JPL PUBLICATION 78-15, VOLUME XII

Characterization of Solar Cells for Space Applications

Volume XII. Electrical Characteristics of Solarex BSF, 2-ohm-cm, 50-Micron Solar Cells (1978 Pilot Line) as a Function of Intensity, Temperature, and Irradiation

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ACKNOWLEDGMENT

The authors gratefully acknowledge the invaluable assistance of Lois Fite and James Hix who wrote the computer programs for performing the data analysis and curve plotting, and Diane Engler who operates the program and produces the plots. The absorptance measurements were performed by Jerry Brown of the TRW Thermophysics Laboratory.

ABSTRACT

Electrical characteristics of Solarex back-surface-field, 2-ohm-cm, 50-micron N/P silicon solar cells are presented in graphical and tabular format as a function of solar illumination intensity, temperature, and irradiation.

CONTENTS

Figures

Tables

SECTION I

INTRODUCTION

A series of reports is being generated to present parametric characterization data on both state-of-the-art and developmental solar cells of interest to the photovoltaic community. These data consist of electrical characteristics of the candidate solar cell under a wide range of temperature and illumination intensity combinations of the type encountered in typical space applications. This series (JPL Publication 78-15) consists of a number of reports, each report being devoted to a particular type of solar cell and identified by a volume number. Previously published reports with their associated solar cell descriptions are listed in the bibliography. Each report consists primarily of working graphs and tables and does not address itself to interpretive conclusions. The formatting of this series of reports is relatively invariant to facilitate comparisons between the characteristics of any of the cell types considered in the series. This report contains a set of parametric data on the Solarex BSF, 2-ohm-cm, 0.005-cm- (2-mil-) thick solar cell, which is a result of the Solarex 1978 pilot line.

SECTION II

CELL DESCRIPTION

The cells reported here were manufactured by Solarex under JPL Contract No. 954883 for the generation of a thin-cell pilot production line. These cells are fabricated from crucible-grown P-type silicon, boron-doped to a nominal resistivity of 2 ohm-cm. The cell dimensions are 2 x 2 x 0.005 cm (2 mils) thick. A back-surface field is added by alloying a layer of evaporated aluminum into the back of the cell. The electrical contact on the top surface consists of solderless Ti-Pd-Ag in a chevron grid pattern with two bus pads. The rear contact is of the same material. The top surface is textured and has a Ta_2O_5 antireflectance coating.

SECTION III

TEST PROGRAM

The solar cells were mounted on a copper test plate using RTG 560. The test plate was in turn mounted to a heat sink with provisions for both heating and cooling so that the cells could be maintained at the desired temperature independent of the solar intensity. All testing was carried out in vacuum at a pressure of less than 1×10^{-6} torr.

The illumination source used was a Spectrolab Model X-25 Mark II Spectrosun filtered solar simulator. This simulator uses an optical integrator lens in the optical system that uniformly distributes a relatively collimated light beam at specific distances from a 2.5-kW short-arc xenon lamp. A system of filters modifies the spectral distribution so that it approximates that of space sunlight. The light beam provides a pattern having a uniformity of $\pm 1\%$ over an area of 225 cm^2 at the test plane. Illumination intensity is varied by position of the simulator in combination with transmission filters. The solar simulator beam is introduced into the vacuum chamber through a window of 7940 fused silica. The solar intensity and spectral integrity of the solar simulator are constantly monitored and maintained using space-calibrated standard cells obtained with the NASA/JPL solar cell balloon flight standardization program. Photographs of the solar cell, the assembled plate, and the experimental characterization test facility are shown in Figures A-1 through A-4 in the Appendix.

The temperature range covered in these measurements was -160 to 140°C, while the solar intensity range covered was 5 mW/cm^2 to 250 mW/cm^2. The data were taken at each environment point in the matrix in the form of an I-V curve. The appropriate parameters were then read from the I-V curves and punched on cards for the computer analysis and curve plotting functions. The cell temperature was monitored by a thermocouple attached to the surface of a separate cell mounted with the cells under test. Prior, intermediate, and posttest ambient measurements were performed daily to insure that the accuracy and stability of the test equipment and the test specimens themselves were maintained within $\pm 2\%$ during the course of the testing program.

After the initial solar cell measurements over the above temperature and intensity range, the test plate was mounted in the evacuated target chamber of the JPL Dynamitron electron accelerator and irradiated with electron fluences ranging from 5×10^{12} to 1×10^{16} e/cm^2. During the irradiation, the cells were maintained at 28°C. I-V curves of the solar cells are measured in situ before and after each irradiation using an Aerospace Controls Model 302 filtered xenon AMO solar simulator. In addition, after the cumulative fluence reached 10^{14} e/cm^2, the solar cells were annealed for approximately 16 hours at 60°C, then remeasured. The annealed cell data is used in this report.

Five unirradiated single cells from the same lot of cells were sent to IRW for absorptance measurements. These measurements were made using a Gier Dunkle integrating sphere spectrometer. The reflectance is measured over the wavelength range 0.28 to 2.5 micrometers. Absorptance is calculated by weighting the reflectance with the AMO spectrum and subtracting from one.

SECTION IV

DISCUSSION OF RESULTS

A computer program computes statistical averages and standard deviations with respect to the measured cells for each intensity-temperature measurement condition. It then produces summary tables, as shown in Tables 1 to 7, that display averages and standard deviations of the cell characteristics in a two-dimensional array format, one dimension representing cell temperature and the second dimension representing incoming light intensity (AMO spectrum). The program then produces plots of the various electrical parameters of interest, with either incident intensity or cell temperature as the independent variable, as shown in Figures 1 to 14. Least square fits to the data points are then made automatically to the measured data points using a second-degree polynominal for most parameters. The curve factors, AMO efficiencies, V_{oc} and V_{mp} data points, are not fit but interconnected from point to point. In addition, the program calculates the temperature coefficients of the pertinent cell electrical parameters of interest, using the aforementioned curve fits, and plots these as a function of temperature, with intensity as a parameter, as shown in Figures 15 through 18. The results of the electron irradiations are shown in Figures 19 through 23.

The figures are intended to be working artifacts; that is, they are formatted in such a way that they can supply information of a general nature or may be used to generate predictions, comparisons, computer input data, etc. To facilitate comparisons and inputting, all units are standardized as follows:

(1) All currents are in units of mA/cm^2.

(2) All voltages are in units of mV.

(3) All power outputs are in units of mW/cm^2.

(4) All curve factors are in dimensionless units.

(5) All efficiencies are in percentages and are based on <u>total</u> cell area.

(6) All temperatures are in °C.

(7) All incoming intensities are in units of mW/cm^2 and are representative of an AMO spectrum.

(8) All geometric dimensions are in units of cm or μm (whichever is most convenient conceptually.

The tables included in this report contain complete numerical information with respect to the average values of the following solar cell electrical parameters: I_{sc}, V_{oc}, IP_{max}, P_{max}, CF, and efficiency at each intensity-temperature combination. For each such parameter at each such intensity-temperature combination, the standard deviation is presented to provide estimates of statistical validity. All efficiency, current, and power output data is on the basis of unit area derived by dividing measured output by total cell area.

The absorptance of these solar cells was found to be 0.79 ± 0.01.

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PREVIOUS VOLUMES

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Volume II. Electrical Characteristics of Solarex 50 Micron Solar Cells as a Function of Intensity and Temperature, August 1978.

Volume III. Electrical Characteristics of OCLI Hybrid MLAR Solar Cells as a Function of Intensity and Temperature, September 1978.

Volume IV. Electrical Characteristics of Spectrolab BSF 200-Micron Helios Cells as a Function of Intensity and Temperature, November 1978.

Volume V. Electrical Characteristics of OCLI 225-Micron MLAR Wraparound Cells as a Function of Intensity, Temperature, and Irradiation, April 1979.

