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February 1991



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RL CATHODE LIFE TEST FACILITY

Mark E. Novak, Dirk T. Bussey, Edward J. Daniszewski

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Rome Laboratory
Air Force Systems Command
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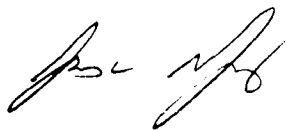
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13. ABSTRACT (Maximum 200 words) This report provides a basic introduction to the Rome Laboratory Cathode Life Test Facility, followed by a compilation of life test data. The Cathode Life Test Facility has been in operation for nine years and has tested 10 different cathode types for a total of approximately 1.5 million hours of life test data.					
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1. Introduction

The RADC Cathode Life Test Facility was placed in service in 1981 in recognition of the fact that projected Space Born requirements would soon require loading densities at or above 2 A/cm^2 with operating life in excess of 100,000 hours. It was therefore necessary to perform an independent evaluation of the several emerging technologies which held promise for that type of performance. The facility was originally created and operated by the Air Force alone but for the last several years has been supported both financially and technically by the NASA Lewis Research Center. In FY 88 Army financial support was provided as well. Day to day operations are conducted by RADC/OCTP. The facility is located in Building 112, Cell 8, Griffiss AFB. Inquiries should be addressed to:

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Griffiss AFB, NY
13441

315-330-4381 or AV 587-4381.

Basic Provisions which include floor space and power outlets with individual circuit breakers are provided for 80 Test Stands although only 40 are available at this time. Each will operate one test vehicle. The Test Stands provide CW power as follows:

A) Power Input: 115 VAC, single phase, 60 Hz. An input line regulator is capable of providing a constant output for line voltage variations of 10%.

B) Cathode Supply: 0 to -6000 VDC (WRG) at 20 ma with 1% regulation.

C) Collector Supply: 0 to +2000 volts (Floating WRC) at 240 ma and 5% regulation.

D) Filament Supply: 0 to 8 VAC, 4 A, 1% regulation, isolated to float at cathode potential.

The test vehicle usually employed is a triode type device designed and built by Varian Associates which originally designated the V-7355 and more recently the V-7356. Other Test Devices can often be used if they accommodate the voltage and current capabilities of the Test Stand. The V-7355 employs a flat cathode, no focusing, air cooling, an aperture anode, and a depressable single stage collector. A Pierce type gun with no compression is utilized

to provide a microperveance of approximately 0.5 with a .05 cm² cathode area (0.1 inch dia.). Cathode Loading of 1, 2, and 4 A/cm² can thus be achieved at 50, 100, and 200 ma respectively. A sapphire viewing window with an electromagnetically operated shutter is mounted to allow direct viewing of the cathode surface for temperature measurement and protection from cathode evaporants at other times. Each vehicle is equipped with a 2 liter/second ion pump. The V-7356 is functionally identical to the earlier version except that several modifications have been made. Earlier models suffered from gun-to-body conduction particularly at the higher current loading densities and the subsequent higher cathode and gun temperatures. The ion pump magnet has also been shielded to reduce its effect on the beam.

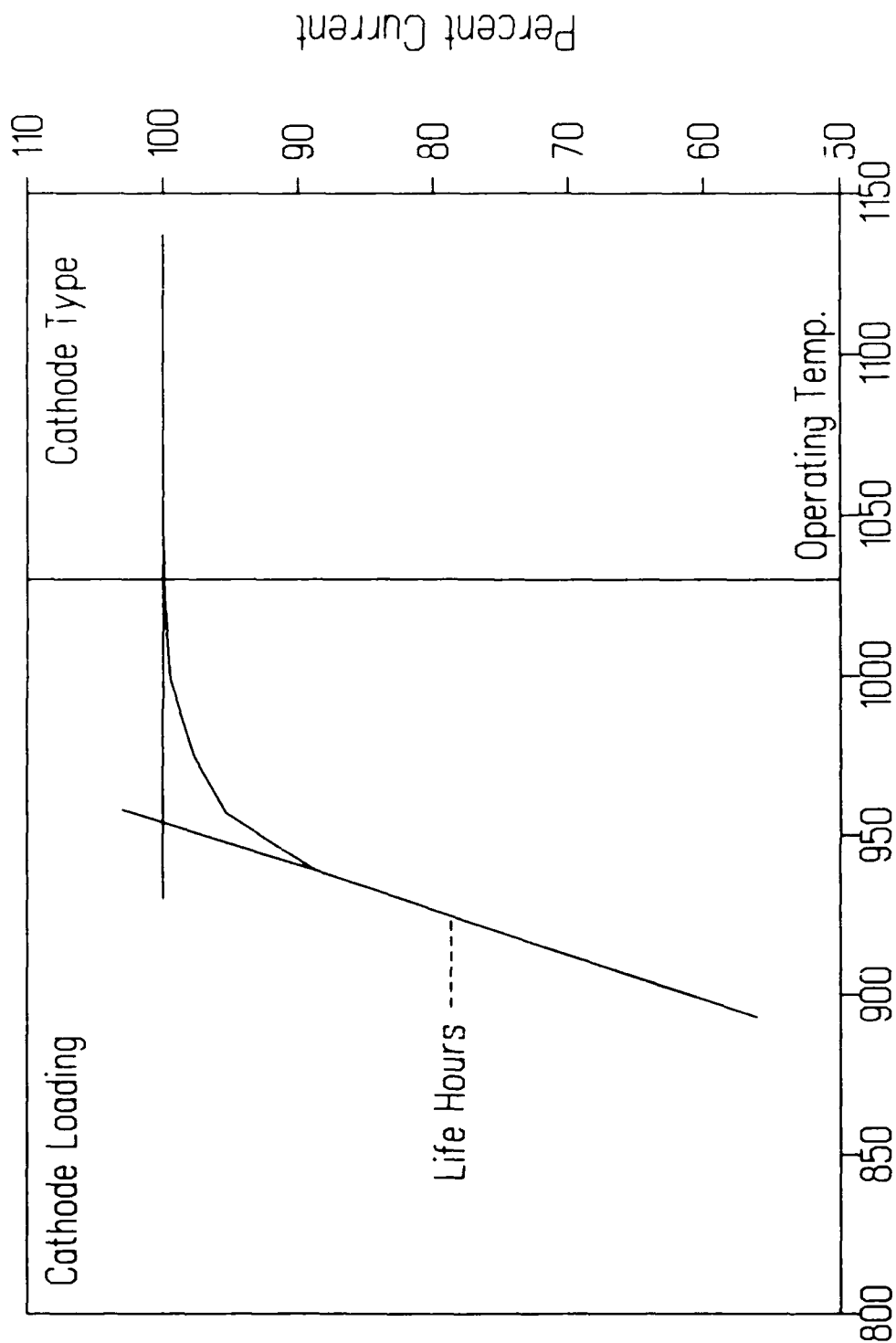
Cathode temperature can be measured with either a "PYRO" disappearing filament pyrometer or an "IRCON" two color device. The IRCON is used for most current applications since it is automatic with electronic readout and it is reproducible with no operator experience which is definitely not the case with the disappearing filament devices.

2. Operation:

Each incoming test vehicle is visually checked and then subjected to a functional check. This begins with the gradual application of Heater power while monitoring gas pressure which is not allowed to rise above the six scale. When nominal filament power (as determined by the manufacturer's data and the intended loading density) is reached with satisfactory vacuum the application of beam and collector voltage is initiated with collector depression maintained at approximately 70%. As the beam voltage is raised, the body current and gas pressure are monitored to see that they do not rise to unacceptable levels. The beam current is set to the loading density desired at a temperature approximately 50 degrees above the knee (Fig. 1) and maintained for approximately 24 hours.

Next, the temperature of the cathode is raised to a more or less arbitrary temperature approximately 100 degrees above the knee temperature at the highest loading density desired. This has been chosen as 1100°C for most cathodes but has recently been reduced to 1050°C for the new NASA reservoir cathodes that operate at very low temperatures. At this point a slow roll off curve is taken. A stabilized current corresponding to the desired loading density is first established. The required beam voltage is recorded and maintained throughout this and all future roll off tests on

CATHODE ACTIVITY PLOT



TEMPERATURE (C True)

FIGURE 1: SN-XXXX

this device. Next the cathode temperature is reduced by approximately 8-10 °C. After five to ten minutes the current is recorded. This step is repeated until the cathode is operating below 50% of the starting level.

At this point the knee temperature is determined. It is defined as the intersection of straight lines drawn through the space charge limited region and the temperature limited region of the roll off curve (Fig. 1). This is accomplished by a small computer program to assure reproducibility and in recognition of the fact that these curve segments are not perfectly straight. After the knee is established, a decision is made as to the desired life test temperature. This varies according to the purpose of the test and to date has been set at 25, 40, and 50 °C above the knee for various test vehicles. The cathode is then set to the appropriate temperature and the beam voltage is raised to produce the current appropriate to the loading density desired. The beam voltage is then maintained at this level permanently except for the short periods when roll off curves are being taken. The "Life Test Voltage" and the "Roll Off Curve Voltage" will be identical when the curve is horizontal in the space charge limited region. In cases where the test vehicle is not perfectly thermally compensated, minor internal dimensional changes often affect perveance with respect to temperature, causing the two voltages to differ slightly. This procedure is used as a convenience to allow tests to be run at exact loading densities ((i.e. 4.0 A/cm² instead of (for example) 3.97 A/cm²)). Tests to date have been confined to loading densities of 1, 2, and 4 A/cm².

To date, 1,445,000 hours of life testing has been accomplished on 10 different cathode types as follows:

1. B: Sixteen B type cathodes employing segregated Tungsten powder were evaluated. Ten employed 9 micron powder, four used 5 micron, and two used 7 micron. The impregnant was a 6:1:2 mixture.

2. M: Eleven "M" type cathodes were evaluated. Eight were built by Semicon and three by Hughes. Two Hughes and one Semicon device remain on test.

3. M³ (Mixed Metal Matrix): Twelve M³ cathodes were evaluated. These are comprised of 80%, 15 micron Tungsten and 20%, 1 micron Iridium with the mixture sintered to 73% theoretical density. The impregnant is a 6:1:2 mixture. Six remain on test and nine are still operable.

4. CD (Co-Deposited): Ten were evaluated. These employ a 4.5 micron particle size Tungsten base impregnated with a 6:1:2 mixture and sintered to 80% theoretical density.

This was overcoated with 5000 A° of co-sputtered 60% Tungsten and 40% Osmium.

5. LaB₆: Two Lanthanum Hexaboride Crystal cathodes were evaluated.

6. CPD (Controlled Porosity Dispenser): Three were evaluated. The CPD is a reservoir cathode with a front surface of foil with artificial pores made by laser drilling.

7. Tri-Layer: Twelve were evaluated. The design consisted of 8 micron segregated powder with the front 0.005 chemically converted to an Osmium/Tungsten mixed metal matrix which is further sputtered with one micron of Osmium 89%-Ruthenium 11% and fired at 1800°C. Finally, a 4200 A° sputter coat of 44% Osmium-56% Tungsten to form the emitting surface. Impregnant was 6:1:2. One unit remains on test.

8. TM (Transition Metal): Ten are currently on test. These employ a Tungsten 95%-Iridium 5% body with a 5000 A° Tungsten 50%-Iridium 50% overcoat. The impregnant is 6:1:2. All remain on test.

9. Siemens MK: Eight were evaluated. Five remain on test. The MK cathodes contain Barium Oxide powder in the reservoir with Tungsten wire for a reducing agent. The emitting surface consists of an Osmium coating sputter deposited onto a standard Tungsten powder diffuser plug.

10. RV (Varian Reservoir): Eight were evaluated. Seven remain on test. These cathodes use a pressed Barium Oxide pellet in the reservoir with Tungsten wire for a reducing agent. The emitting surfaces consist of a sputter deposited 70% Tungsten-30% Osmium (Sigma Phase) coating (three cathodes) and a sputter deposited 45% Tungsten-55% Osmium coating (four cathodes). The diffuser plugs are made from 14 micron segregated Tungsten powder.

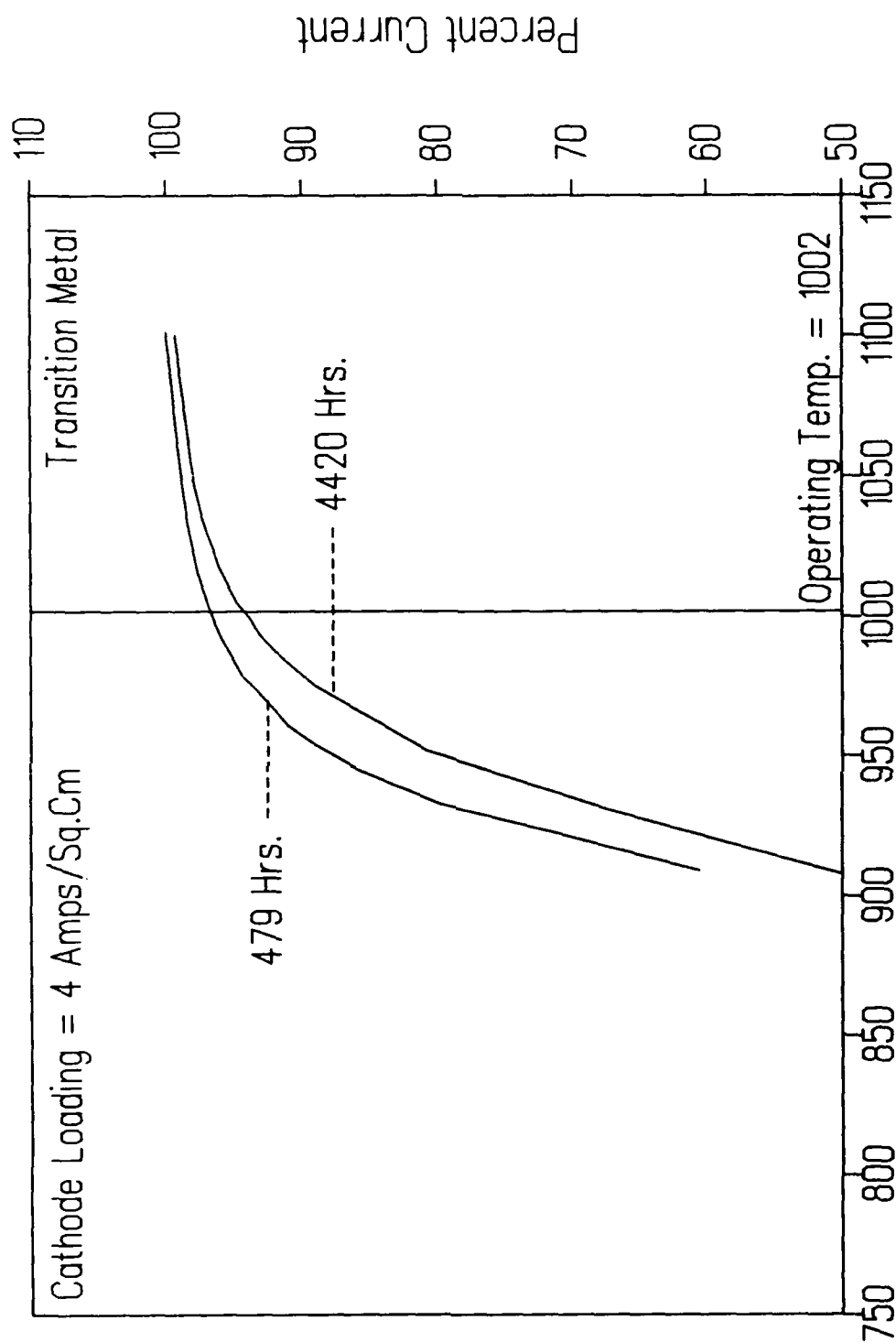
3. Interim Conclusions:

At present, the M cathode is generally employed for high power millimeter wave space tube applications. However, at 1 A/cm² loading it is only marginally suitable for many applications requiring anode or heater adjustment with time. Further, 1 A/cm² often requires too high a beam compression for optimum focusing. A space qualified cathode providing 2 A/cm² for 100,000 hours without modification of filament power or accelerating voltage is clearly needed. The Mixed Metal Matrix (MMM) is the clear choice at this time. Of the cathodes tested to date with significant life accumulation, the MMM clearly appears to be the superior design. Six are being evaluated at 2 A/cm² and each has accumulated over

50,000 hours (5.7 years) of real time testing. Over this period, the maximum degradation of any single device has been 3.5% with the average only 0.8%. This, coupled with the inherent ruggedness of the MMM cathode makes it a clear choice for space qualification. The Varian RV and TM cathodes have potential, but have only begun life testing. At least another two years of evaluation is required to fully assess their potential.

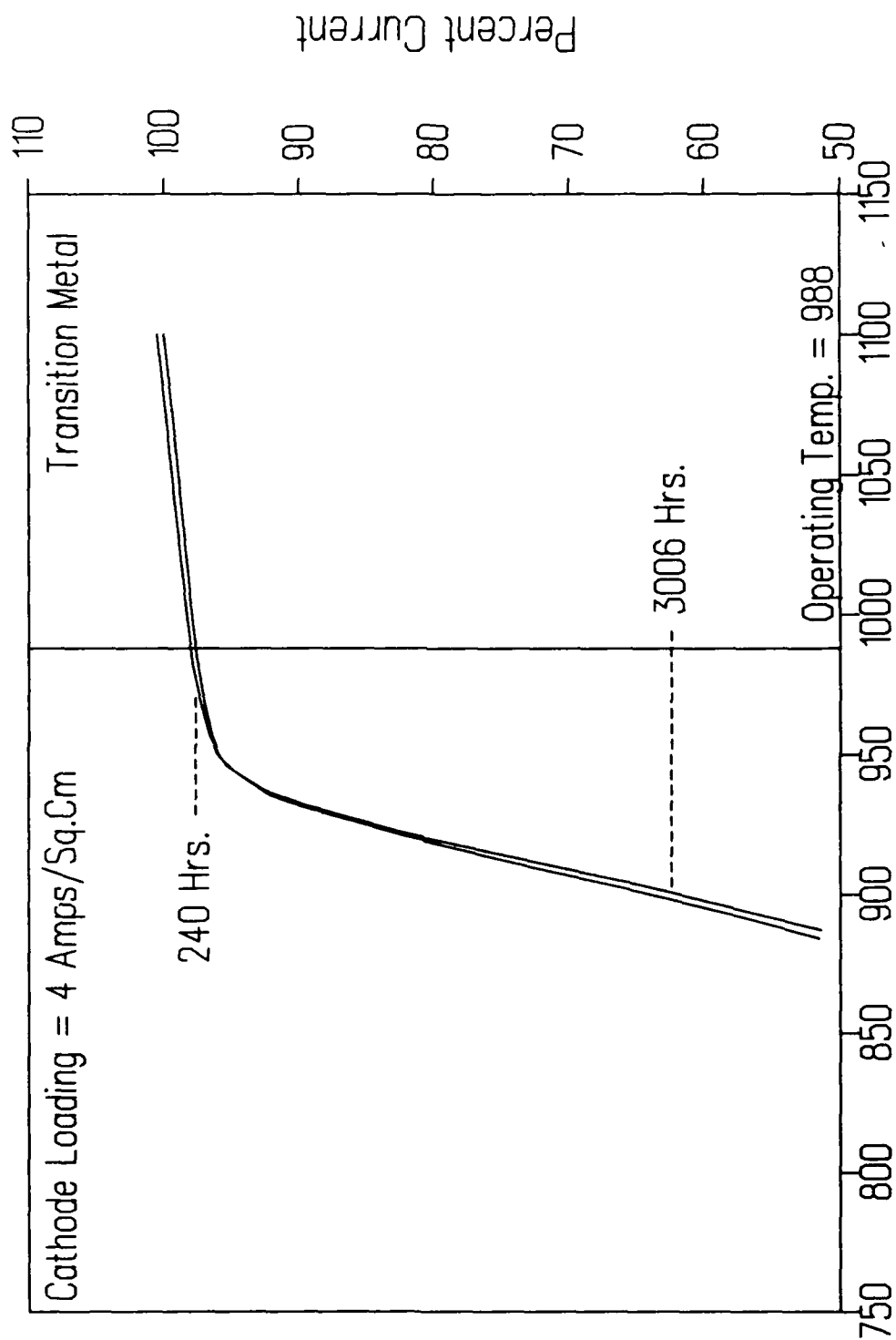
APPENDIX A:
CATHODE ACTIVITY PLOTS

CATHODE ACTIVITY PLOT



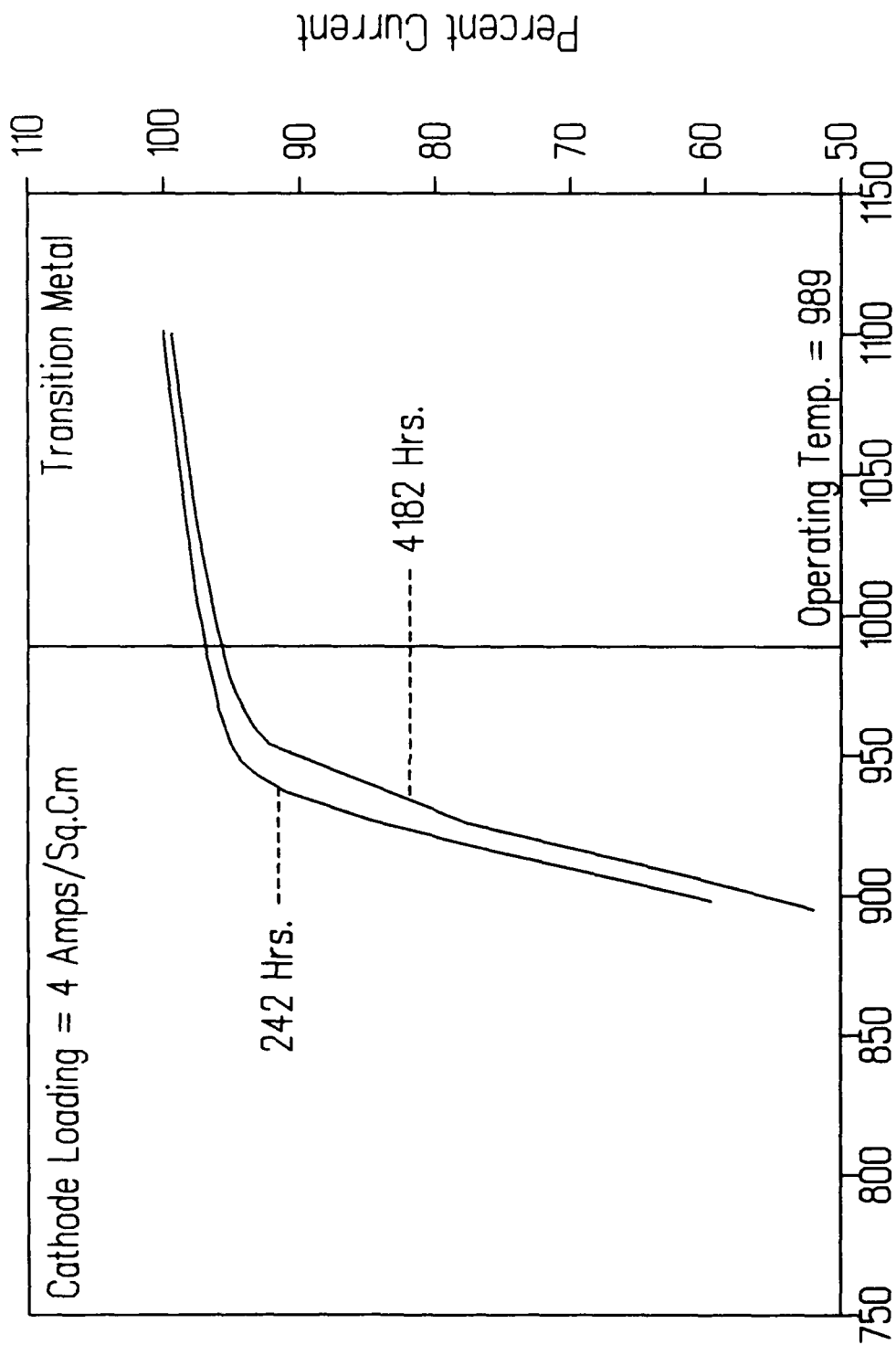
Temperature (C True)
FIGURE 2: SN-TM-B1135

