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CATHODE LIFE TEST FACILITY

ANNUAL REPORT

Period Covered

February 2001 – March 2002

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Crane Division

Naval Surface Warfare Center

(NAVSURFWARCENDIV)

300 Highway 361

Crane, IN 47522-5001

EXECUTIVE SUMMARY

The Cathode Life Test Facility (CLTF) is an independent laboratory that offers a controlled environment and a consistent data-collection methodology for life testing existing and experimental cathode systems. The data is collected to stimulate development of longer life cathode systems for use in microwave tubes supplied to the Government.

This document outlines the results of the cathode testing performed at the CLTF during the period February 2001 to March 2002. The CLTF is sponsored by TriService, Naval Research Laboratory (NRL) and NASA, and is operated by Crane Division, Naval Surface Warfare Center (NSWC) Crane, Indiana.

The goals of this report are

- **to present data collected from cathodes being tested at the CLTF,**
- **to analyze the data and note performance trends among the different types of cathodes, and**
- **to inform the cathode community of current and future developments of the CLTF.**

During this report period the following occurred:

- **Twenty cathode test vehicles accumulated 173,501 hours.**
- **The CLTF was re-located to Building 3168 at NSWC Crane.**

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CATHODE LIFE TEST FACILITY ANNUAL REPORT

1. INTRODUCTION

In November 1992, the Cathode Life Test Facility (CLTF) located at Rome Laboratories was transferred to Crane Division, Naval Surface Warfare Center (NSWC) Crane, Indiana. The facility has operated for approximately 20 years. During this period, many types of cathodes have been tested at the facility and the various cathode test vehicles have accumulated 3,959,889 hours of life testing (see Figure 1). During the period covered by this report, twenty test vehicles were tested.

This report summarizes CLTF activities by NSWC Crane from February 2001 through March 2002. The primary aims of this report are

- **to present data collected from cathodes being tested at the CLTF,**
- **to analyze the data and note performance trends among the different types of cathodes, and**
- **to inform the cathode community of current and future CLTF developments.**

In addition, the report

- **outlines the data-collection and reduction techniques used to prepare the roll-off curves, kneepoint migration plots, Practical Work Function Distribution (PWFD) plots and long-term performance plots presented in this report, and**
- **contains appendices that (1) list the capabilities, equipment, and daily operations of the CLTF, and (2) summarize maintenance actions performed during the past year that may affect the interpretation of the data contained in the report.**

A series of appendices details CLTF facilities, operations, and methods used to collect data. The remaining appendices contain summary plots of the data. Appendices A and B describe facility operations and contain summary data pertaining to all cathode systems. Methods of data analysis are in Appendix C. The Appendix D contains plots comparing emission degradation of the different types of cathodes tested at CLTF. Each remaining appendix (E through K) contains the long-term performance plot for a cathode system, followed by the Miram plots and the kneepoint migration plots for the individual test vehicles tested during the last annual test cycle (March 2002).

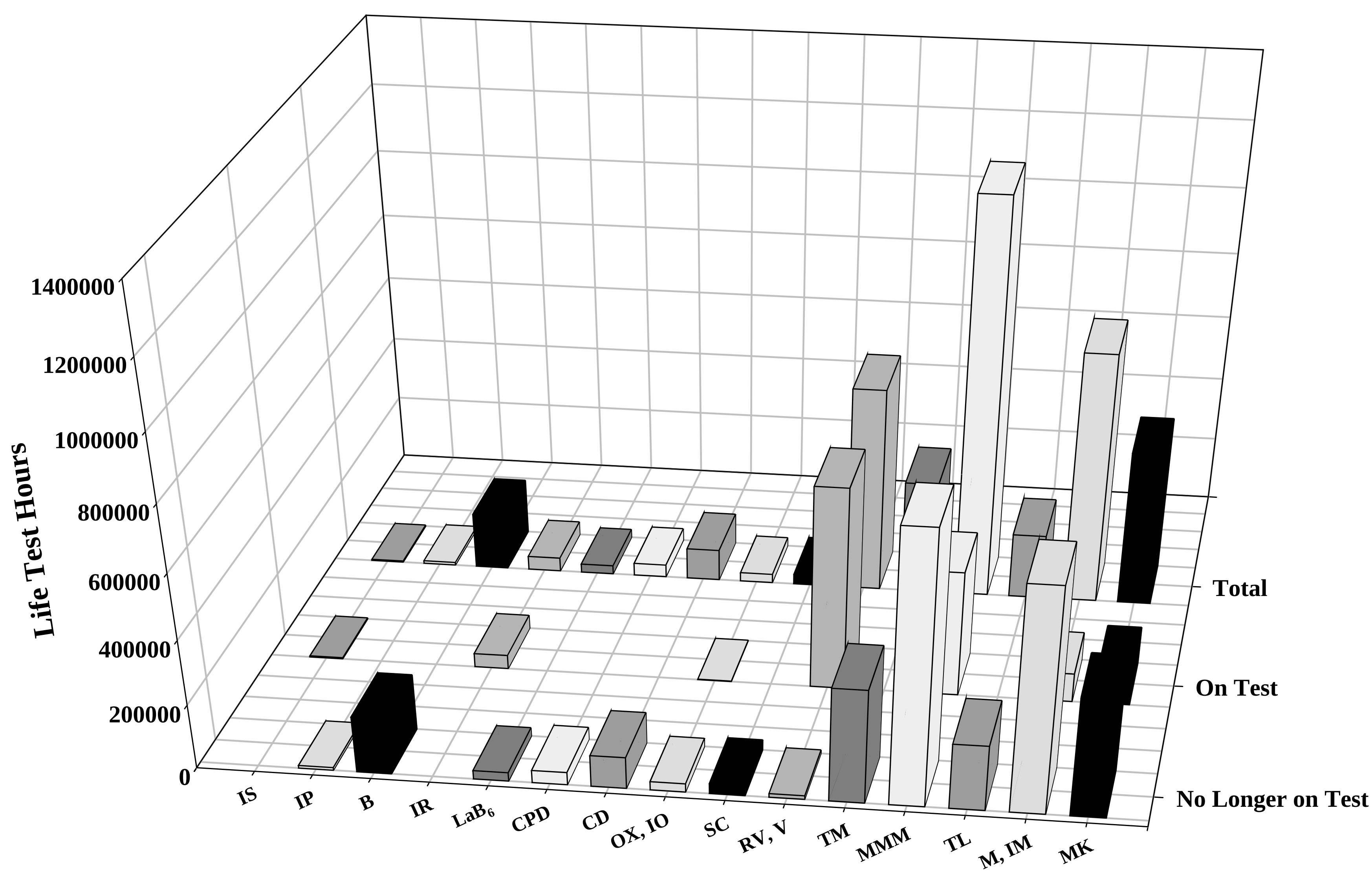

Figure 1. Life Test Hours by Cathode Type

1.1 Personnel Description

1.1.1 NSWC Crane Personnel

Mr. L. Dressman (Code 80943) of NSWC Crane is the project engineer and supervises the technical operations of the facility. Mr. R. Sparks (Code 80943) is responsible for the daily activities of the laboratory, including gathering data, and maintaining and repairing the facility.

Questions concerning CLTF operation and requests to participate in the cathode life study should be addressed to Mr. Dressman at

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Attn: Lawrence Dressman
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300 Highway 361
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1.1.2 TSC Personnel

Mr. R. Justice and Mr. A. Qualls of Technology Service Corporation (TSC) authored this report under the direction of NSWC Crane. In addition, Mr. Justice and Mr. Qualls support the CLTF in data analysis.

1.2 Summary

During this report period the following occurred:

- **Twenty cathode test vehicles accumulated 173,501 hours.**
- **The CLTF was re-located to Building 3168 at NSWC Crane.**

2. CATHODE DESCRIPTION

2.1 Cathode Description

In its 20 years of operation, the CLTF has received various types of cathodes for testing. In the past, the descriptive data that vendors supplied with each cathode vehicle was informal. Consequently, the level of detail and the format of this data varied considerably among the vendors, making comparison of the cathode systems difficult. NSWC Crane has reviewed the available information on the present and past cathode systems tested at the CLTF; Table 1 summarizes the data. A review of Table 1 indicates the disparity among the descriptions. Some cathodes are not listed in the table because data is unavailable; data for other cathodes is incomplete.

2.1.1 Cathode Type Designations

The cathode manufacturers assign the letter designations for the different cathodes. If the manufacturer does not assign a designation, CLTF personnel create one. Each designation represents a specific cathode design. The M designation refers to the standard M-type cathode commonly used in the microwave tube industry. The M-type cathode has a sintered tungsten matrix impregnated with barium oxide and lesser amounts of calcium oxide and aluminum oxide. The emitting surface has an osmium/ruthenium film.

The MMM designation refers to a mixed metal matrix cathode with a matrix composition of 80% tungsten and 20% iridium. The matrix is impregnated with typical M-type cathode impregnant compounds. The TM designation refers to another mixed metal matrix cathode. The TM-type cathodes have a matrix of 95%

tungsten and 5% iridium, impregnated with standard compounds. The emitting surface has a tungsten/iridium film.

The RV designation refers to a reservoir type cathode. RV-type cathodes loaded at 10 A/cm^2 are given the V designation to avoid having RV cathodes with duplicate serial numbers. The RV and V-type cathodes have a porous tungsten button with a tungsten/osmium coating. Behind this button is a barium oxide pellet from which barium diffuses to the button to replenish the emitting surface. The MK designation also refers to a reservoir type cathode. The MK-type cathodes also have a barium oxide reservoir, but have an osmium-coated tungsten emitter.

IO, IP, and IS designations refer to cathodes manufactured by Istok in Moscow, Russia, and supplied to the CLTF by Lawrence Livermore National Laboratory (LLNL). The IO designated cathodes are oxide-coated cathodes. The IM designation refers to Istok manufactured M-type osmium-coated dispenser cathodes. IS devices are scandate dispenser cathodes.

The IR designation refers to iridium-coated tungsten dispenser cathodes with a 5:3:2 impregnant mixture.

2.2 Data Collection

All daily power supply readings are recorded in the Cathode Life Test Daily Meter Logs and are available for analysis. (See Appendix B for the data-gathering and logging procedures used in the CLTF.) Laboratory personnel use this data to assess the performance of each test station and to ensure operating parameters remain constant. Although it is possible to track cathode degradation using this data, the CLTF does not do so because

- **the large number of data points makes interpretation difficult, and**
- **changes over time in power supply calibration bias the daily readings.**

To produce meaningful degradation analyses, the technique used to measure cathode performance must remain constant throughout the life test period. Therefore, the CLTF bases cathode performance on information obtained from the annual roll-off curves. This data is used to create the graphs contained in the appendices. Appendix C explains the presentation of this data. As discussed in Appendix B, Section B1.1.2, each roll-off curve is recorded after the power supply has been completely recalibrated. This procedure minimizes errors caused by uncalibrated power supply metering.

Table 1. Physical Summary of Cathode Systems Tested at the CLTF

DISPENSER AND RESERVOIR TYPES								
Type	**S/N**	**Matrix Density**	**Matrix Composition**	**Particle Size (microns)**	**Impregnant Molar Ratio**	**Percent Impregnation**	**Film Type**	**Film Thickness (Ångstroms)**
IR	002	80%	100%W	4.5	5:3:2 $BaO:CaO:Al_2O_3$	75 minimum	Ir	4000-6000
IR	006	80%	100%W	4.5	5:3:2 $BaO:CaO:Al_2O_3$	75 minimum	Ir	4000-6000
M	001	80%	100%W	4.5	5:3:2 $BaO:CaO:Al_2O_3$	75 minimum	Os/Ru	4000-6000
M	005	80%	100%W	4.5	5:3:2 $BaO:CaO:Al_2O_3$	75 minimum	Os/Ru	4000-6000
MMM	116	71.52%	80%W/20%Ir	15-16/325 mesh	6:1:2 $BaO:CaO:Al_2O_3$	79.11	None	–
MMM	118	73.35%	80%W/20%Ir	15-16/325 mesh	6:1:2 $BaO:CaO:Al_2O_3$	65.14	None	–
MMM	119	73.09%	80%W/20%Ir	15-16/325 mesh	6:1:2 $BaO:CaO:Al_2O_3$	65.6	None	–
MMM*	120	73.10%	80%W/20%Ir	15-16/325 mesh	6:1:2 $BaO:CaO:Al_2O_3$	65.91	None	–
MMM*	121	73.08%	80%W/20%Ir	15-16/325 mesh	6:1:2 $BaO:CaO:Al_2O_3$	68	None	–
MMM*	122	72.94%	80%W/20%Ir	15-16/325 mesh	6:1:2 $BaO:CaO:Al_2O_3$	73	None	–

* No longer on test.

Table 1. Physical Summary of Cathode Systems Tested at the CLTF

DISPENSER AND RESERVOIR TYPES								
Type	**S/N**	**Matrix Density**	**Matrix Composition**	**Particle Size (microns)**	**Impregnant Molar Ratio**	**Percent Impregnation**	**Film Type**	**Film Thickness (Ångstroms)**
MMM*	123	73.33%	80%W/20%Ir	Not Available	6:1:2 $BaO:CaO:Al_2O_3$	60	None	–
MMM*	124	72.98%	80%W/20%Ir	15-16/325 mesh	6:1:2 $BaO:CaO:Al_2O_3$	70	None	–
MMM*	125	73.00%	80%W/20%Ir	15-16/325 mesh	6:1:2 $BaO:CaO:Al_2O_3$	74	None	–
RV*	A002	Not Available	100%W Diffuser Plug	14	High Density BaO Pellet	Does Not Apply	W/Os	5164
RV*	A003	Not Available	100%W Diffuser Plug	14	High Density BaO Pellet	Does Not Apply	W/Os	5617
RV	A005	Not Available	100%W Diffuser Plug	14	High Density BaO Pellet	Does Not Apply	W/Os	5019
RV	A006	Not Available	100%W Diffuser Plug	14	High Density BaO Pellet	Does Not Apply	W/Os	4688
RV	A007	Not Available	100%W Diffuser Plug	14	High Density BaO Pellet	Does Not Apply	W/Os	4688
RV	A008	Not Available	100%W Diffuser Plug	14	High Density BaO Pellet	Does Not Apply	W/Os	5164
RV	A009	Not Available	100%W Diffuser Plug	14	High Density BaO Pellet	Does Not Apply	W/Os	Not Available
SC*	003	80%	100%W	4.5	5:3:2 + X $BaO:CaO:Al_2O_3$ + Scandium Oxide	75 Minimum	None	–

Table 1. Physical Summary of Cathode Systems Tested at the CLTF

DISPENSER AND RESERVOIR TYPES								
Type	**S/N**	**Matrix Density**	**Matrix Composition**	**Particle Size (microns)**	**Impregnant Molar Ratio**	**Percent Impregnation**	**Film Type**	**Film Thickness (Ångstroms)**
V	Typical	Not Available	100%W Diffuser Plug	Not Available	High Density BaO Pellet	Does Not Apply	W/Os	Not Available
TL*	12	80%	W+/W/Os	8	6:1:2 $BaO:CaO:Al_2O_3$	Not Available	Os/Ru+W/Os	4020
TM*	B1135	Not Available	95%W/5%Ir	Not Available	6:1:2 $BaO:CaO:Al_2O_3$	66	50%W/50%Ir	593
TM*	B1240	Not Available	95%W/5%Ir	Not Available	6:1:2 $BaO:CaO:Al_2O_3$	73	50%W/50%Ir	4910
TM*	B1350	Not Available	95%W/5%Ir	Not Available	6:1:2 $BaO:CaO:Al_2O_3$	67	50%W/50%Ir	6034
TM*	B1352	Not Available	95%W/5%Ir	Not Available	6:1:2 $BaO:CaO:Al_2O_3$	69	50%W/50%Ir	5932
TM*	B1455	Not Available	95%W/5%Ir	Not Available	6:1:2 $BaO:CaO:Al_2O_3$	73	50%W/50%Ir	6598
TM*	B1462	Not Available	95%W/5%Ir	Not Available	6:1:2 $BaO:CaO:Al_2O_3$	72	50%W/50%Ir	6598
TM*	B1565	Not Available	95%W/5%Ir	Not Available	6:1:2 $BaO:CaO:Al_2O_3$	70	50%W/50%Ir	5181
TM*	B1667	Not Available	95%W/5%Ir	Not Available	6:1:2 $BaO:CaO:Al_2O_3$	65	50%W/50%Ir	4210
TM*	B1671	Not Available	95%W/5%Ir	Not Available	6:1:2 $BaO:CaO:Al_2O_3$	67	50%W/50%Ir	5211
TM*	B1672	Not Available	95%W/5%Ir	Not Available	6:1:2 $BaO:CaO:Al_2O_3$	68	50%W/50%Ir	5211

Table 1. Physical Summary of Cathode Systems Tested at the CLTF

DISPENSER AND RESERVOIR TYPES								
Type	**S/N**	**Matrix Density**	**Matrix Composition**	**Particle Size (microns)**	**Impregnant Molar Ratio**	**Percent Impregnation**	**Film Type**	**Film Thickness (Ångstroms)**
MK	**Typical**	**Not Available**	**100%W Diffuser Plug**	**Not Available**	**BaO Powder**	**Does Not Apply**	**Os**	**Not Available**
IM	**9, 10**	**Not Available**	**100%W**	**Not Available**	**6:1:2 $BaO:CaO:Al_2O_3$**	**8-9% Mass Gain**	**Os**	**4000-6000**
IS	**8**	**Not Available**	**100%W**	**Not Available**	**6:1:1:1 $BaO:CaO:Al_2O_3:Sc_2O_3$**	**10-11% Mass Gain**	**None**	**–**
IP	**5**	**Does Not Apply**	**Solid Pt/Ba Alloy Emitter**	**Does Not Apply**	**Does Not Apply**	**Does Not Apply**	**None**	**–**

Oxide Types							
Type	**S/N**	**Coating Density**	**Coating Thickness**	**Carbonate Particle Size (microns)**	**Carbonate Molar Ratio**	**Coating Substrate**	**Coating Method**
IO*	**1**	**6-10 mg/cm^2**	**30-35 microns**	**1-2**	**47-43-10 mol % BaO-CaO-SrO**	**Ni Sponge on Solid Ni**	**Air Sputtering**
IO	**3**	**25-40 mg/cm^2**	**Not Available**	**Not Available**	**Ni-doped Carbonate**	**Ni Sponge**	**Vacuum/ Pressure Impregnated and Pressed**

3. ANALYSIS AND PERFORMANCE SUMMARY

3.1 Roll-off Results and Conclusions

3.1.1 M-Type Cathodes

M 001 has accumulated 23,965 operating hours and the rate of kneepoint migration has stabilized at a lower value than was expected from the data taken in the first 10,000 hours. The M 001 PWFD is slightly higher than the Best of Class M-type cathode (see Appendix C for an explanation of Best of Class). M 005 appears to have a low work function for an M-type cathode, resulting in an operating temperature of only 885° C. The M 005 PWFD is significantly better than the Best of Class. M 005 also shows a kneepoint migration rate that is less than expected from the early test data.

IM 009 and IM 010 are M-type cathodes manufactured by Istok for LLNL. These cathodes are designed to operate at 10 A/cm^2. With approximately 22,000 hours of life testing, these roll-off curves have changed little. The PWFDs of these cathodes were originally lower than the Best of Class M-type cathode, but have increased in the last 10,000 hours. The initial data for all Istok cathodes was taken from digitized hard copies of Miram curve data from initial life testing at Istok. It is advisable to keep in mind that different equipment and test methods were used in the measurements of the initial data in the roll-off plots of all the Istok cathodes. The roll-off data of the Istok cathodes appears to suggest a temperature offset between Istok measurements and CLTF measurements. The numerical roll-off data is not available for the first 5000 hours of life tests, consequently kneepoint migration plots could not be produced for Istok cathodes.

3.1.2 MK-Type Cathodes

MK 12 is the only MK cathode still on test. It has accumulated 117,853 hours of testing. The relatively round knee of the roll-off curve belies the performance of this cathode when considering the relatively modest overall movement of the temperature-limited region.

The operating temperature for most cathodes undergoing life test is approximately fifty degrees above the knee of the initial roll-off curve. These cathodes have operating temperatures at more than 100 degrees above the knee. The PWFD of this cathode is currently near the Best of Class. The kneepoint migration plot for MK 12 suggests that its work function changed unpredictably over time.

3.1.3 MMM-Type Cathodes

MMM-type cathodes still on test have accumulated between 126,045 and 133,801 life hours. The Miram curves for these cathodes (e.g., MMM 119) show anomalous increases in emission in the space-charge-limited region. These levels of increased emission are likely due to a gradual change in electron gun geometry. Temperature-limited emission is unaffected by gun perveance and therefore, it is useful to consider only the temperature-limited portion of these Miram curves. The PWFD plots for these cathodes are all greater than the Best of Class. The kneepoint migration plots for the MMM-type cathodes exhibit a roughly stable or slightly increasing kneepoint temperature. The kneepoint migration intersects the operating temperature at values greater than 150,000 hours.

The life data for these cathodes is promising. At a loading of 1 A/cm^2, the cathodes have a potential life of more than 150,000 hours in TWT applications; testing at 2 A/cm^2 indicates 80,000 hours of life could be achieved.

3.1.4 RV and V-Type Cathodes

The RV-type cathodes have accumulated between 91,696 and 94,518 hours of life testing. These cathodes all increased in emission for approximately the first 2,000 hours of life testing. The Miram curves now show that some of these cathodes are still above or near their original curves. The PWFD for RV A007 is lower than the Best of Class for this type of cathode. After more than 90,000 hours of life testing, the kneepoint migration plots still indicate a low rate of kneepoint temperature increase.

Although the space-charge-limited emission of these cathodes is not consistent from cathode to cathode, the temperature-limited emission of these cathodes indicates a low work function. Projected life for these cathodes is over 100,000 hours at 2 A/cm^2. For space applications, the advantages this cathode has over a typical dispenser cathode would justify the higher initial cost. Developing a production source for RV-type cathodes should be considered.

Tests on 10 A/cm^2 V-type reservoir cathodes are proceeding. V 002 and V 003 are being life tested with only heater power applied. Roll-off data is taken with a Miram Curve Generator. The Miram Curve Generator is an automated pulsed power supply. V 002 has accumulated 30,694 hours and has increased space-charge-limited emission but slightly decreased temperature-limited-emission. All V-type cathodes have a PWFD greater than the Best of Class reservoir cathode. V 003 is at 31,518 hours and has increased space-charge-limited emission, but temperature-limited emission is only slightly less than it was at 5371 hours. The operating temperature of V 003 has been reduced from 1150° C to 1079° C, which is 50 degrees above the knee.

V 005 and V 150 are being life tested fully loaded at 10 A/cm^2 continuous emission. Both life test stations are undergoing repair; consequently no roll-off data is presented.

3.1.5 IR-Type Cathodes

These cathodes have been in operation for 22,587 and 20,455 hours. Since initial data was taken, the kneepoints of these cathodes have moved to higher temperatures. The rate of kneepoint temperature increase is not as great as was indicated earlier in life testing. Because historical data is unavailable for this type of cathode the PWFD plots for the IR cathodes are compared to the Best of Class for the M-type cathode.

3.1.6 IS-Type Cathodes

IS 008 is a scandium impregnated dispenser cathode manufactured by Istok. The current IS 008 roll-off data looks better than expected but this is probably due to the difference in measurement techniques (see discussion in section 3.1.1). The PWFD plot for IS 008 is compared to the Best of Class scandate cathode.

3.1.7 IO-Type Cathodes

IO 003 data indicates it is at end-of-life. This cathode will be turned off. IO 001 has reached end-of-life and has been turned off.

3.2 Long-Term Performance

Table 2 provides emission current degradation data taken during the last roll-off. Unlike other data presented in this report, this data is taken under life test conditions, after power supply calibration. Current degradation data taken throughout life testing is plotted in the long-term performance plots in Appendices D through I. Appendix D provides plots of averages for each cathode type on the same graph. When comparing long-term performance plots of different cathode types, it is important to remember that these are averages, and each cathode type has cathodes that performed above and below the average. It is also important to consider the number of life test hours that have been completed by any two types of cathodes being compared. As the cathodes accumulate more hours, the increased degradation brings down the average over the entire life test. Long-term performance plots are not produced for cathodes that are life tested with only heater voltage applied.

Cathode-to-cathode consistency within a cathode type also can be evaluated using the long-term performance plots. The long-term performance scatter plots at the beginning of Appendices E through K provide the contribution of each cathode to the average for each type.

Table 2. Emission Degradation

Cathode Type	S/N	Life Hours	Loading	Operating Temperature	Percent Change in Current
M	001	23,965	2	928 °C_T	-0.8
M	005	21,317	2	885 °C_T	-0.2
MK	12	117,853	2	1020 °C_B	-0.9
MMM	116	133,801	1	969 °C_T	16.0
MMM	118	126,045	1	994 °C_T	13.0
MMM	119	130,651	1	969 °C_T	21.8
RV	A005	94,383	2	952 °C_T	1.1
RV	A006	91,696	4	968 °C_T	0.8
RV	A007	92,510	4	948 °C_T	5.6
RV	A008	94,518	2	933 °C_T	2.5
RV	A009	94,499	2	934 °C_T	-0.4
V_H	B002	30,694	10	1131 °C_T	–
V_H	B003	31,514	10	1079 °C_T	–
IM_H	9	22,480	10_P	1077 °C_B	–
IM_H	10	22,097	10_P	1077 °C_B	–
IS_H	8	17,779	6_P	957 °C_T	–
IR	002	22,587	2	975 °C_T	-0.4
IR	006	20,455	2	947 °C_T	-0.8

°C_T = True Temperature (two-color pyrometer)

°C_B = Brightness Temperature (disappearing filament pyrometer)

$_H$ = Life tested heater-only, emission tested using Miram Curve Generator

$_P$ = Designed for pulsed operation

4. FUTURE WORK

4.1 Publication and Presentation of Data

The CLTF annual report is distributed within the Department of Defense (DoD), NASA, and to the industry participants. Further, the CLTF data is reported at conferences such as the International Vacuum Electron Sources Conference. NSWC Crane intends to continue to ensure the widest possible distribution by publishing of the annual report and reporting data at appropriate conferences.

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APPENDIX A

SUMMARY AND DESCRIPTION OF CLTF PLANT, EQUIPMENT AND CATHODE TEST VEHICLES

(Unclassified)

(2 Pages Attached)

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APPENDIX A

SUMMARY AND DESCRIPTION OF CLTF PLANT, EQUIPMENT AND CATHODE TEST VEHICLES

A1. BACKGROUND

The CLTF is an independent laboratory offering a controlled environment and a consistent data-collection methodology for life testing existing and experimental cathode systems. This data is collected to stimulate development of longer life cathode systems for use in microwave tubes supplied to the Government.

A2. FACILITY

During this report period the CLTF was re-located to the main laboratory in Building 3168 of the NSWC Crane Microwave Components Directorate (Code 809). Approximately 840 square feet are devoted to the laboratory, which contains the main test facility and a repair stock storage area.

The facility is equipped with 26 cathode life test sets manufactured by Cober Electronics, and two 15 kW test sets developed at NSWC Crane. Each cathode test vehicle has its own power supply and most share an ion pump power supply with other cathode test vehicles. Table A-1 contains the power supply specifications for both types of power supplies. Appendix B reviews the laboratory operations and summarizes maintenance actions that may affect the interpretation of the life data presented in this report.