Volume VI. Electrical Characteristics of Spectrolab BSF, BSR, Textured, 10 ohm-cm, 50 Micron Advanced OAST Solar Cells as a Function of Intensity, Temperature, and Irradiation, June 1979.

Volume VII. Electrical Characteristics of Spectrolab HEWAC BSF, Textured, 10 ohm-cm, 225 Micron Solar Cells as a Function of Intensity and Temperature, June 1979.

Volume VIII. Electrical Characteristics of Spectrolab BSF, BSR, Textured, 10 ohm-cm, 290 Micron Solar Cells (K7) as a Function of Intensity, Temperature, and Irradiation, July 1979.

Volume IX. Electrical Characteristics of Spectrolab BSF, Textured, 10 ohm-cm, 200 Micron Solar Cells as a Function of Intensity, Temperature, and Irradiation, September 1979.

Volume X. Electrical Characteristics of Spectrolab BSF, Textured, 10 ohm-cm, 300 Micron Solar Cells as a Function of Intensity and Temperature, October 1979.

Volume XI. Electrical Characteristics of Spectrolab 2 ohm-cm Wraparound Solar Cells as a Function of Intensity and Temperature, January 1980.

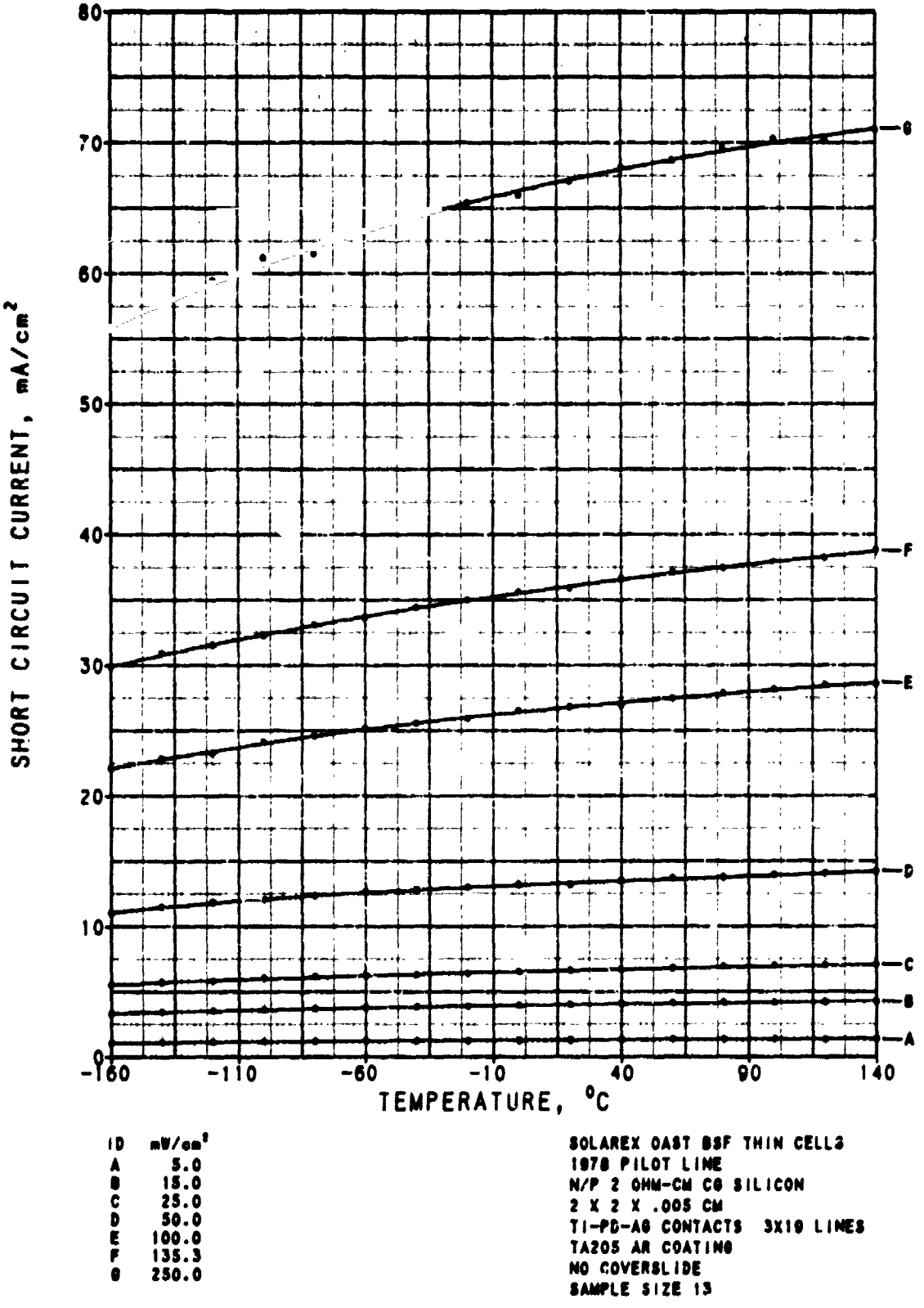
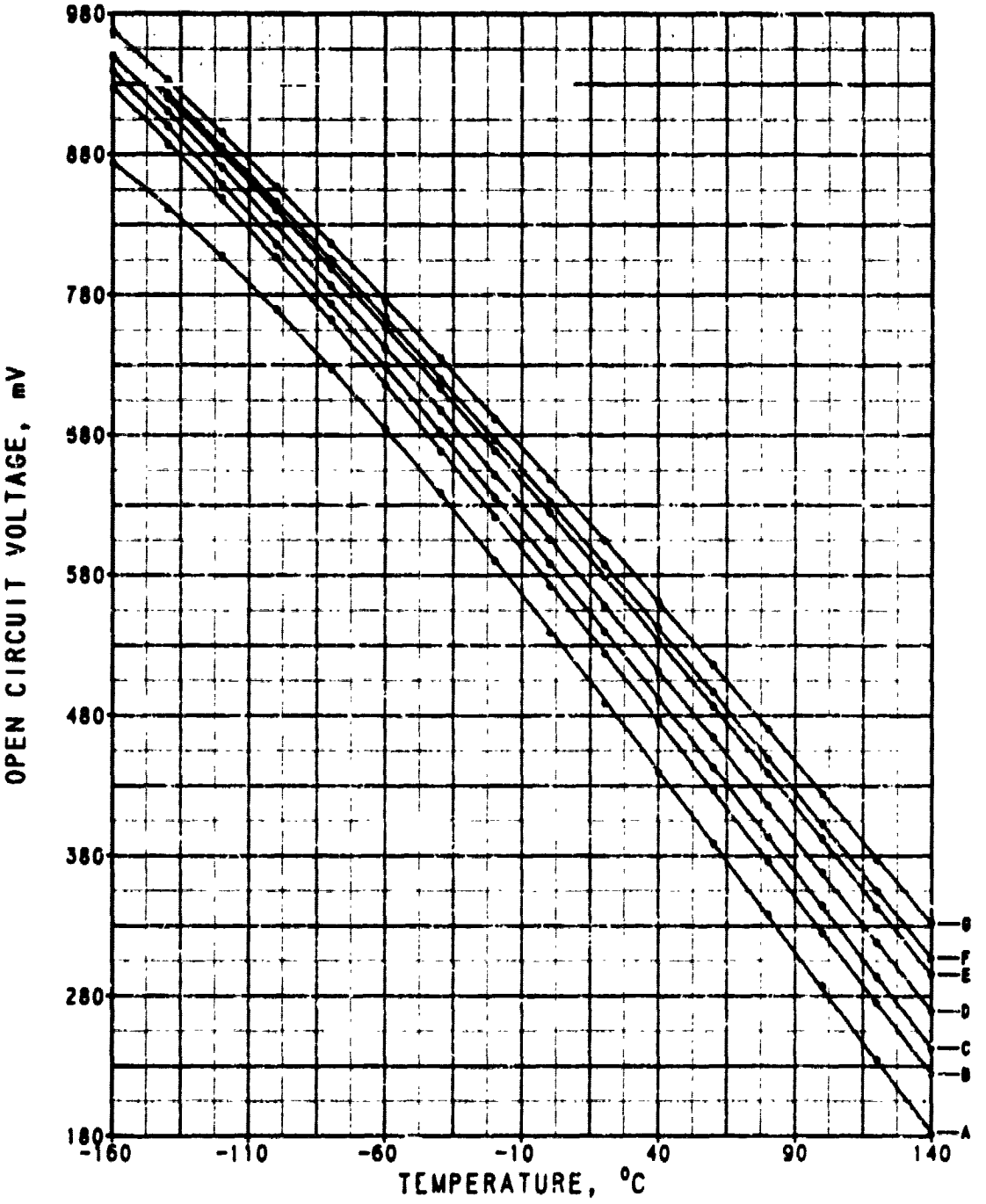