CATHODE ACTIVITY PLOT



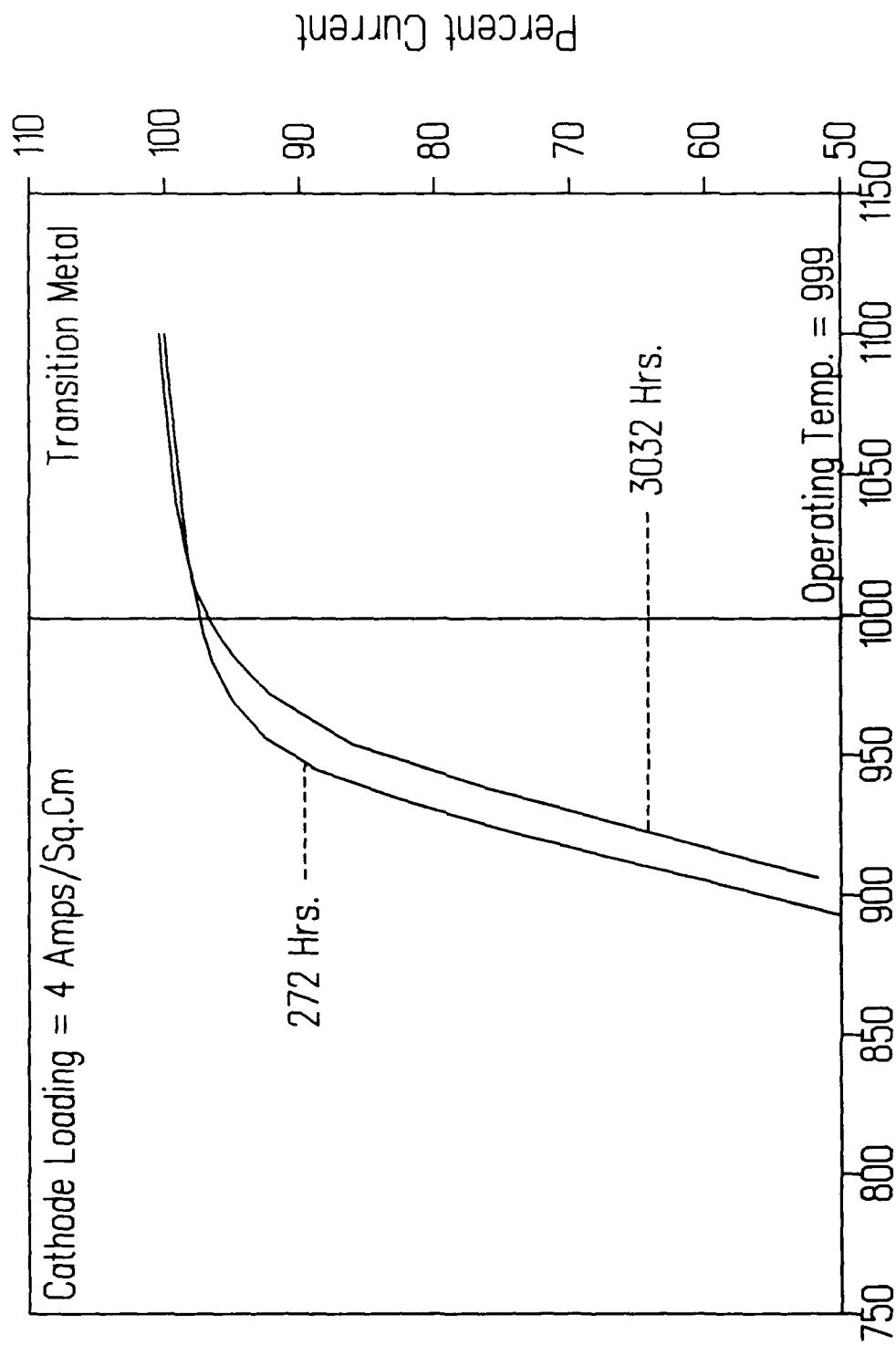
Temperature { C True }
FIGURE 3: SN-TM-B1240

CATHODE ACTIVITY PLOT



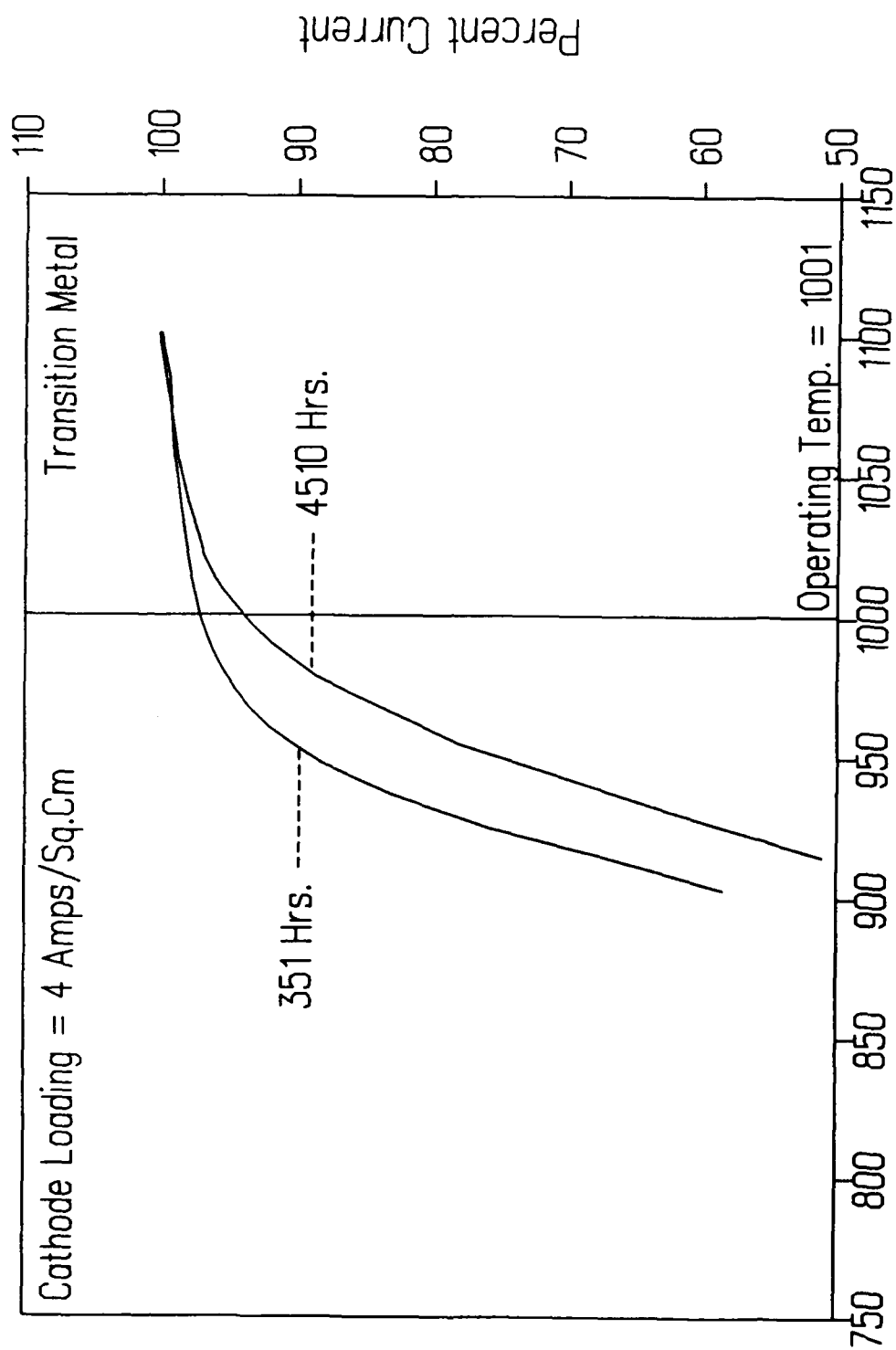
Temperature (C True)
FIGURE 4: SN-TM-B1350

CATHODE ACTIVITY PLOT



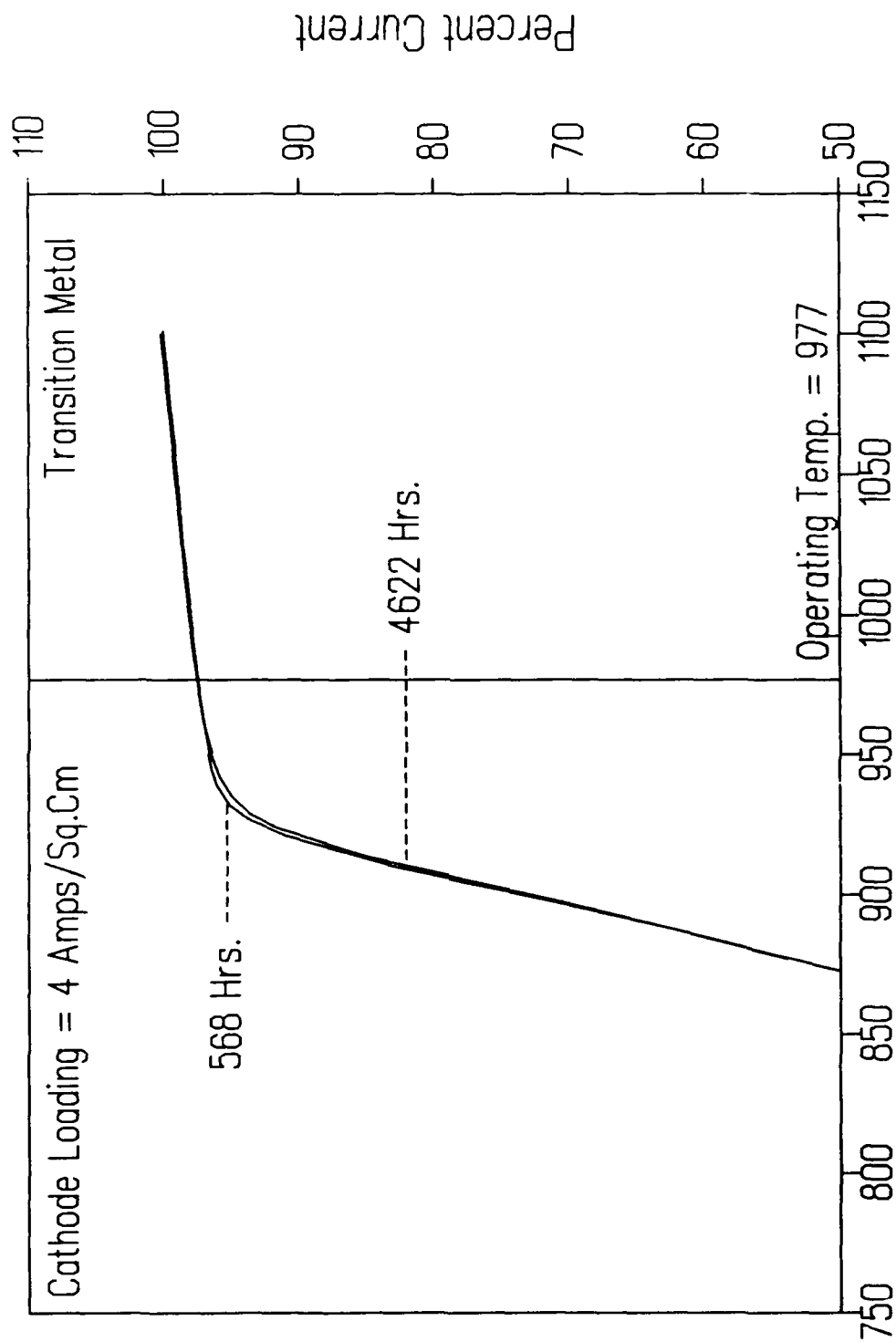
Temperature (C True)
FIGURE 5: SN-TM-B1352

CATHODE ACTIVITY PLOT



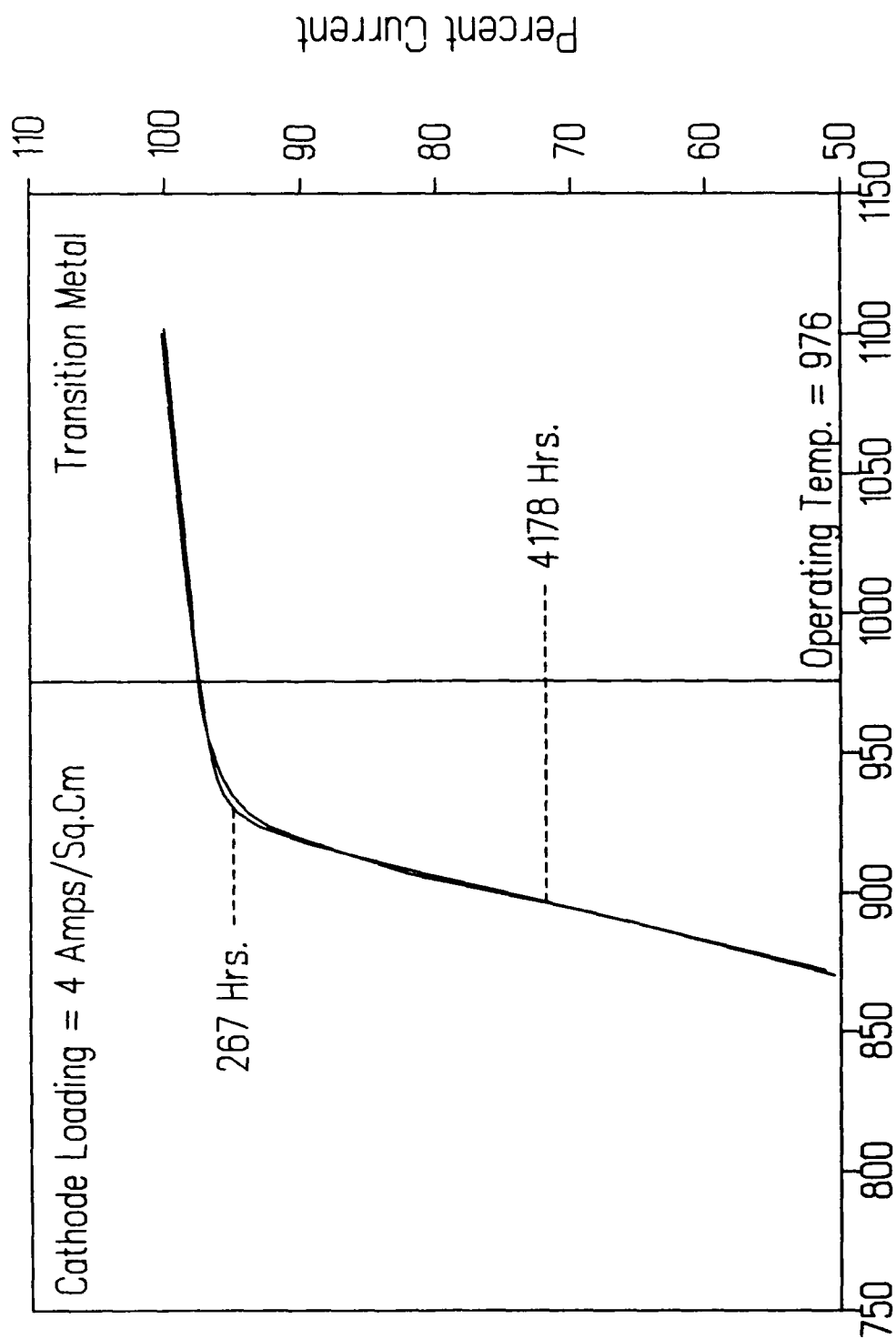
Temperature (C True)
FIGURE 6: SN-TM-B1455

CATHODE ACTIVITY PLOT



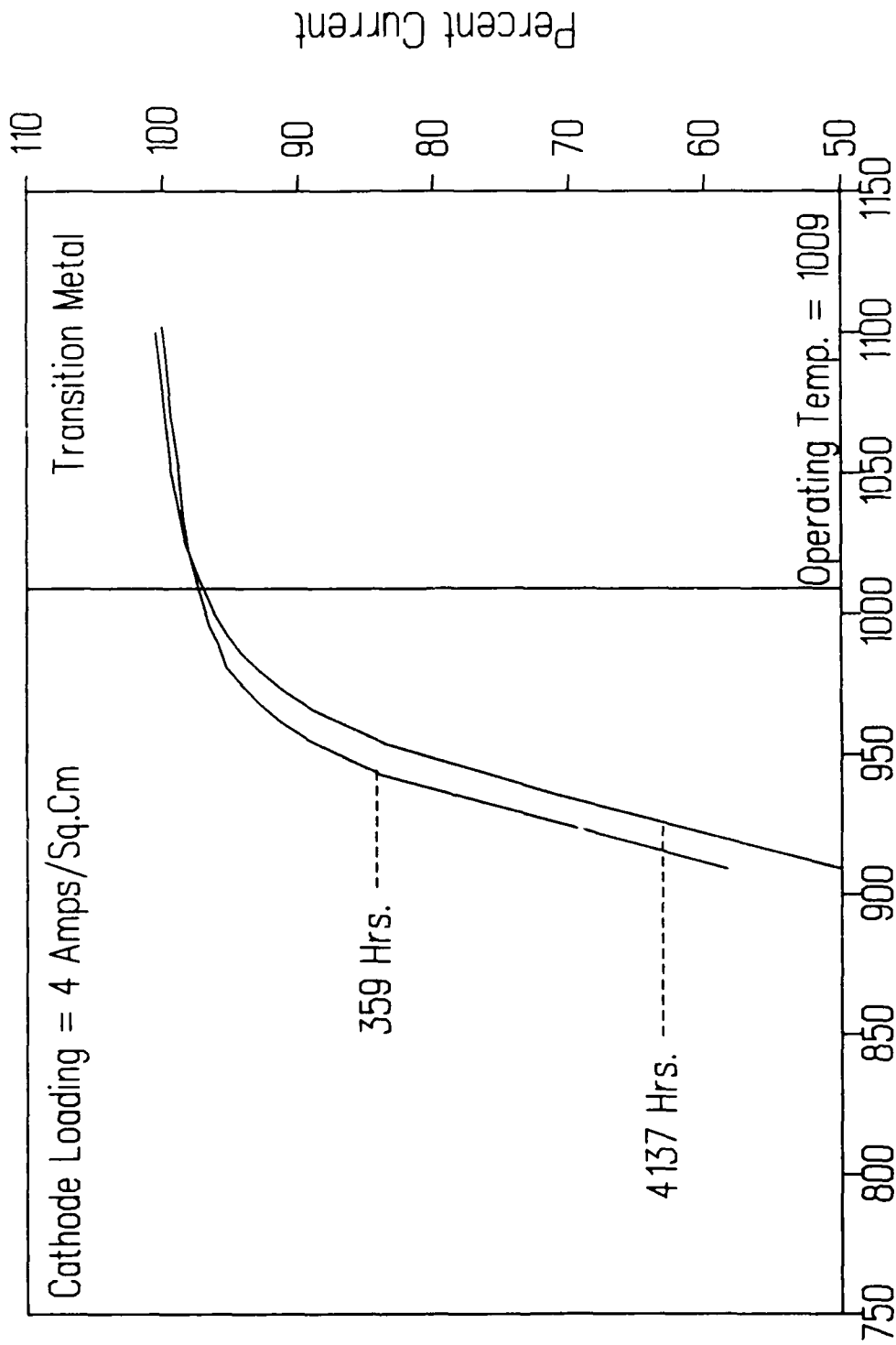
Temperature { C True }
FIGURE 7: SN-TM-B1462