The cathodes tested by the CLTF are packaged into test vehicles by the agency requesting the test. Each cathode test vehicle contains (1) a vacuum envelope (most have an integral ion pump), (2) the test cathode mounted in a gun assembly containing a heater filament and the electrodes necessary to load the cathode to a predetermined current density, and (3) a suitable collector. NSWC Crane has drawings for its preferred configuration, CPI model #V-7355; however, NSWC Crane will consider other options.

Table A-1. Cober Power Supply Electrical Specifications

1. **Input Voltage 115 Vac, 1 Phase, 60 Hz**
    - **Line Regulated**
2. **Cathode Power Supply**
    - **Output Voltage Manually adjustable from 0 to -6 kVdc**
    - **Output Current 0-240 mA**
    - **Regulation better than 1%**
    - **Ripple Less than 4 volts peak-to-peak**
3. **Collector Power Supply**
    - **Output Voltage Fixed Ratio (30%) of cathode voltage**
    - **Ripple Less than 5%**
4. **Filament Power Supply**
    - **Output Voltage Variable from 0 to 10 Vac**
    - **Output Current 4 A rms, maximum**
    - **Regulation Better than 1%**

15-KILOWATT CATHODE POWER SUPPLY SPECIFICATIONS

1. **Input Voltage 208 Vac, 3 Phase, 60 Hz**
    - **Line Regulated**
    - **Load Regulated**
2. **Cathode Power Supply**
    - **Output Voltage 0 to -10 kVdc**
    - **Output Current 0 to 1.5 Adc**
    - **Regulation 0.01%**
3. **Filament Power Supply**
    - **Output Voltage 13 Vac**
    - **Output Current 5 Aac, maximum**

APPENDIX B

DESCRIPTION OF CLTF OPERATIONS AND MAINTENANCE ACTIONS

(Unclassified)

(2 Pages Attached)

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APPENDIX B

DESCRIPTION OF CLTF OPERATIONS AND MAINTENANCE ACTIONS

B1. FACILITY OPERATION

This appendix summarizes the general operation of the CLTF.

- **It describes the routine operations of the facility.**
- **It discusses non-routine events that interrupted the normal life test cycle during the past year and how they may affect data interpretation.**
- **It presents the criteria used to determine when cathode test vehicles are removed from testing.**

B1.1 Scheduled Operations

B1.1.1 Daily Operations

Each day laboratory personnel read, then record all power supply voltages and currents in the Cathode Life Test Daily Meter Logs. All power supply drifts are eliminated by resetting each power supply to the voltage listed on the voltage settings reference card attached to each power supply. All ion pump readings are checked for any change in test vehicle vacuum level. Any major problems discovered during the daily checks are reported to the project engineer.

B1.1.2 Annual Calibrations and Testing

Power supply calibrations are performed and cathode roll-off curves are produced annually. Each power supply is calibrated before performing the cathode roll-off test. The data from each cathode roll-off test is used to create a Miram curve, a PWFD plot, and to add data points to the kneepoint migration and long-term degradation plots. The calibration procedure, roll-off test procedure and Miram curve generation guidelines are contained in the Rome Laboratory technical report "Cathode Life Prediction" (Rome Laboratory report number RL-TR-91-321, dated December 1991). The latest roll-off curves, which form the database for this report, were completed in March 2002.

B1.2 Non-Routine Events

This section describes the unscheduled events that occurred during the past year. It includes the power outages that occurred and lists power supply malfunctions and the corrective actions taken. Also, it documents the addition and removal of test vehicles.

B1.2.1 Re-location

All test sets were shut down on 2 August 2001 for facility re-location. Test sets were re-energized on 30 August 2001. Each power supply affected was returned to service following the procedures detailed in Rome Laboratory report, RL-TR-91-321.

B1.2.2 Power Supply Malfunctions

Four power supply repair actions were recorded in the period covered by this report. The actions that interrupted life testing are listed in Table B-1.

B1.2.3 Test Vehicle Activity

IO 1 is at end-of-life and has been removed from test. IO 3 appears to be at end-of-life and will undergo further evaluation to determine if it will be removed from test.

B2. DETERMINING END-OF-LIFE

At present, end-of-life for a cathode is determined from its Miram curve (see Appendix C for a discussion of Miram curves) and is defined as a 5% reduction in the cathode current at its operating temperature. However, in the past, life tests were commonly continued until a replacement test vehicle became available. Each test vehicle is reviewed after the annual roll-off curves are produced and those cathodes that have reached end-of-life are removed from test.

Table B-1. Power Supply Repairs

POWER SUPPLY	FAILURE/REPAIR
CO12632A	Replaced K12.
CO12637A	Replaced ETM.
CO12643A	Replaced body current meter.
CO12646B	Replaced ETM.

APPENDIX C

DATA ANALYSIS METHODS

(Unclassified)

(3 Pages Attached)

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APPENDIX C

DATA ANALYSIS METHODS

C1. DATA REDUCTION

Cathode performance data is presented in four standard forms: (1) as Miram curves for each cathode vehicle, (2) as least-squares-fitted plots of emission versus time for each cathode system, (3) as kneepoint migration plots that summarize the change in kneepoint temperature of the cathode during life testing, and (4) as PWFDs.

C1.1 Miram Curves

Miram curves standardize data presentations in two ways: (1) each plot shows the cathode's operating temperature as a vertical line referenced to the X axis (temperature), and (2) all currents are expressed as a percentage of the cathode's current at the first data point (highest temperature) of the initial roll-off curve. Each cathode's annual Miram curve is plotted with the cathode's initial Miram curve. Plotting these curves on a single chart visually presents the changes in the cathode's performance. A typical chart is shown in Figure C-1.

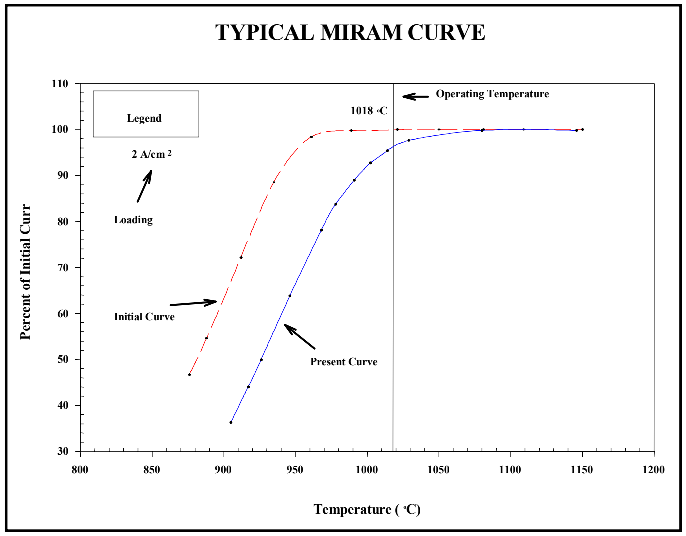


Figure C-1

C1.2 Long-Term Performance Plots

In addition to displaying the data as Miram curves for each cathode vehicle, the long-term performance of each cathode system is presented as a degradation plot. In each plot, the scaled current at the operating temperature is plotted as a function of life hours. The resultant plot shows the behavior of the cathode system over time and provides a convenient method of comparing the potential life of different cathode systems.

C1.3 Kneepoint Migration

NSWC Crane developed a computer program to calculate kneepoints of roll-off data. This program uses a graphical interface to allow the user to select points that will be used to calculate the kneepoint. The kneepoint is defined as the intersection of the "best fit" line to the data in the space-charge-limited region with the "best fit" line to the data in the temperature-limited region (see Figure C-2). This report contains kneepoint migration plots that show how quickly the knee temperature of a cathode approaches its operating temperature. A new Windows version of the kneepoint calculation program is available to interested parties. To obtain a copy of this software, contact Mr. Dressman at NSWC Crane (see Section 1.1.1).

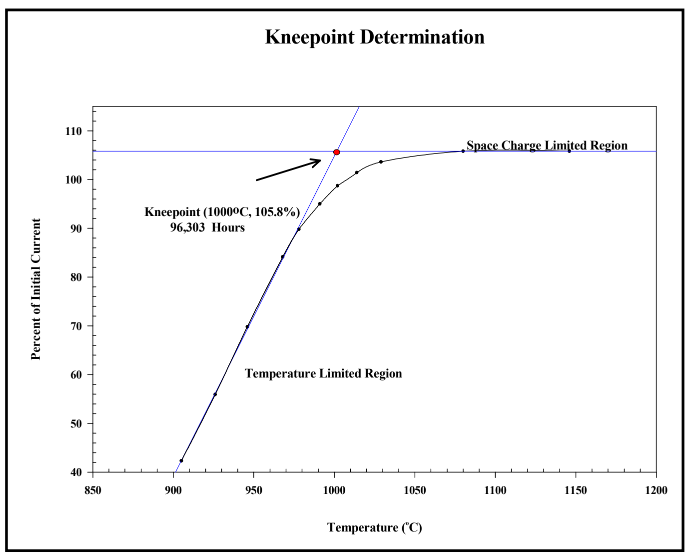


Figure C-2

C1.4 Practical Work Function Distribution

This report also includes PWFD plots for all cathodes currently being tested. This data is plotted in the bottom right corner of the Miram curve graph for each cathode (see Figure C-3). The work function data for the PWFD is calculated from the Richardson-Dushman equation

$$J = 120T^2 e^{-\phi/KT}$$

using Miram curve data.[1] The function $f(\phi)$ is simply the Miram curve percent current scale reflected about the 50% point. If emission data was not taken at 50% then the data was interpolated to give the PWFD a well-defined peak. George Miram developed the PWFD to provide a standard method for assessing cathode quality and predicting life expectancy. For high-quality cathodes, the PWFD width will not change and the peak will not shift throughout its useful life. Initial cathode quality can be assessed by comparing the PWFD of the cathode to the PWFD of the "Best of Class" (see Figure C-4). The Best of Class represents the best PWFD achieved so far for that type of cathode. Cathodes developed with a PWFD peak lower in work function than the current Best of Class will become the Best of Class.

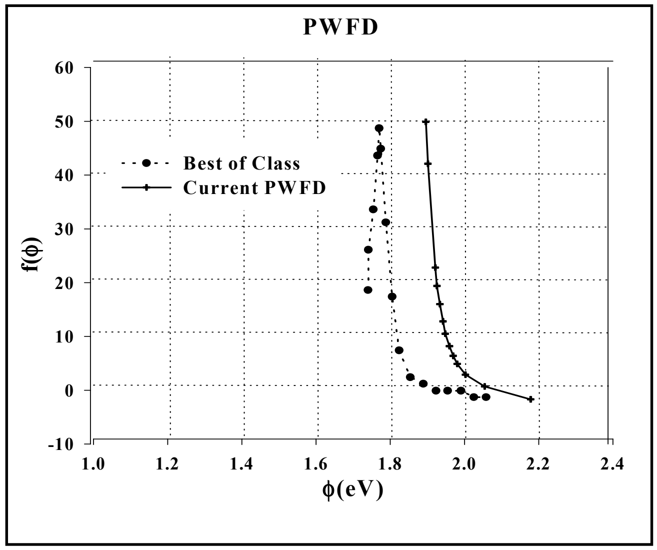


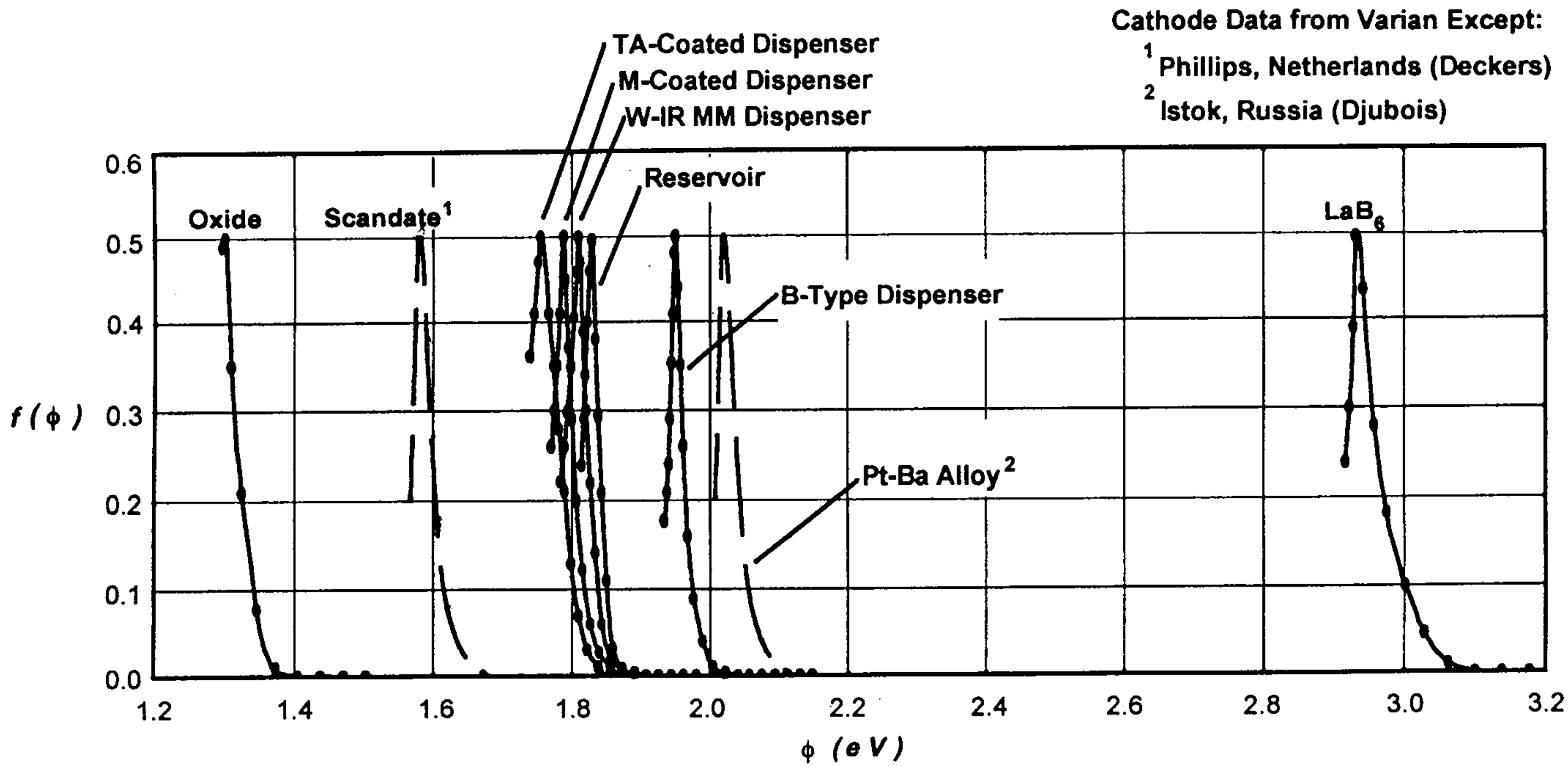
Figure C-3

C1.5 Data Organization

All roll-off data taken at the CLTF is stored in a computer database. The database contains more than 1000 records and is updated after each annual roll-off. Information from this database is available upon request. Requests for data should be directed to Mr. Dressman at NSWC Crane (see Section 1.1.1).

[1] G. V. Miram and M. Cattelino, *Life Test Facility for Thermionic Cathodes*, 1994 TriService/NASA Cathode Workshop.

Quality of Thermionic Cathodes "Best of Class" PWFD



G. V. Miram, and M. Cattelino, 1994
Life Test Facility for Thermionic Cathodes
Conference Record 1994 Tri-Service/NASA Cathode Workshop, Cleveland, 29-31 March.

Figure C-4

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APPENDIX D

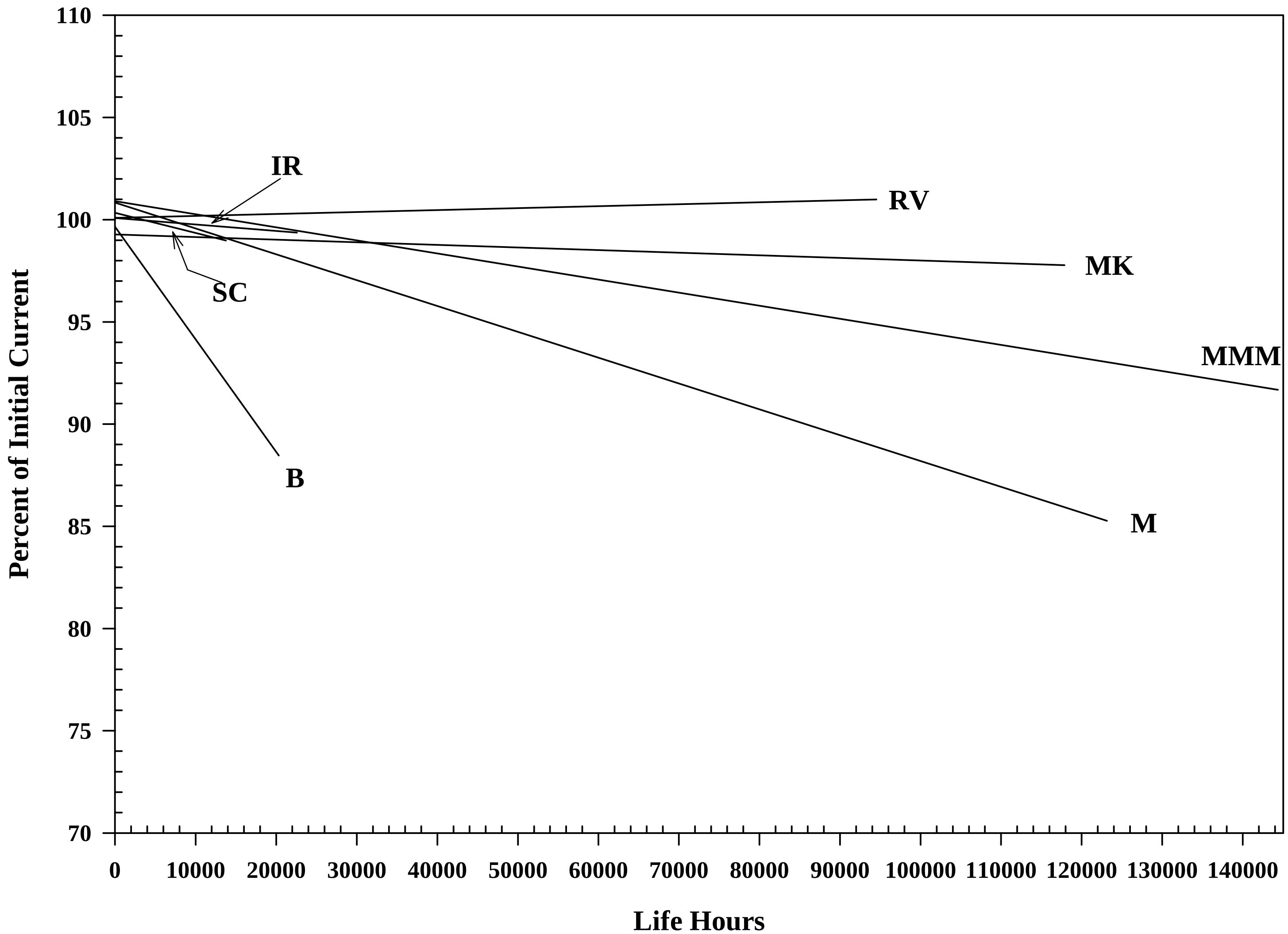
LONG-TERM PERFORMANCE PLOTS

(Unclassified)

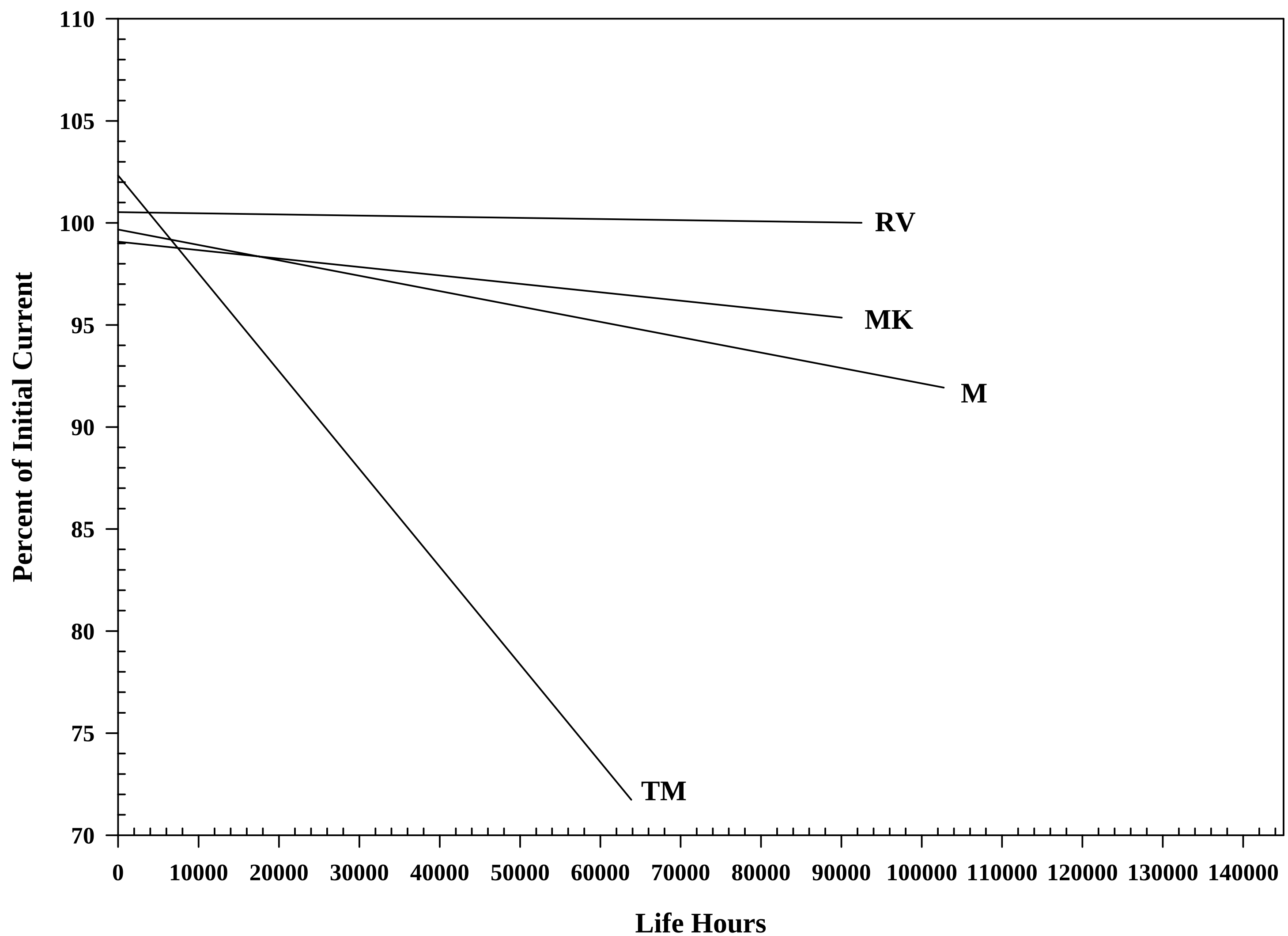
(2 Pages Attached)

LONG-TERM PERFORMANCE

2 A/cm^2



LONG-TERM PERFORMANCE
4 A/cm^2



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APPENDIX E

DATA SUMMARY

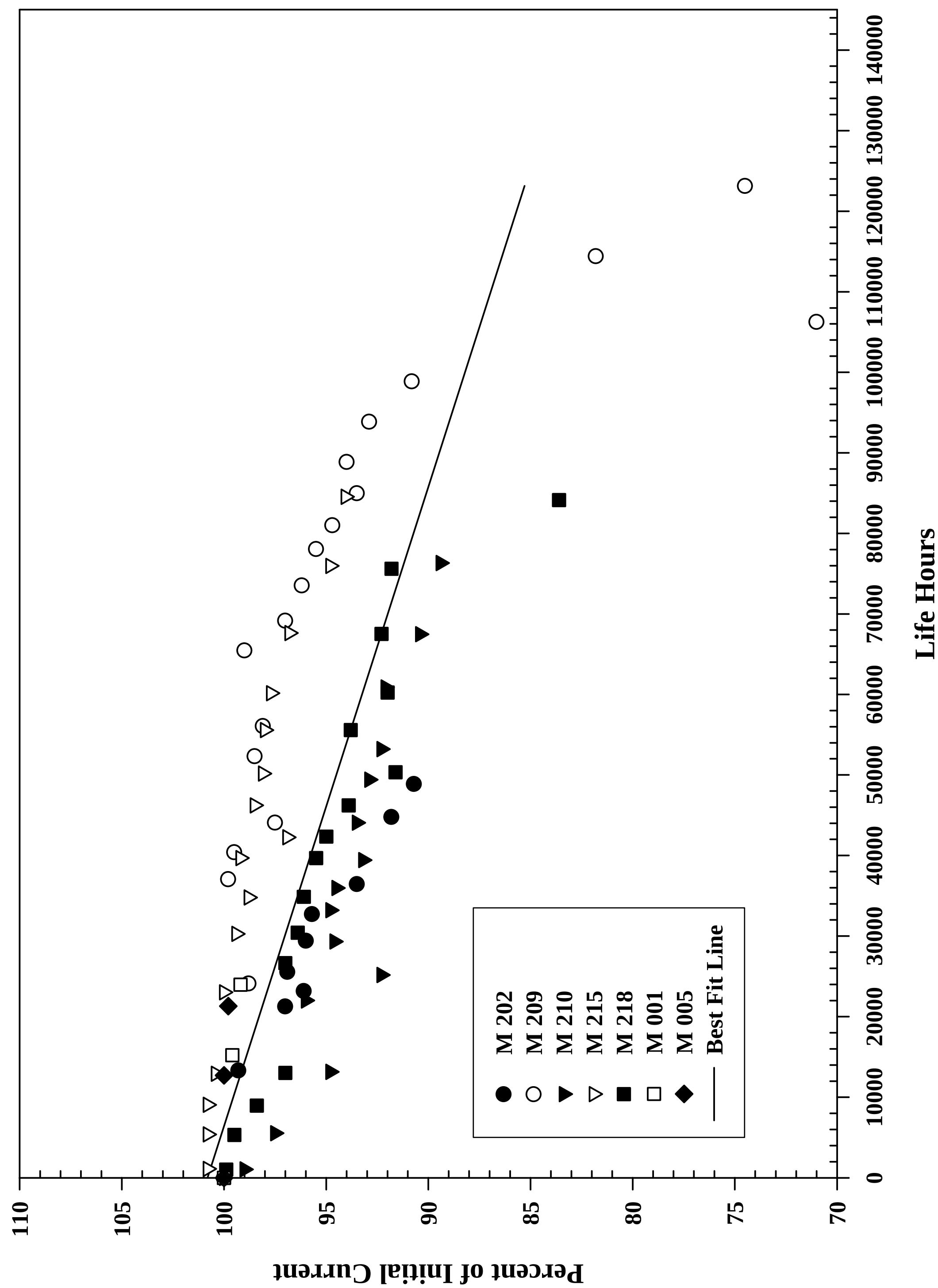
M AND IM CATHODE SYSTEMS

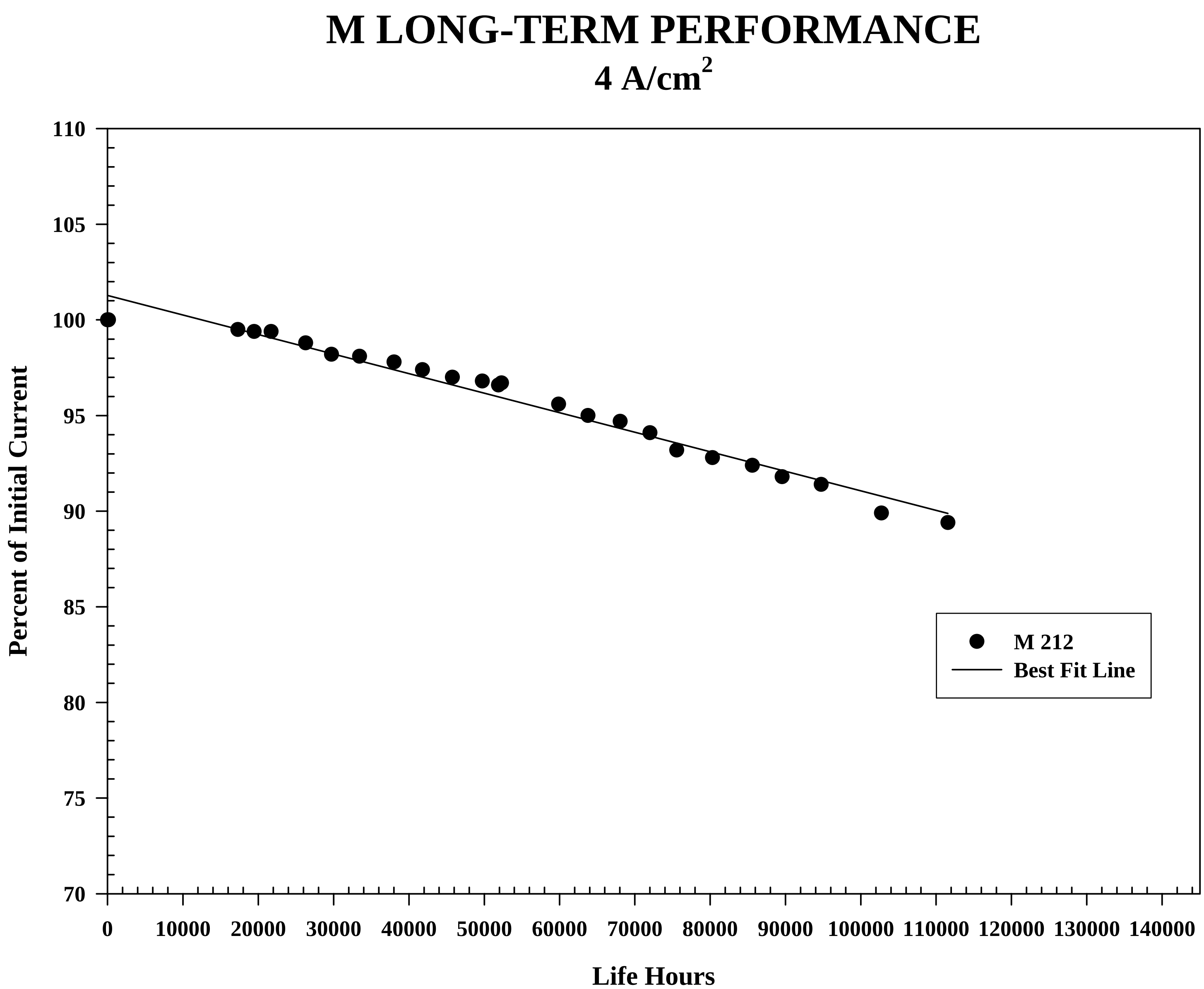
(Unclassified)