Figure 1. Average I_{sc}/cm^2 as a Function of Temperature



ID	mW/cm²
A	5.0
B	15.0
C	25.0
D	50.0
E	100.0
F	135.3
G	250.0

SOLAREX OAST BSF THIN CELLS
1978 PILOT LINE
N/P 2 OHM-CM CG SILICON
2 X 2 X .005 CM
TI-PD-AG CONTACTS 3X19 LINES
TA2O5 AR COATING
NO COVERSLIDE
SAMPLE SIZE 13

Figure 2. Average V_{oc} as a Function of Temperature

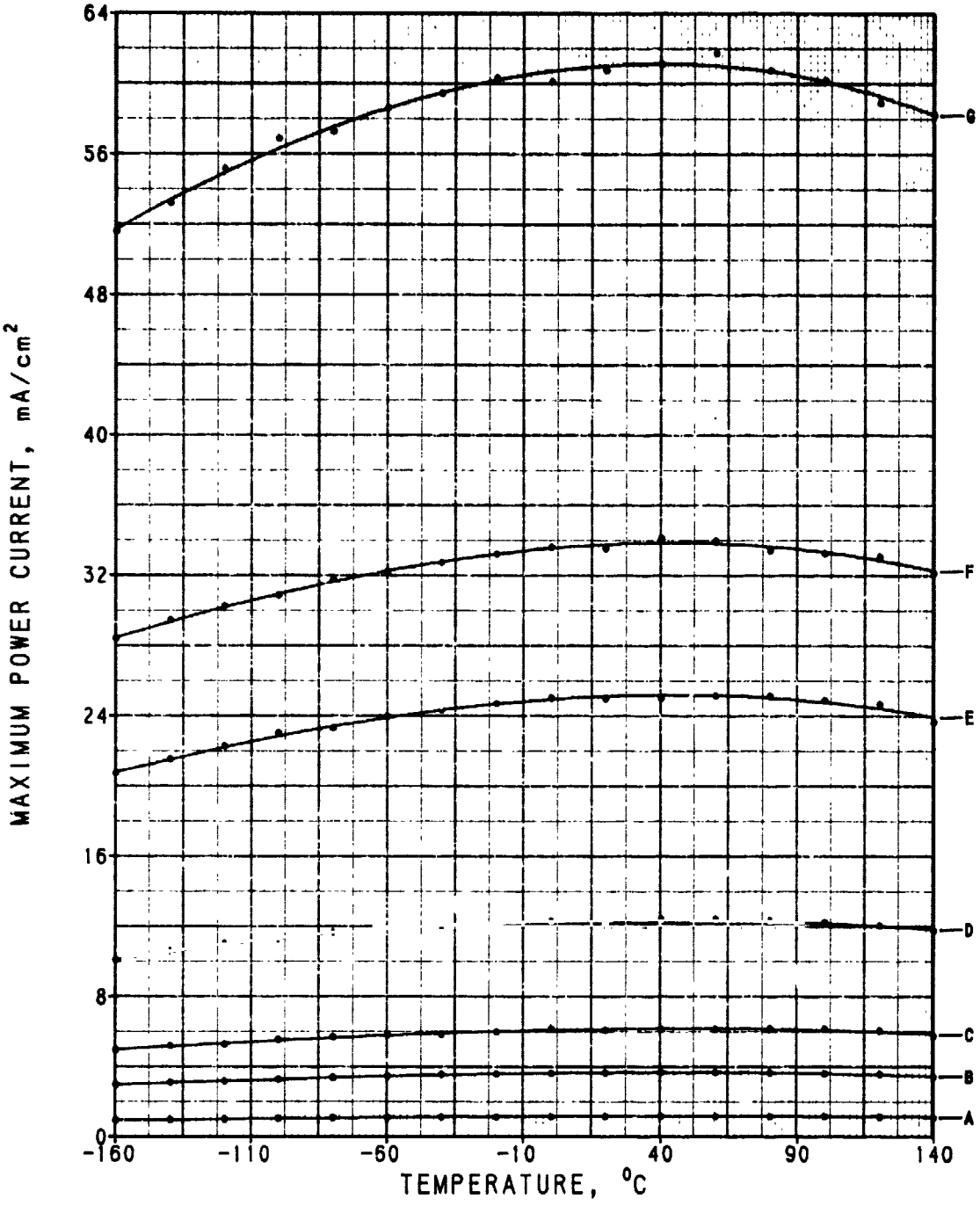