CATHODE ACTIVITY PLOT



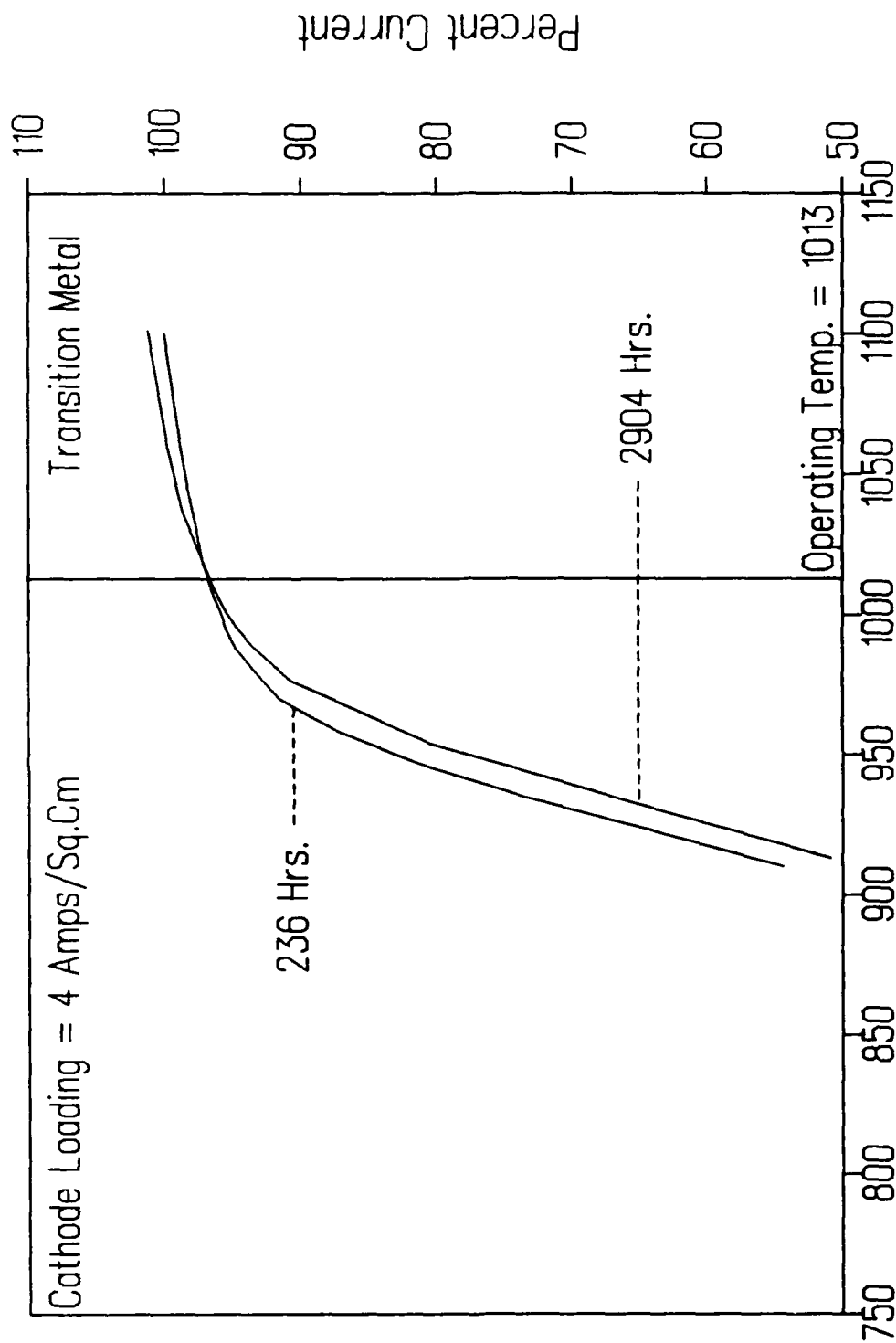
Temperature { C True }
FIGURE 8: SN-TM-B1565

CATHODE ACTIVITY PLOT



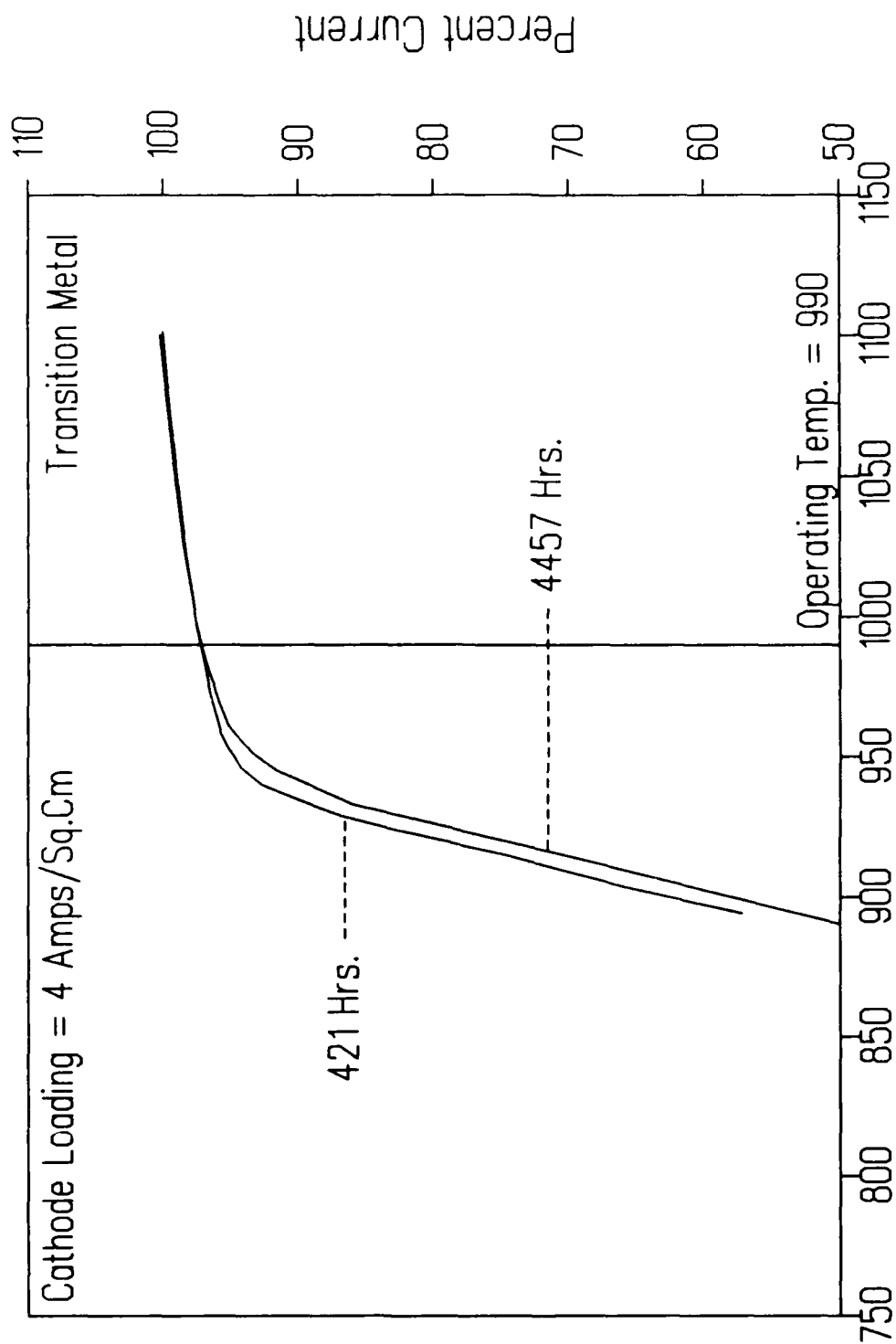
Temperature (C True)
FIGURE 9: SN-TM-B1667

CATHODE ACTIVITY PLOT



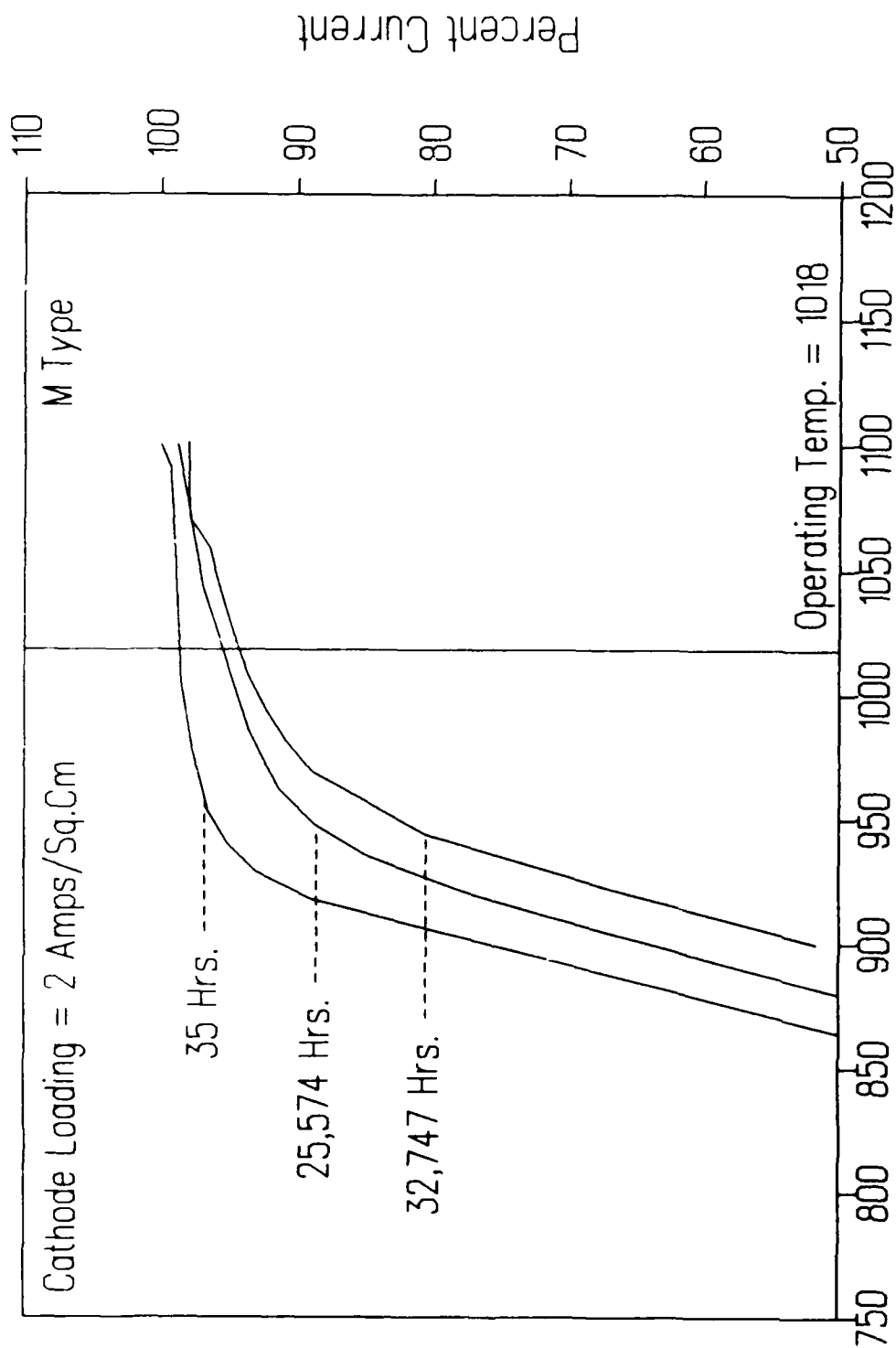
Temperature (C True)
FIGURE 10: SN-TM-B1671

CATHODE ACTIVITY PLOT



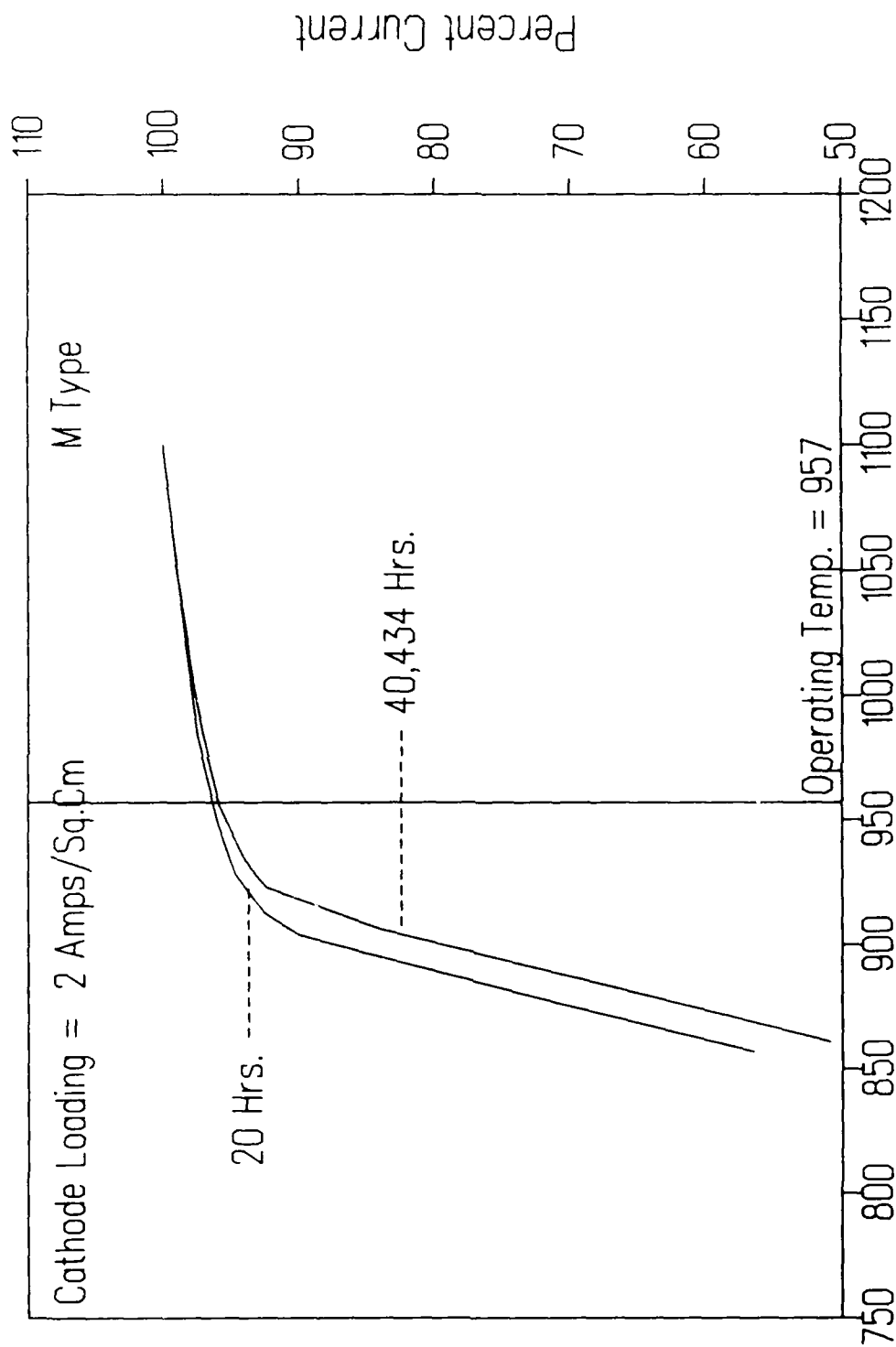
Temperature (C True)
FIGURE 11: SN-TM-B1672