(8 Pages Attached)

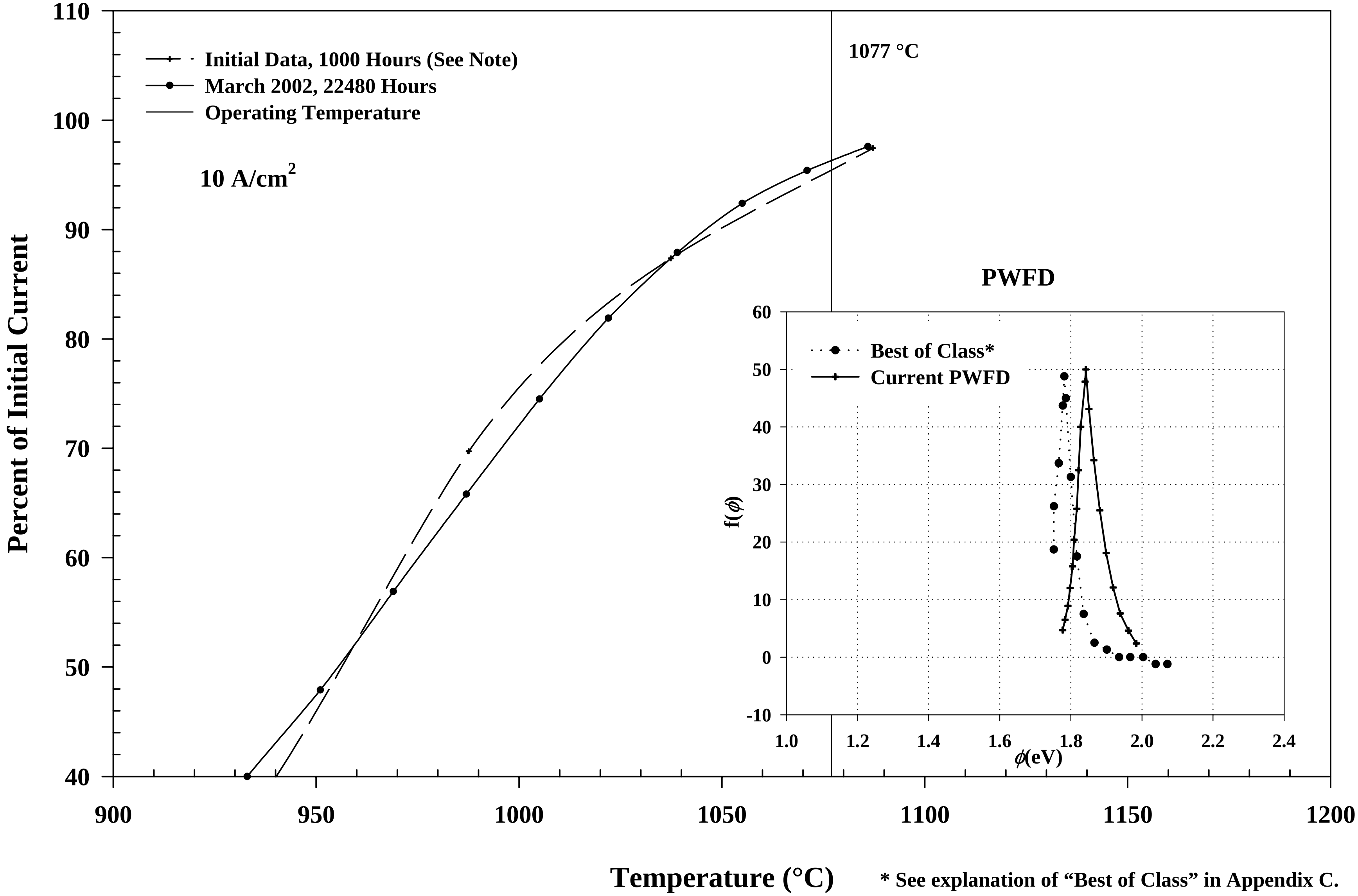
M LONG-TERM PERFORMANCE

2 A/cm^2




M LONG-TERM PERFORMANCE
4 A/cm2
Percent of Initial Current
110
105
100
95
90
85
80
75
70
0
10000
20000
30000
40000
50000
60000
70000
80000
90000
100000
110000
120000
130000
140000
Life Hours
M 212
Best Fit Line

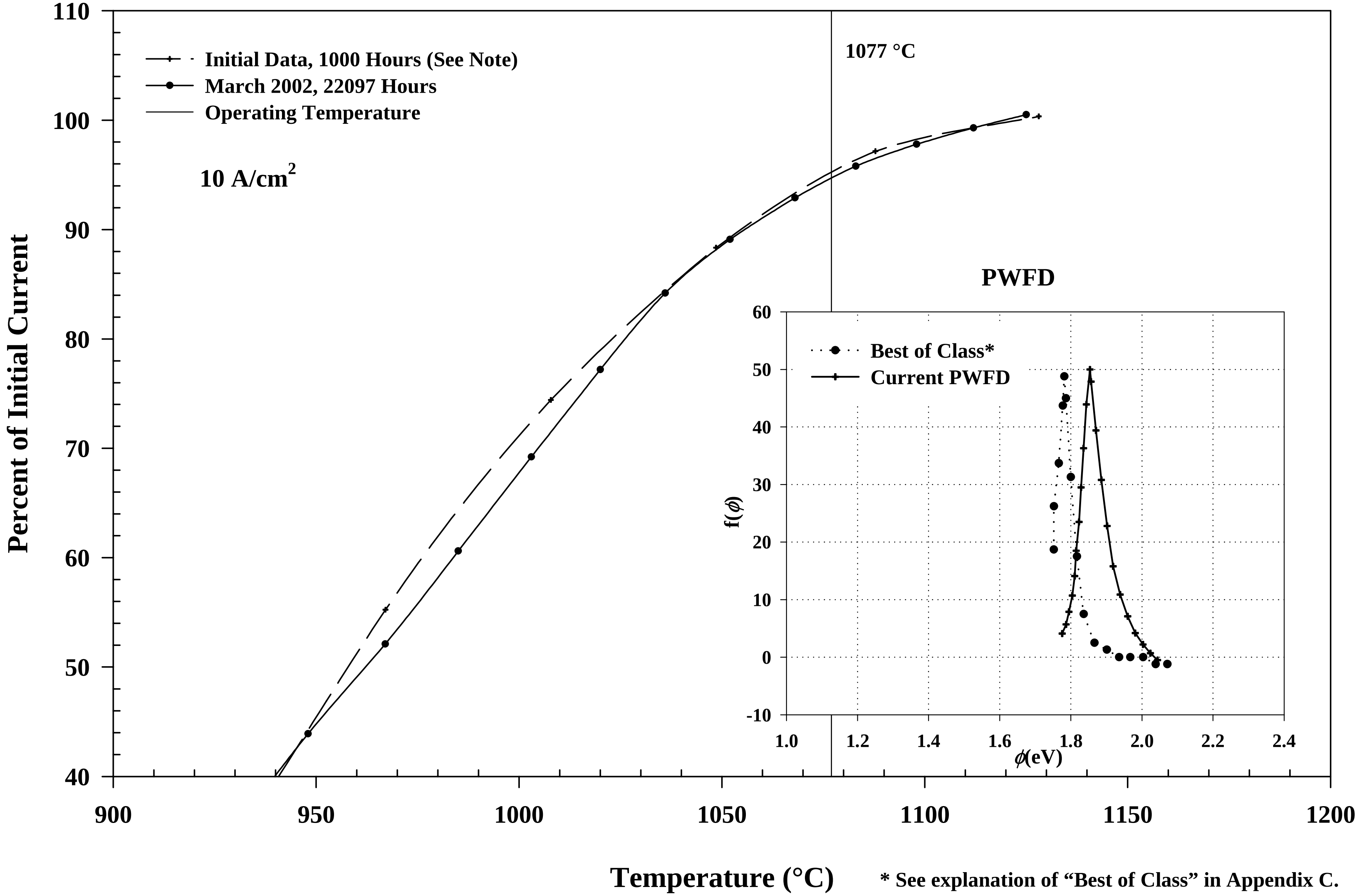
IM 009 MIRAM CURVE



* See explanation of "Best of Class" in Appendix C.

NOTE: Initial data taken at Istock using different test methods and equipment.

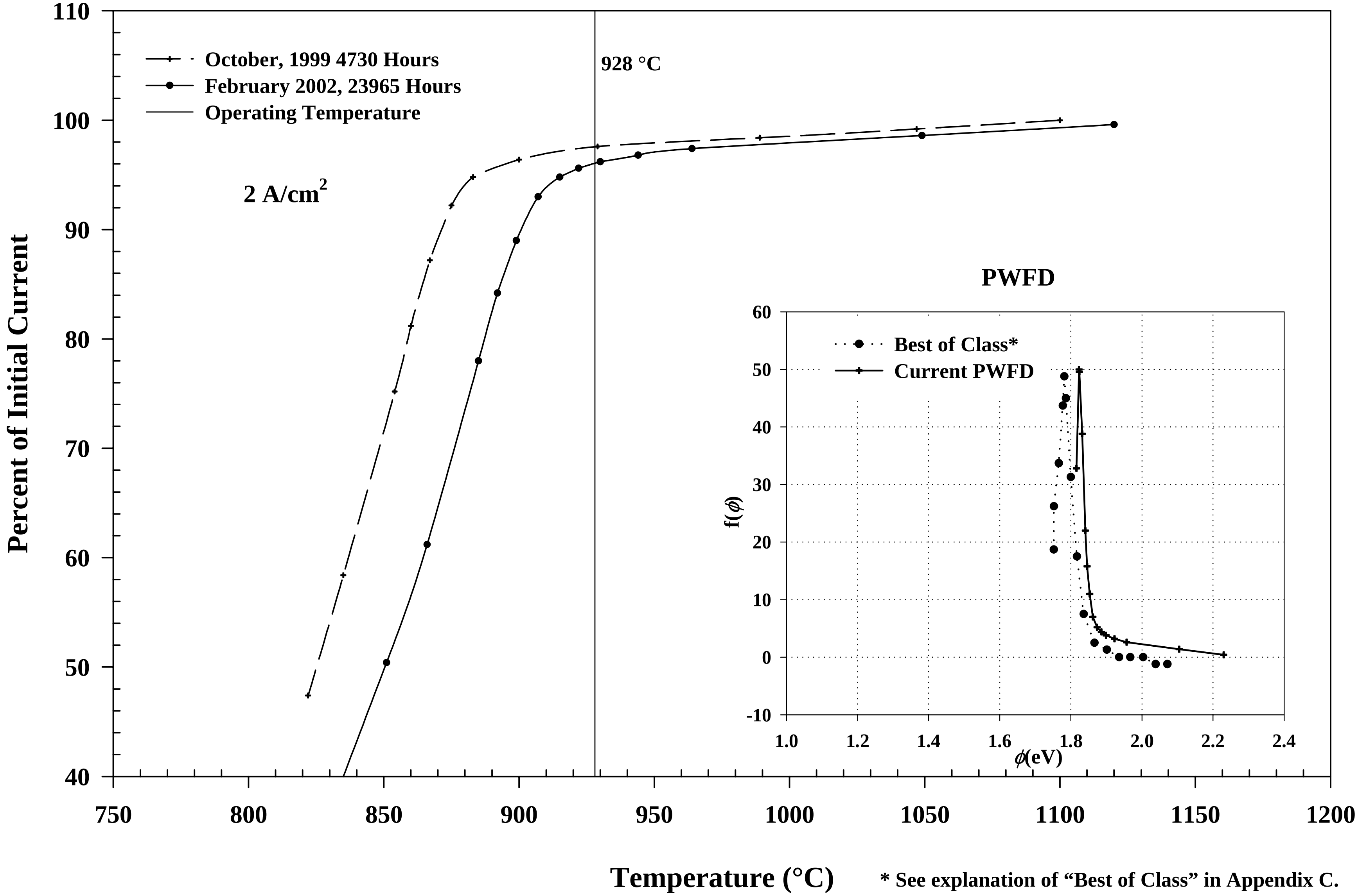
IM 010 MIRAM CURVE



* See explanation of “Best of Class” in Appendix C.

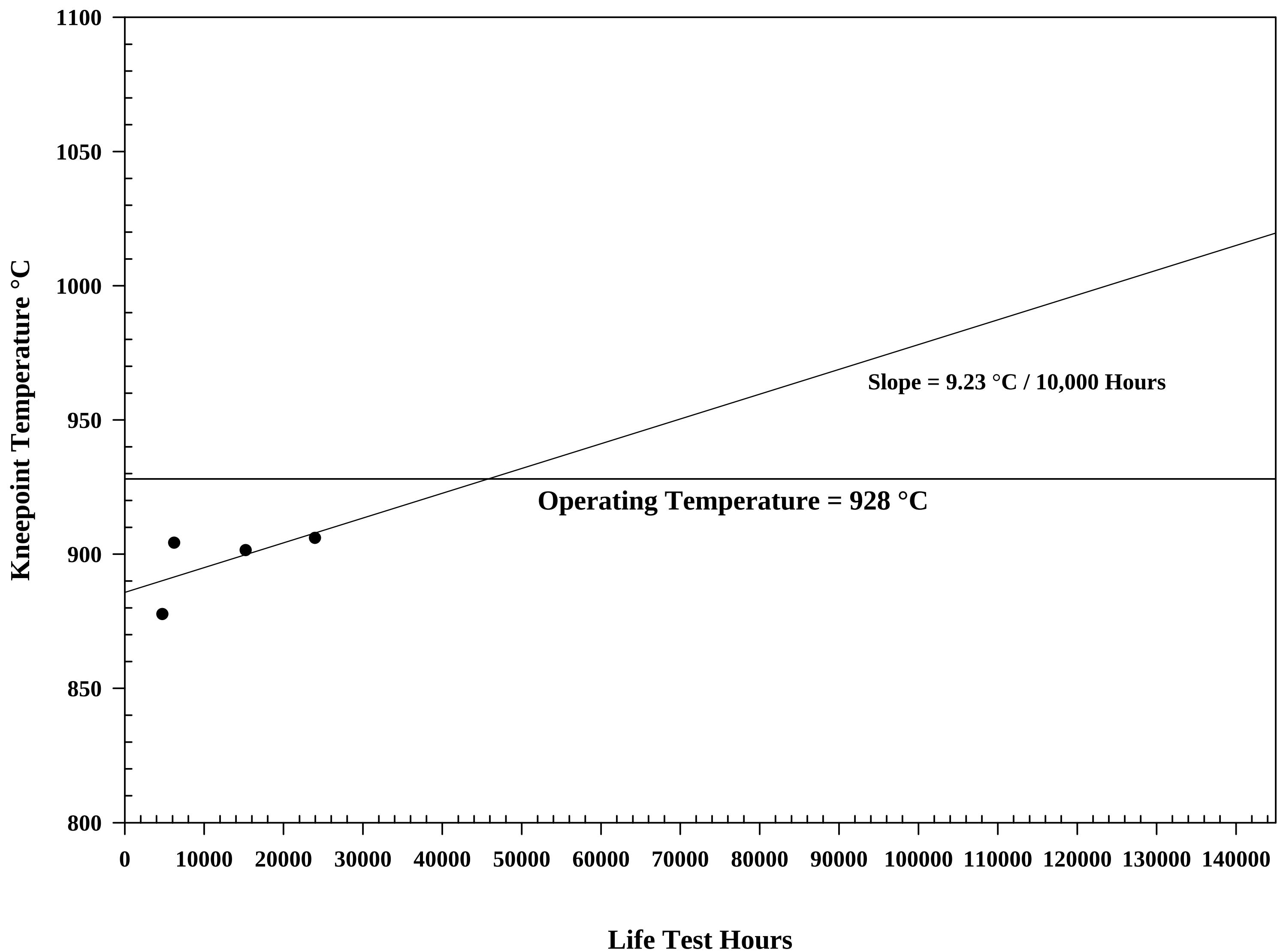
NOTE: Initial data taken at Istock using different test methods and equipment.

M 001 MIRAM CURVE

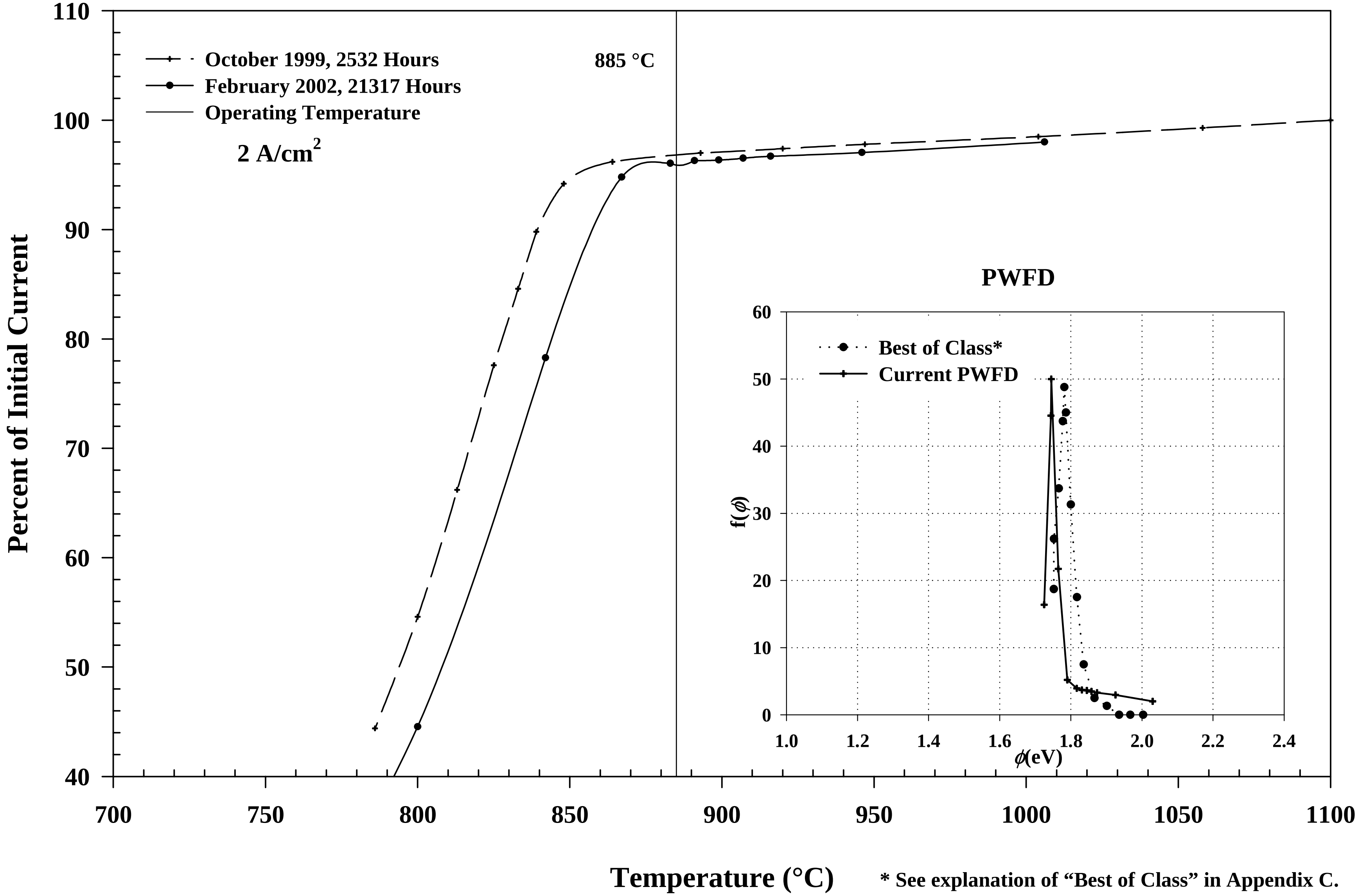


* See explanation of “Best of Class” in Appendix C.

M 001 KNEEPOINT MIGRATION

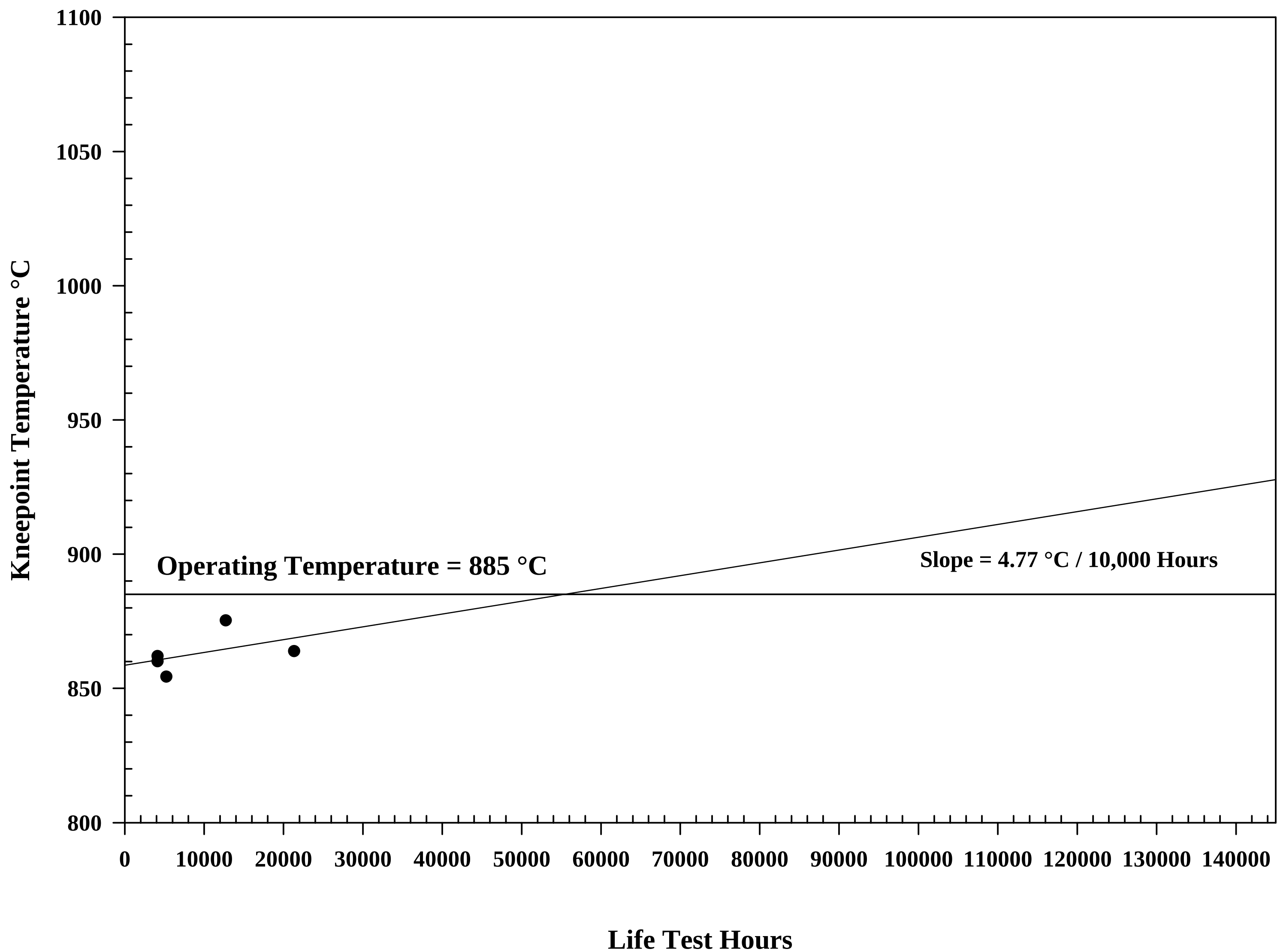


M 005 MIRAM CURVE



* See explanation of “Best of Class” in Appendix C.