Figure 3. Average I_{mp}/cm^2 as a Function of Temperature

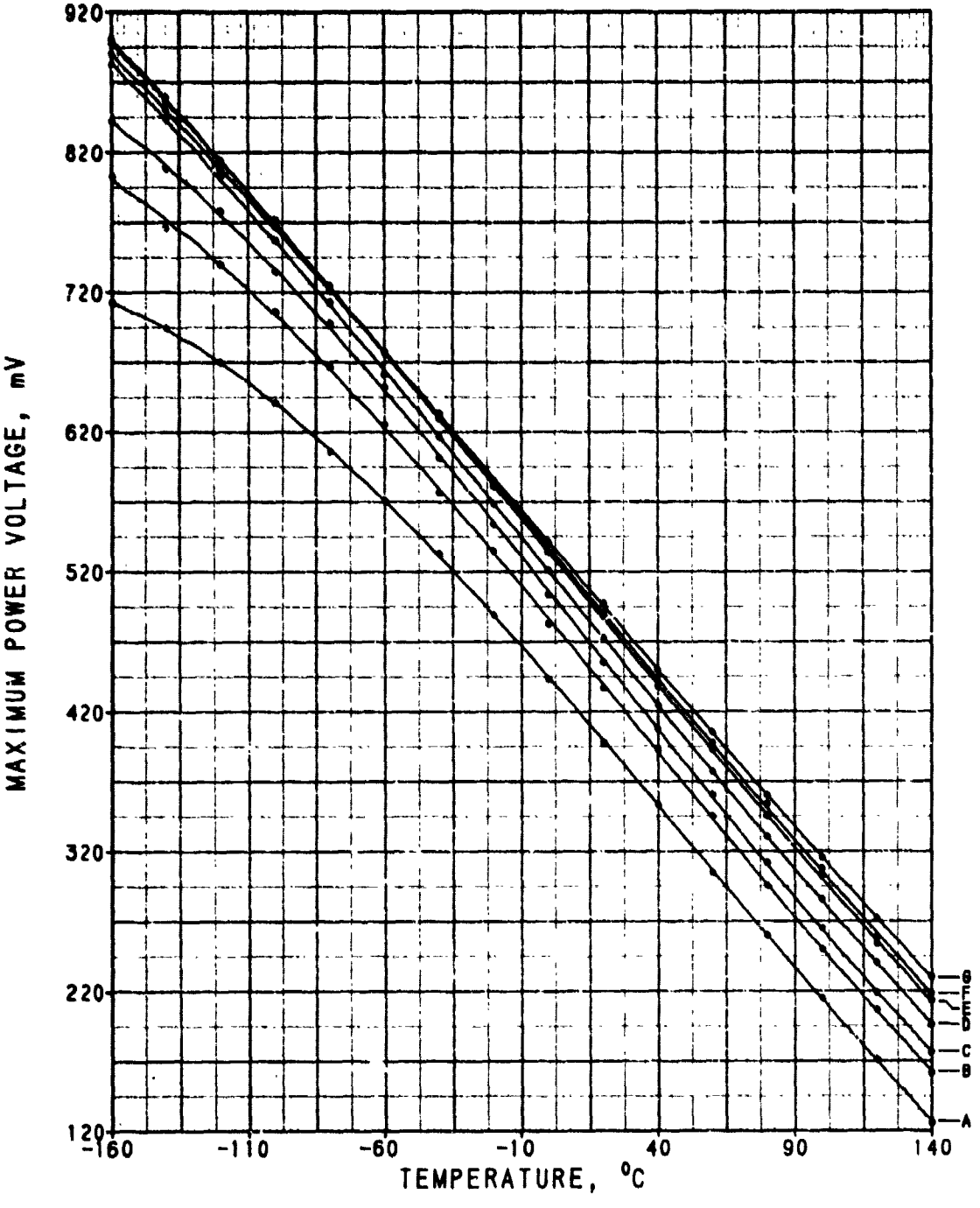
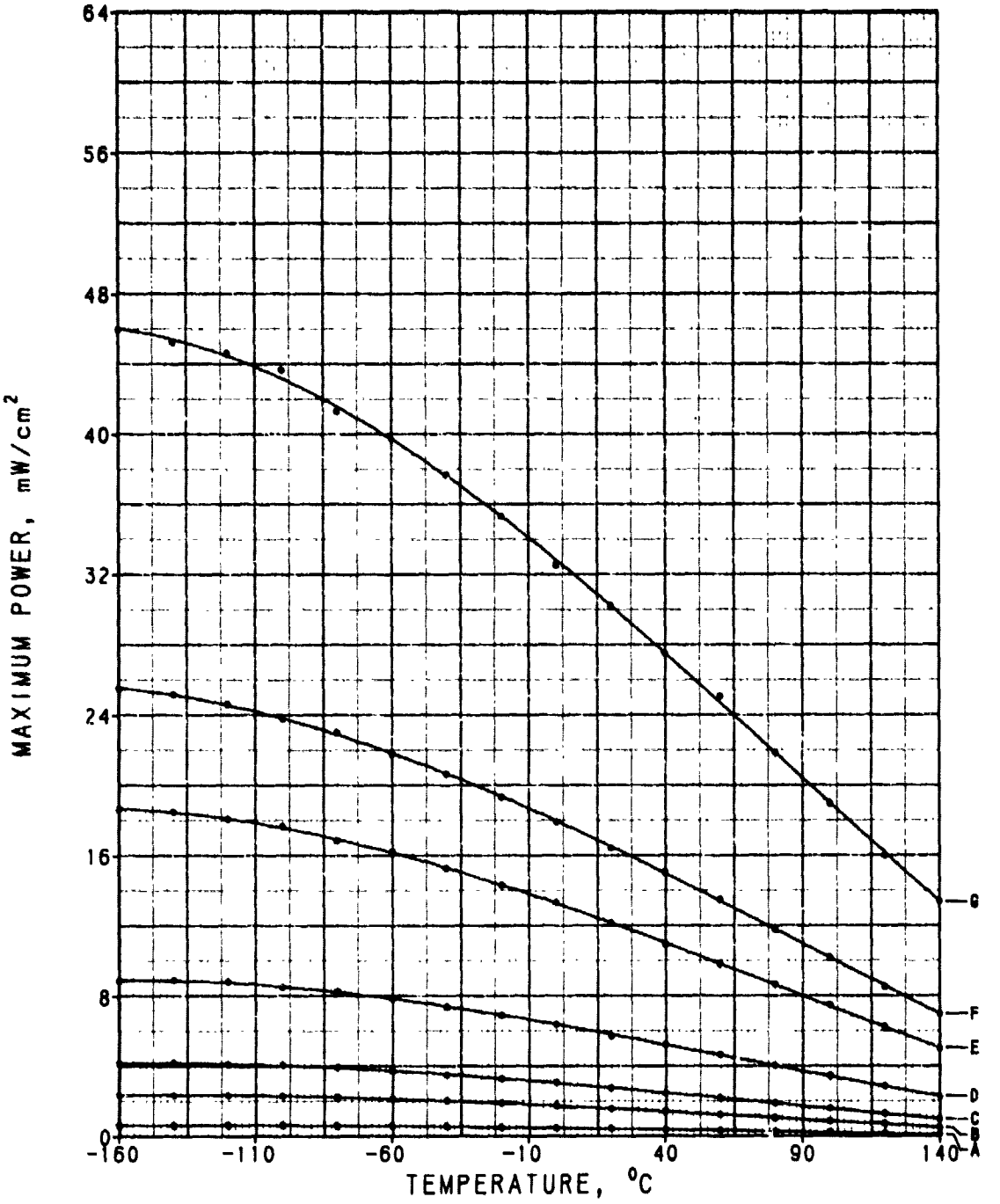


Figure 4. Average V_{mp} as a Function of Temperature



ID	mW/cm²
A	5.0
B	15.0
C	25.0
D	50.0
E	100.0
F	135.3
G	250.0

SOLAREX OAST BSF THIN CELLS
1978 PILOT LINE
N/P 2 OHM-CM CG SILICON
2 X 2 X .005 CM
TI-PD-AG CONTACTS 3X19 LINES
TA2O5 AR COATING
NO COVERSLIDE
SAMPLE SIZE 13