CATHODE ACTIVITY PLOT



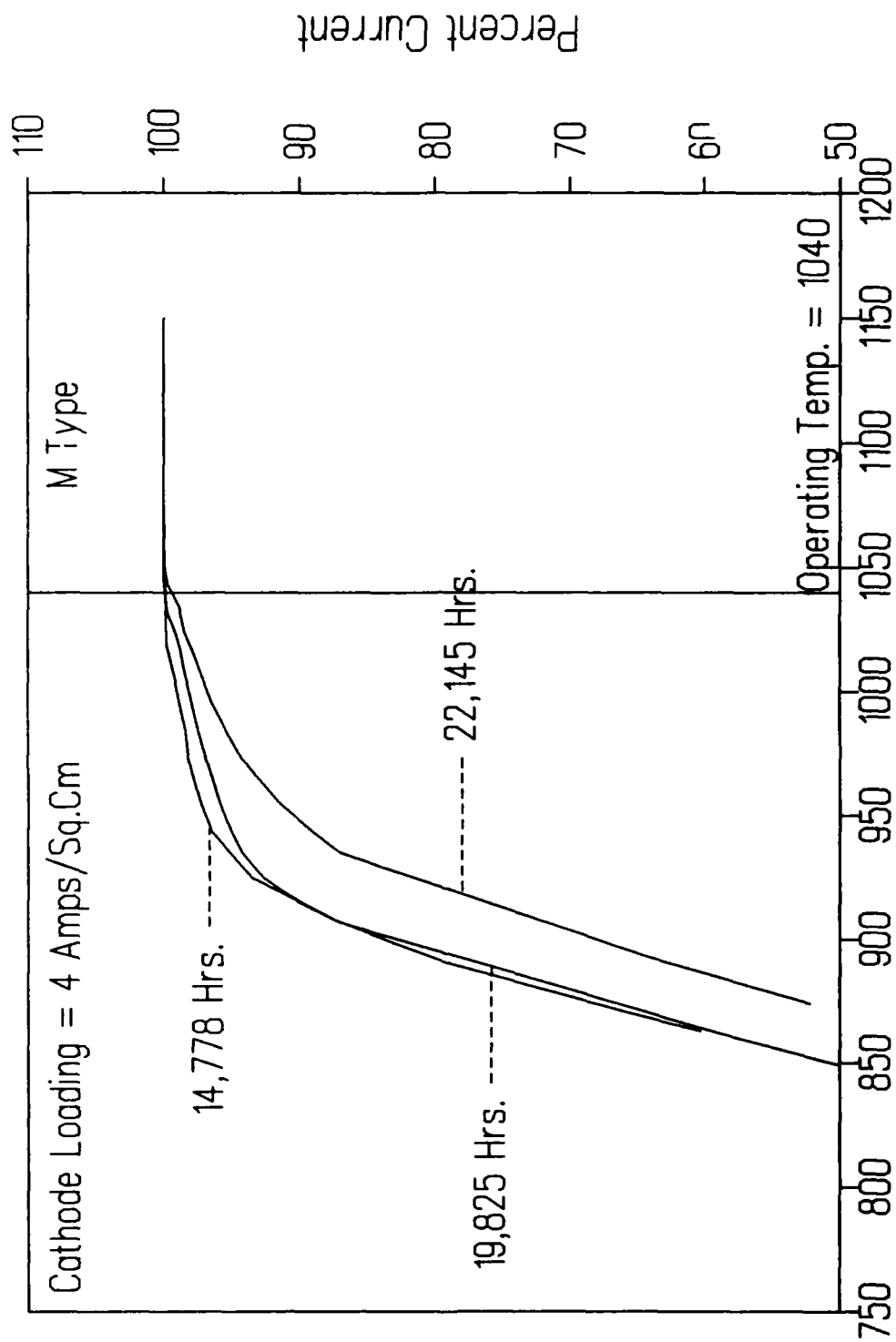
Temperature (C True)
FIGURE 12: SN-202

CATHODE ACTIVITY PLOT



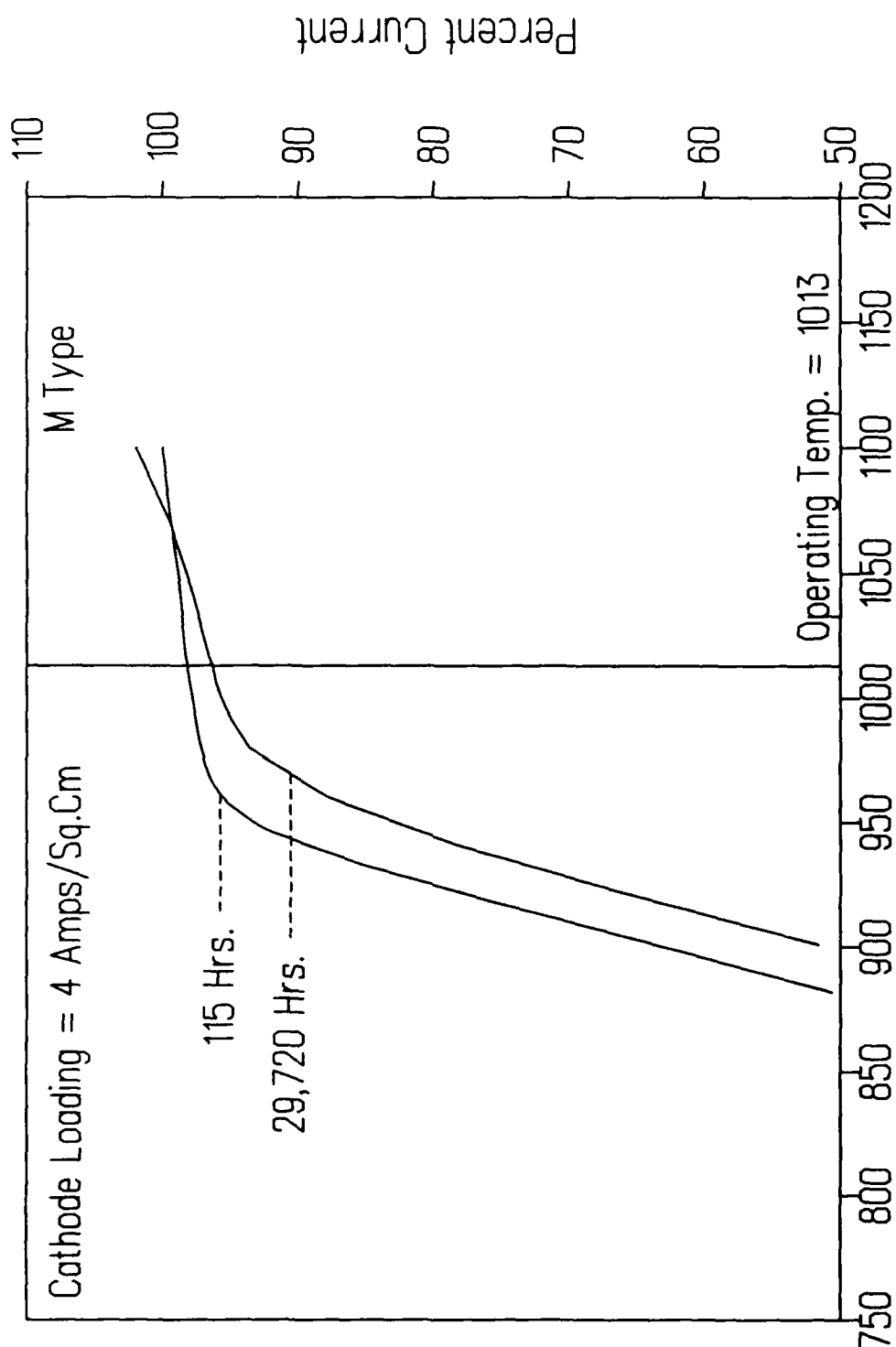
Temperature (C True)
FIGURE 13: SN-209

CATHODE ACTIVITY PLOT



Temperature (C True)
FIGURE 14: SN-211

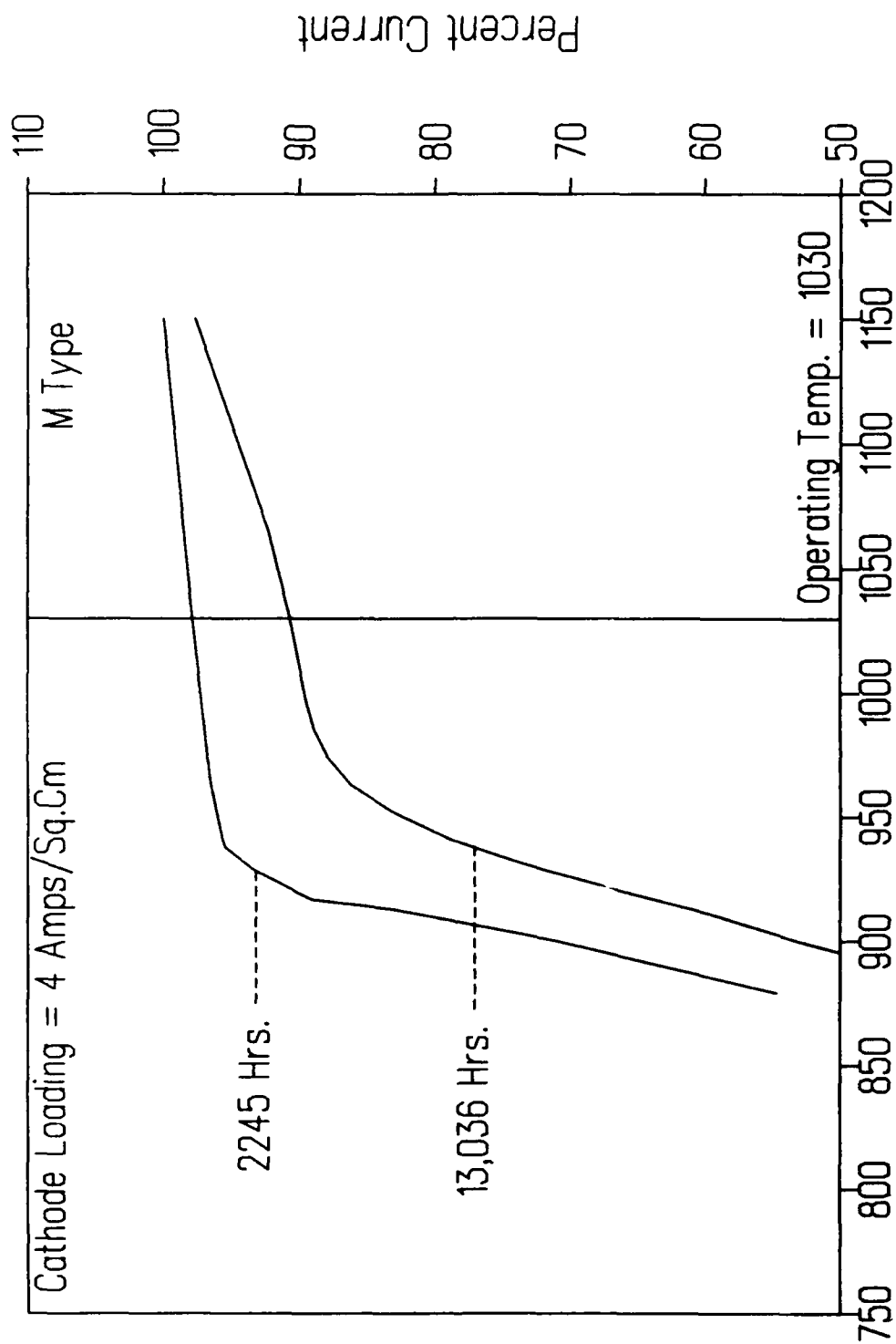
CATHODE ACTIVITY PLOT



Temperature (C True)

FIGURE 15: SN-212

CATHODE ACTIVITY PLOT



Temperature (C True)

FIGURE 16: SN-214

CATHODE ACTIVITY PLOT

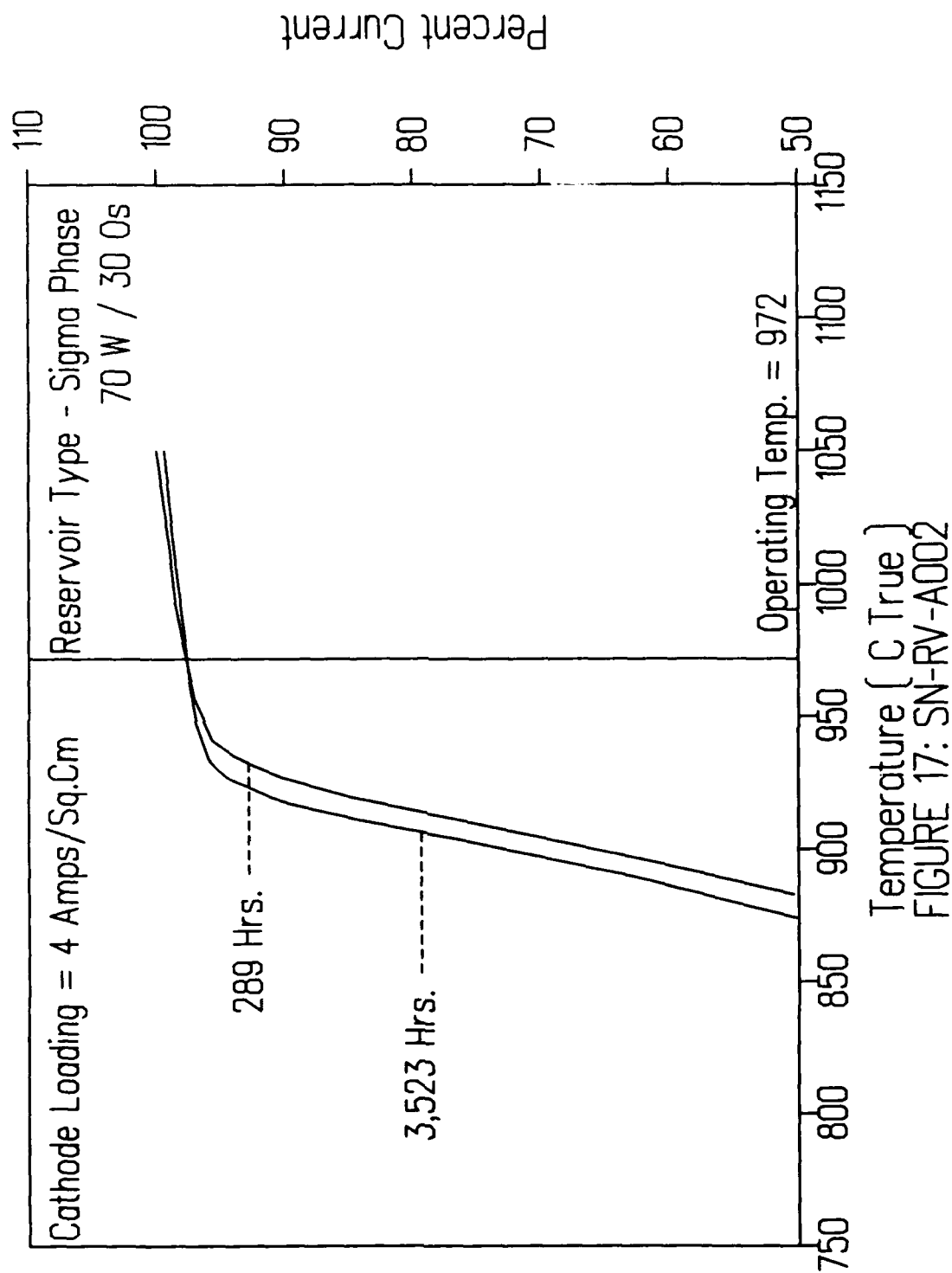
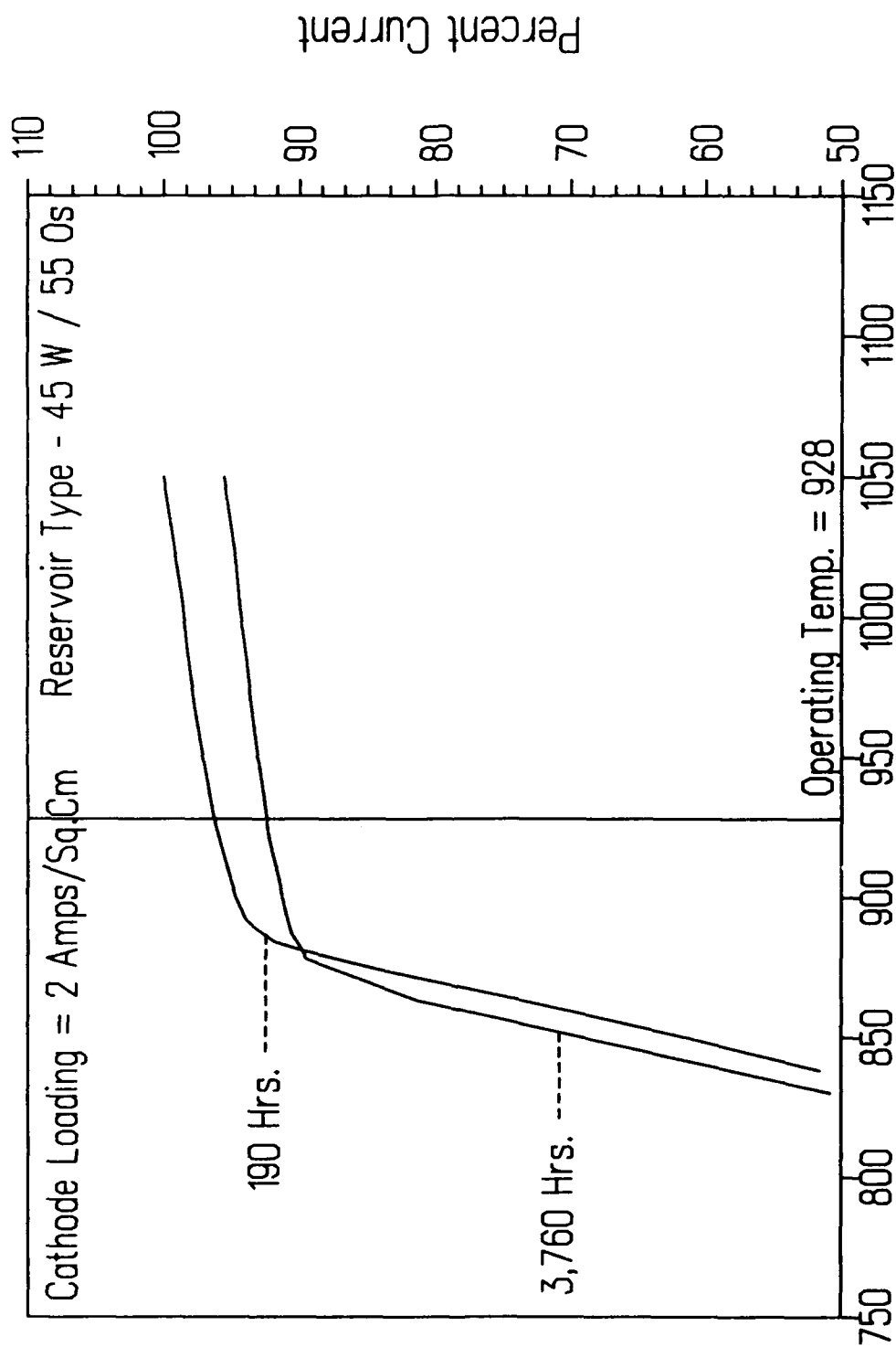


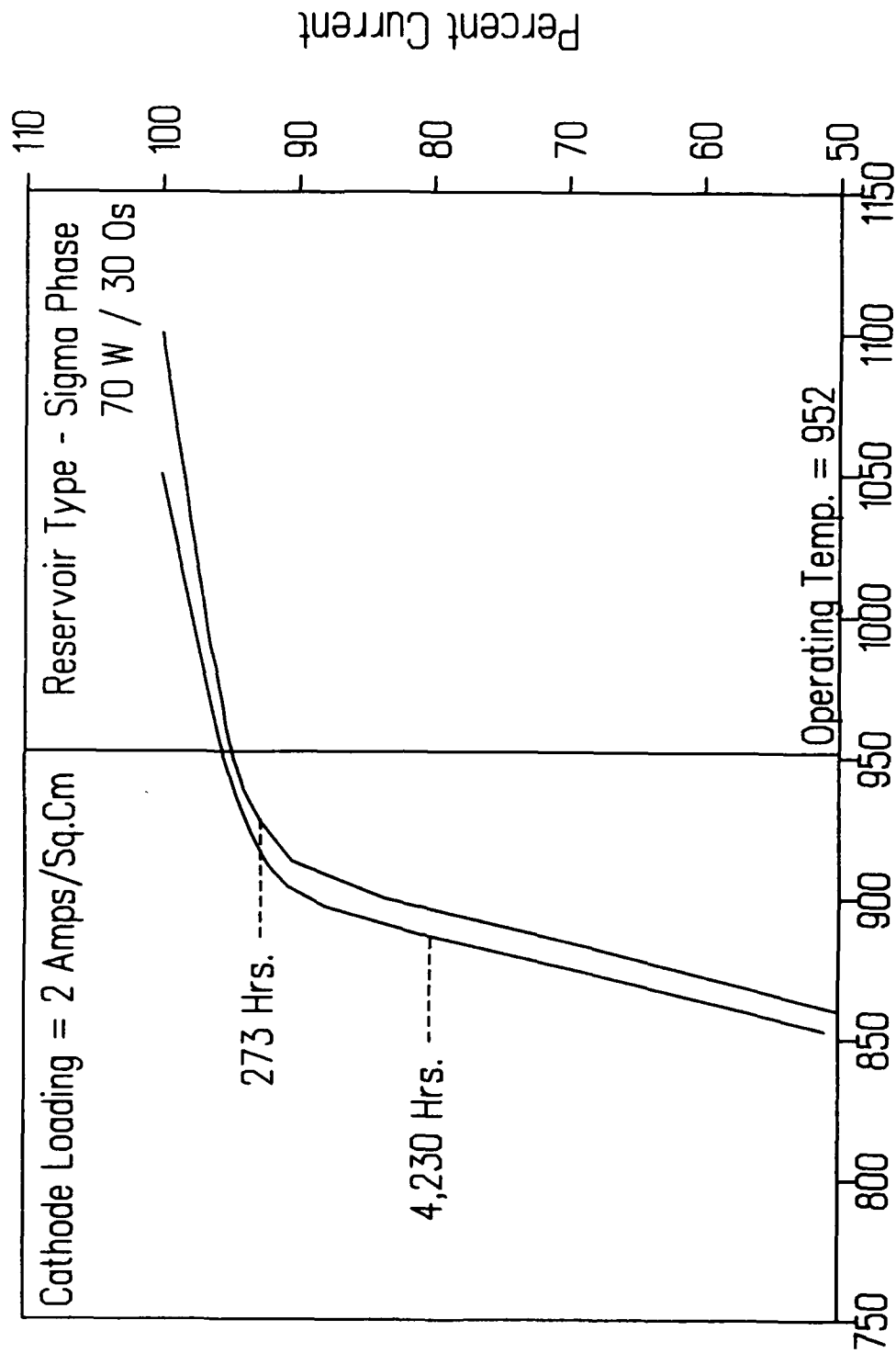
FIGURE 17: SN-RV-A002

CATHODE ACTIVITY PLOT



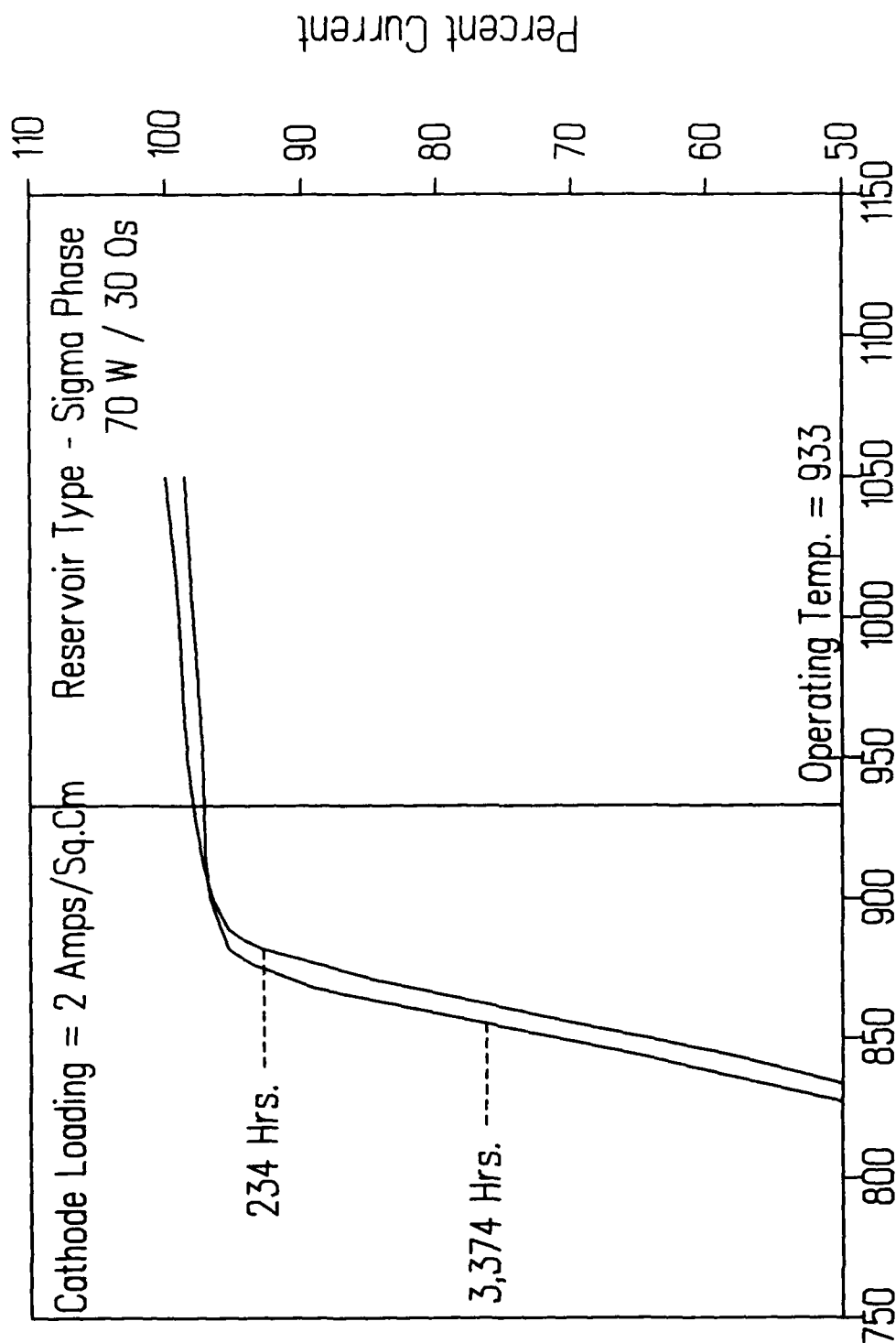
Temperature (C True)
FIGURE 18: SN-RV-A003