M 005 KNEEPOINT MIGRATION



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APPENDIX F

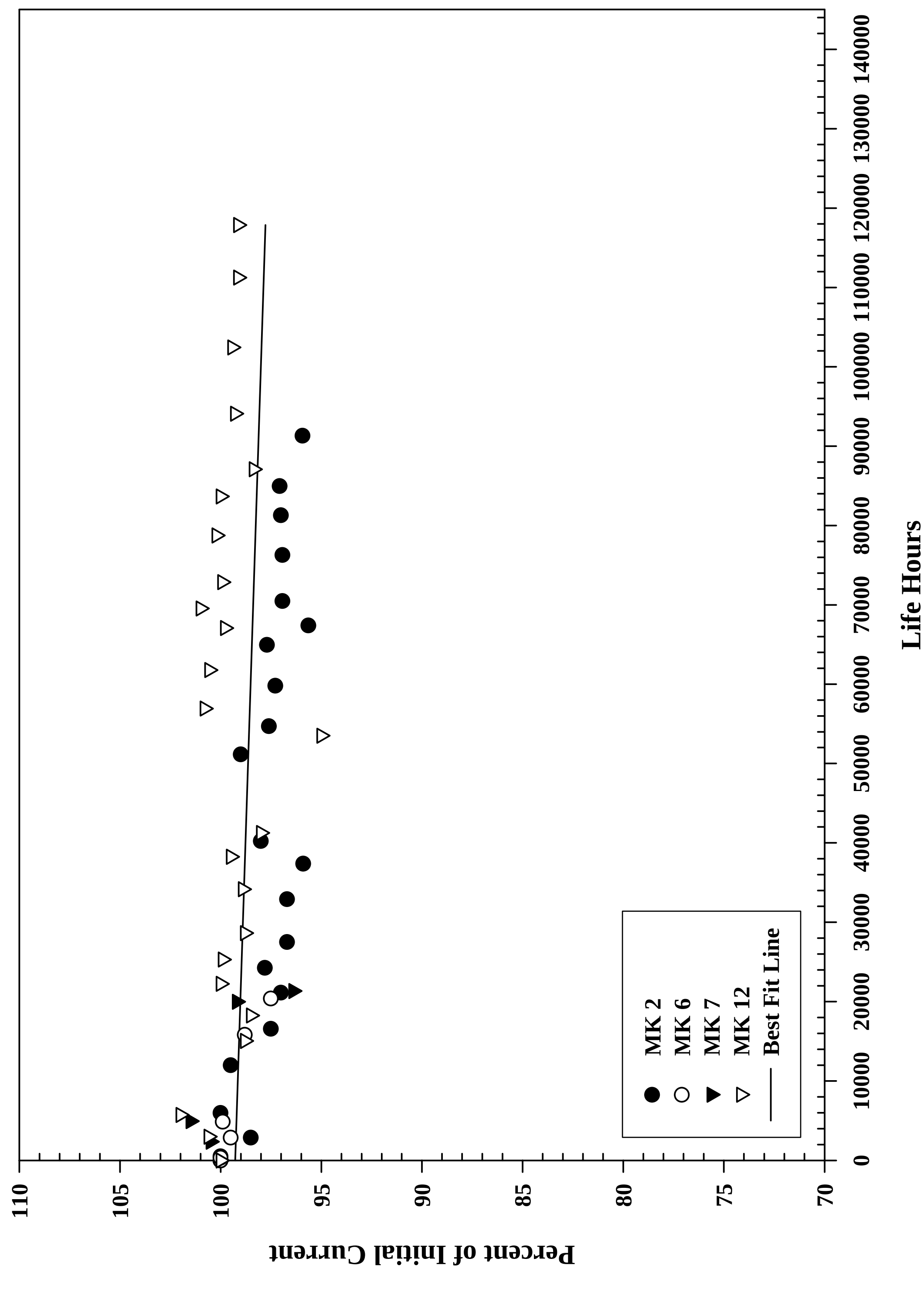
DATA SUMMARY

MK CATHODE SYSTEM

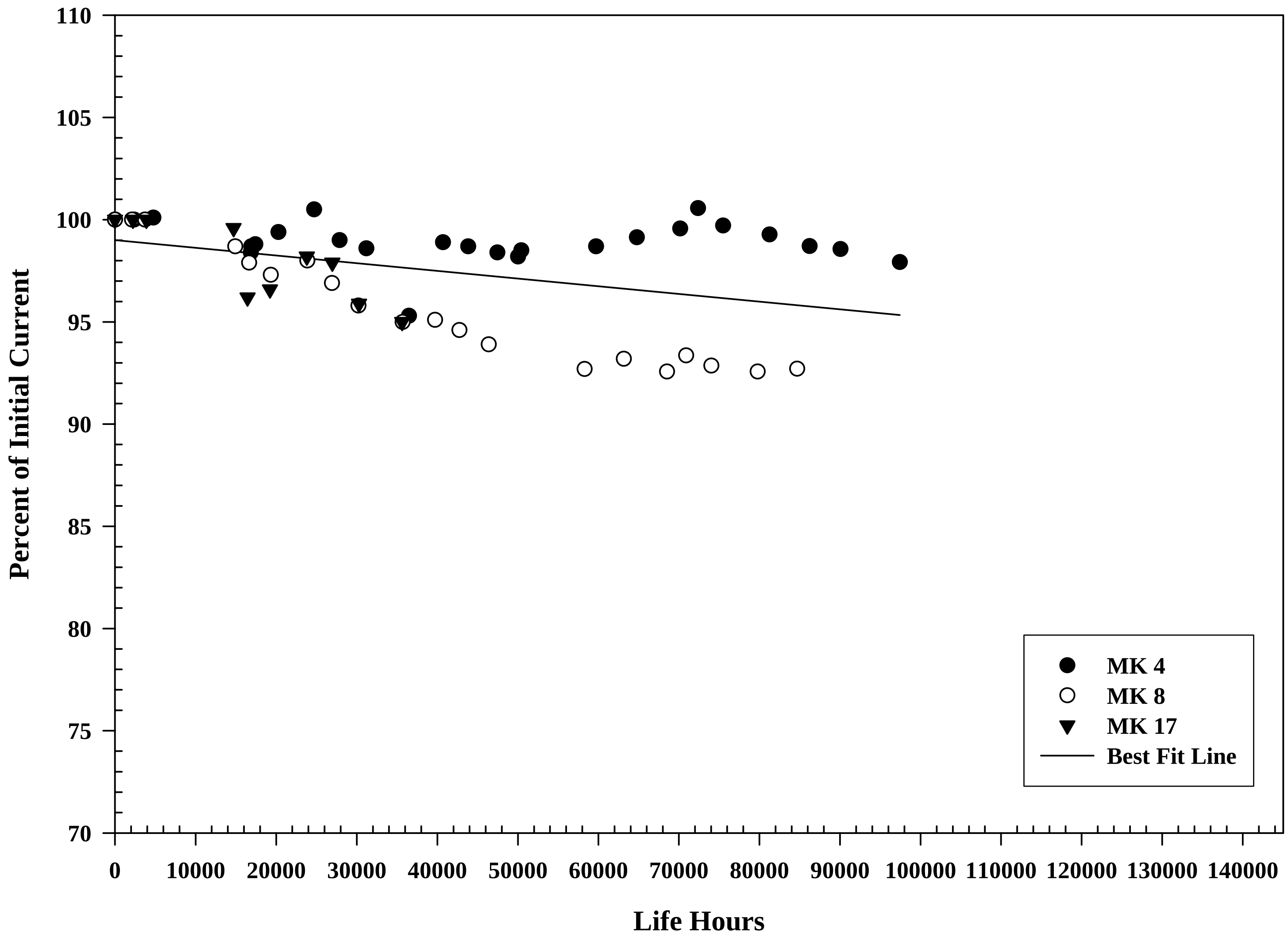
(Unclassified)

(4 Pages Attached)

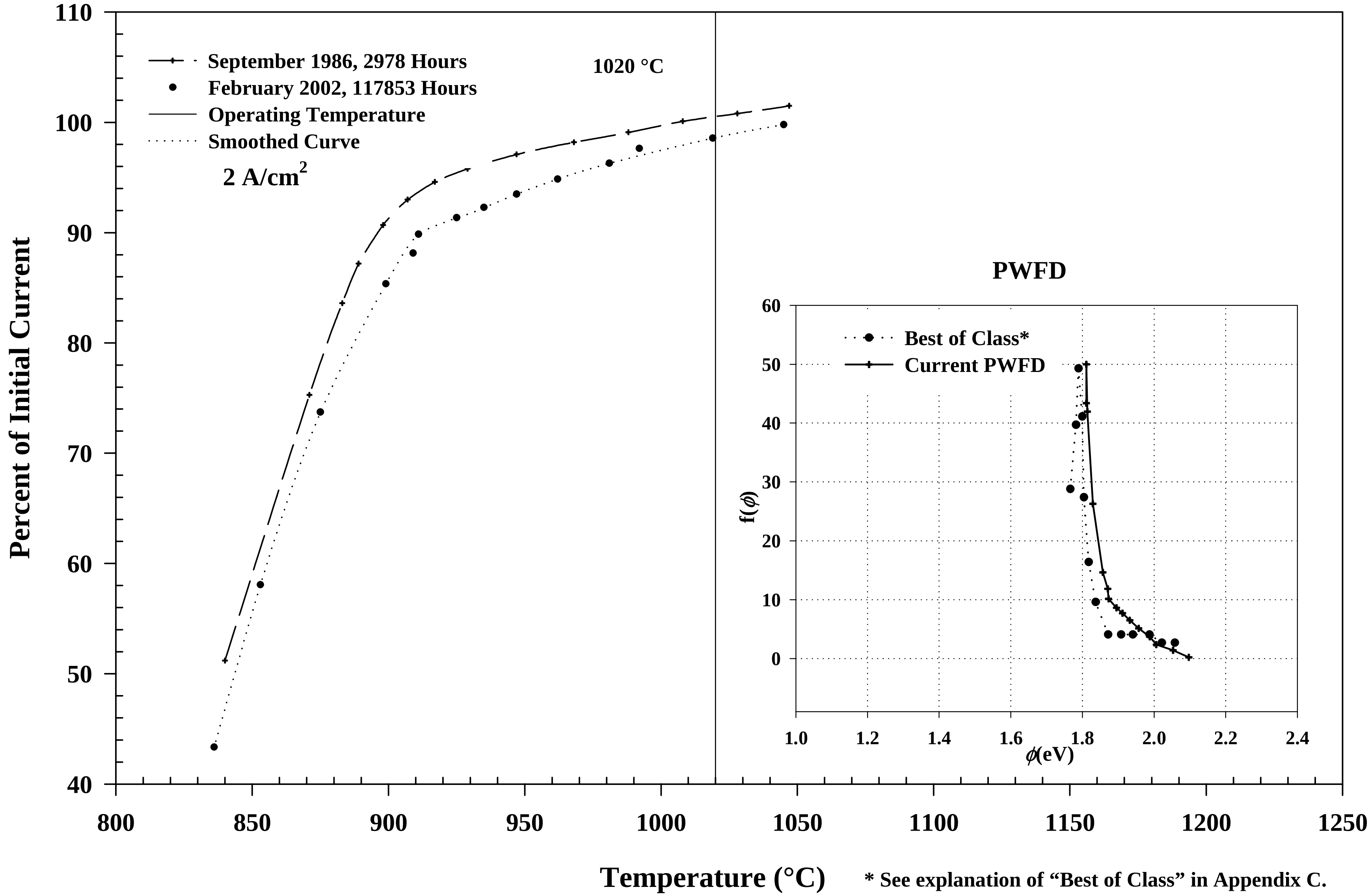
MK LONG-TERM PERFORMANCE
2 A/cm^2



MK LONG-TERM PERFORMANCE
4 A/cm^2

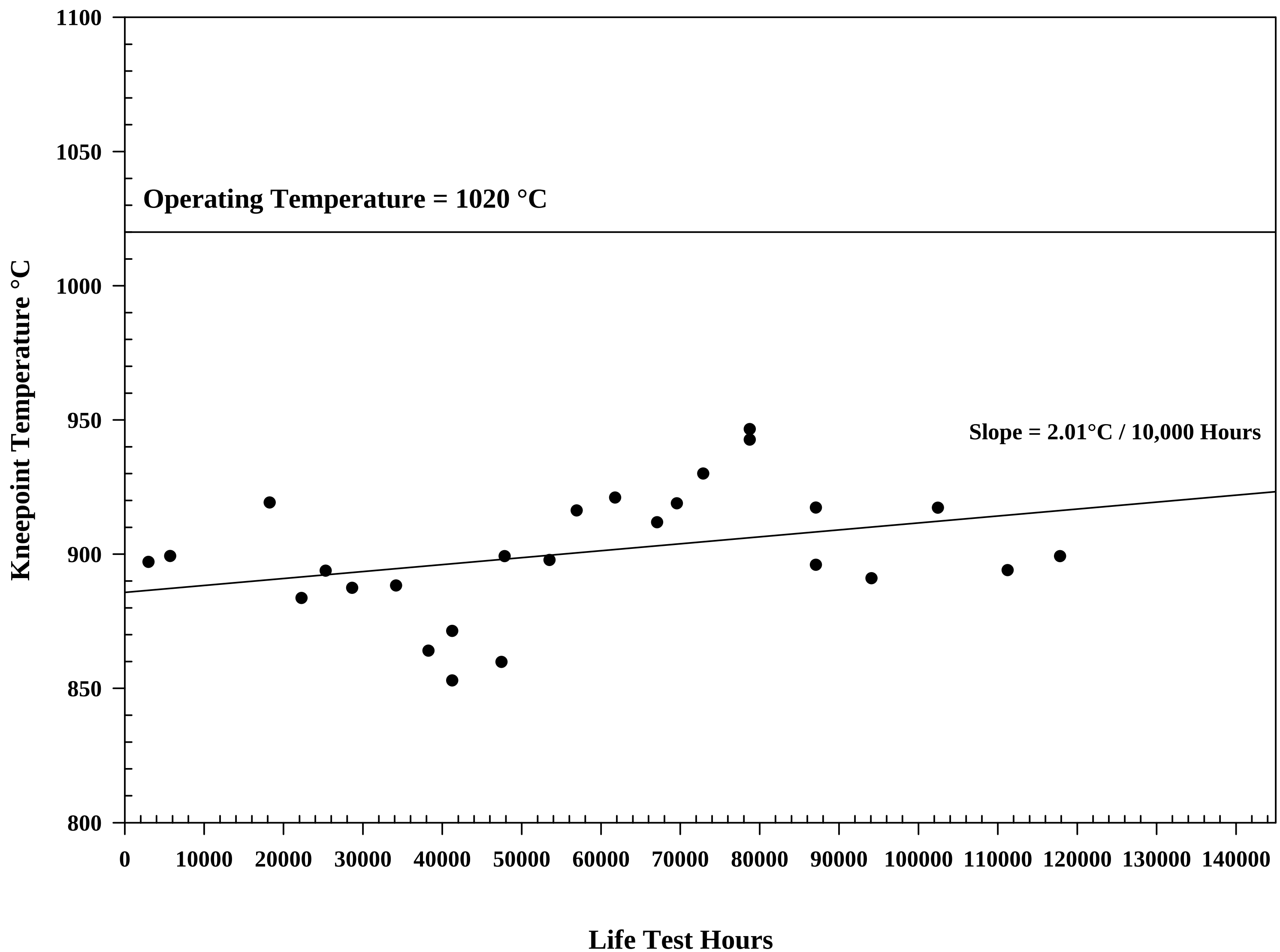


MK 12 MIRAM CURVE



* See explanation of "Best of Class" in Appendix C.

MK 12 KNEEPOINT MIGRATION



APPENDIX G

DATA SUMMARY

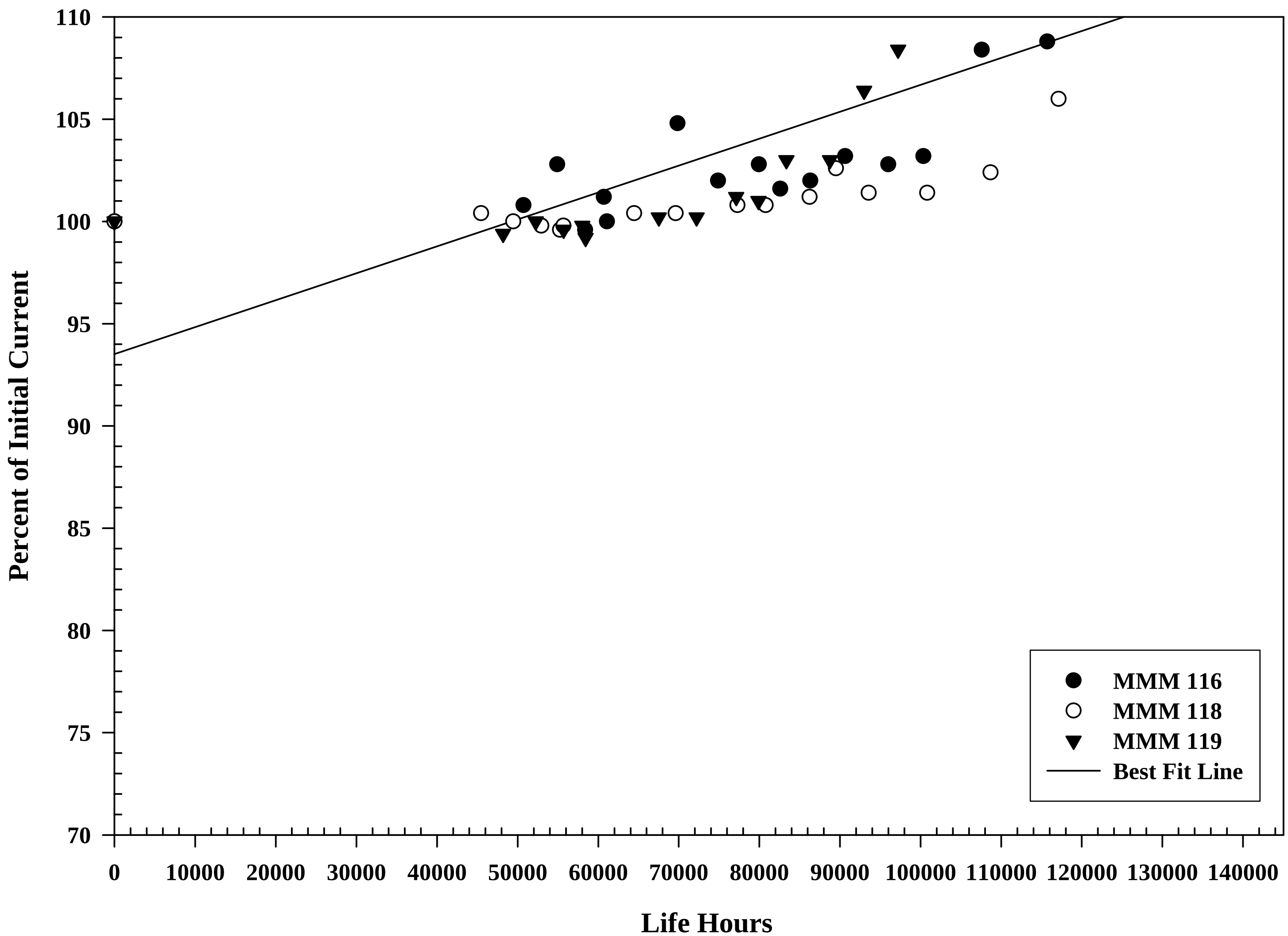
MMM CATHODE SYSTEM

(Unclassified)

(8 Pages Attached)