Figure 5. Average P_{max}/cm^2 as a Function of Temperature

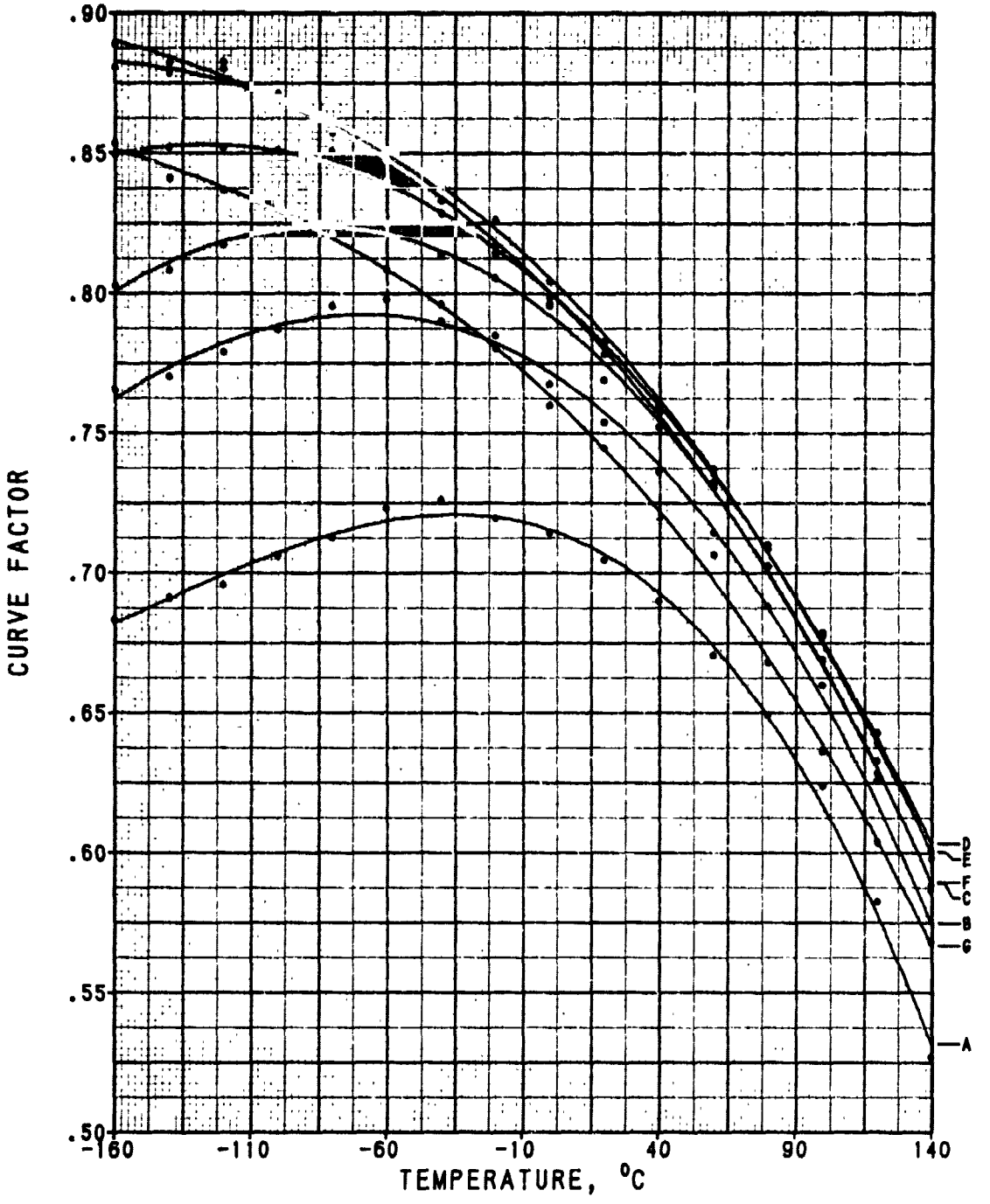


Figure 6. Average Curve Factor as a Function of Temperature

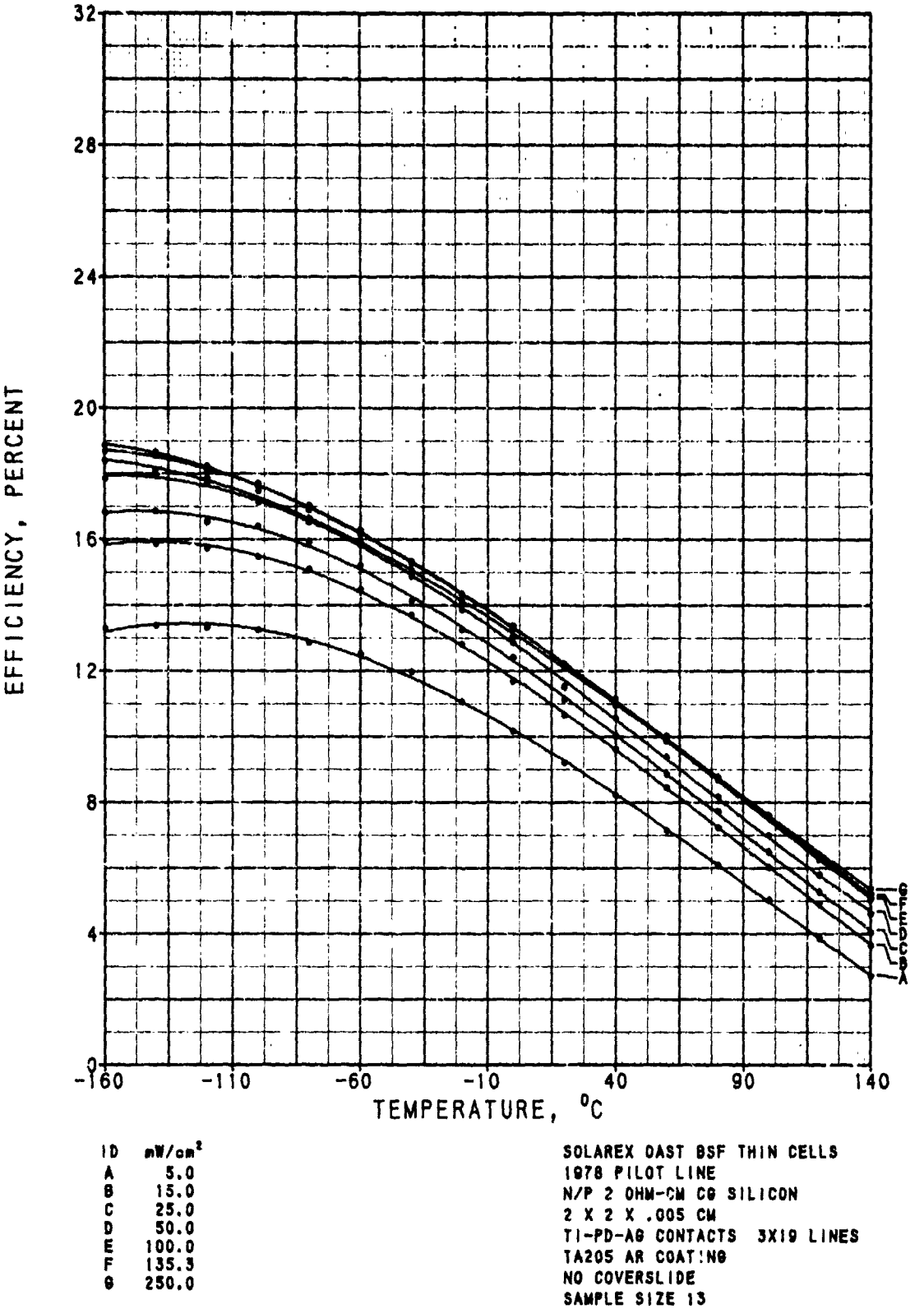
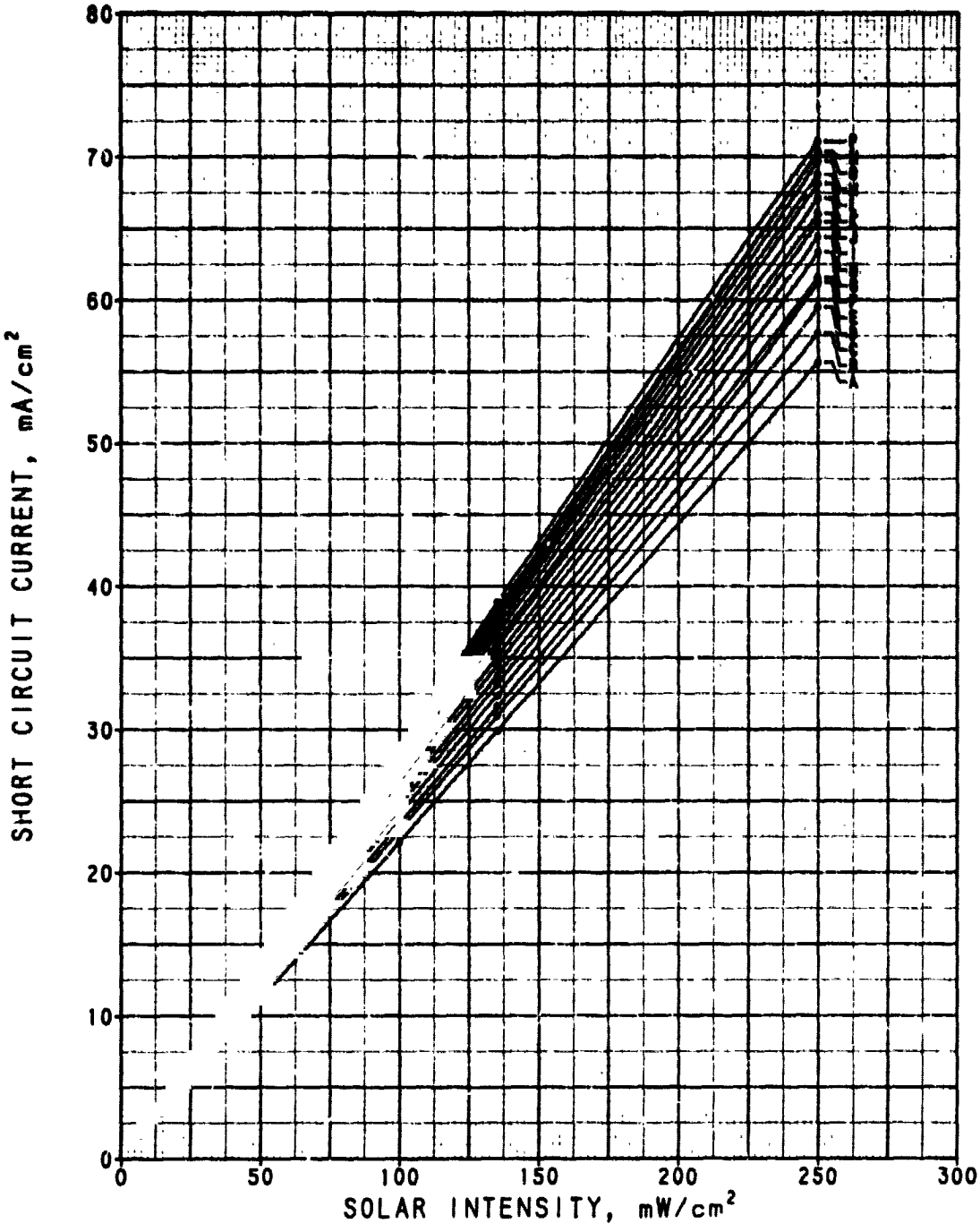