CATHODE ACTIVITY PLOT



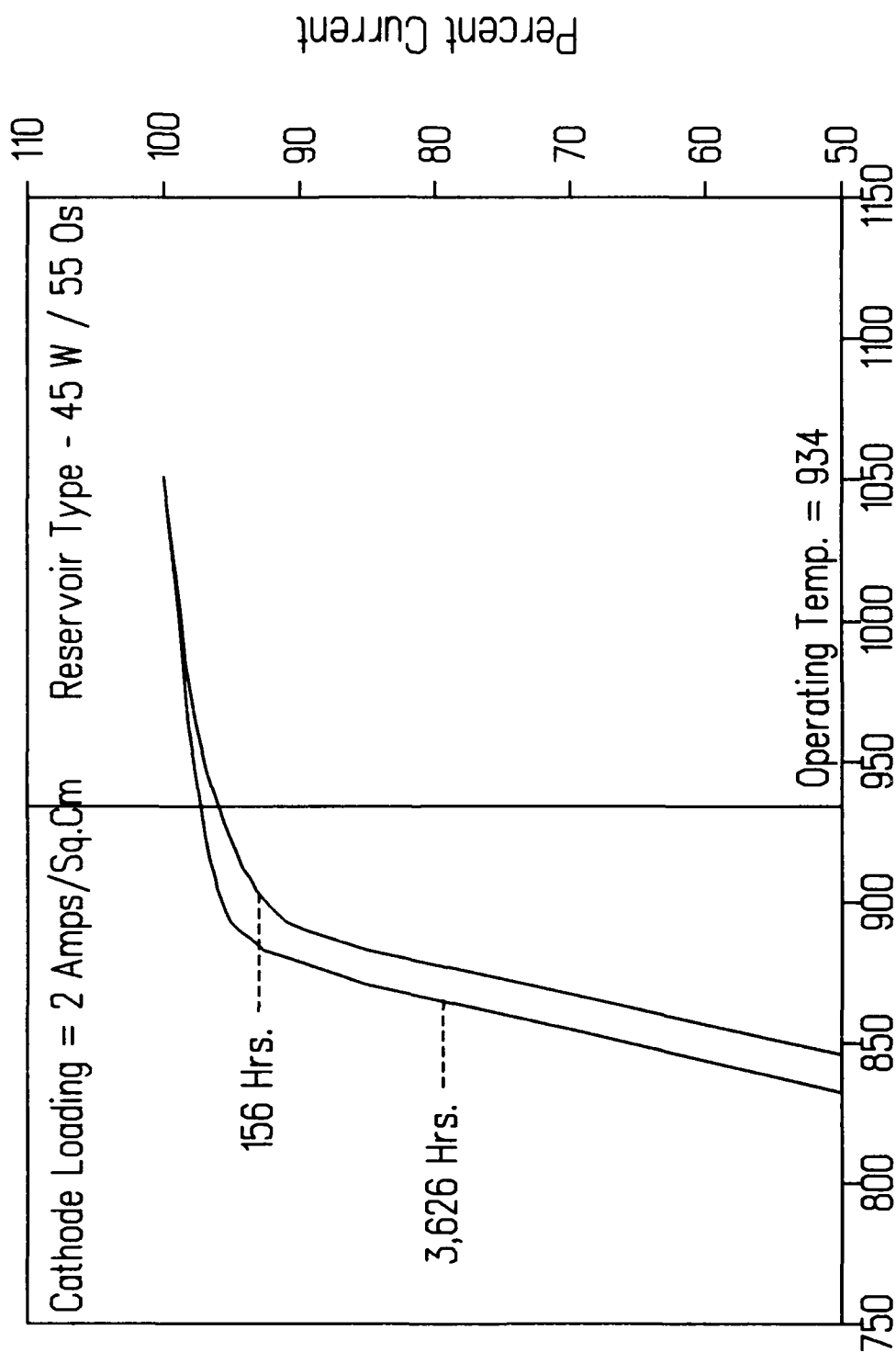
Temperature (C True)
FIGURE 19: SN-RV-A005

CATHODE ACTIVITY PLOT



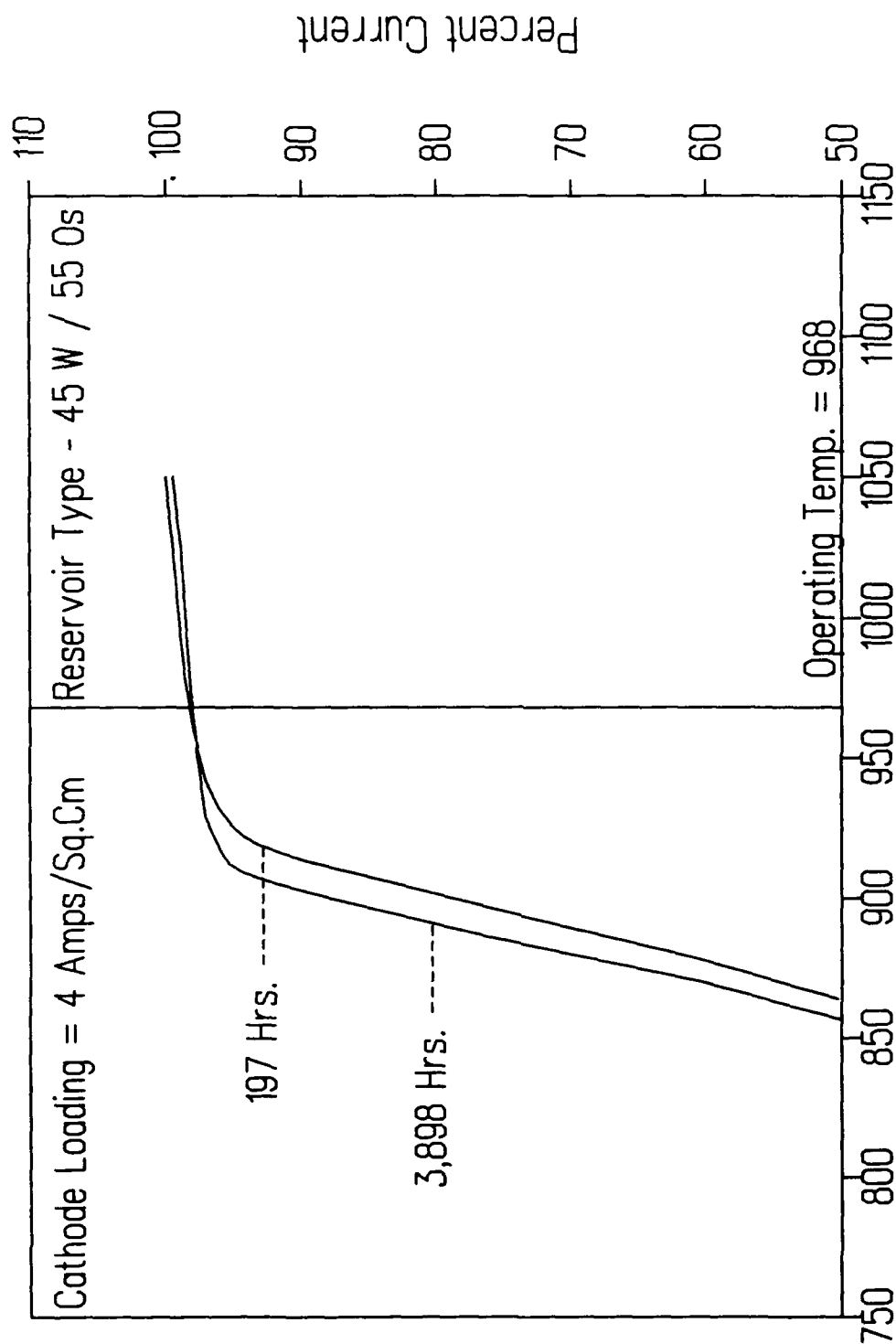
Temperature (C True)
FIGURE 20: SN-RV-A008

CATHODE ACTIVITY PLOT



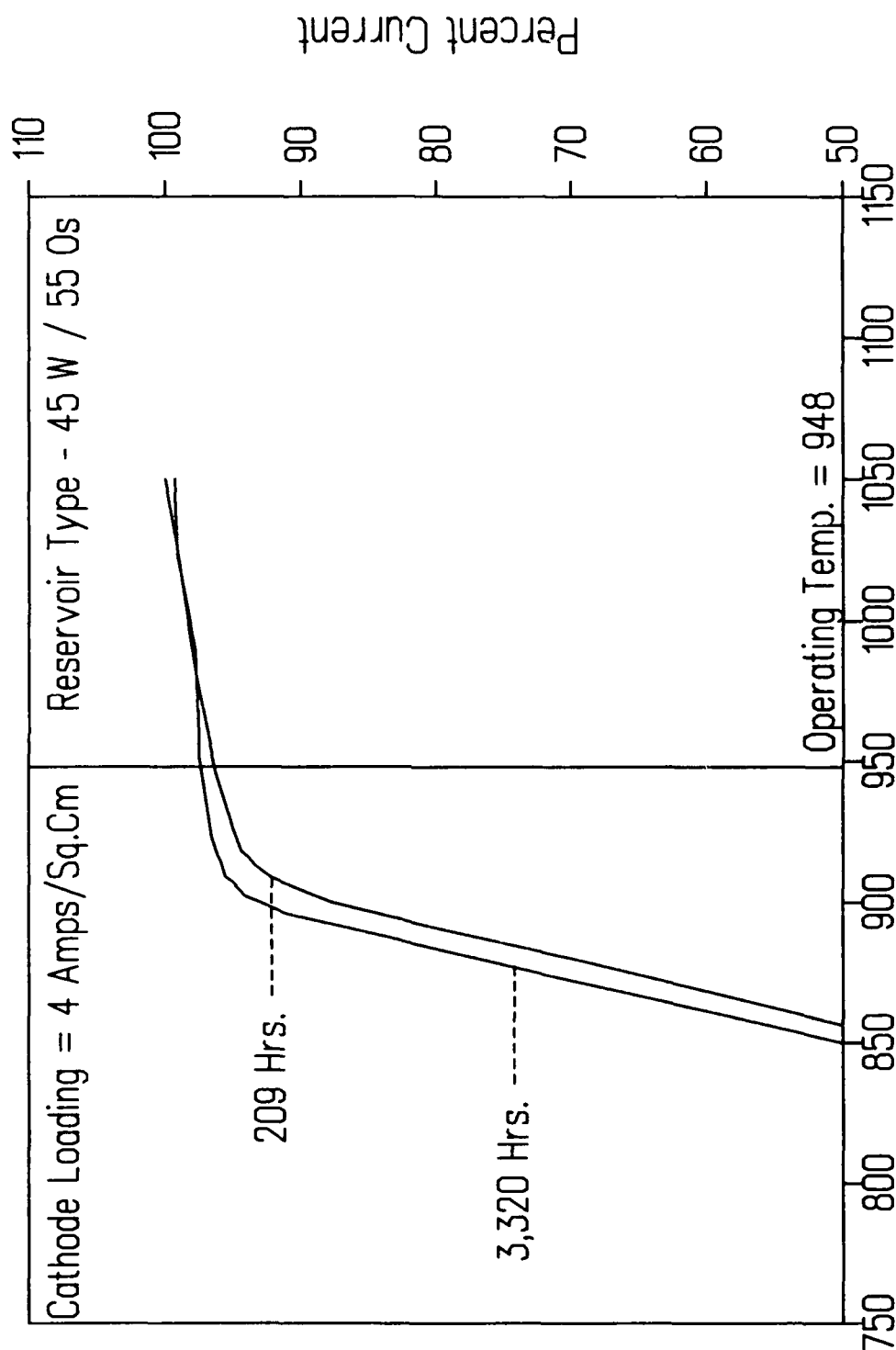
Temperature (C True)
FIGURE 21: SN-RV-A009