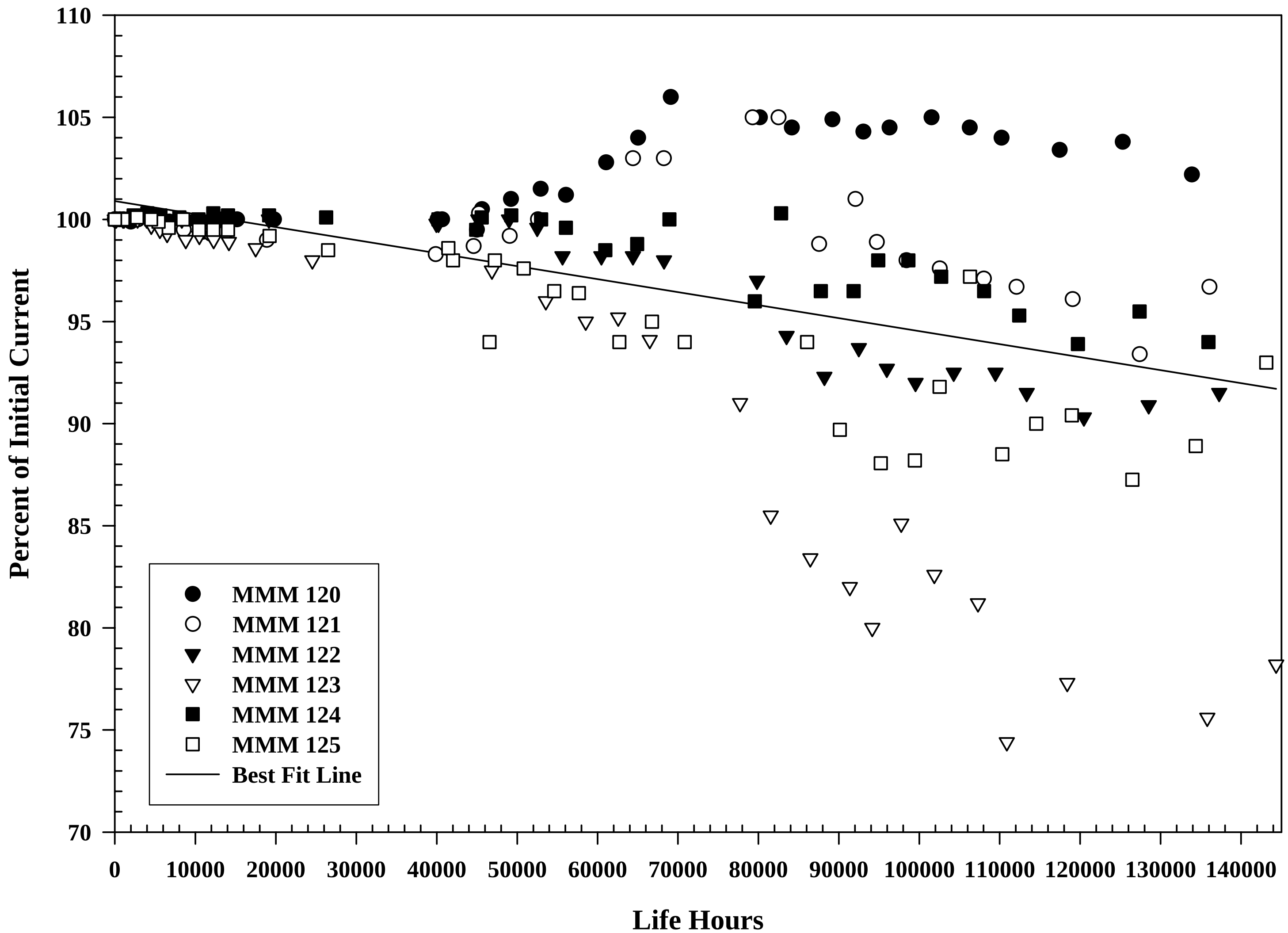
MMM LONG-TERM PERFORMANCE

1 A/cm^2

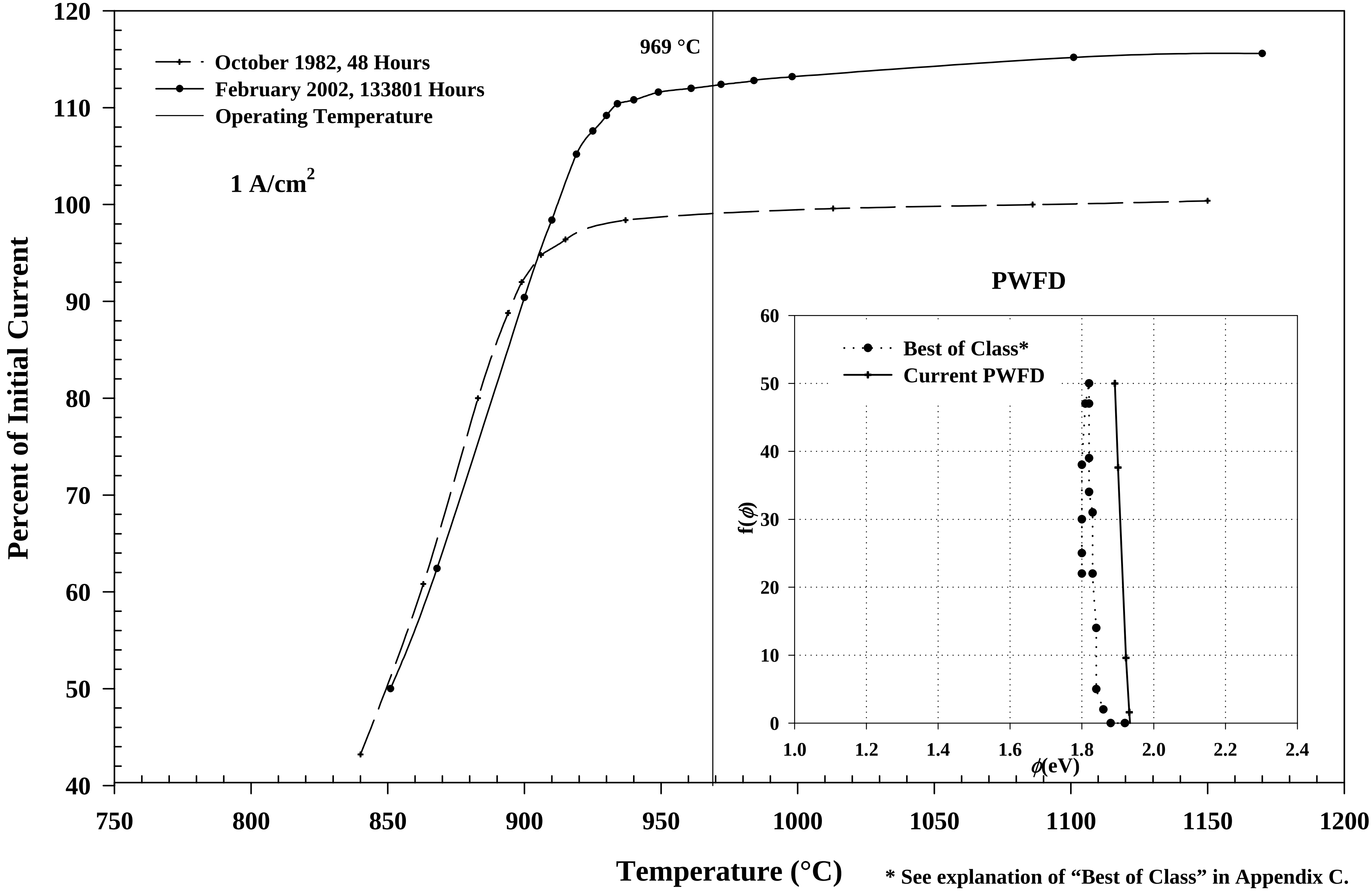


MMM LONG-TERM PERFORMANCE

2 A/cm^2

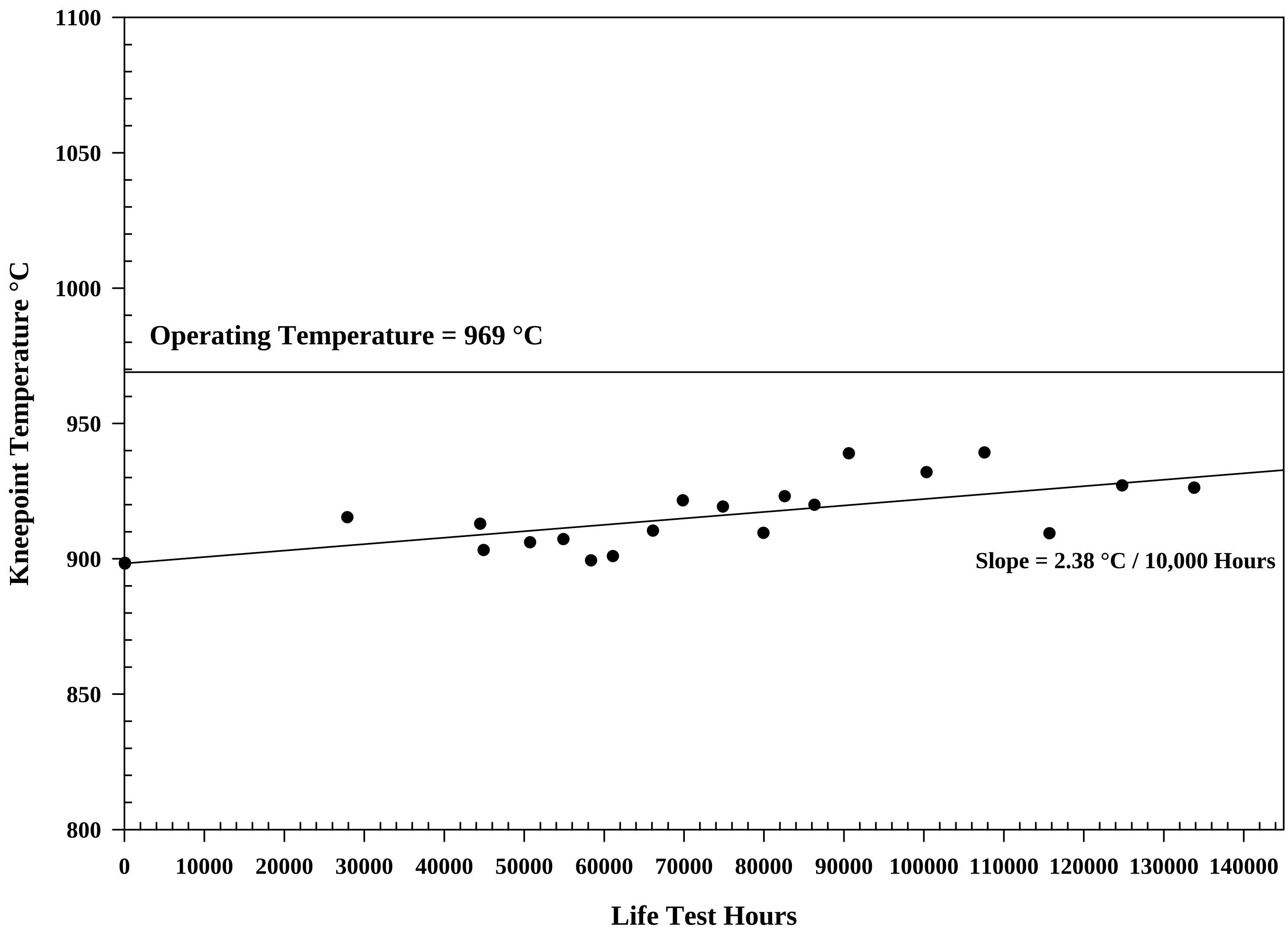


MMM 116 MIRAM CURVE

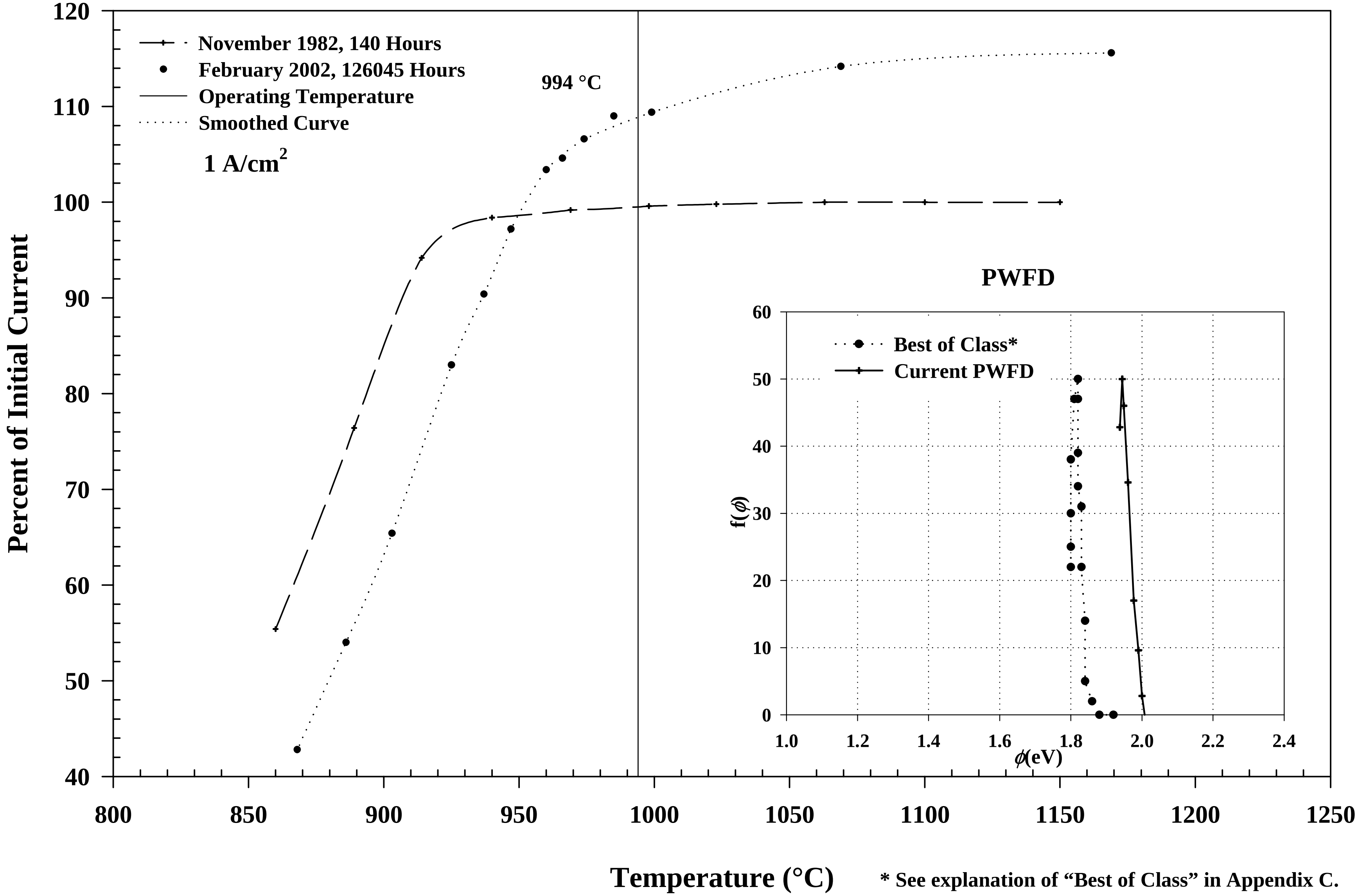


* See explanation of “Best of Class” in Appendix C.

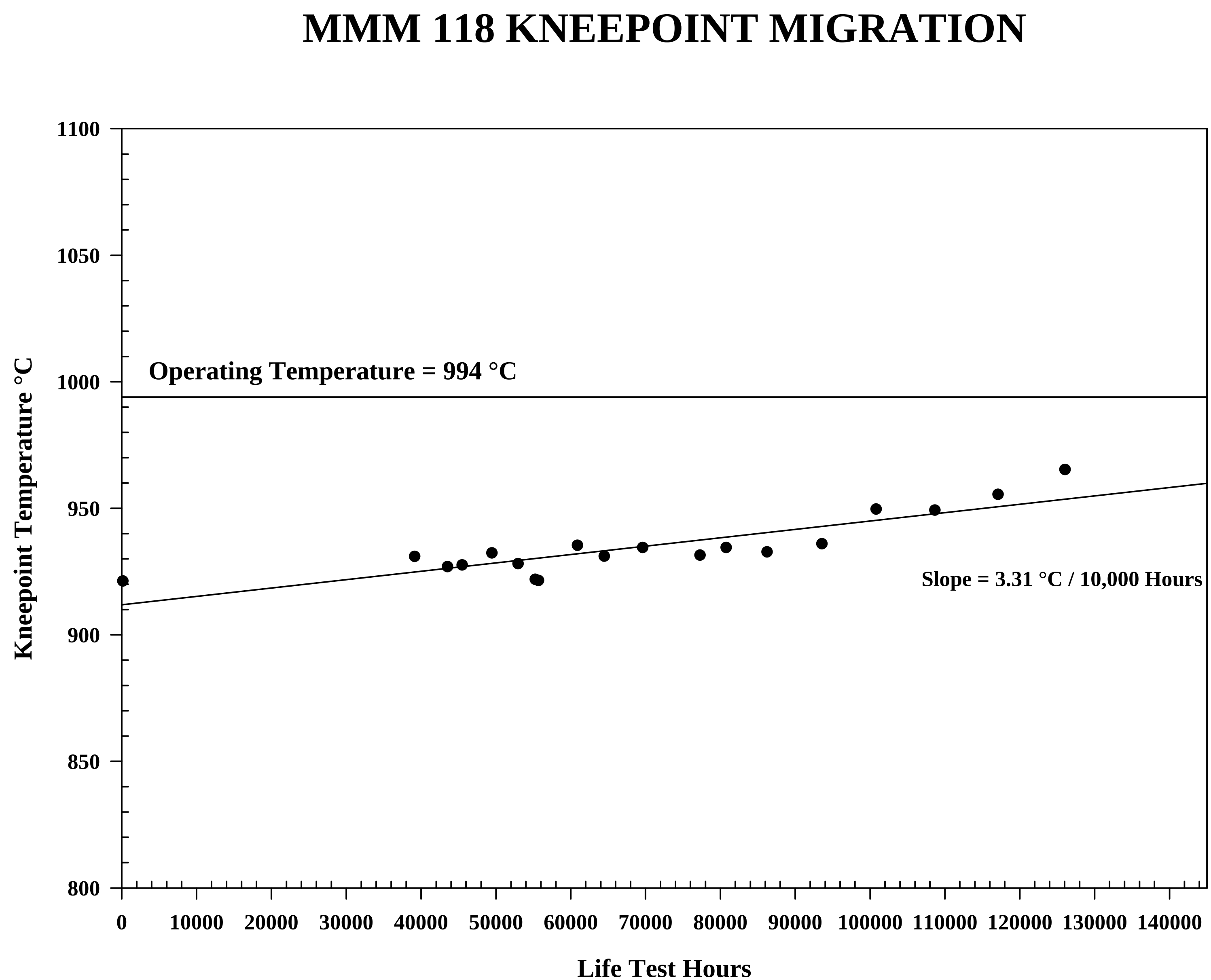
MMM 116 KNEEPOINT MIGRATION



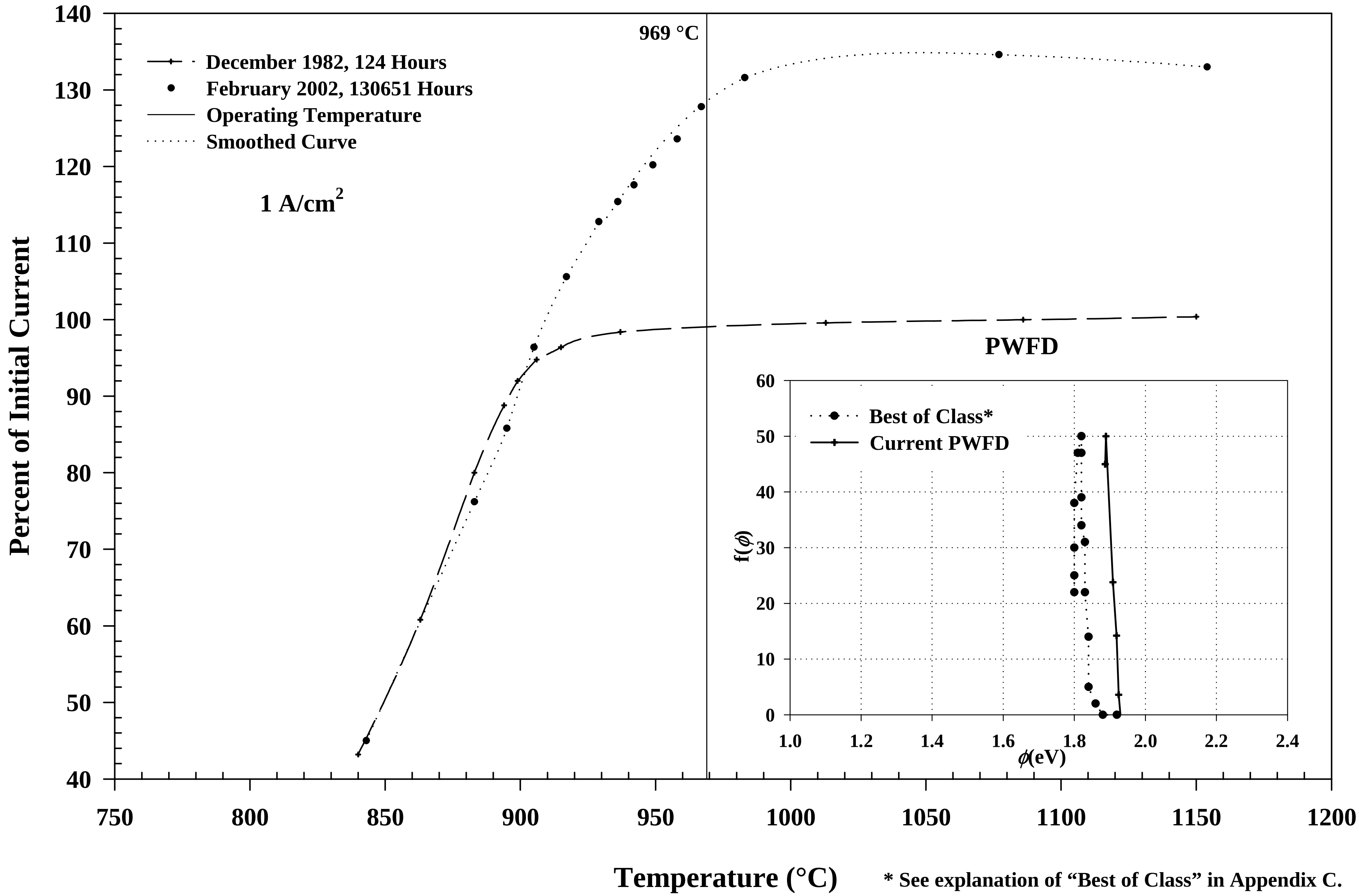
MMM 118 MIRAM CURVE



* See explanation of "Best of Class" in Appendix C.

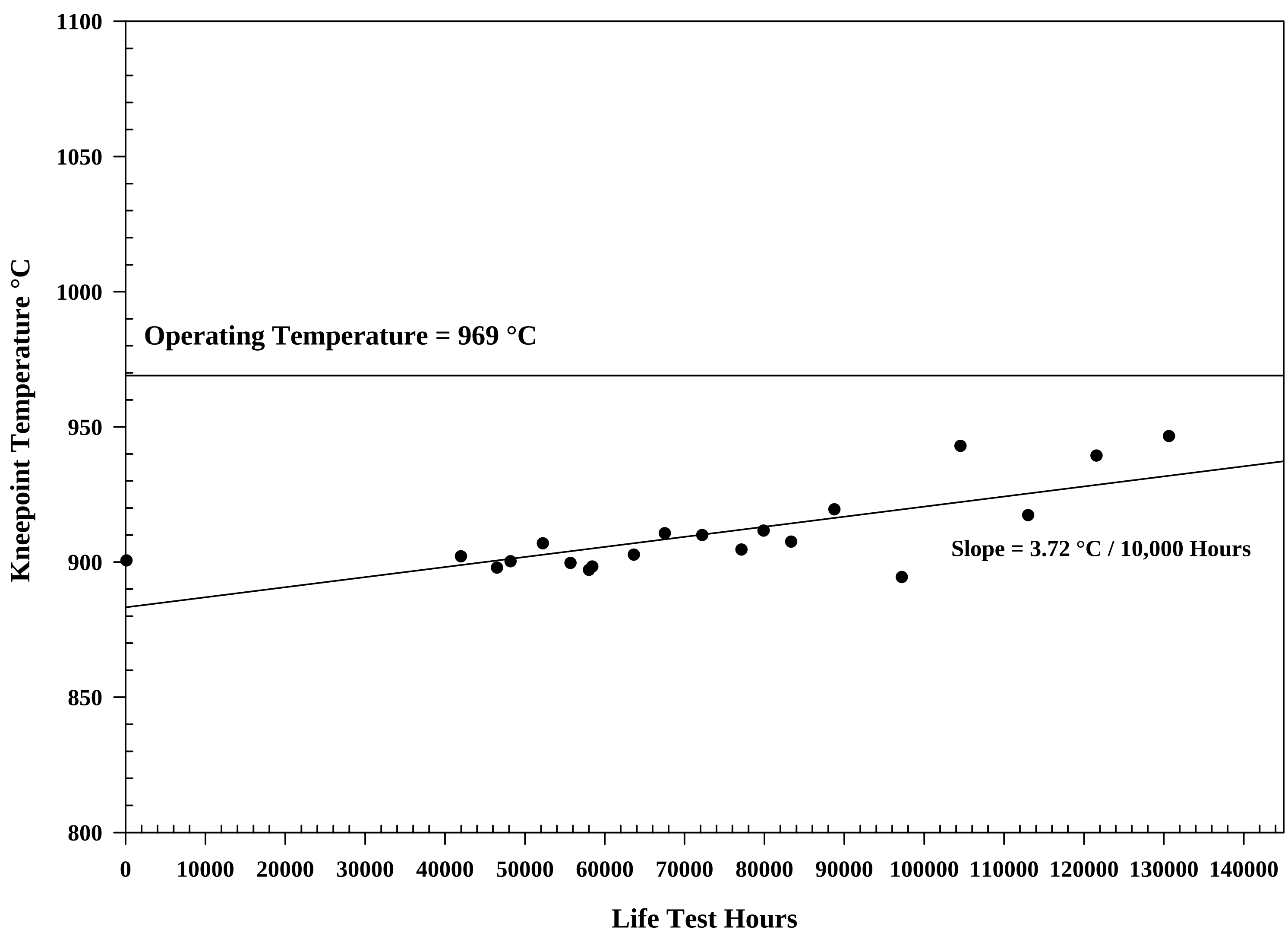

MMM 118 KNEEPOINT MIGRATION
Operating Temperature = 994 °C
Slope = 3.31 °C / 10,000 Hours
Kneepoint Temperature °C
Life Test Hours
1100
1050
1000
950
900
850
800
0
10000
20000
30000
40000
50000
60000
70000
80000
90000
100000
110000
120000
130000
140000

MMM 119 MIRAM CURVE



* See explanation of "Best of Class" in Appendix C.

MMM 119 KNEEPOINT MIGRATION



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APPENDIX H

DATA SUMMARY

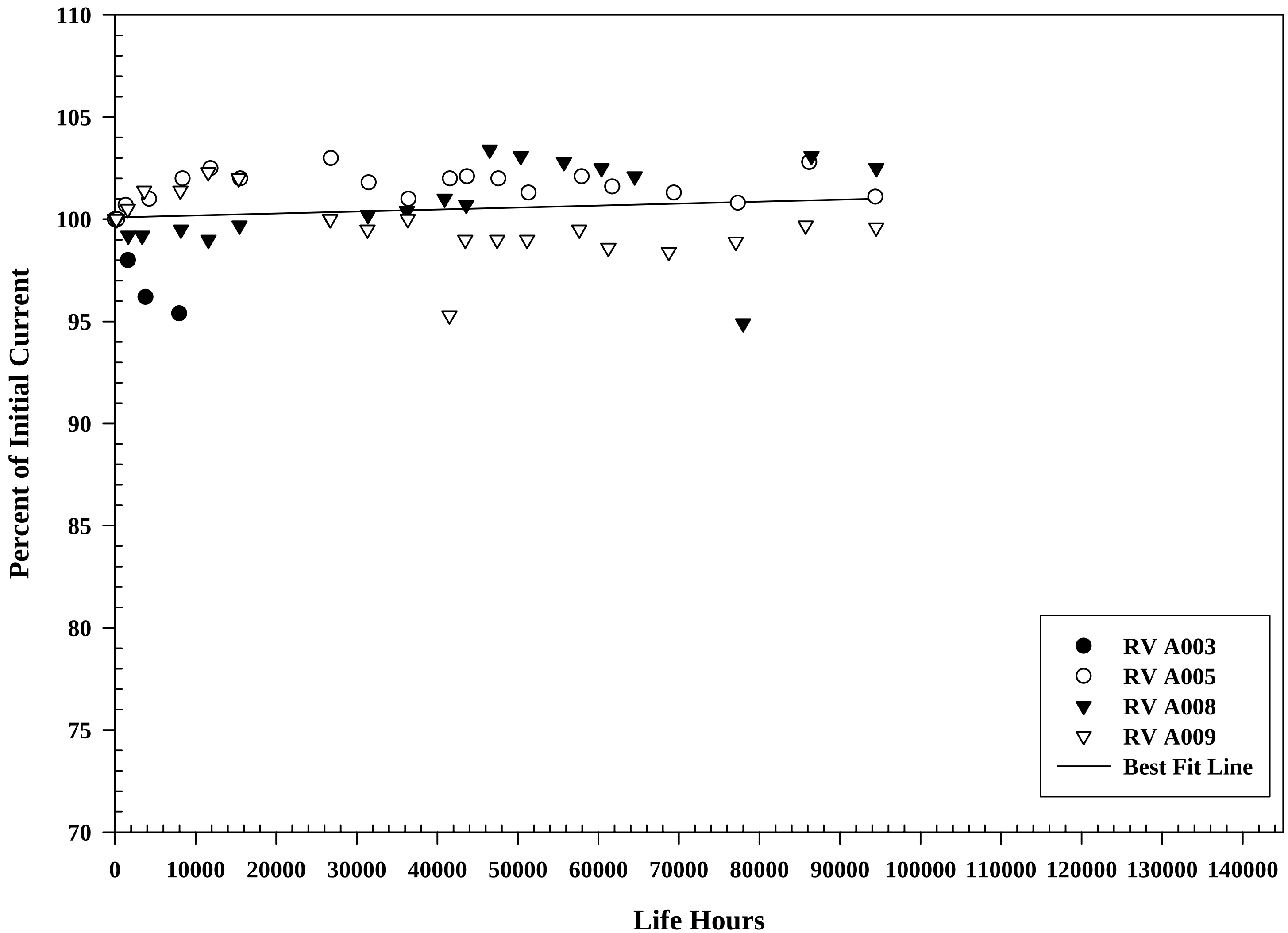
RV AND V CATHODE SYSTEMS

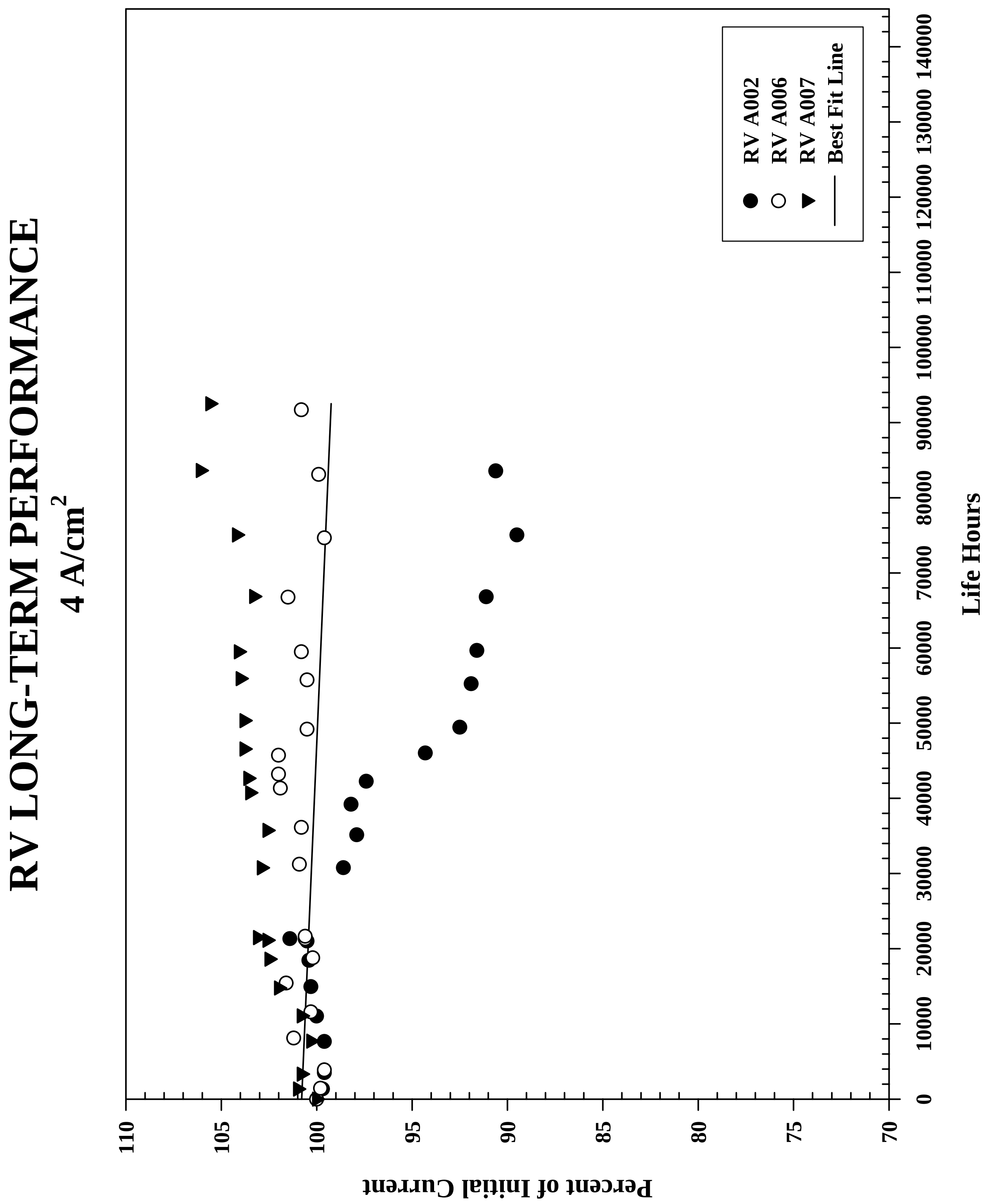
(Unclassified)

(16 Pages Attached)