Figure 7. Average AMO Efficiency as a Function of Temperature



ID	°C	ID	°C
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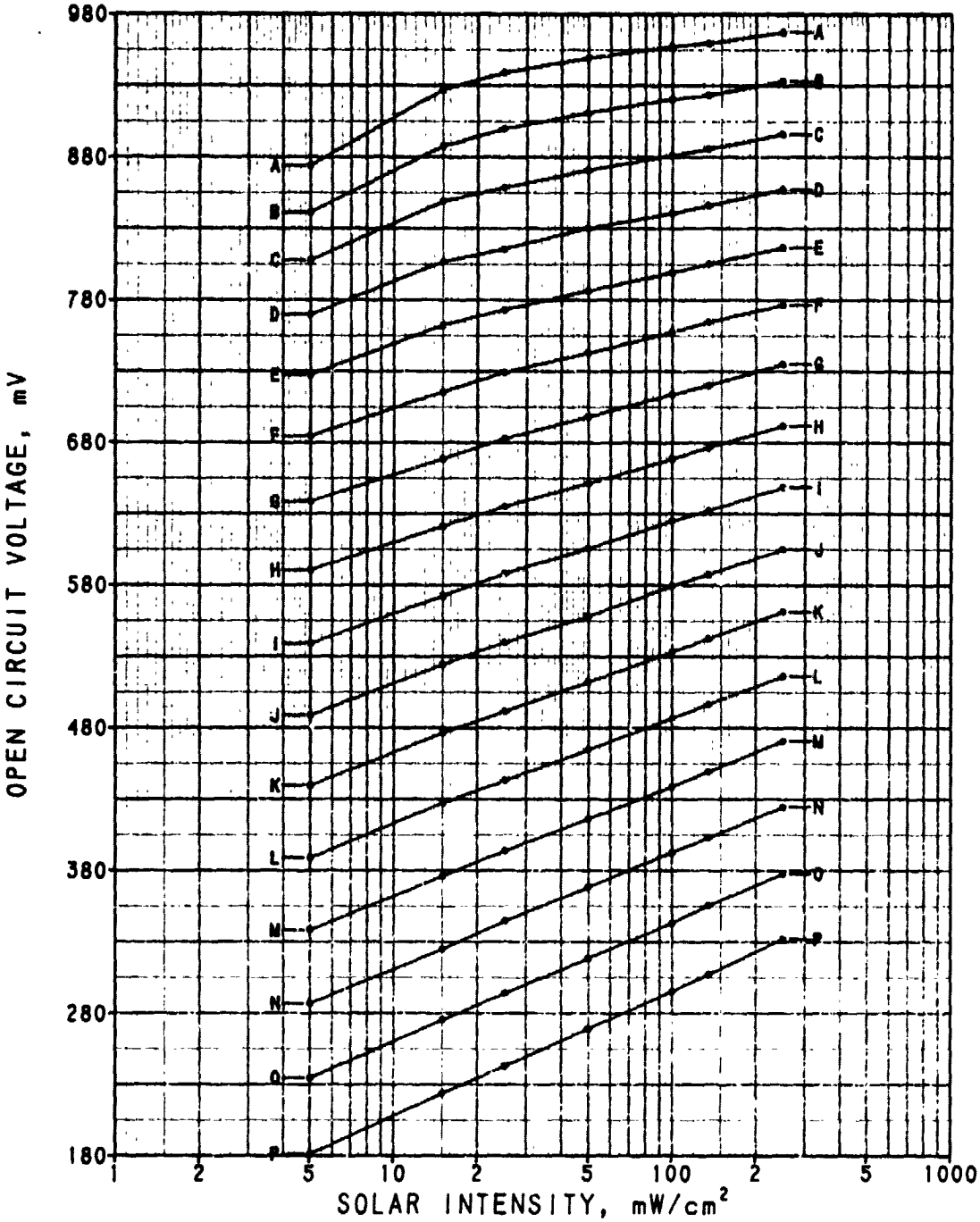
B	-140.0	J	20.0
C	-120.0	K	40.0
D	-100.0	L	60.0
E	-80.0	M	80.0
F	-60.0	N	100.0
G	-40.0	O	120.0
H	-20.0	P	140.0

SOLAREX OAST BSF THIN CELLS
1978 PILOT LINE
N/P 2 OHM-CM CG SILICON
2 X 2 X .005 CM
TI-PD-AG CONTACTS 3X19 LINES
TA2O5 AR COATING
NO COVERSLIDE
SAMPLE SIZE 13

Figure 8. Average I_{sc}/cm^2 as a Function of Intensity



ID	°C	ID	°C
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B	-140.0	J	20.0
C	-120.0	K	40.0
D	-100.0	L	60.0
E	-80.0	M	80.0
F	-60.0	N	100.0
G	-40.0	O	120.0
H	-20.0	P	140.0

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1978 PILOT LINE
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TA2O5 AR COATING
NO COVERSLIDE
SAMPLE SIZE 13