CATHODE ACTIVITY PLOT



Temperature (C True)
FIGURE 22: SN-RV-A006

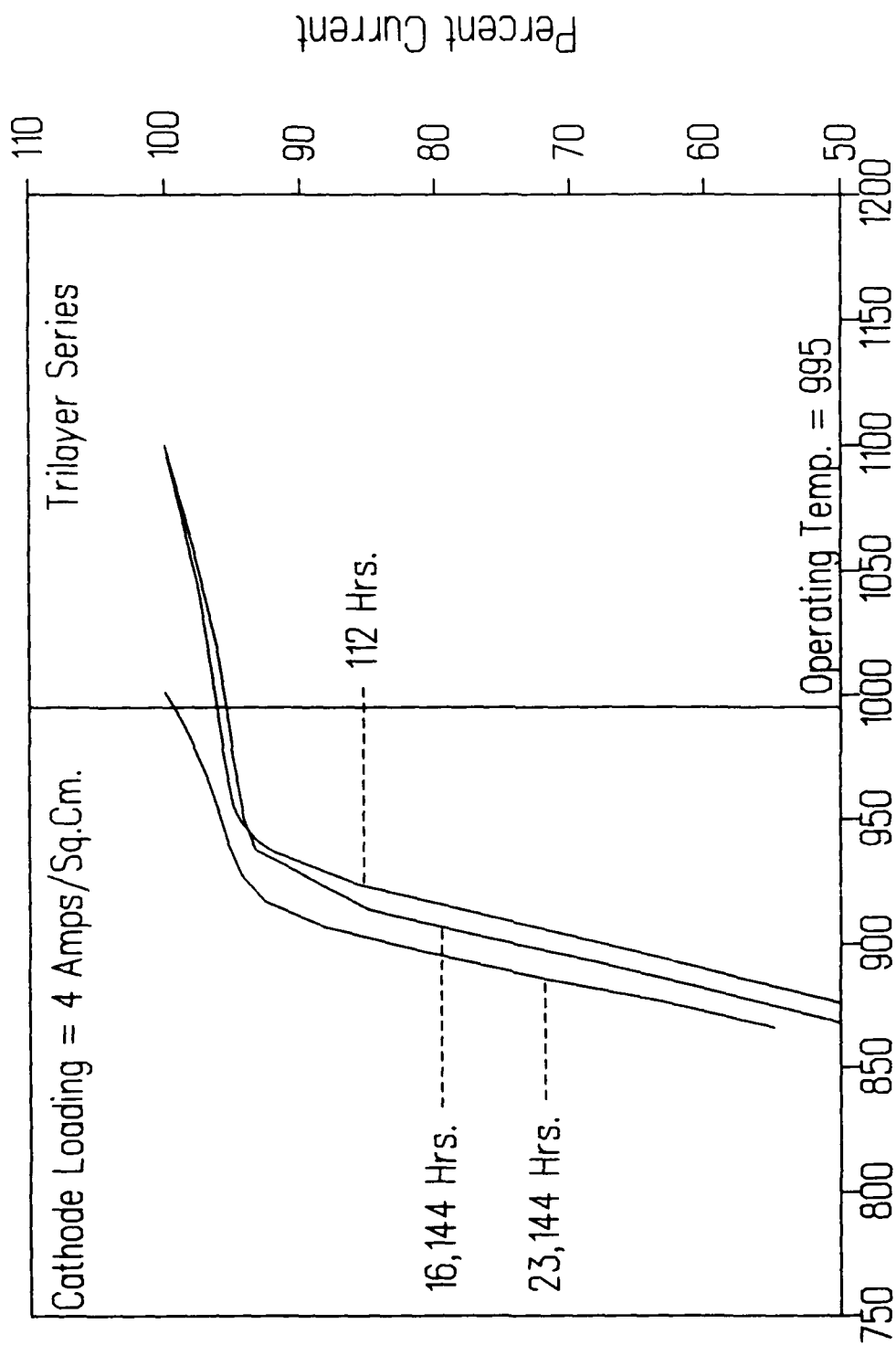
CATHODE ACTIVITY PLOT



Temperature { C True }

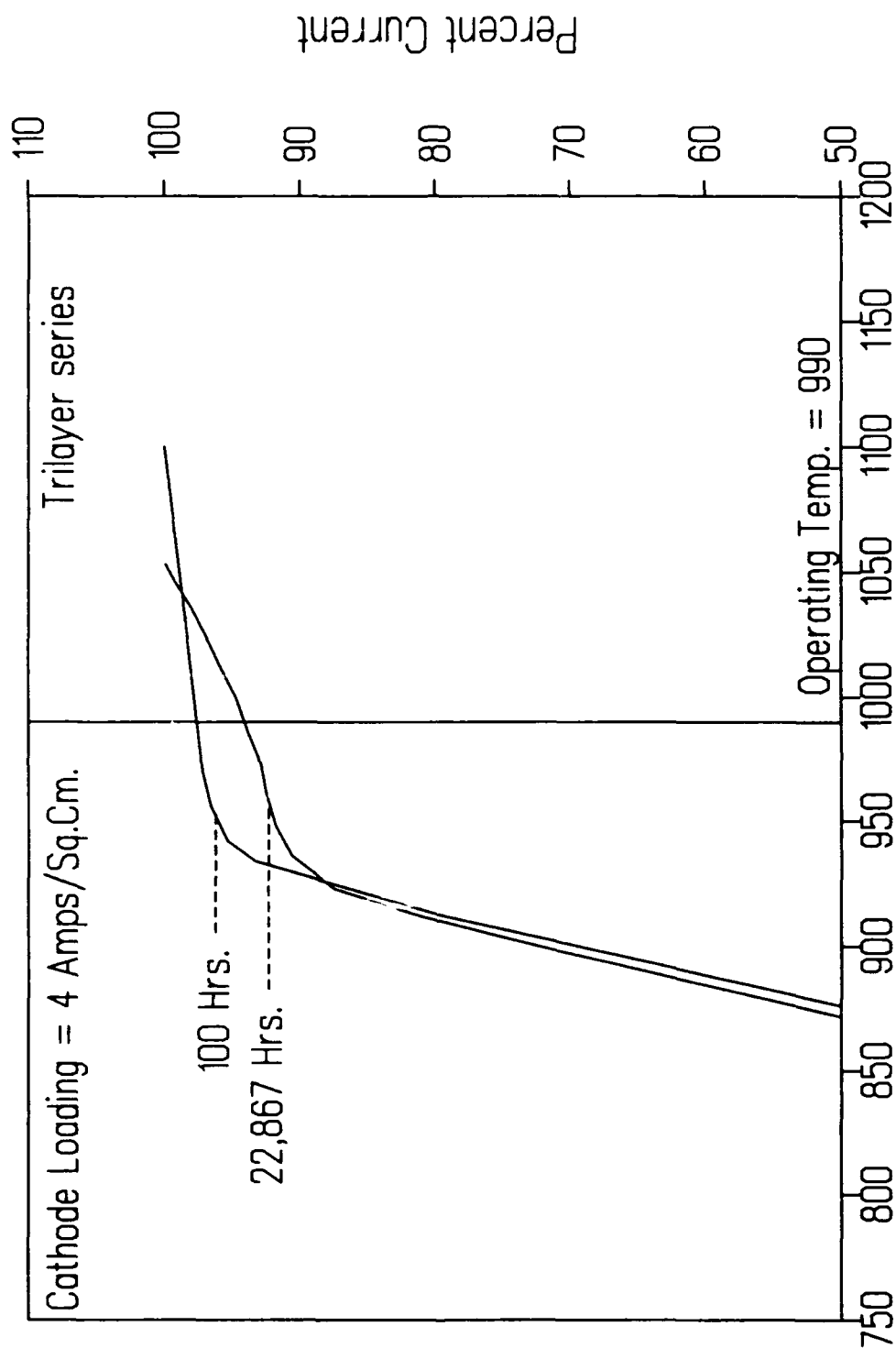
FIGURE 23: SN-RV-A007

CATHODE ACTIVITY PLOT



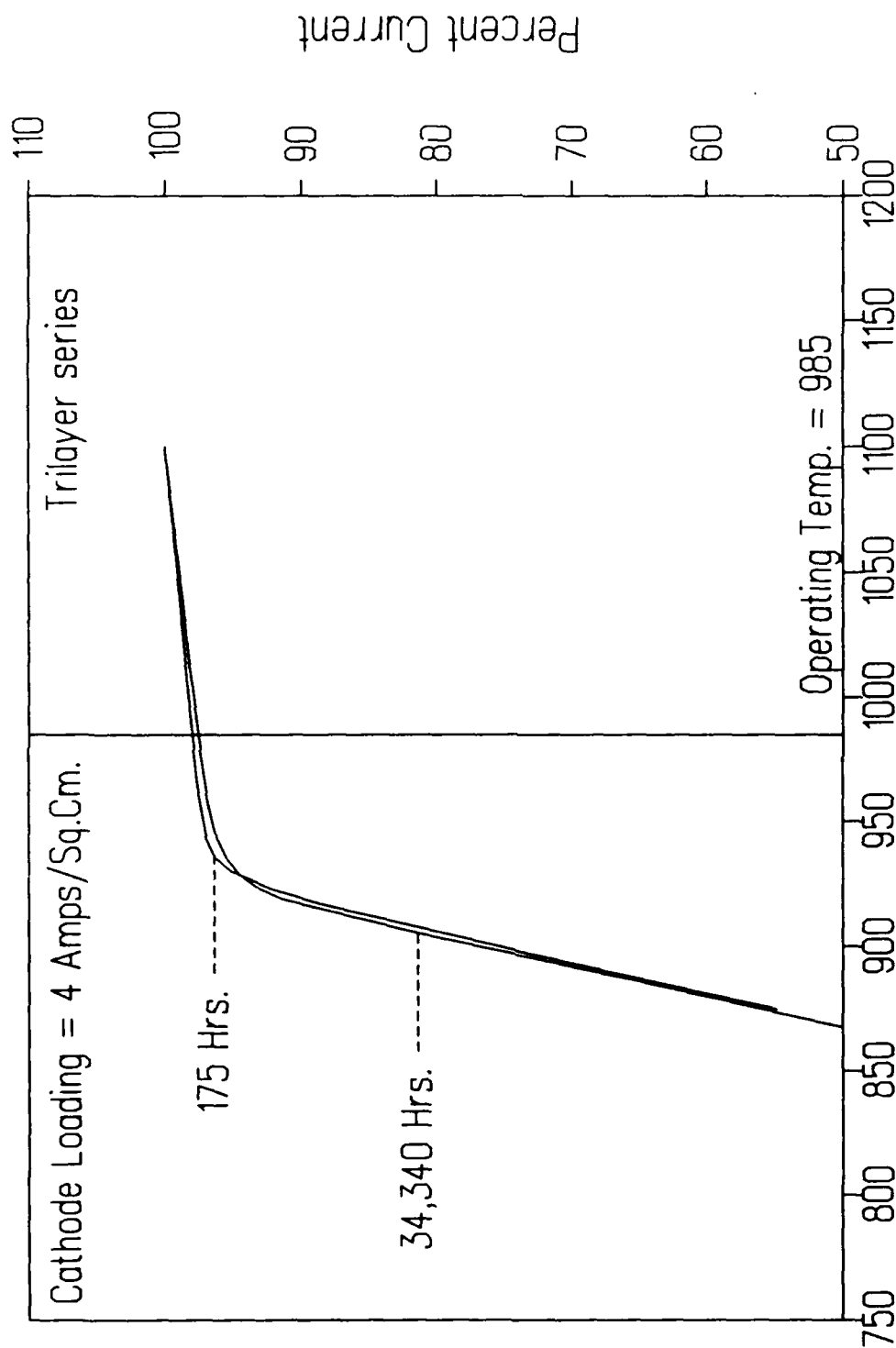
Temperature (C True)
FIGURE 24: SN-007

CATHODE ACTIVITY PLOT



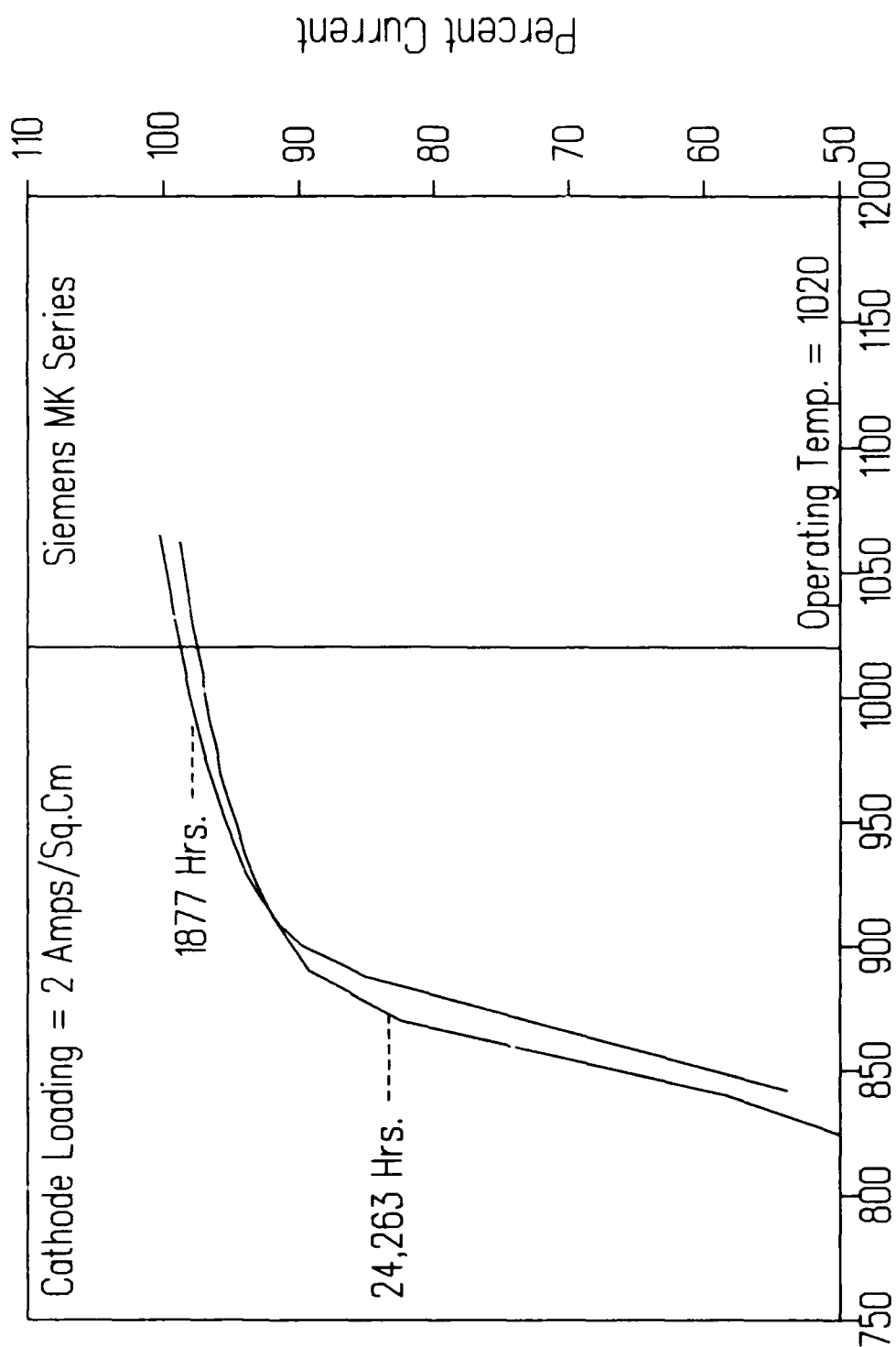
Temperature (C True)
FIGURE 25: SN-009

CATHODE ACTIVITY PLOT



Temperature (C True)
FIGURE 26: SN-012

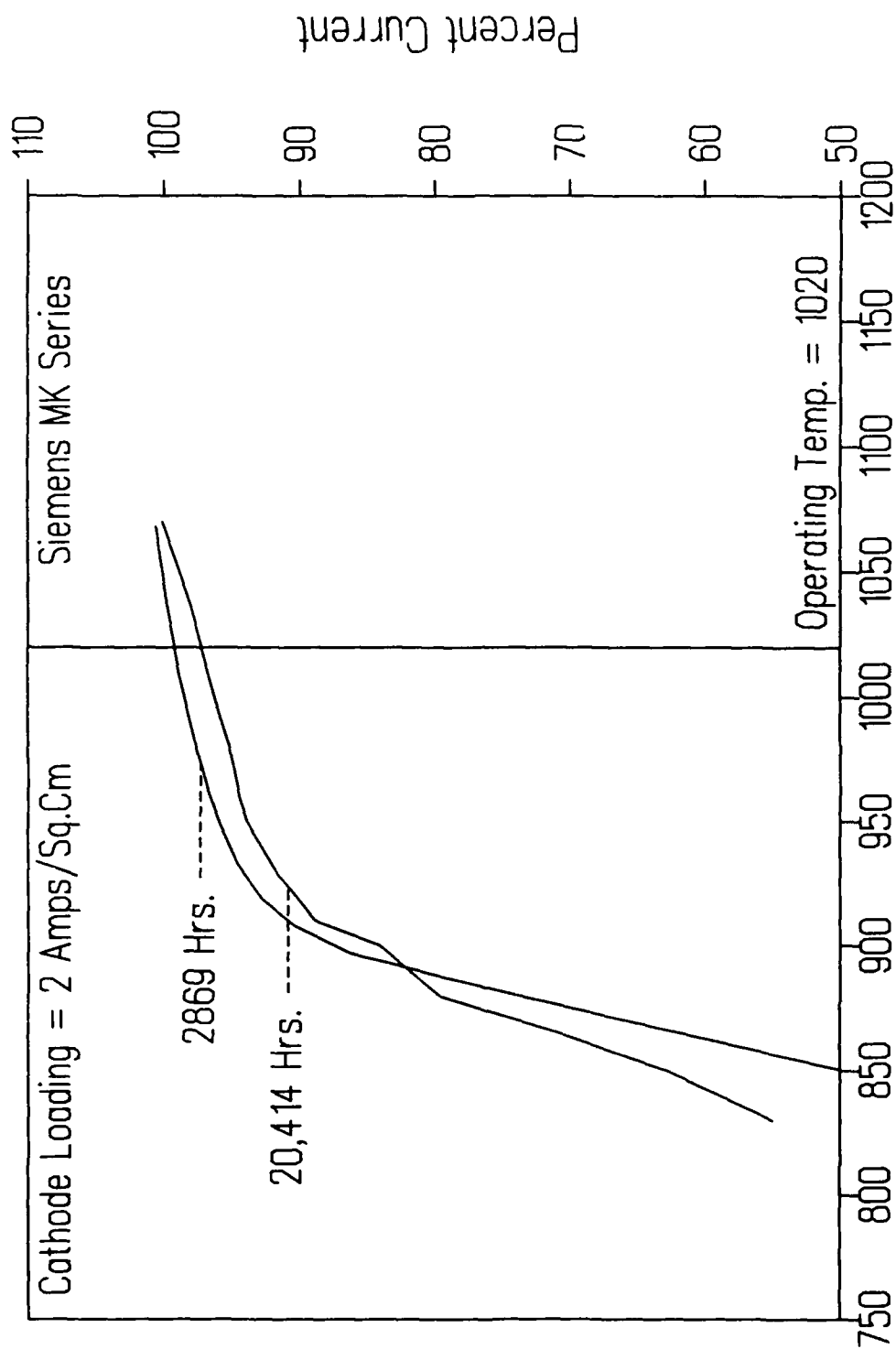
CATHODE ACTIVITY PLOT



Temperature (C Bright)

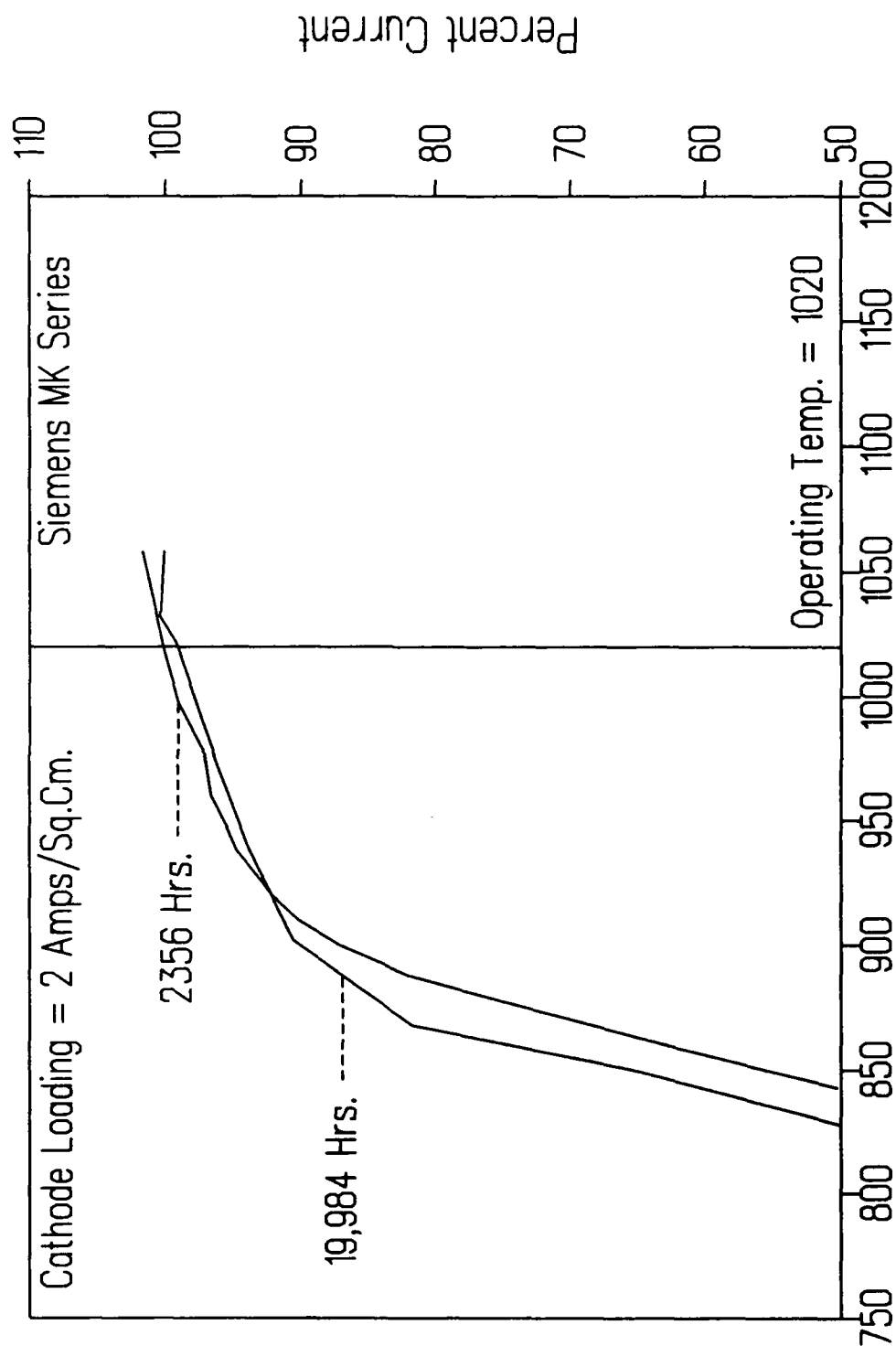
FIGURE 27: SN-MK-2

CATHODE ACTIVITY PLOT



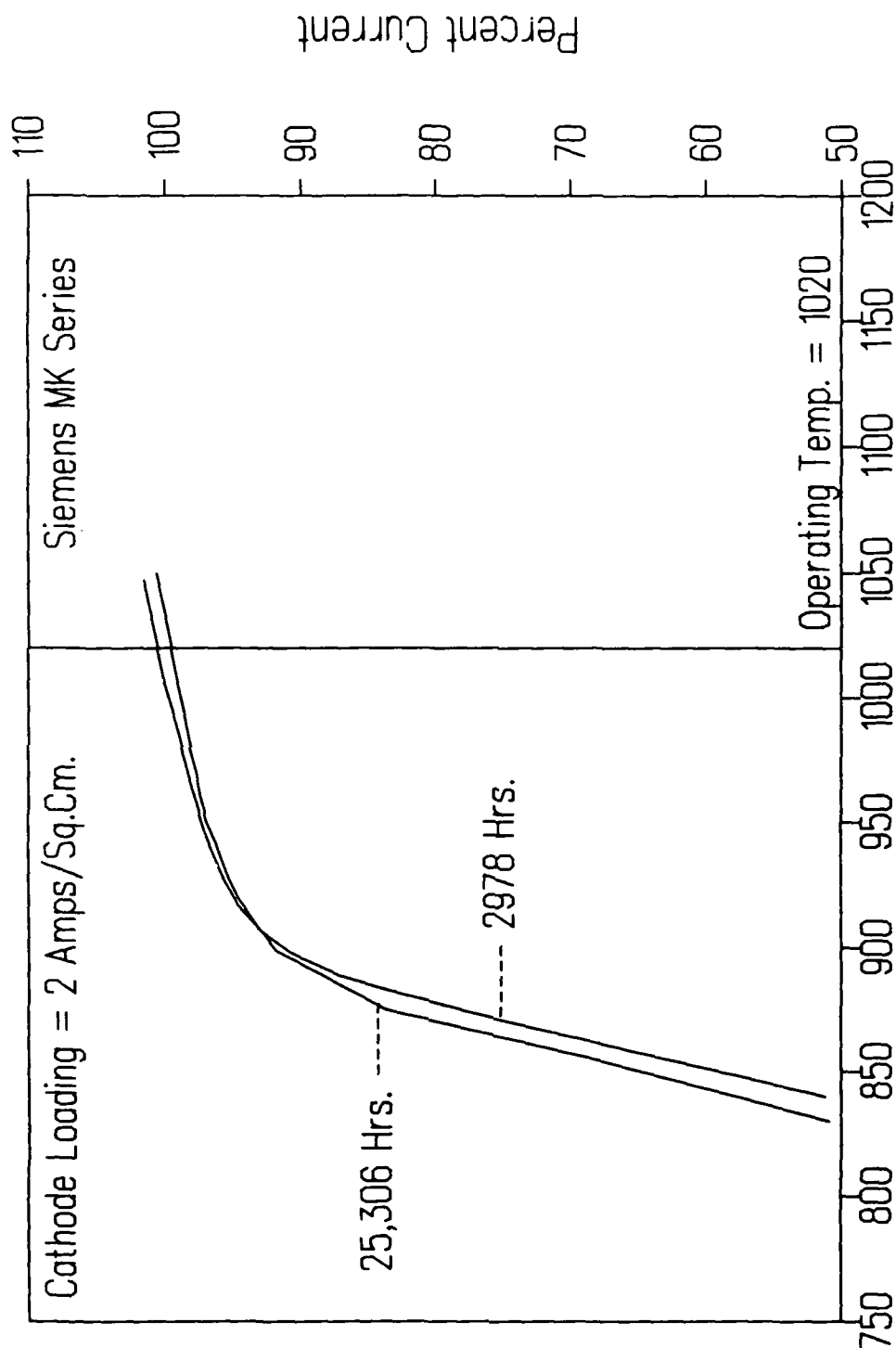
Temperature (C Bright)
FIGURE 28: SN-MK-6

CATHODE ACTIVITY PLOT



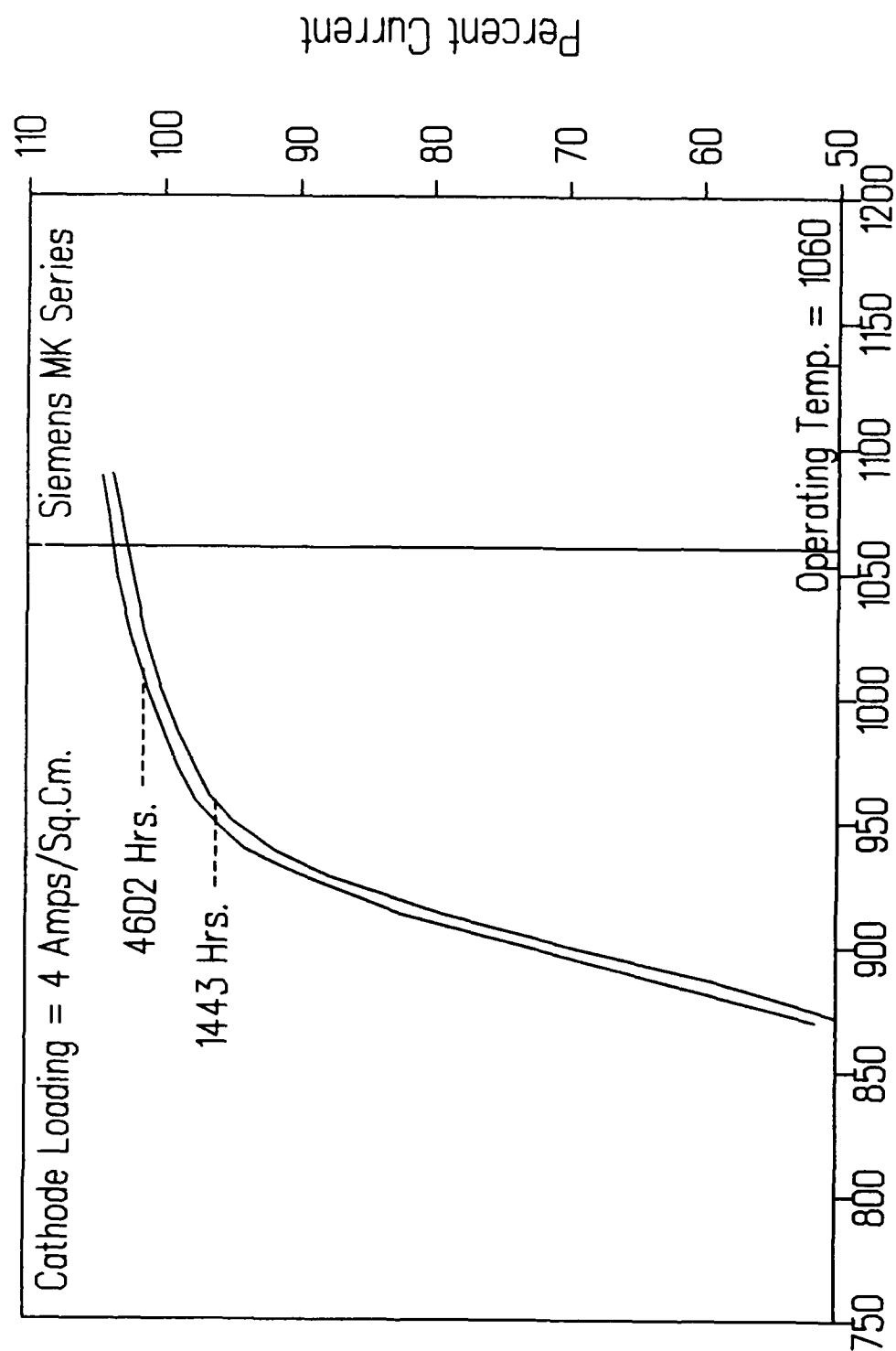
Temperature (C Bright)
FIGURE 29: SN-MK-7