RV LONG-TERM PERFORMANCE

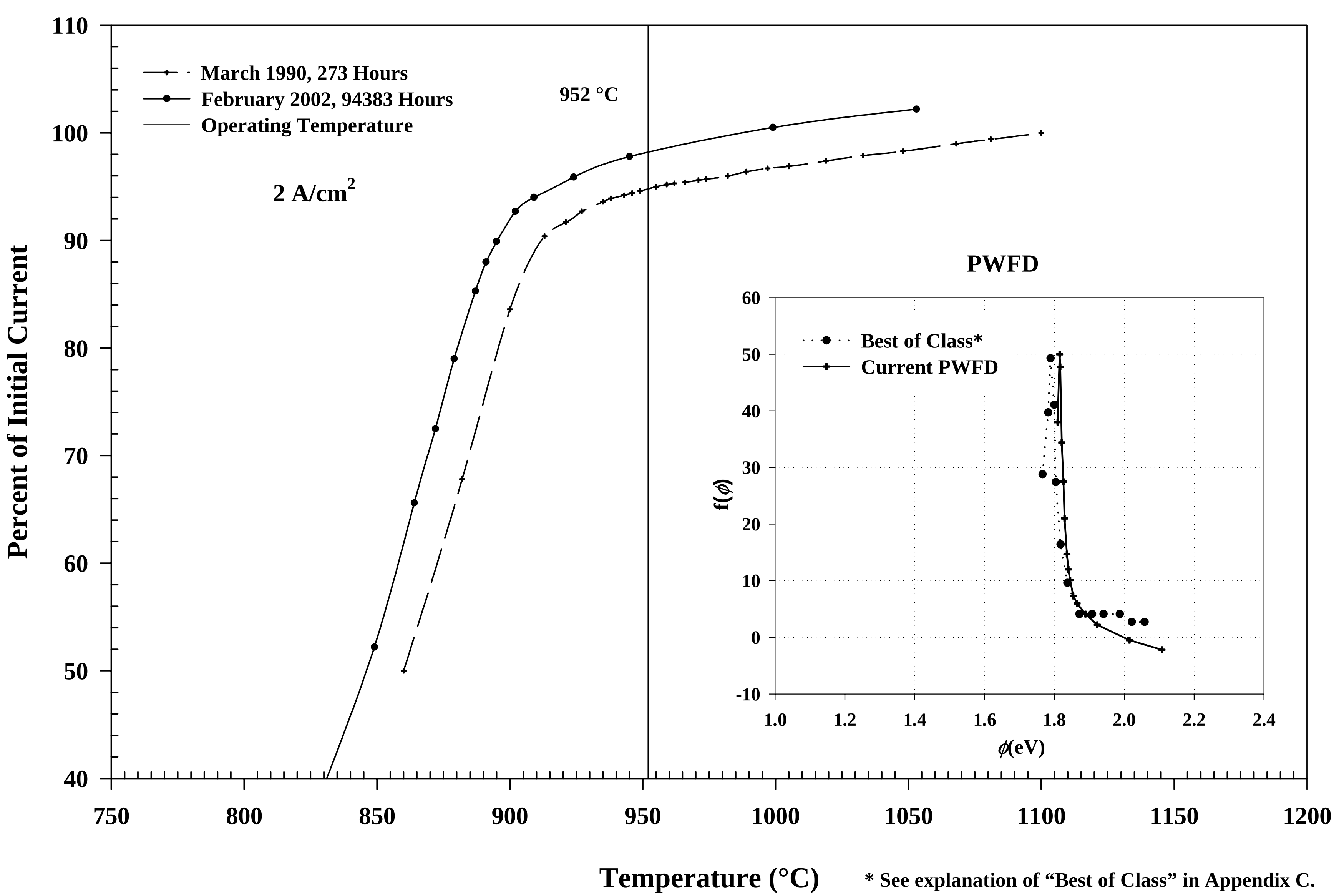
2 A/cm^2





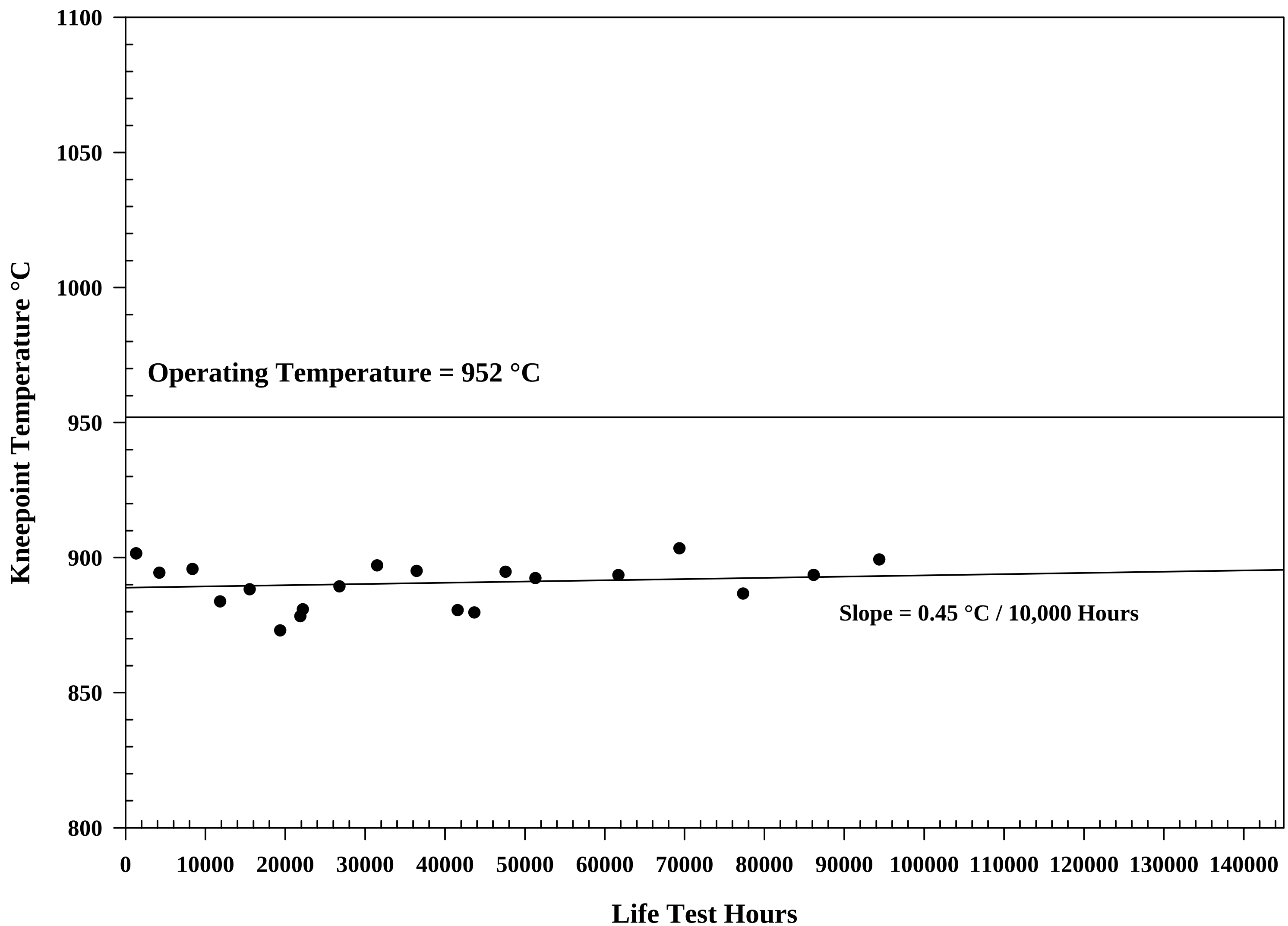
RV LONG-TERM PERFORMANCE
4 A/cm2
Percent of Initial Current
Life Hours
RV A002
RV A006
RV A007
Best Fit Line
110
105
100
95
90
85
80
75
70
0
10000
20000
30000
40000
50000
60000
70000
80000
90000
100000
110000
120000
130000
140000

RV A005 MIRAM CURVE

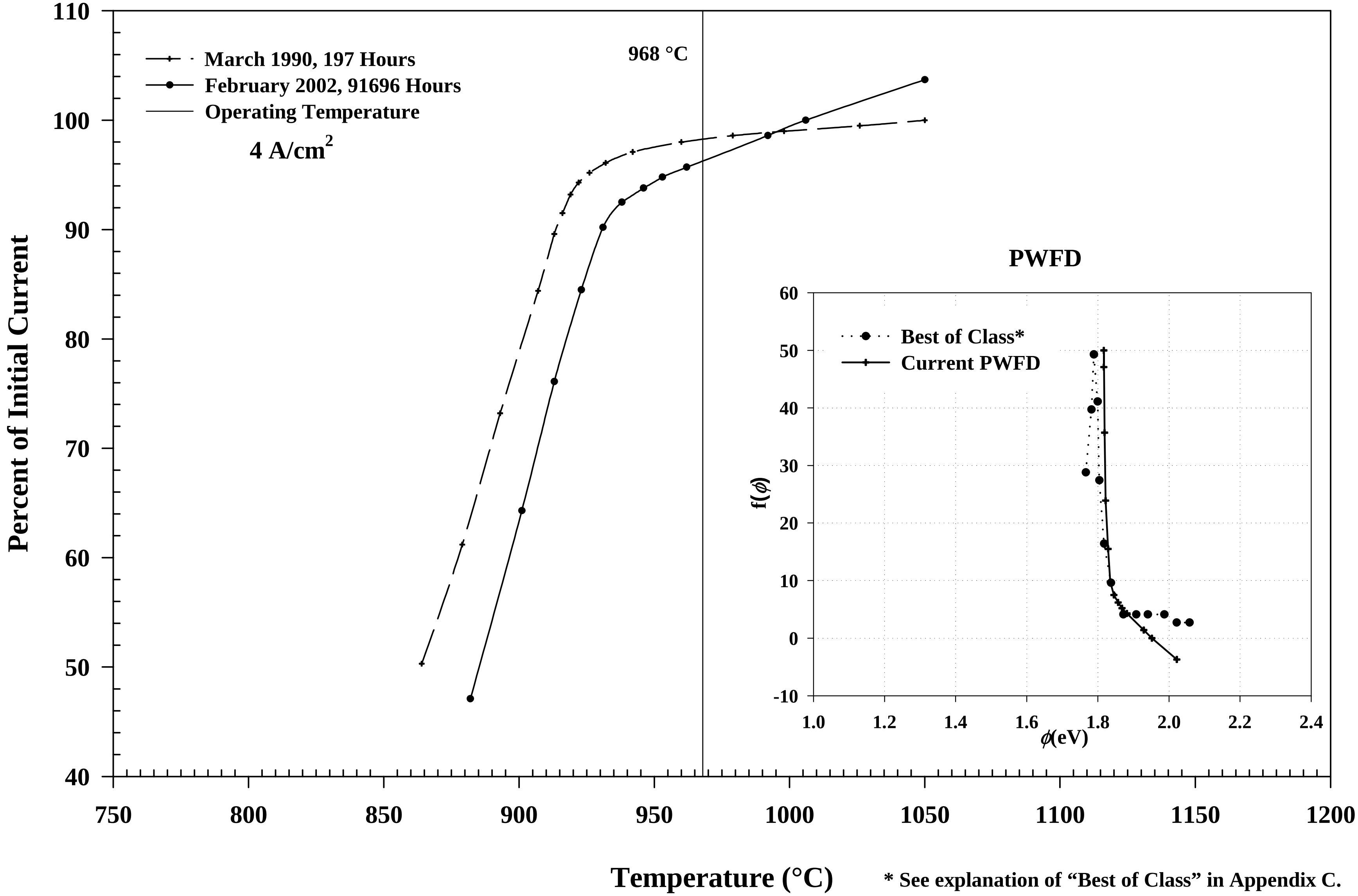


* See explanation of “Best of Class” in Appendix C.

RV A005 KNEEPOINT MIGRATION

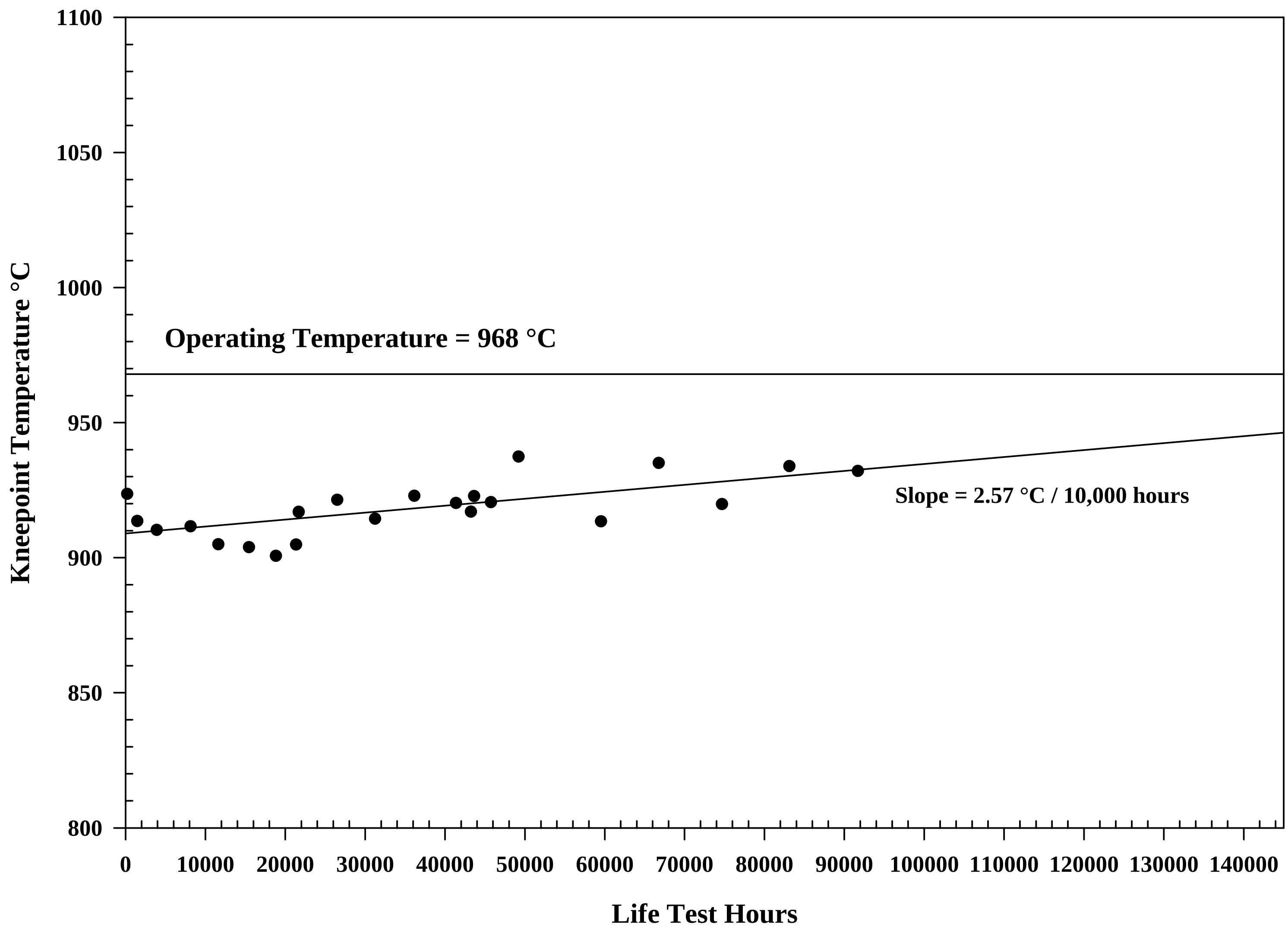


RV A006 MIRAM CURVE

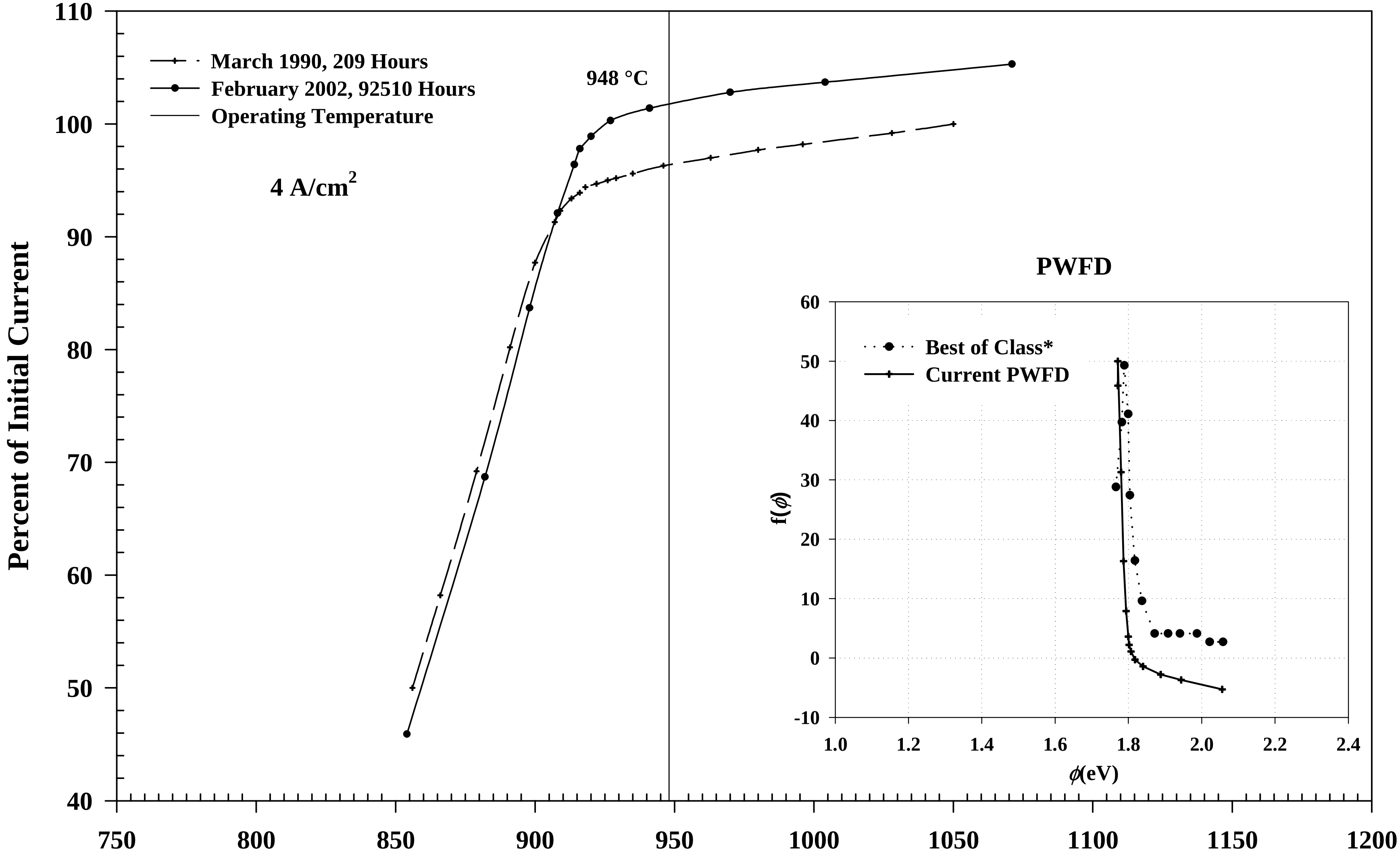


* See explanation of “Best of Class” in Appendix C.

RV A006 KNEEPOINT MIGRATION

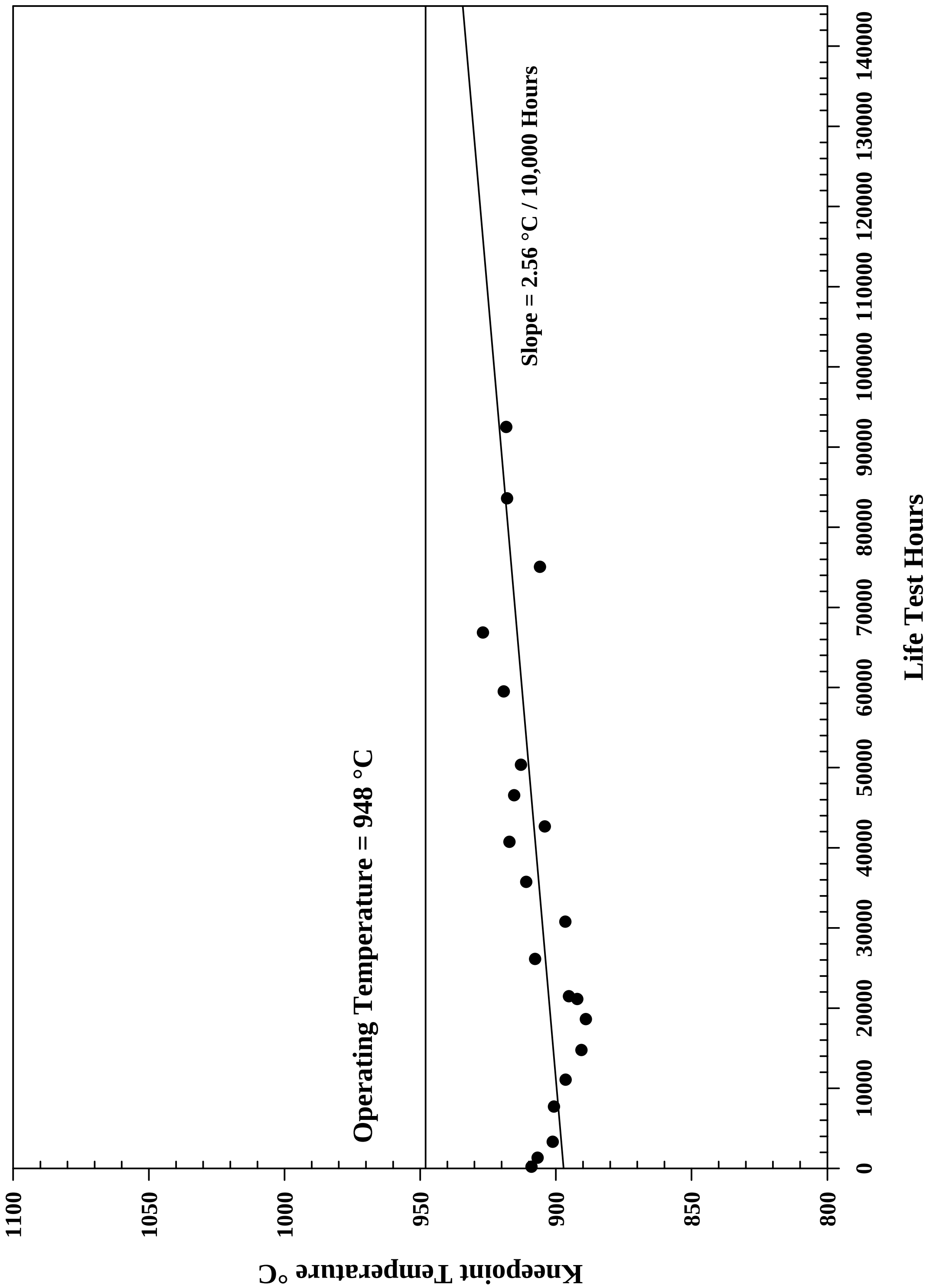


RV A007 MIRAM CURVE

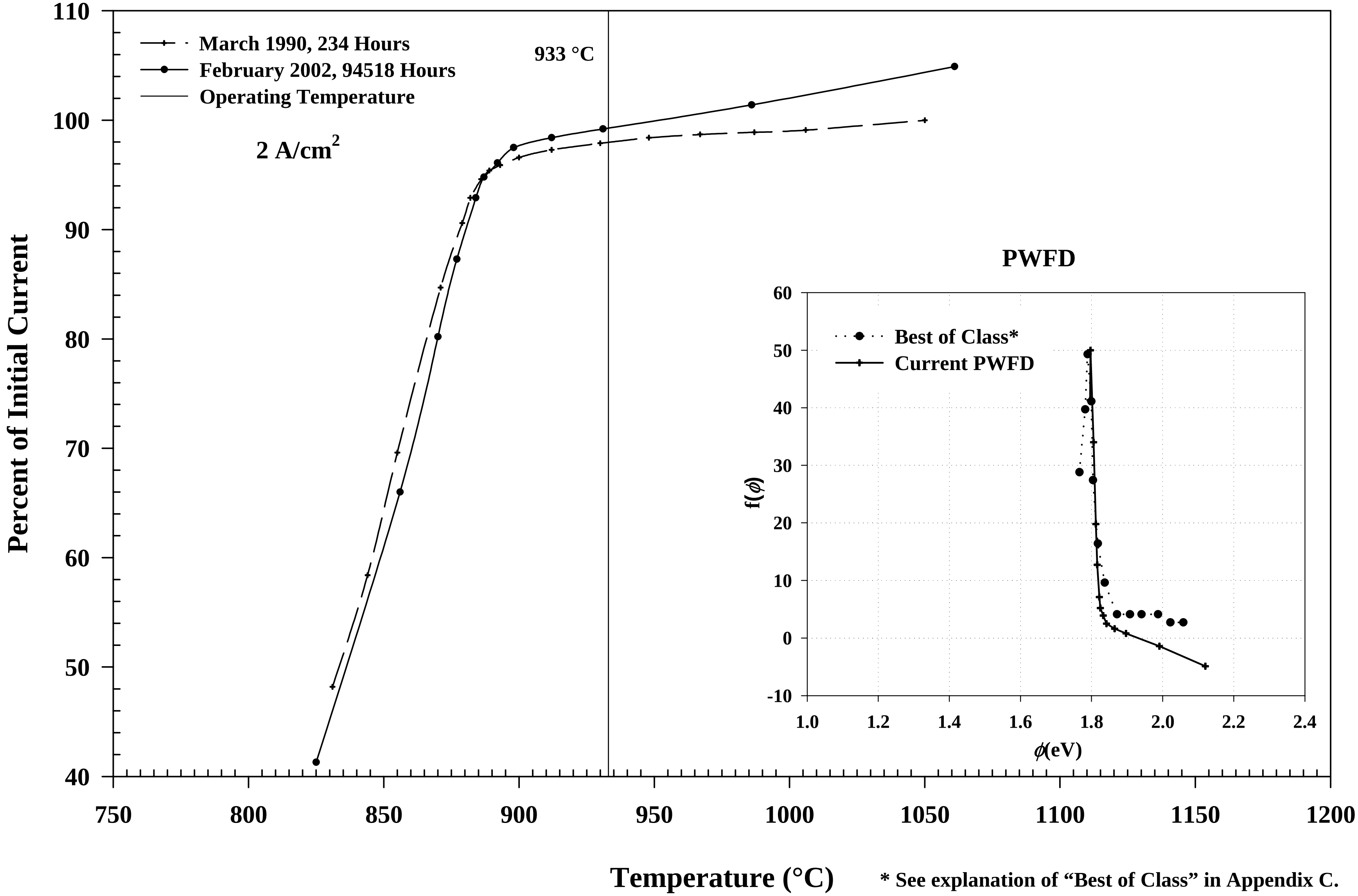


* See explanation of "Best of Class" in Appendix C.