Figure 9. Average V_{oc} as a Function of Intensity

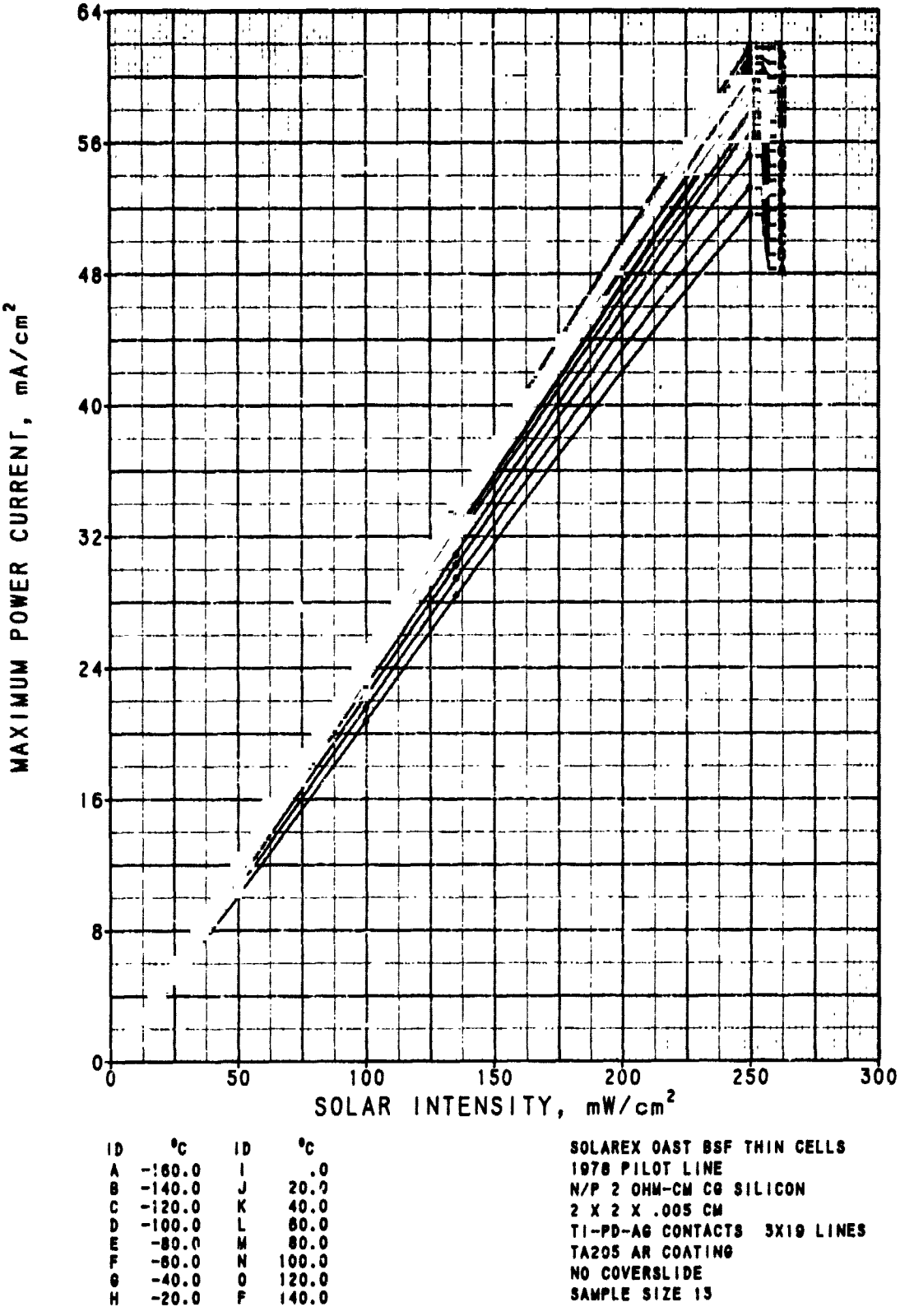
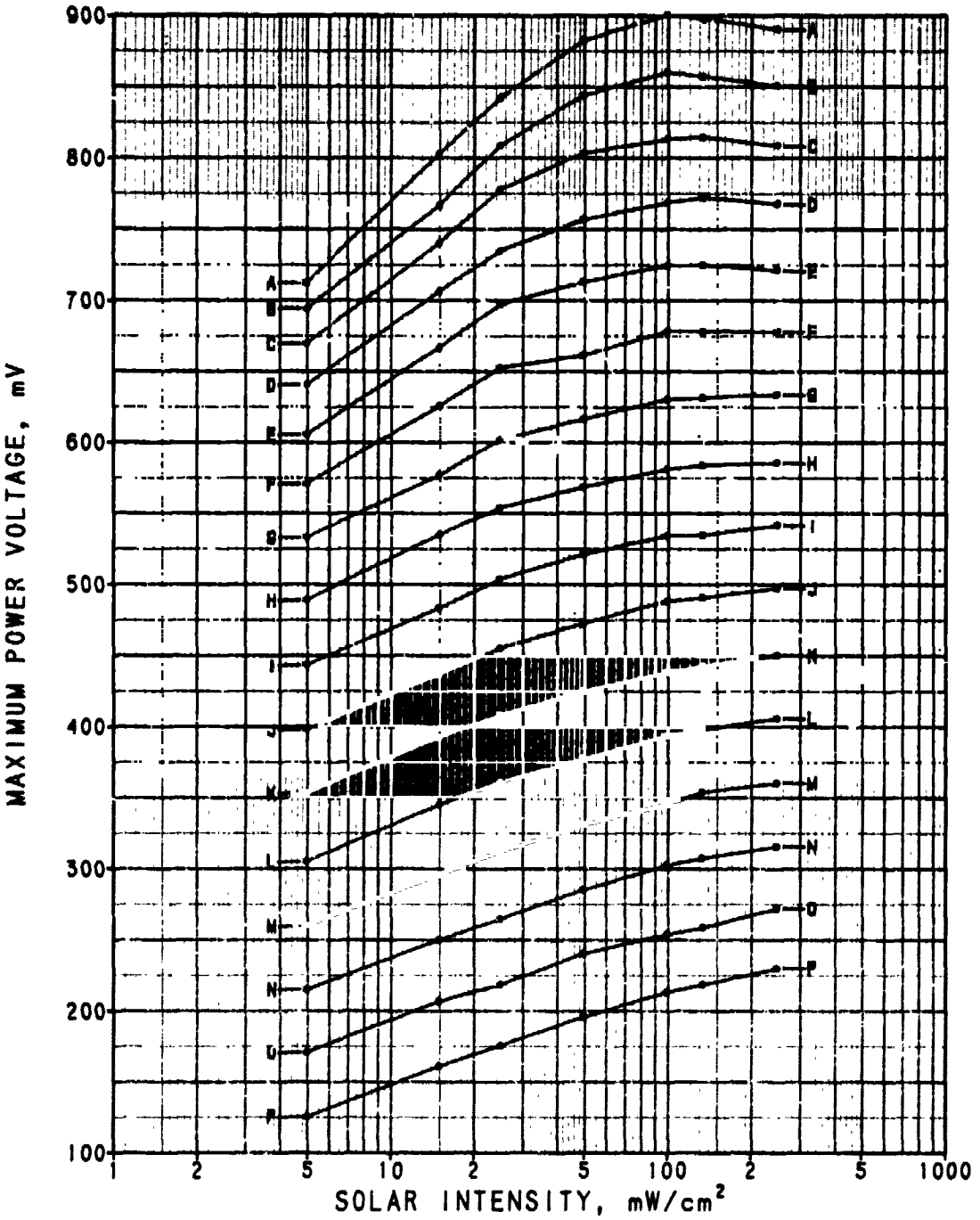