CATHODE ACTIVITY PLOT



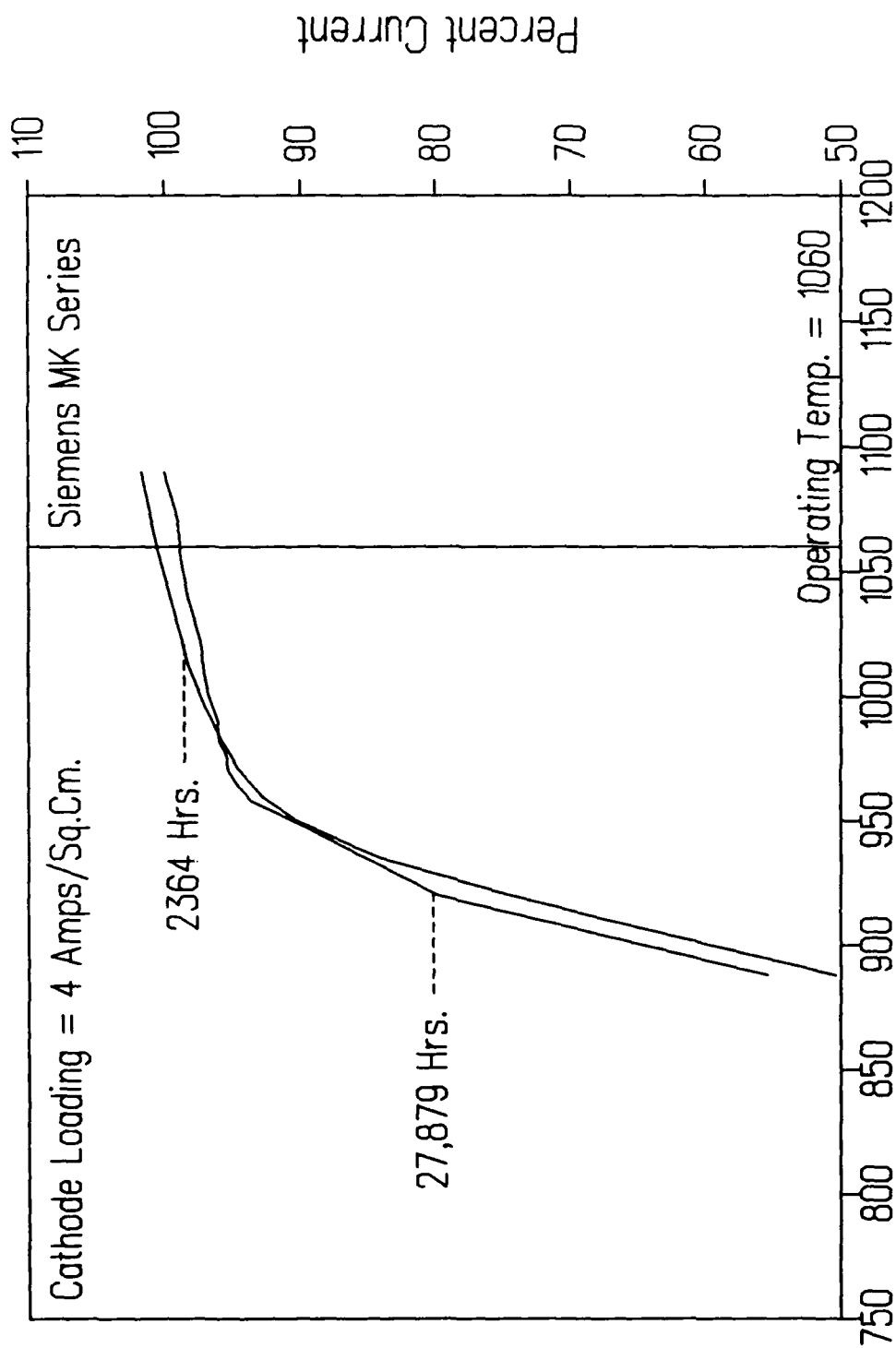
Temperature { C Bright }
FIGURE 30: SN-MK-12

CATHODE ACTIVITY PLOT



Temperature (C Bright)
FIGURE 31: SN-MK-3

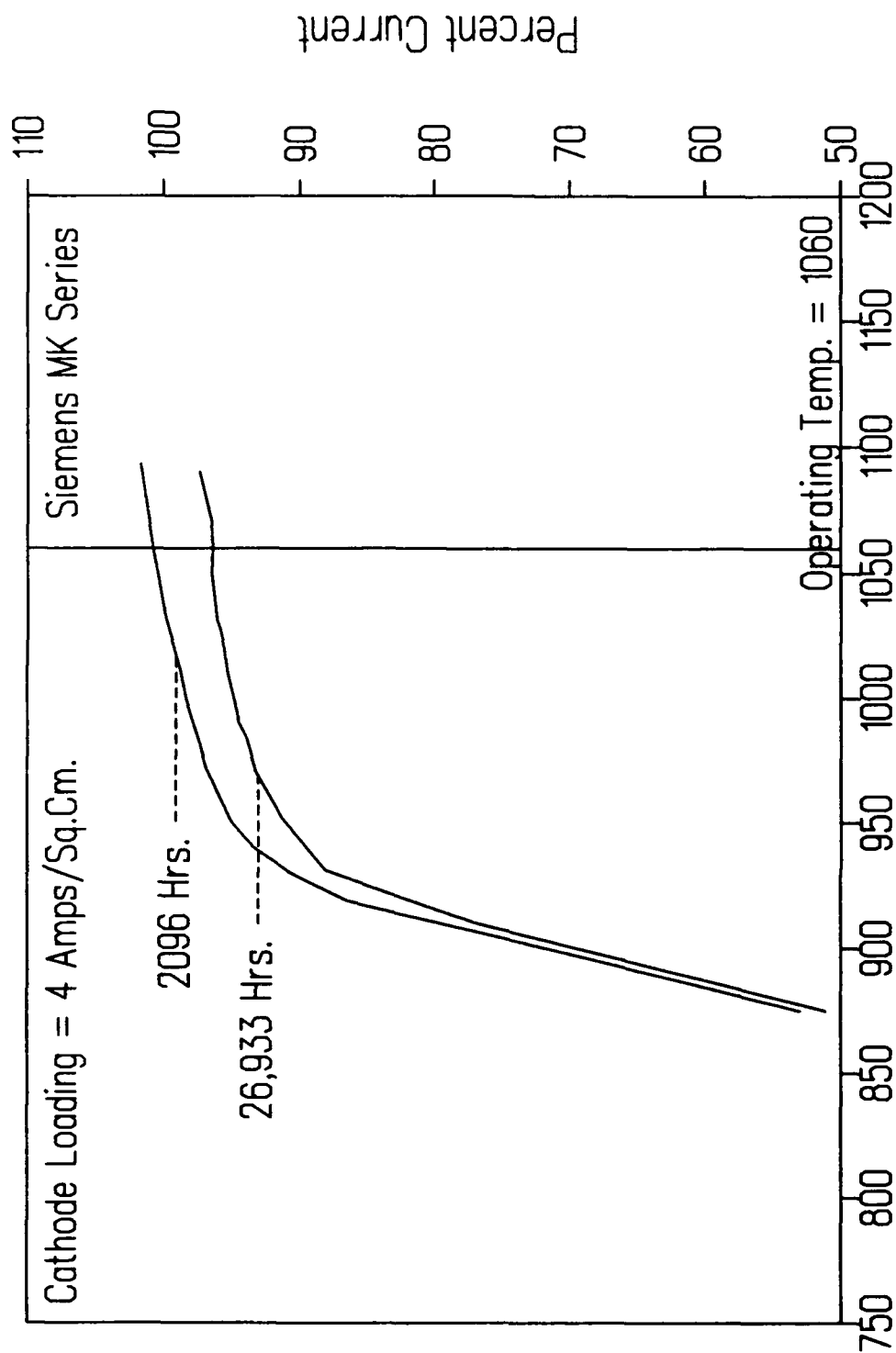
CATHODE ACTIVITY PLOT



Temperature (C Bright)

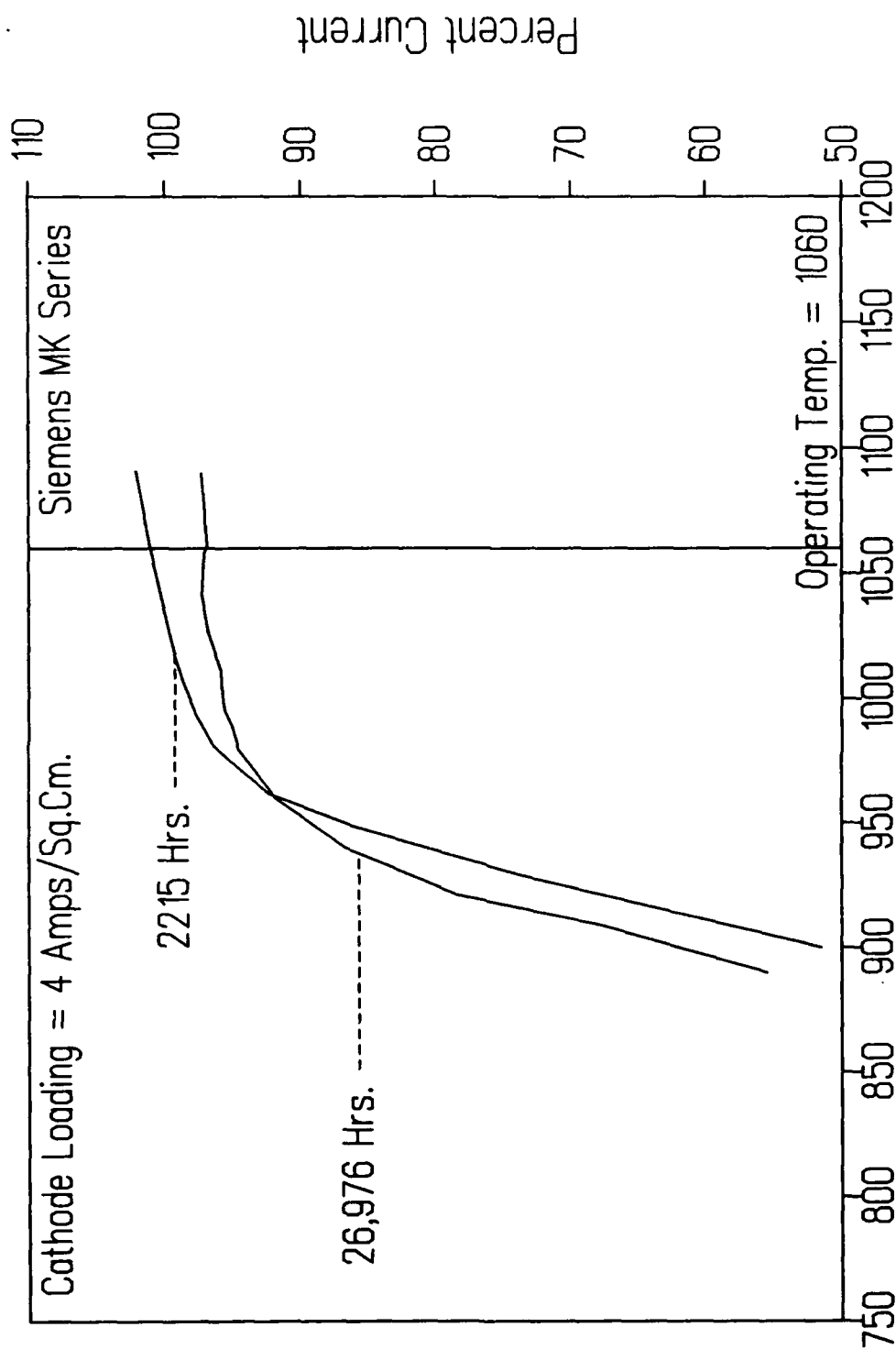
FIGURE 32: SN-MK-4

CATHODE ACTIVITY PLOT



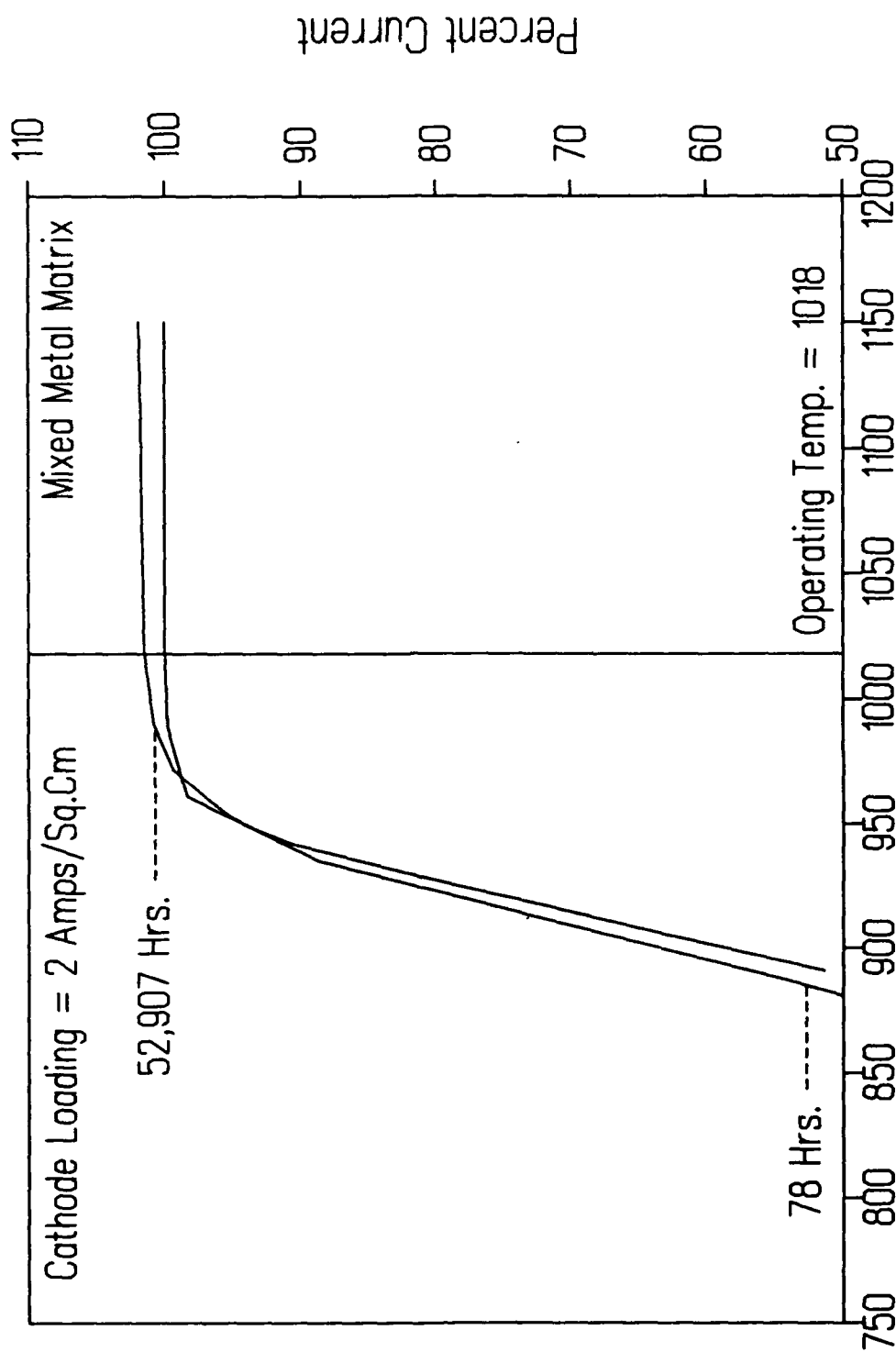
Temperature (C Bright)
FIGURE 33: SN-MK-8

CATHODE ACTIVITY PLOT



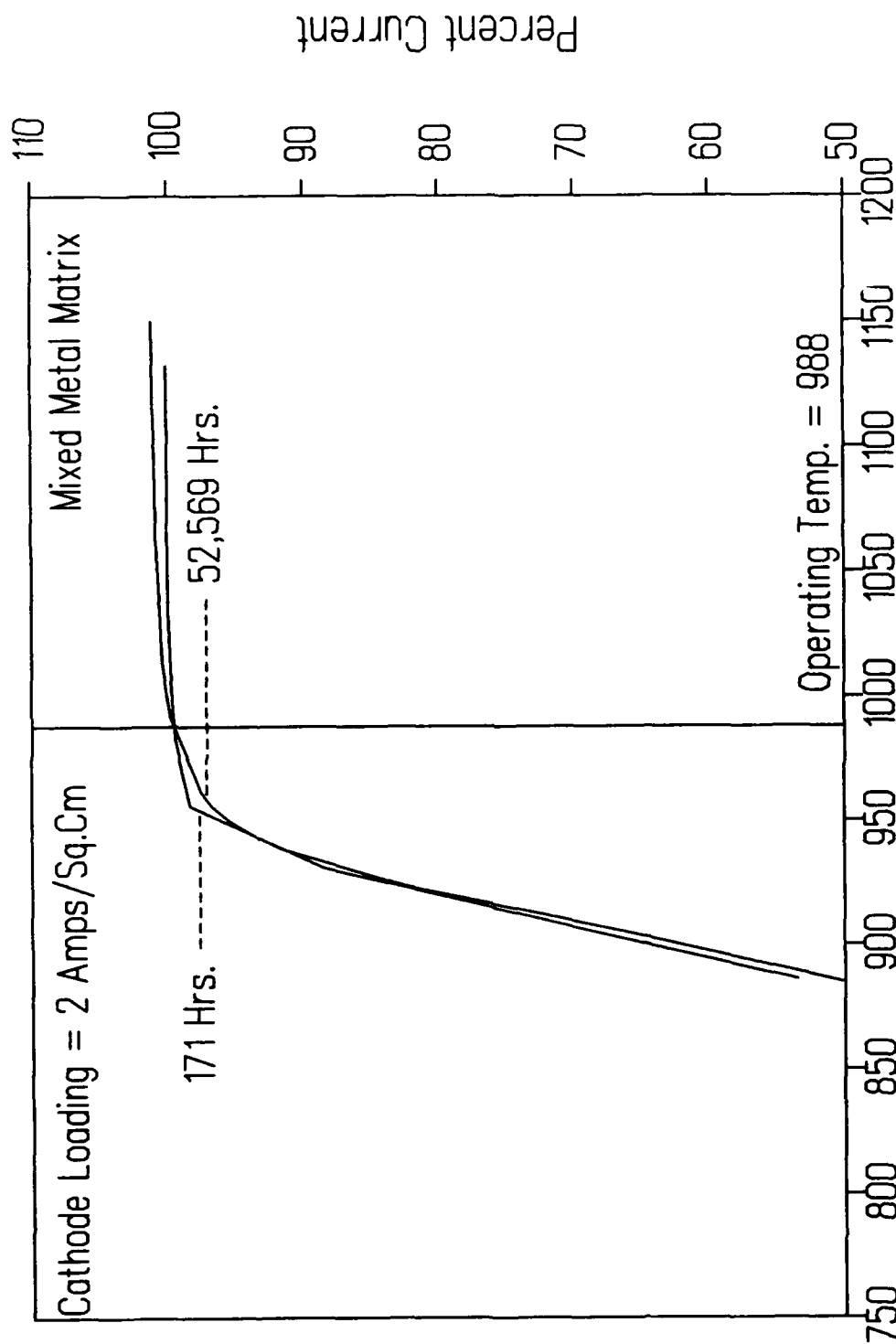
Temperature (C Bright)
FIGURE 34: SN-MK-17