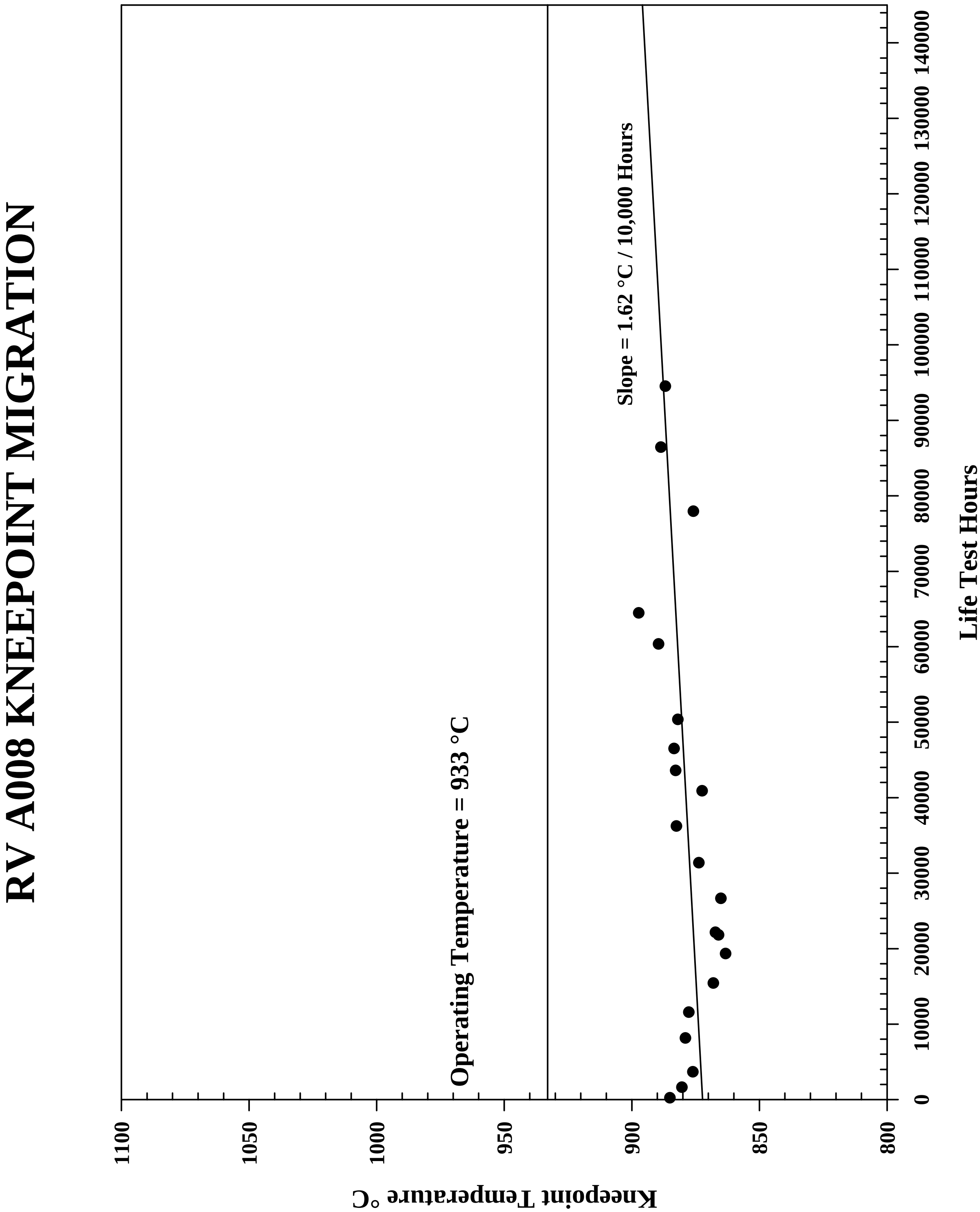
RV A007 KNEEPOINT MIGRATION



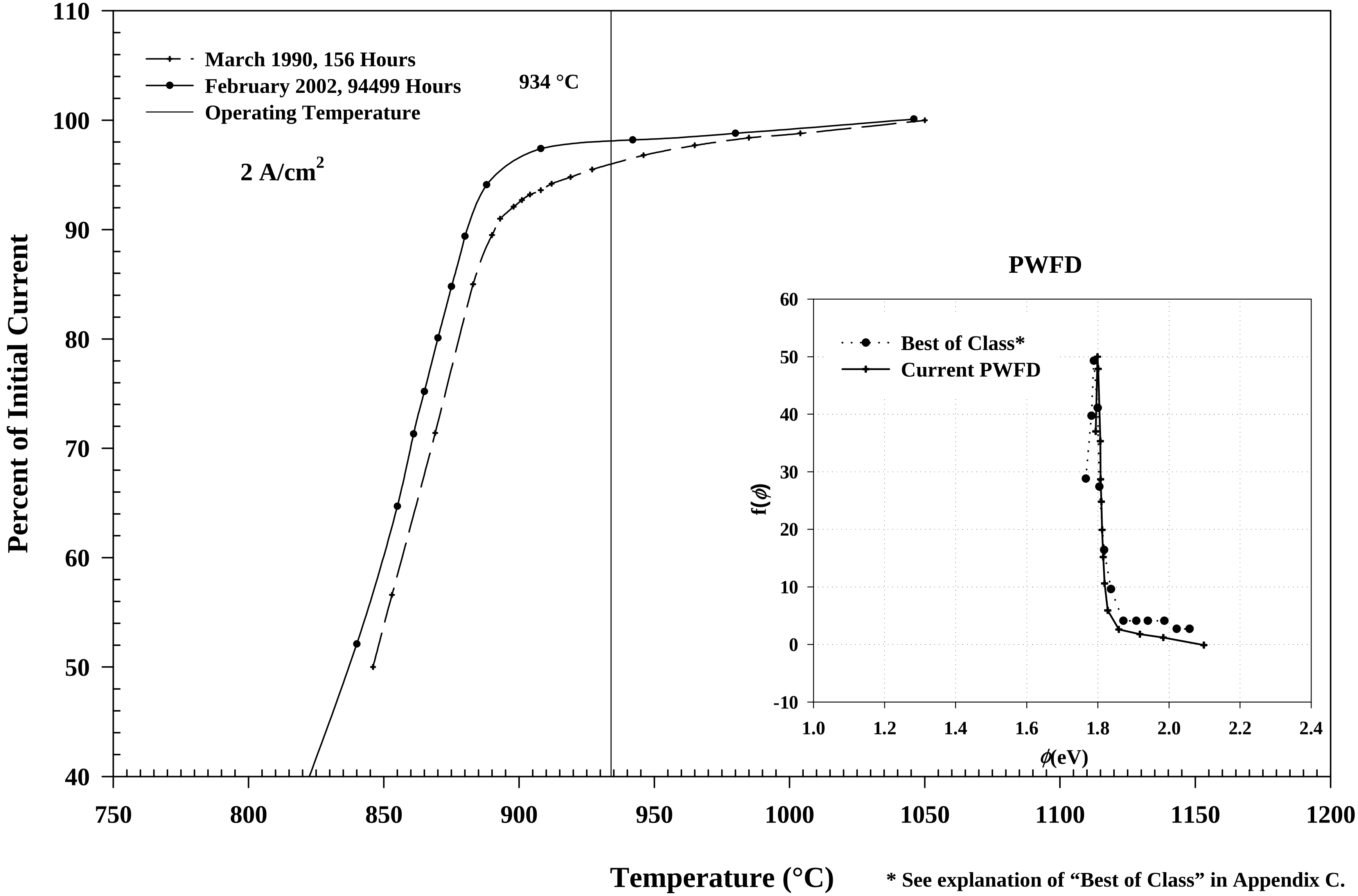
RV A008 MIRAM CURVE



* See explanation of “Best of Class” in Appendix C.

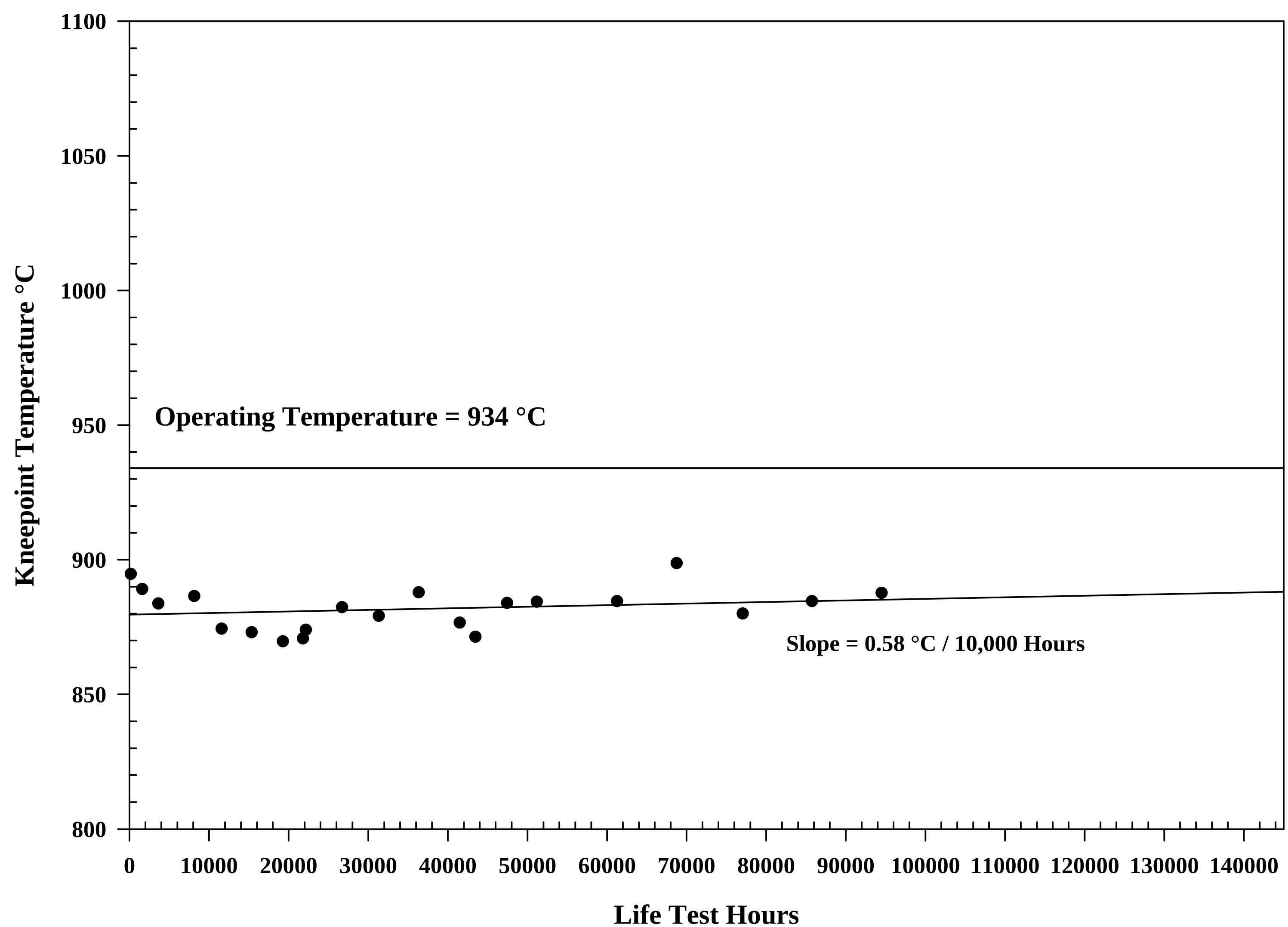

RV A008 KNEEPOINT MIGRATION
Operating Temperature = 933 °C
Slope = 1.62 °C / 10,000 Hours
Kneepoint Temperature °C
Life Test Hours
1100
1050
1000
950
900
850
800
0
10000
20000
30000
40000
50000
60000
70000
80000
90000
100000
110000
120000
130000
140000

RV A009 MIRAM CURVE

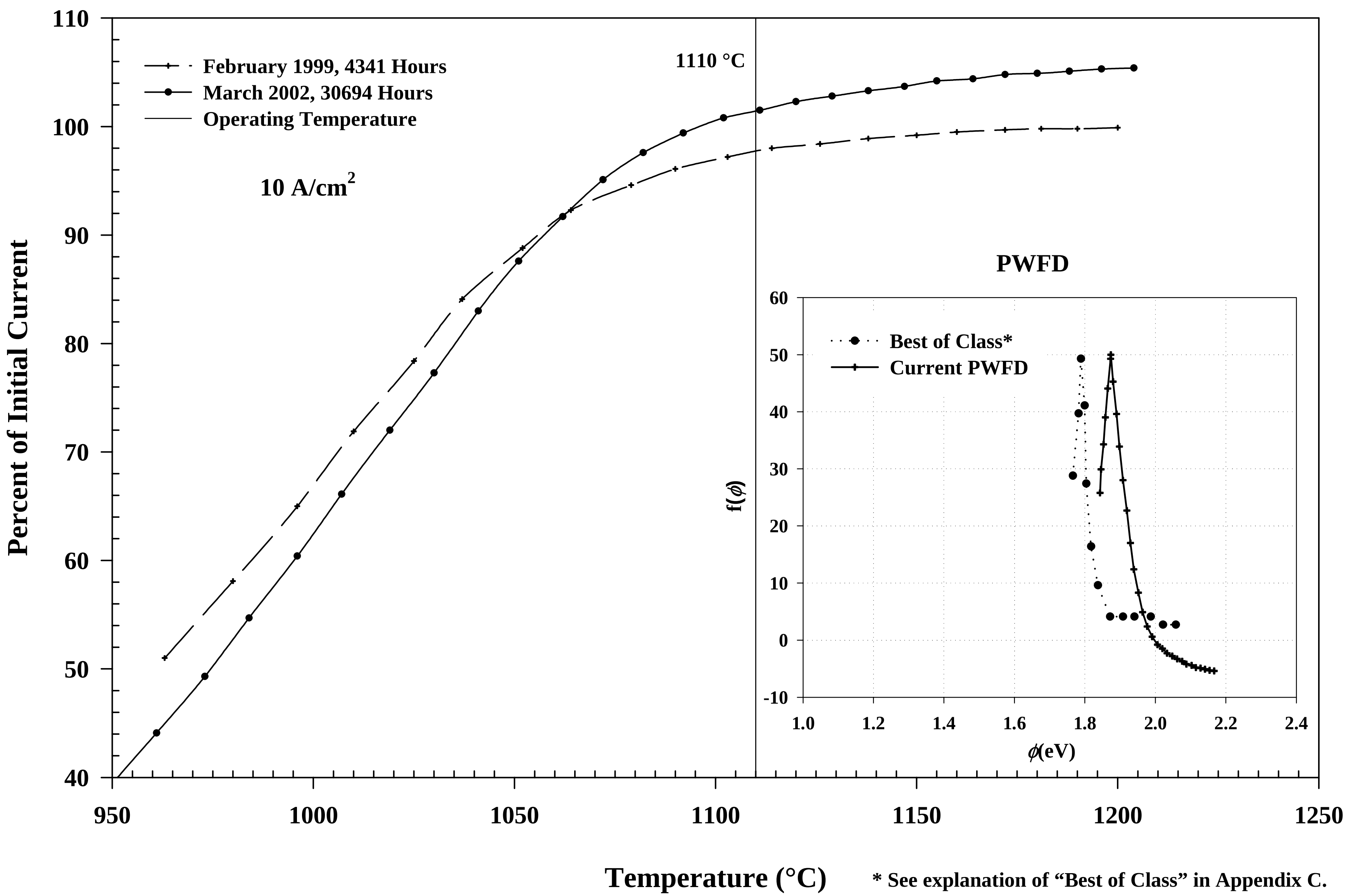


* See explanation of "Best of Class" in Appendix C.

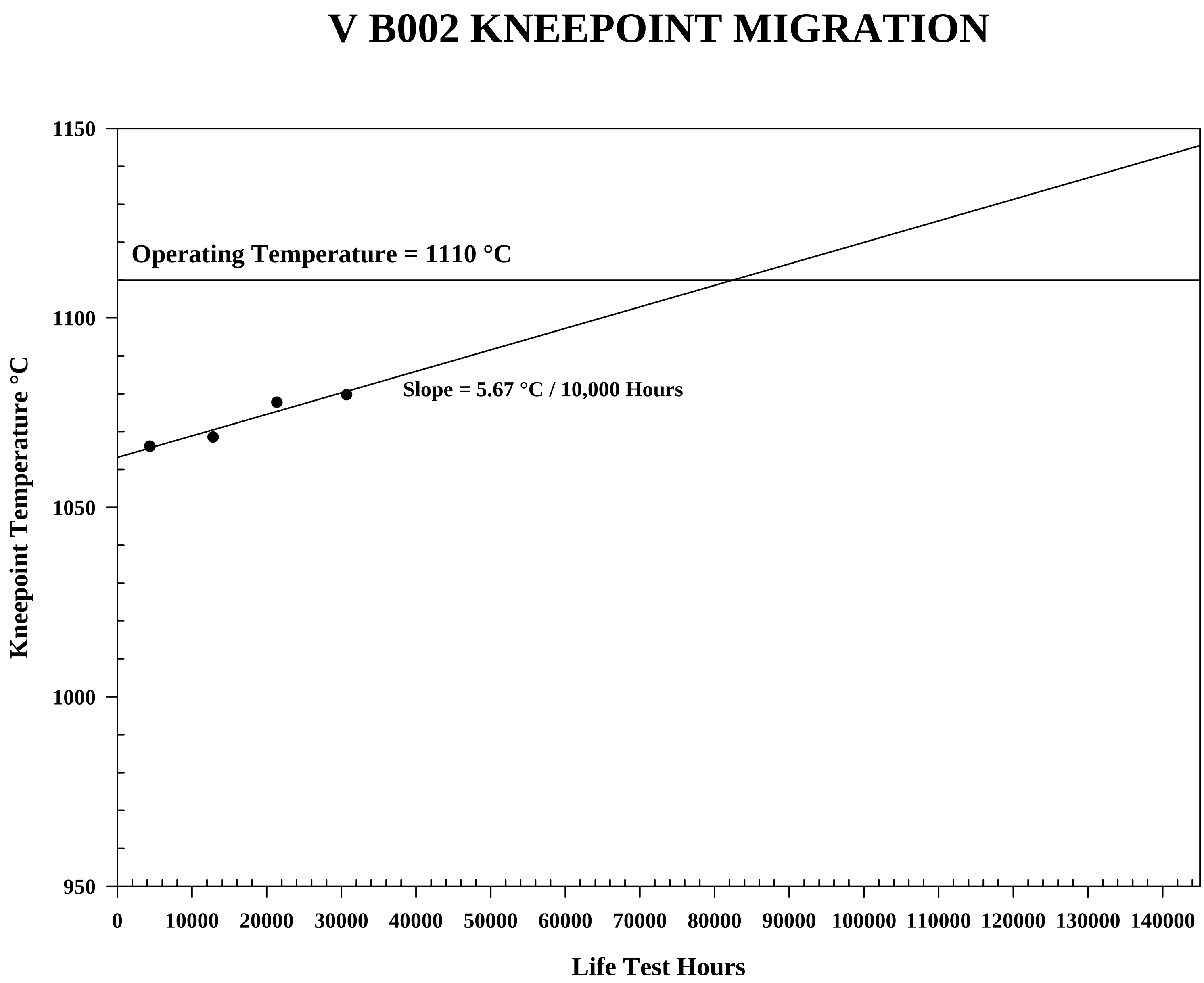
RV A009 KNEEPOINT MIGRATION



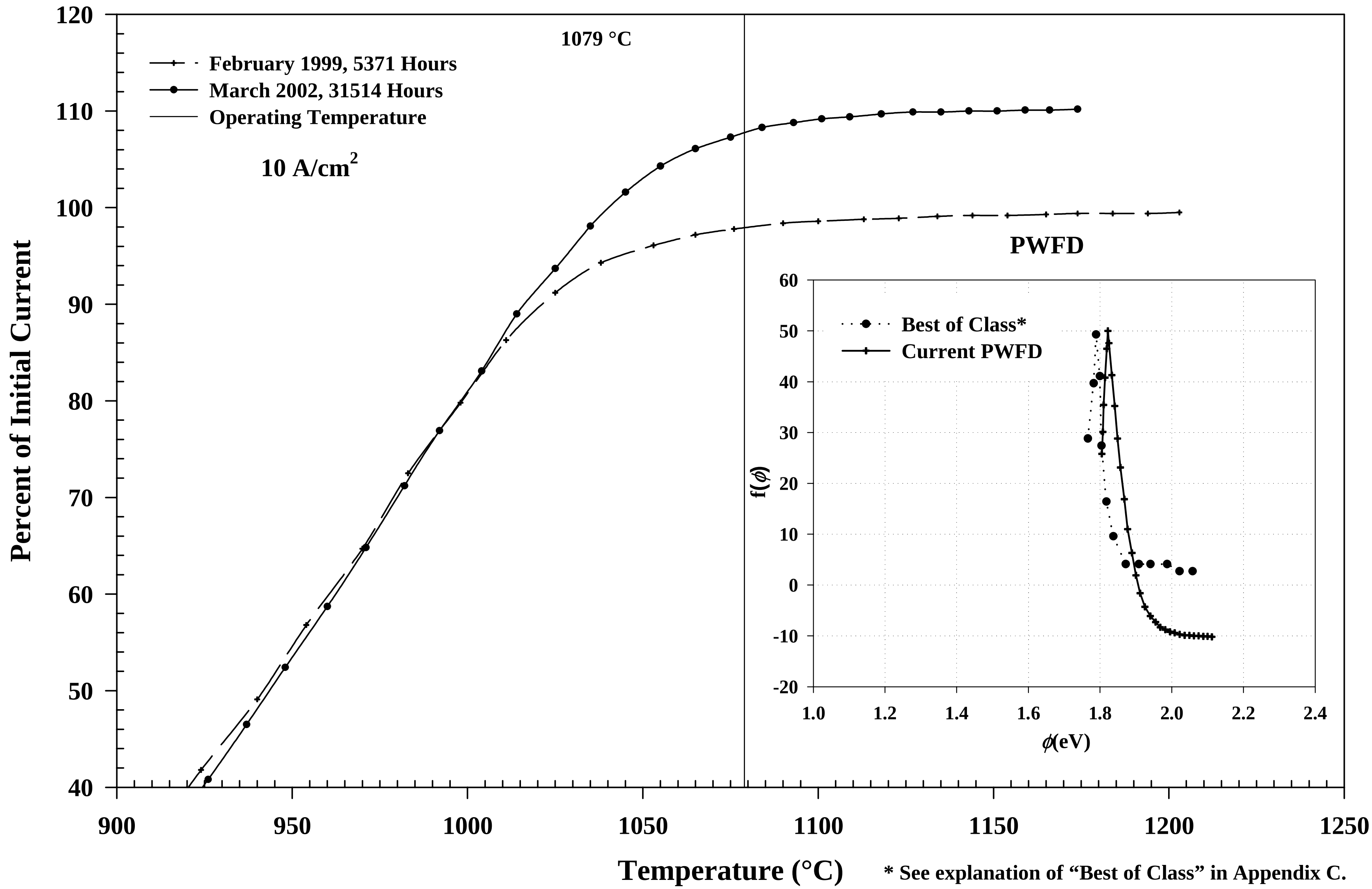
V B002 MIRAM CURVE



* See explanation of "Best of Class" in Appendix C.

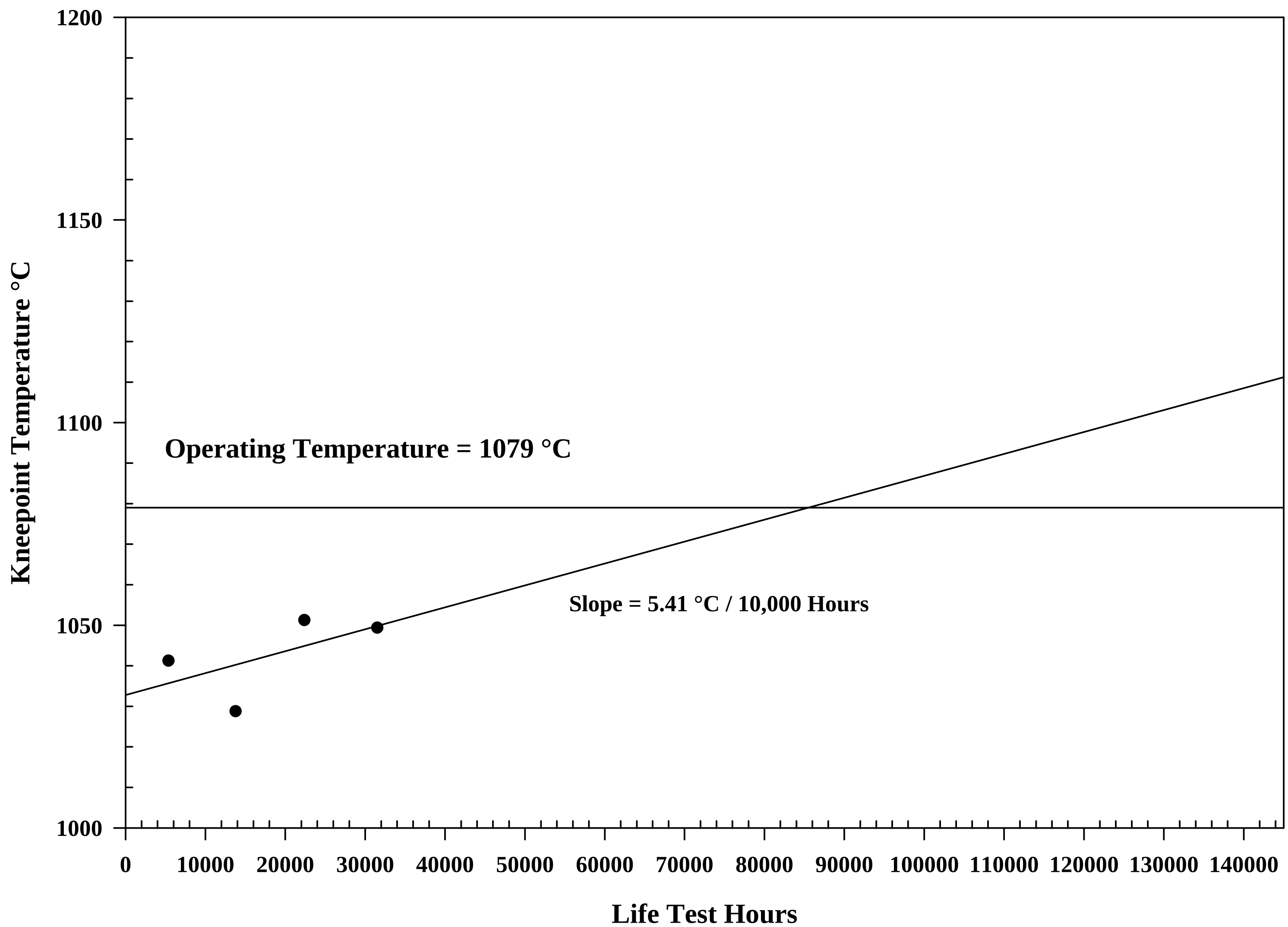

V B002 KNEEPOINT MIGRATION
Operating Temperature = 1110 °C
Slope = 5.67 °C / 10,000 Hours
Kneepoint Temperature °C
1150
1100
1050
1000
950
0
10000
20000
30000
40000
50000
60000
70000
80000
90000
100000
110000
120000
130000
140000
Life Test Hours

V B003 MIRAM CURVE



* See explanation of "Best of Class" in Appendix C.

