)	(80V)		
	O-20	0	48.0	36.8	60.0	769	42.6
	E_p=70V	120	45.9	36.0	54.2	826	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
				(32V)	(46V)		
T4-850°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
				(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

5.0 PLANS FOR THE FOURTH INTERIM PERIOD

The work schedule for the fourth interim period of this study, from January 1 to March 31, 1968, will include the following items.

a. Continue life testing of sixteen diodes with pore-dispenser cathodes (T1 thru T4 conditions).

b. Continue life testing of eight diodes with oxide-coated cathodes under T3 and T4 conditions.

c. Start life testing of eight diodes with oxide-coated cathodes under T1 and T2 conditions.

d. Continue investigation of coated-particle cathodes under dc and pulsed conditions.