CATHODE ACTIVITY PLOT



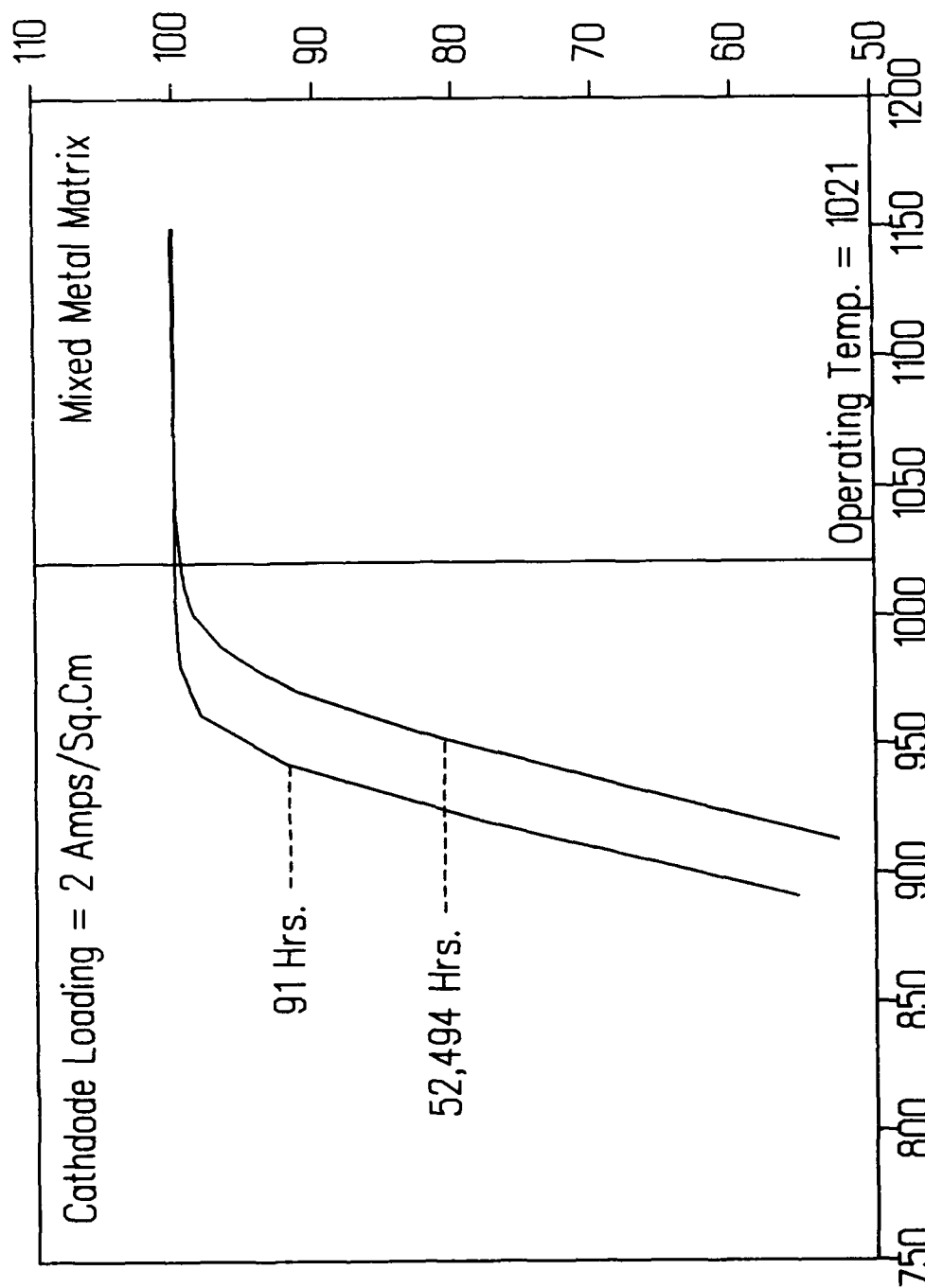
Temperature (C True)
FIGURE 35: SN-120

CATHODE ACTIVITY PLOT



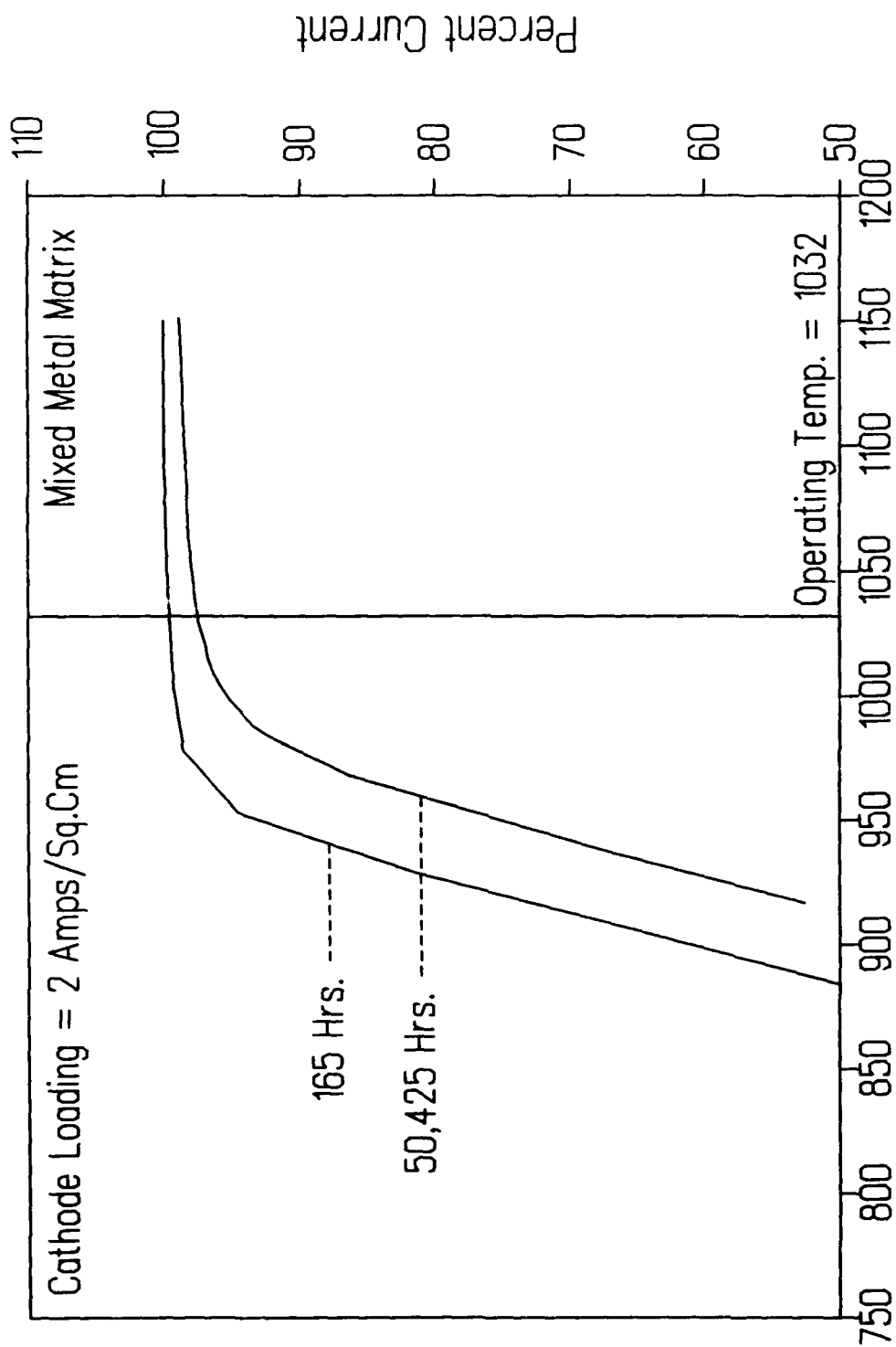
Temperature (C True)
FIGURE 36: SN-121

CATHODE ACTIVITY PLOT



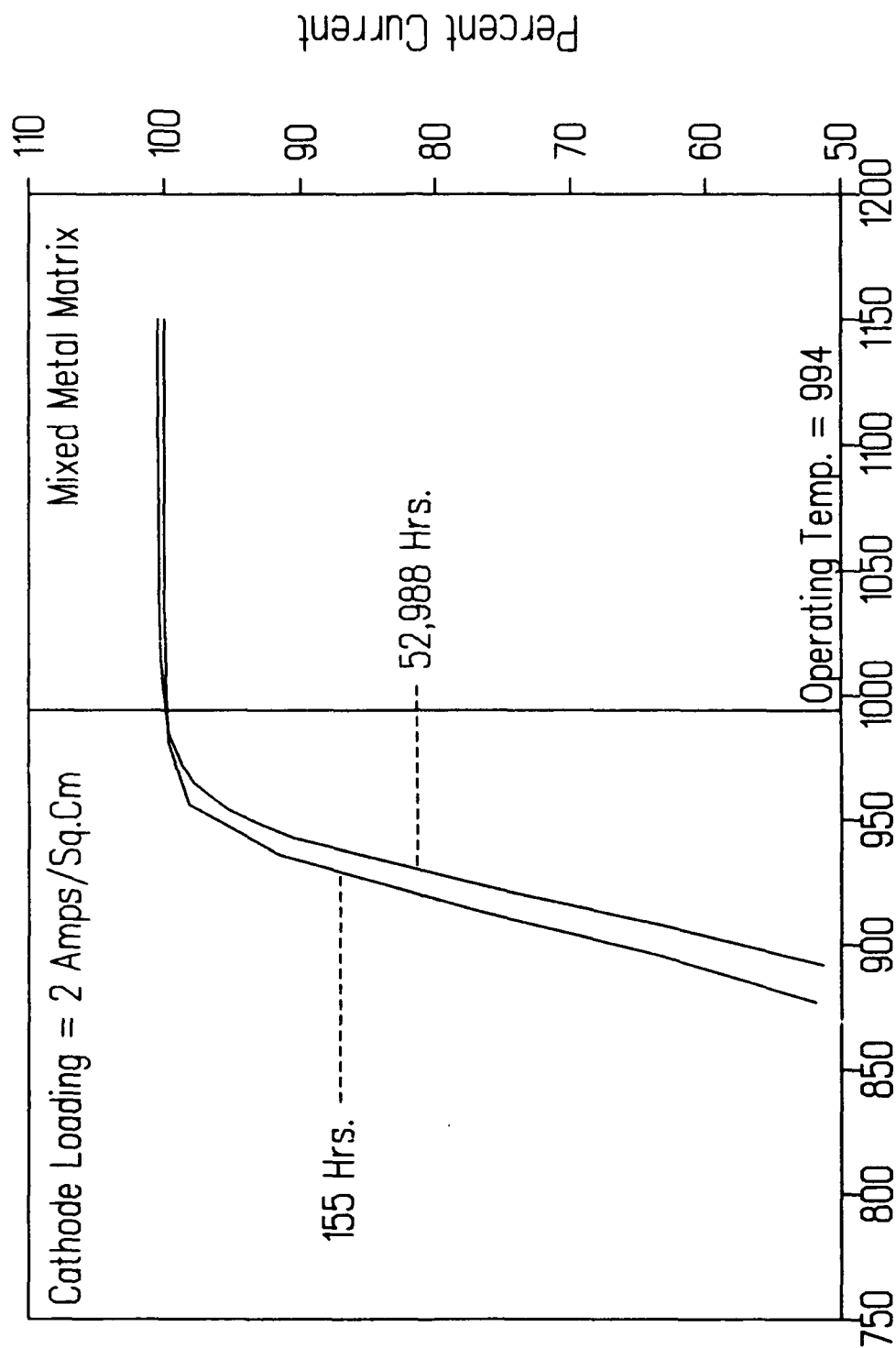
Temperature (C True)
FIGURE 37: SN-122

CATHODE ACTIVITY PLOT



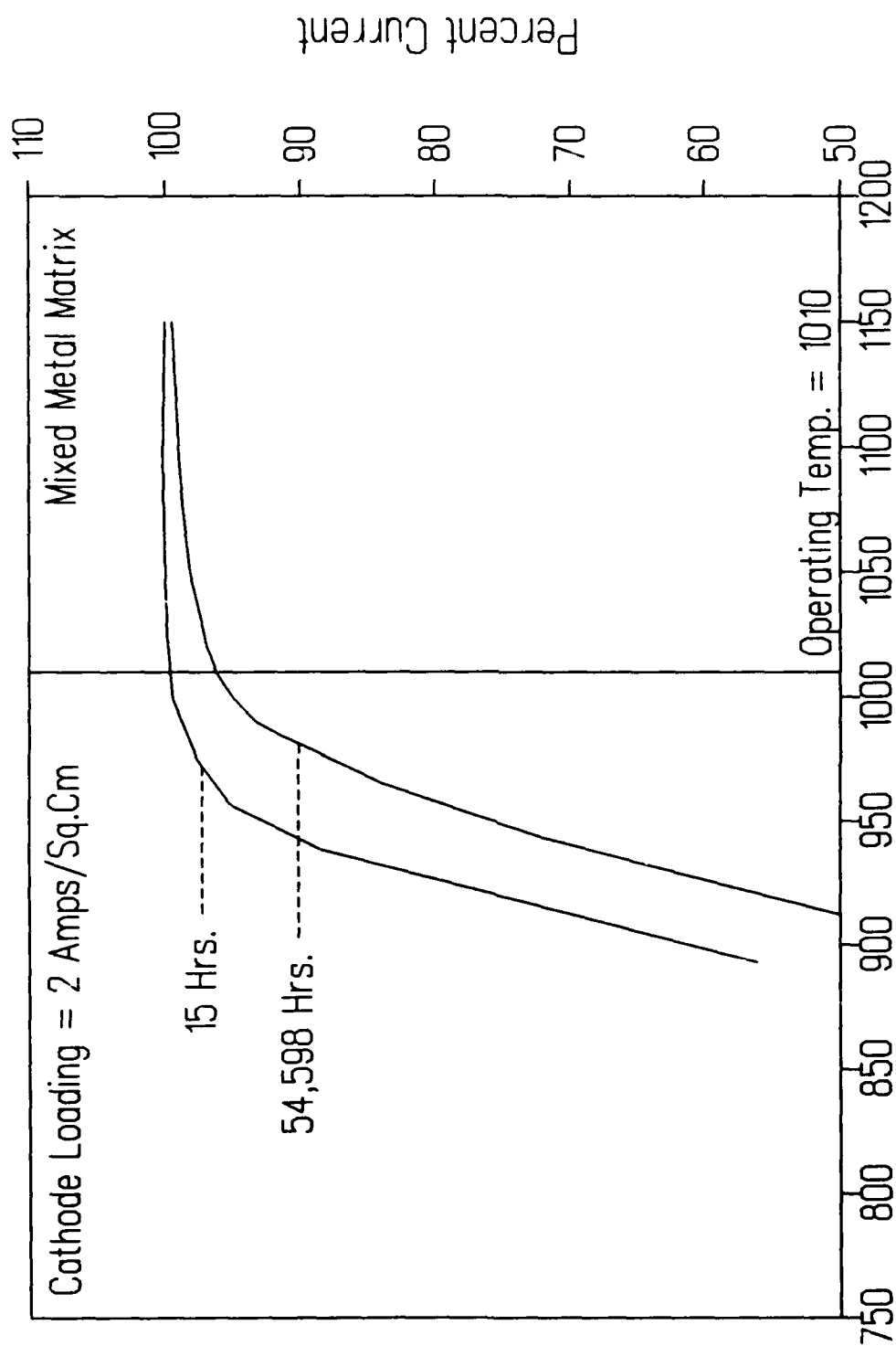
Temperature (C True)
FIGURE 38: SN-123

CATHODE ACTIVITY PLOT



Temperature (C True)
FIGURE 39: SN-124

CATHODE ACTIVITY PLOT



Temperature (C True)
FIGURE 40: SN-125

APPENDIX B:
TABLE OF RESULTS

CATHODE TYPE	SN	LOADING (A/sq.cm)	OP. TEMP. (Degrees C)	LIFE (hours)	EMISSION (% Deg.)	STATUS
Semicon M	200	1	938 Br	26,951	-1.0	b
Semicon M	201	1	989 Br	27,136	-3.0	b
Semicon M	204	1	1040 Br	27,035	-3.4	b
Semicon M	205	1	989 Br	16,345	-0.8	b
Semicon M	208	1	938 Br	22,144	-0.2	b
Semicon M	202	2	1018 Tr	32,747	-4.5	
Semicon M	209	2	957 Tr	40,434	-0.5	
Semicon M	203	4	1010 Br	20,169	-0.3	b
Hughes M	211	4	1040 Tr	22,145	-0.8	a
Hughes M	212	4	1013 Tr	29,720	-2.4	
Hughes M	214	4	1030 Tr	13,036	-1.6	a
Varian MMM	116	1	969 Tr	44,482	0.0	b
Varian MMM	118	1	994 Tr	37,842	-0.2	b
Varian MMM	119	1	968 Tr	41,980	0.0	b
Varian MMM	120	2	1018 Tr	52,907	+1.5	
Varian MMM	121	2	988 Tr	52,569	0.0	
Varian MMM	122	2	1021 Tr	52,494	-0.4	
Varian MMM	123	2	1032 Tr	50,425	-2.1	
Varian MMM	124	2	994 Tr	52,988	0.0	
Varian MMM	125	2	1010 Tr	54,598	-3.5	
Varian MMM	126	4	1070 Tr	14,635	-1.7	a
Varian MMM	127	4	1125 Tr	1,482	-20.1	c
Varian MMM	128					a

Tr = True (IRCON Two Color Pyrometer)

Br = Brightness (Pyrometer Corp. Disappearing Filament Pyrometer)

a = non-cathode related failure

b = removed for a more promising test

c = removed from test because of cathode degradation

CATHODE TYPE	SN	LOADING (A/sq.cm)	OP. TEMP. (Degrees C)	LIFE (hours)	EMISSION (% Deg.)	STATUS
Varian Tri	001	2	950 Tr	24,617	-0.2	b
Varian Tri	002	2	955 Tr	1,270	-0.1	a
Varian Tri	010	2	960 Tr	20,202	-0.2	b
Varian Tri	014	2	950 Tr	17,561	-0.8	b
Varian Tri	005	4	1000 Tr	275	0.0	a
Varian Tri	006	4	990 Tr	1,200	0.0	a
Varian Tri	007	4	995 Tr	23,144	-0.8	a
Varian Tri	008	4	1000 Tr	241	0.0	a
Varian Tri	009	4	990 Tr	22,867	-3.5	a
Varian Tri	012	4	985 Tr	34,340	-1.0	
Varian Tri	011			41		a
Varian Tri	013			37		a
Siemens MK	2	2	1020 Br	24,263	-1.5	
Siemens MK	6	2	1020 Br	20,414	-2.1	a
Siemens MK	7	2	1020 Br	19,984	-1.1	a
Siemens MK	12	2	1020 Br	25,306	-1.1	
Siemens MK	3	4	1060 Br	4,602	+0.9	a
Siemens MK	4	4	1060 Br	27,879	-1.6	
Siemens MK	8	4	1060 Br	26,933	-4.5	
Siemens MK	17	4	1060 Br	26,976	-4.2	

Tr = True (IRCON Two Color Pyrometer)

Br = Brightness (Pyrometer Corp. Disappearing Filament Pyrometer)

a = non-cathode related failure

b = removed for a more promising test

c = removed from test because of cathode degradation

CATHODE TYPE	SN	LOADING (A/sq.cm)	OP. TEMP. (Degrees C)	LIFE (hours)	EMISSION (% Deg.)	STATUS
Varian TM	B1135	4	1002 Tr	4,420	-2.7	
Varian TM	B1240	4	988 Tr	3,006	-0.4	
Varian TM	B1350	4	989 Tr	4,182	-1.1	
Varian TM	B1352	4	999 Tr	3,032	-0.5	
Varian TM	B1455	4	1001 Tr	4,510	-3.2	
Varian TM	B1462	4	977 Tr	4,622	0.0	
Varian TM	B1565	4	976 Tr	4,178	0.0	
Varian TM	B1667	4	1009 Tr	4,137	-0.4	
Varian TM	B1671	4	1013 Tr	2,904	0.0	
Varian TM	B1672	4	990 Tr	4,457	0.0	
Varian RV	A003	2	928 Tr	1,592	-2.3	
Varian RV	A005s	2	952 Tr	1,323	-0.8	
Varian RV	A008s	2	933 Tr	1,641	-1.2	
Varian RV	A009	2	934 Tr	1,582	-0.6	
Varian RV	A002s	4	972 Tr	1,364	-0.4	
Varian RV	A004s	4				a
Varian RV	A006	4	968 Tr	1,455	-0.6	
Varian RV	A007	4	948 Tr	1,331	-0.8	

Tr = True (IRCON Two Color Pyrometer)

Br = Brightness (Pyrometer Corp. Disappearing Filament Pyrometer)

a = non-cathode related failure

b = removed for a more promising test

c = removed from test because of cathode degradation

CATHODE TYPE	SN	LOADING (A/sq.cm)	OP. TEMP. (Degrees C)	LIFE (hours)	EMISSION (% Deg.)	STATUS
Varian B	101z	1	1050 Br	12,505	-10.2	c
Varian B	103z	1	1050 Br	1,770	-0.7	a
Varian B	104z	1	1050 Br	24,654	-2.9	b
Varian B	105z	1	1050 Br	8,351	-0.2	a
Varian B	111z	1	1050 Br	23,327	-4.5	b
Varian B	102x	2	1120 Br	5,396	-9.0	a
Varian B	106z	2	1080 Br	22,012	-9.8	b
Varian B	108x	2	1080 Br	20,438	-10.6	c
Varian B	112x	2	1060 Br	1,332	0.0	a
Varian B	113x	2	1090 Br	3,724	-3.4	a
Varian B	114y	2	1090 Br	20,298	-10.1	c
Varian B	115z	2	1100 Br	13,956	-10.5	c
Varian B	117y	2	1070 Br	1,673	0.0	a
Varian B	107z	4	1140 Br	5,623	-12.1	c
Varian B	109z	4	1120 Br	8,016	-11.6	c
Varian B	110z	4	1140 Br	2,318	-6.6	a
Hughes CPD	129	1	960 Tr	2,070	-5.8	a
Hughes CPD	207	2	1000 Tr	21,106	0.0	b
Hughes CPD	206	4	1045 Tr	15,959	0.0	b

Tr = True (IRCON Two Color Pyrometer)

Br = Brightness (Pyrometer Corp. Disappearing Filament Pyrometer)

a = non-cathode related failure

b = removed for a more promising test

c = removed from test because of cathode degradation

x = 5 micron grain size

y = 7 micron grain size

z = 9 micron grain size

CATHODE TYPE	SN	LOADING (A/sq.cm)	OP. TEMP. (Degrees C)	LIFE (hours)	EMISSION (% Deg.)	STATUS
Varian CD	134	1	880 Tr	14,054	-0.7	b
Varian CD	141	1	900 Tr	60	0.0	a
Varian CD	130	2	1050 Tr	90	0.0	a
Varian CD	131	2	915 Tr	12,120	-1.1	b
Varian CD	135	2	920 Tr	15,020	-0.9	b
Varian CD	136	2	950 Tr	11,982	-1.1	b
Varian CD	140	2	950 Tr	12,017	-1.2	b
Varian CD	132	4	960 Tr	12,109	-1.8	b
Varian CD	133	4	960 Tr	12,014	-1.0	b
Varian CD	139	4	990 Tr	8,710	-1.4	b
Varian CD	138	Broken	upon	delivery.		
ORC* LaB ₆	216	1	1605 Tr	14,477	0.0	b
ORC* LaB ₆	217	2/3	1605 Tr	12,358	0.0	b

*ORC - Oregon Research Center

Tr = True (IRCON Two Color Pyrometer)

Br = Brightness (Pyrometer Corp. Disappearing Filament Pyrometer)

a = non-cathode related failure

b = removed for a more promising test

c = removed from test because of cathode degradation