V B003 KNEEPOINT MIGRATION



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APPENDIX I

DATA SUMMARY

IR CATHODE SYSTEM

(Unclassified)

(5 Pages Attached)

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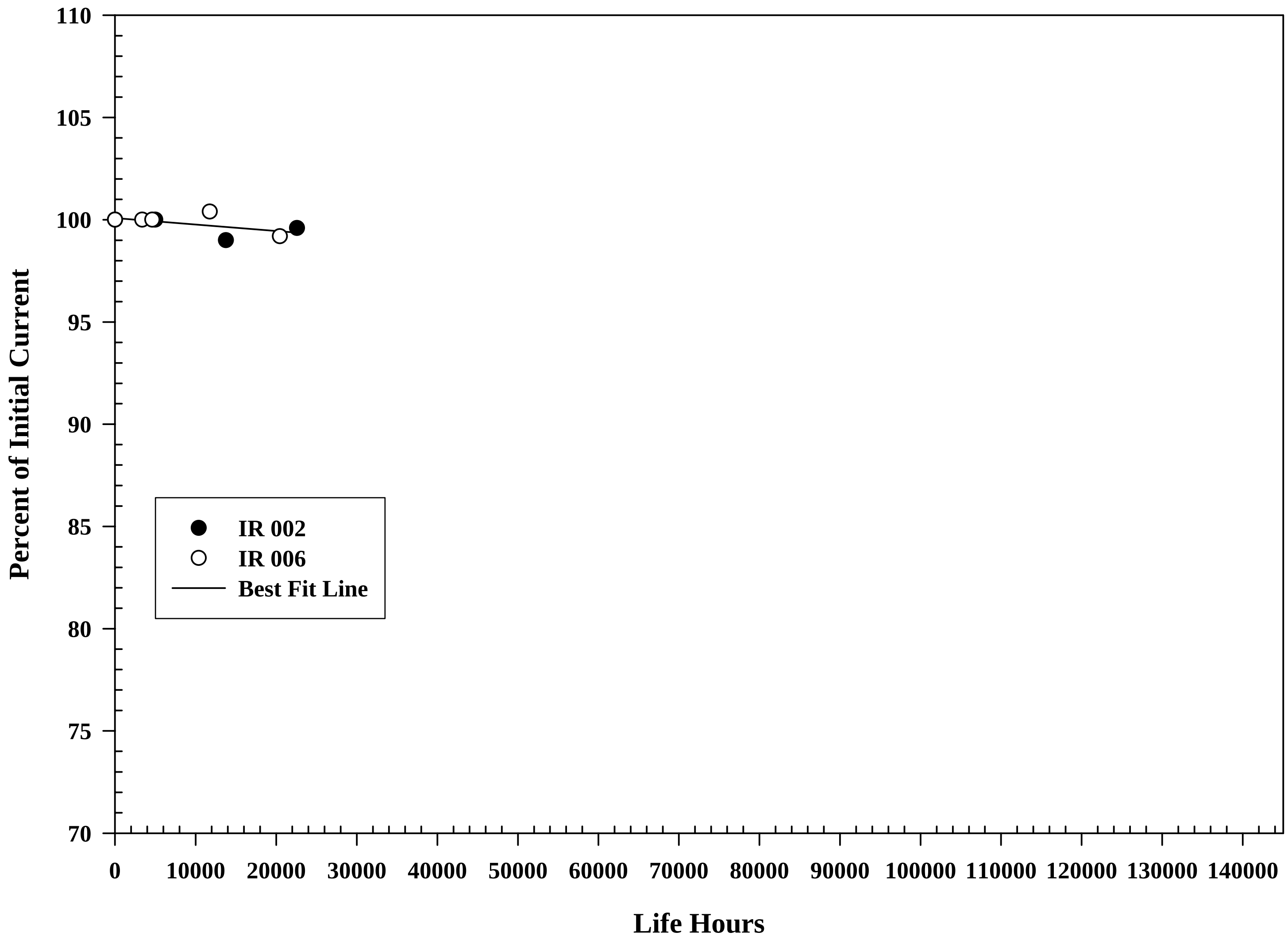
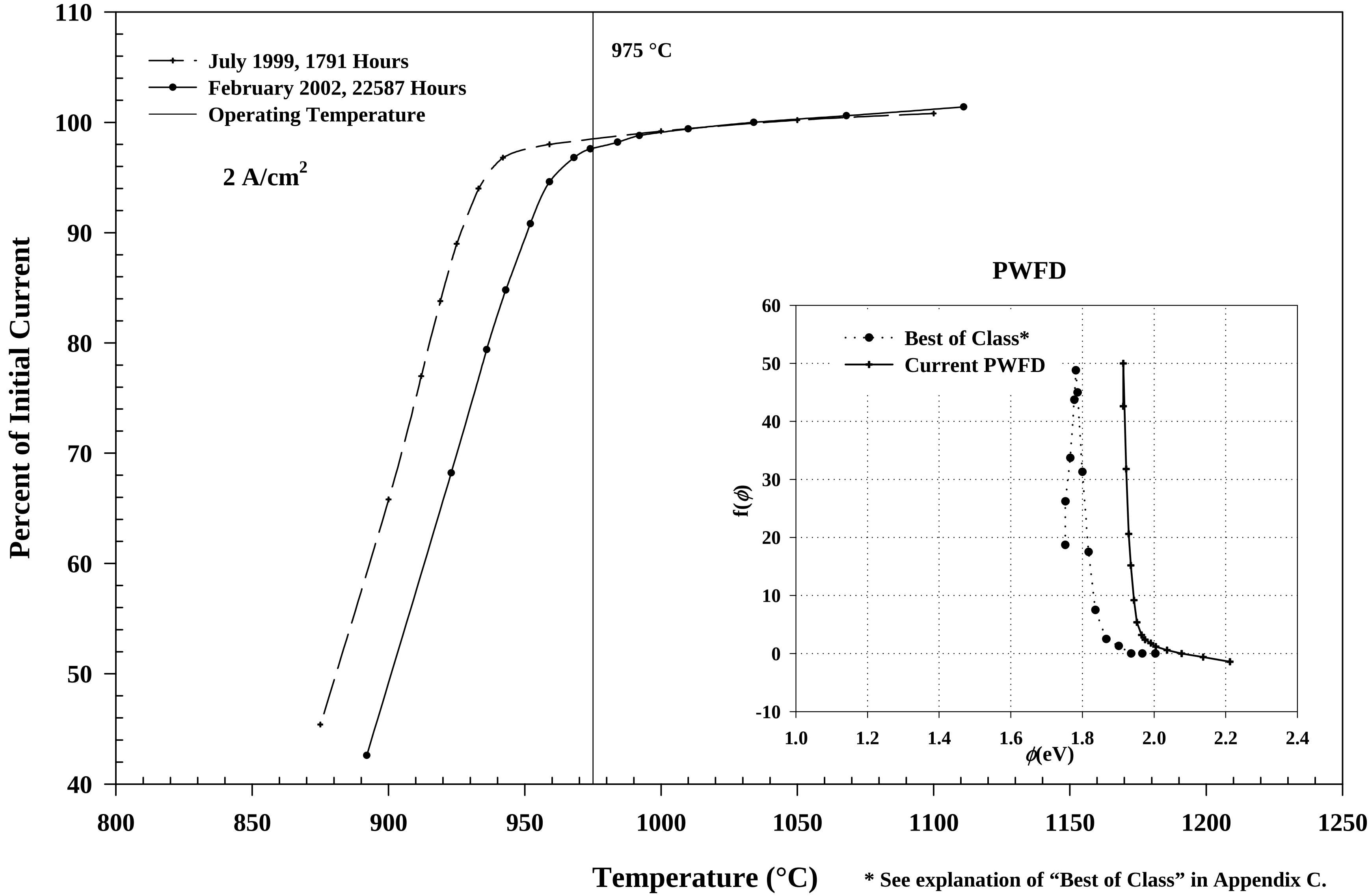
IR LONG-TERM PERFORMANCE

2 A/cm^2

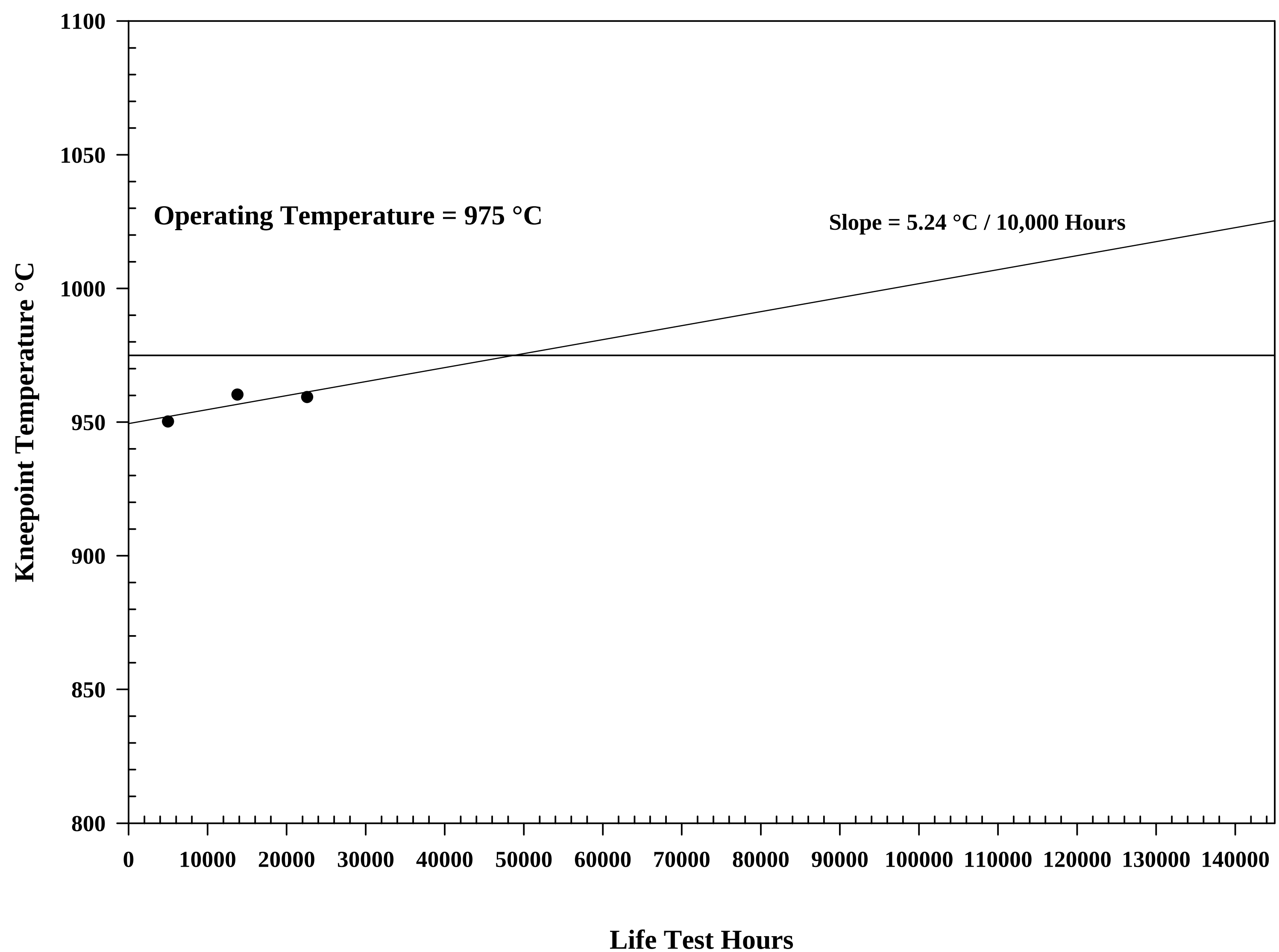


IR 002 MIRAM CURVE

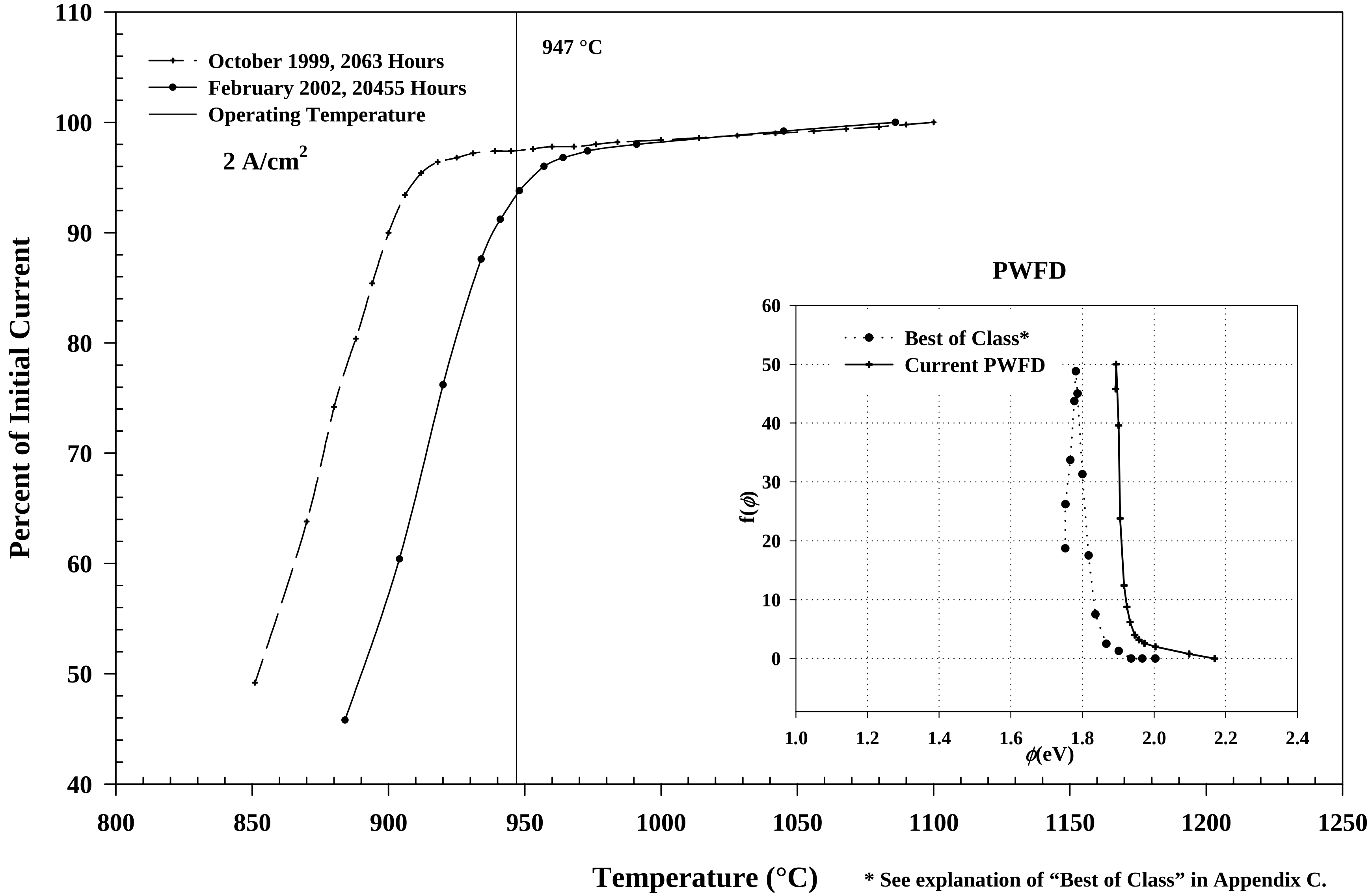


* See explanation of "Best of Class" in Appendix C.

IR 002 KNEEPOINT MIGRATION

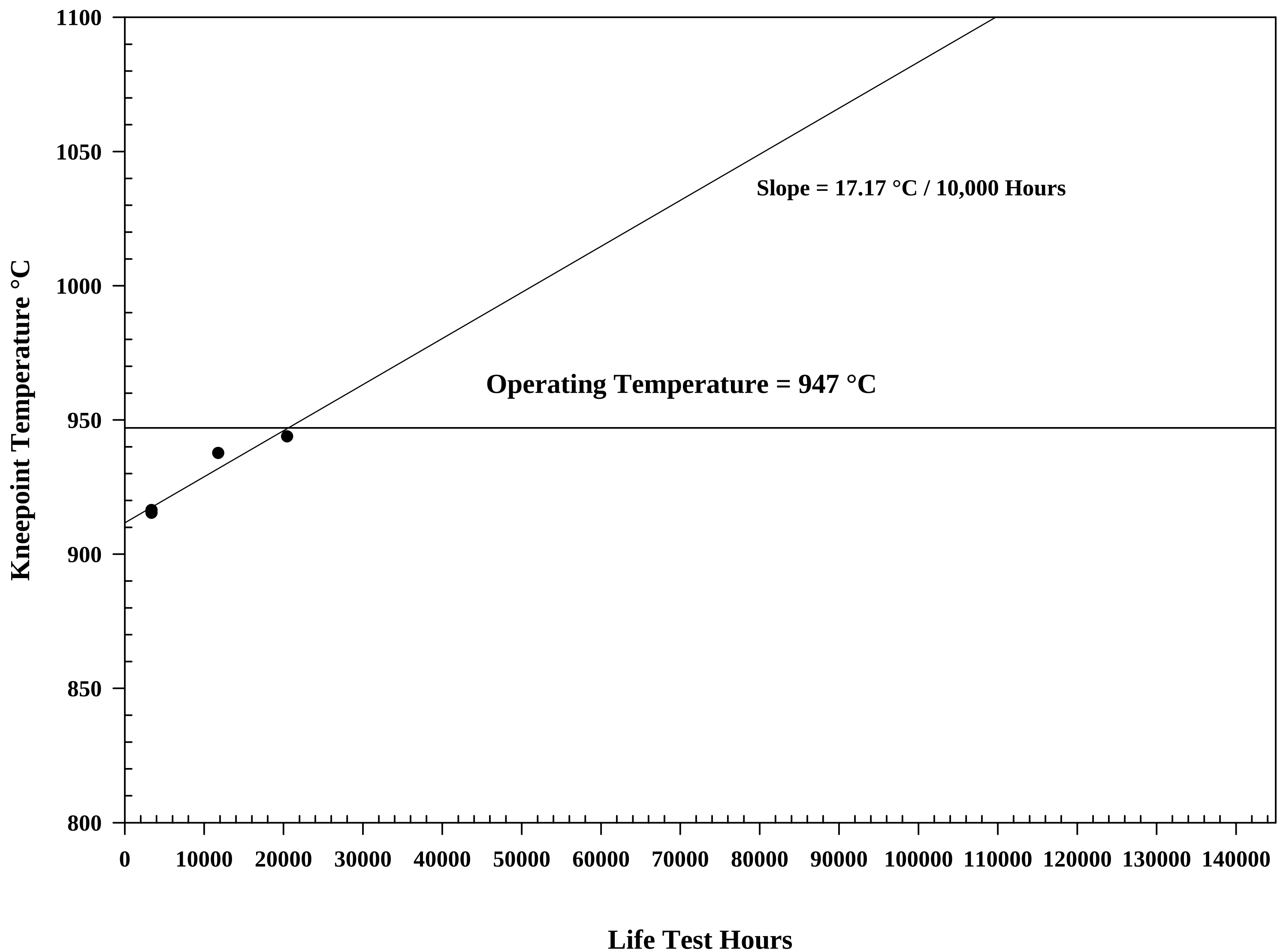


IR 006 MIRAM CURVE



* See explanation of "Best of Class" in Appendix C.

IR 006 KNEEPOINT MIGRATION



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APPENDIX J

DATA SUMMARY

IS CATHODE SYSTEM

(Unclassified)

(1 Page Attached)

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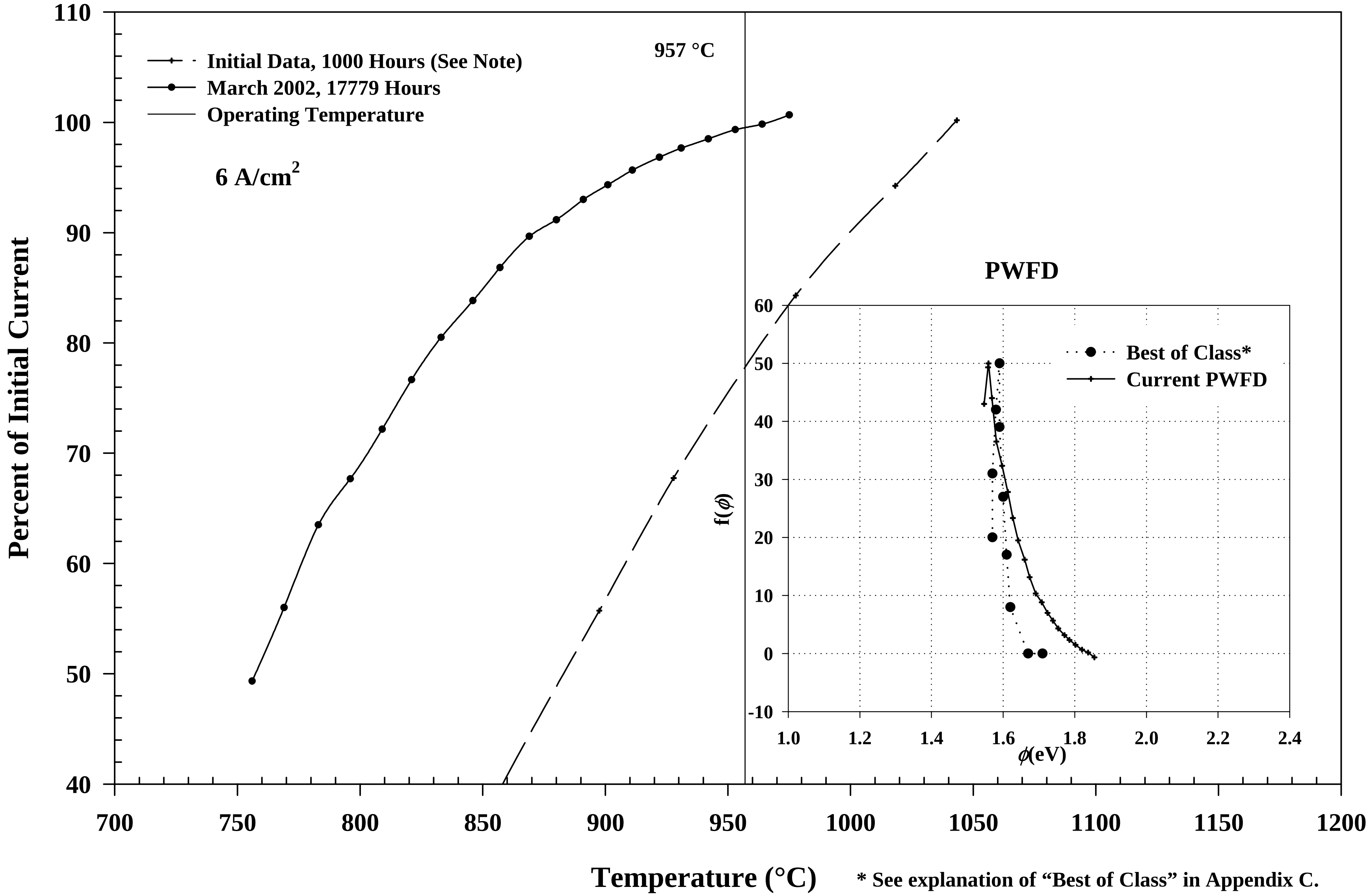
IS 008 MIRAM CURVE



* See explanation of “Best of Class” in Appendix C.

NOTE: Initial data taken at Istock using different test methods and equipment.

APPENDIX K

DATA SUMMARY

IO CATHODE SYSTEM

(Unclassified)

(1 Page Attached)

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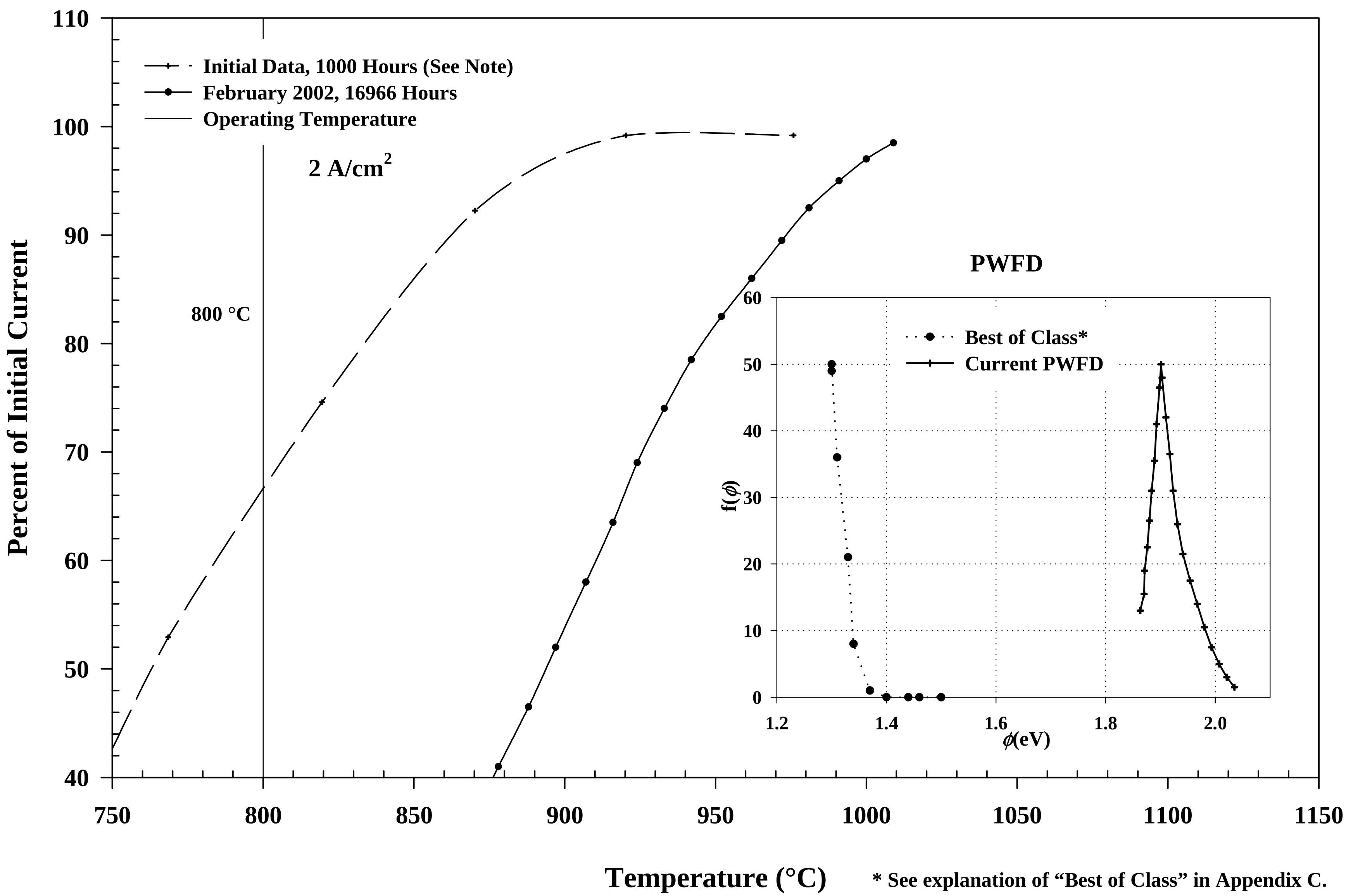
IO 003 MIRAM CURVE



* See explanation of "Best of Class" in Appendix C.

NOTE: Initial data taken at Istock using different test methods and equipment.

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