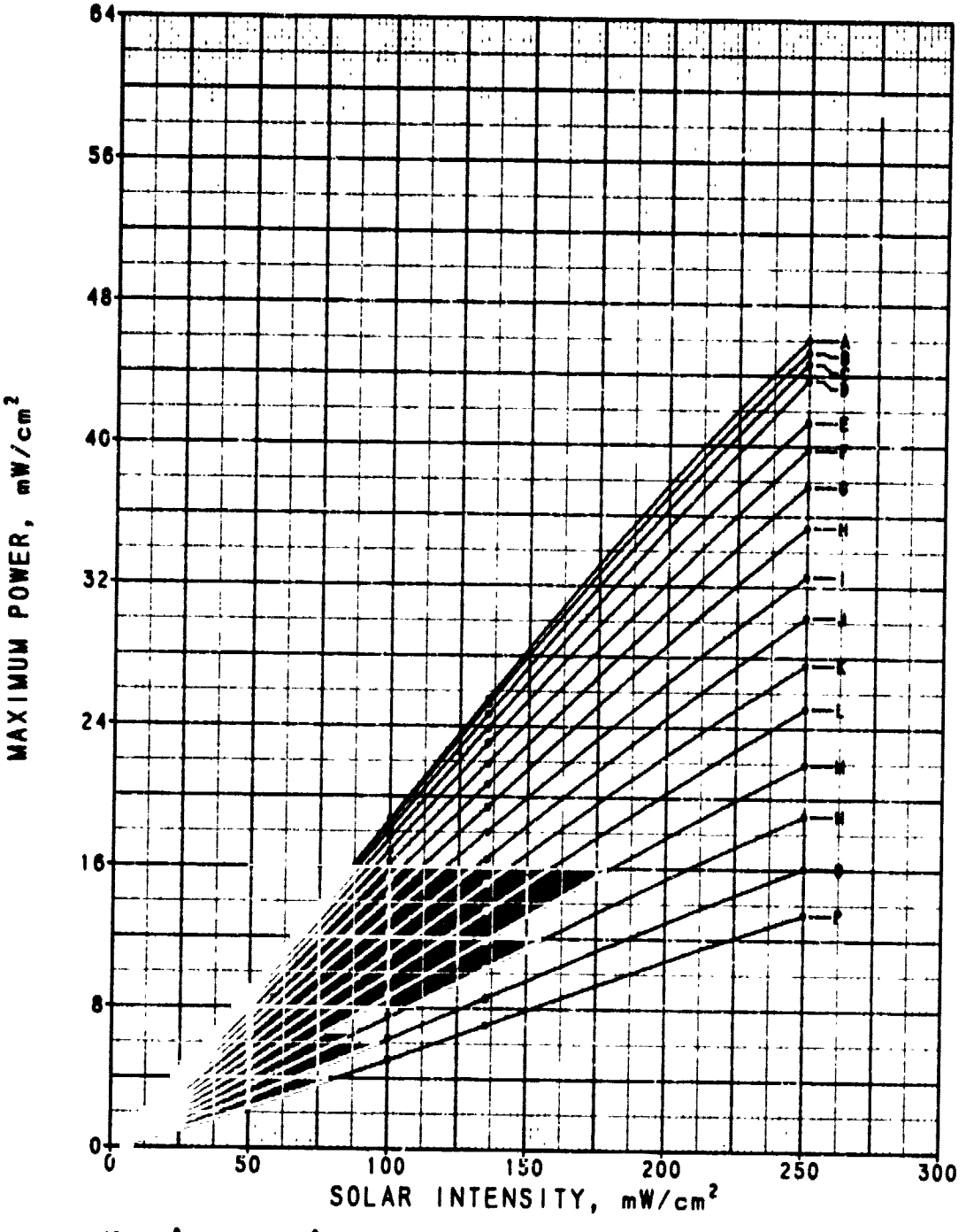
Figure 10. Average I_{mp}/cm^2 as a Function of Intensity



ID	°C	ID	°C
A	-160.0	I	.0
B	-140.0	J	20.0
C	-120.0	K	40.0
D	-100.0	L	60.0
E	-80.0	M	80.0
F	-60.0	N	100.0
G	-40.0	O	120.0
H	-20.0	P	140.0

SOLAREX OAST BSF THIN CELLS
1978 PILOT LINE
N/P 2 OHM-CM CG SILICON
2 X 2 X .005 CM
TI-PD-AG CONTACTS 3X19 LINES
TA2O5 AR COATING
NO COVERSLIDE
SAMPLE SIZE :3

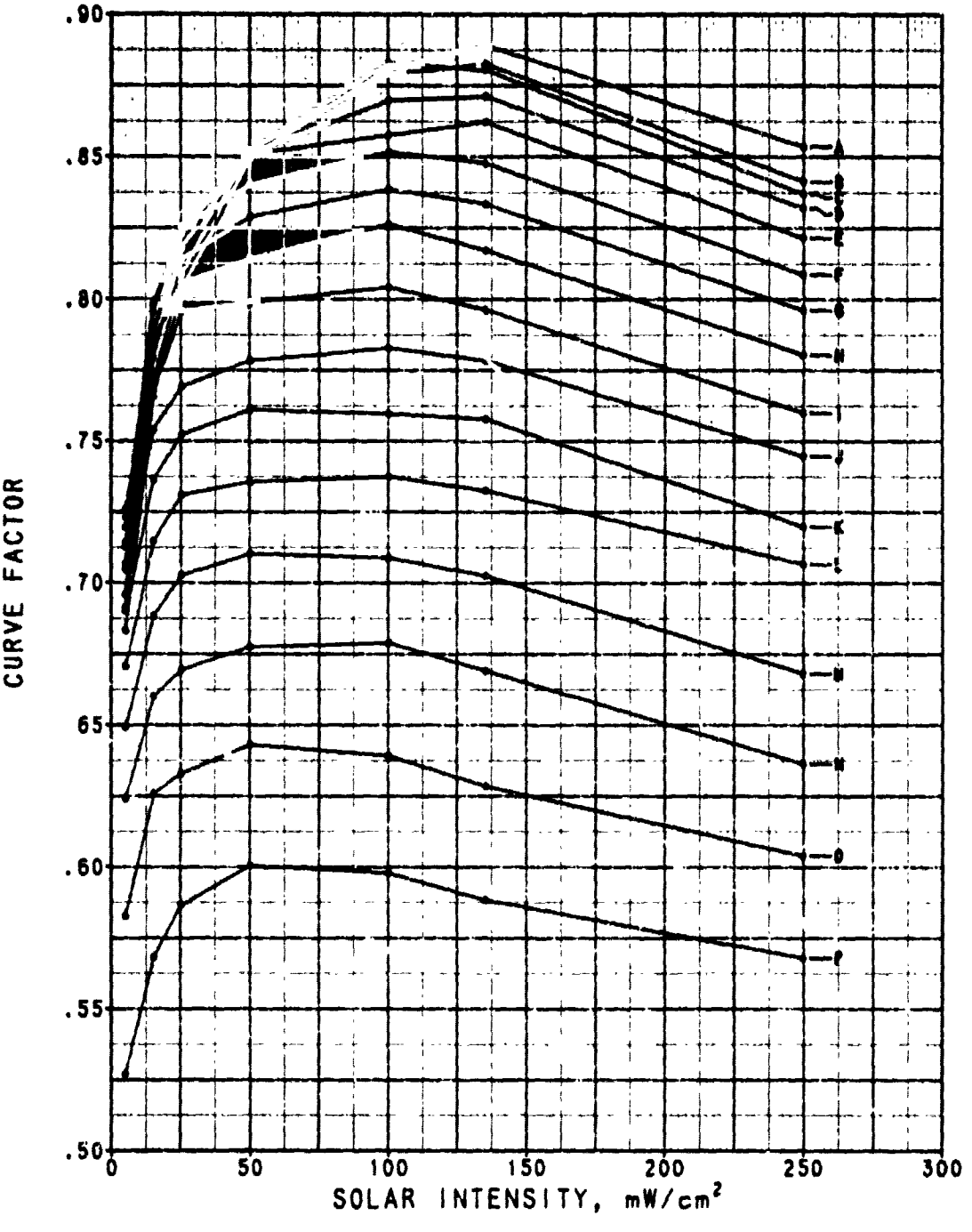
Figure 11. Average V_{mp} as a Function of Intensity



ID	°C	ID	°C
A	-160.0	I	.0
B	-140.0	J	20.0
C	-120.0	K	40.0
D	-100.0	L	60.0
E	-80.0	M	80.0
F	-60.0	N	100.0
G	-40.0	O	120.0
H	-20.0	P	140.0

SOLAREX OAST BSF THIN CELLS
1978 PILOT LINE
N/P 2 OHM-CM CG SILICON
2 X 2 X .005 CM
TI-PD-AG CONTACTS 3X19 LINES
TA2O5 AR COATING
NO COVERSLIDE
SAMPLE SIZE 13

Figure 12. Average P_{max}/cm^2 as a Function of Intensity



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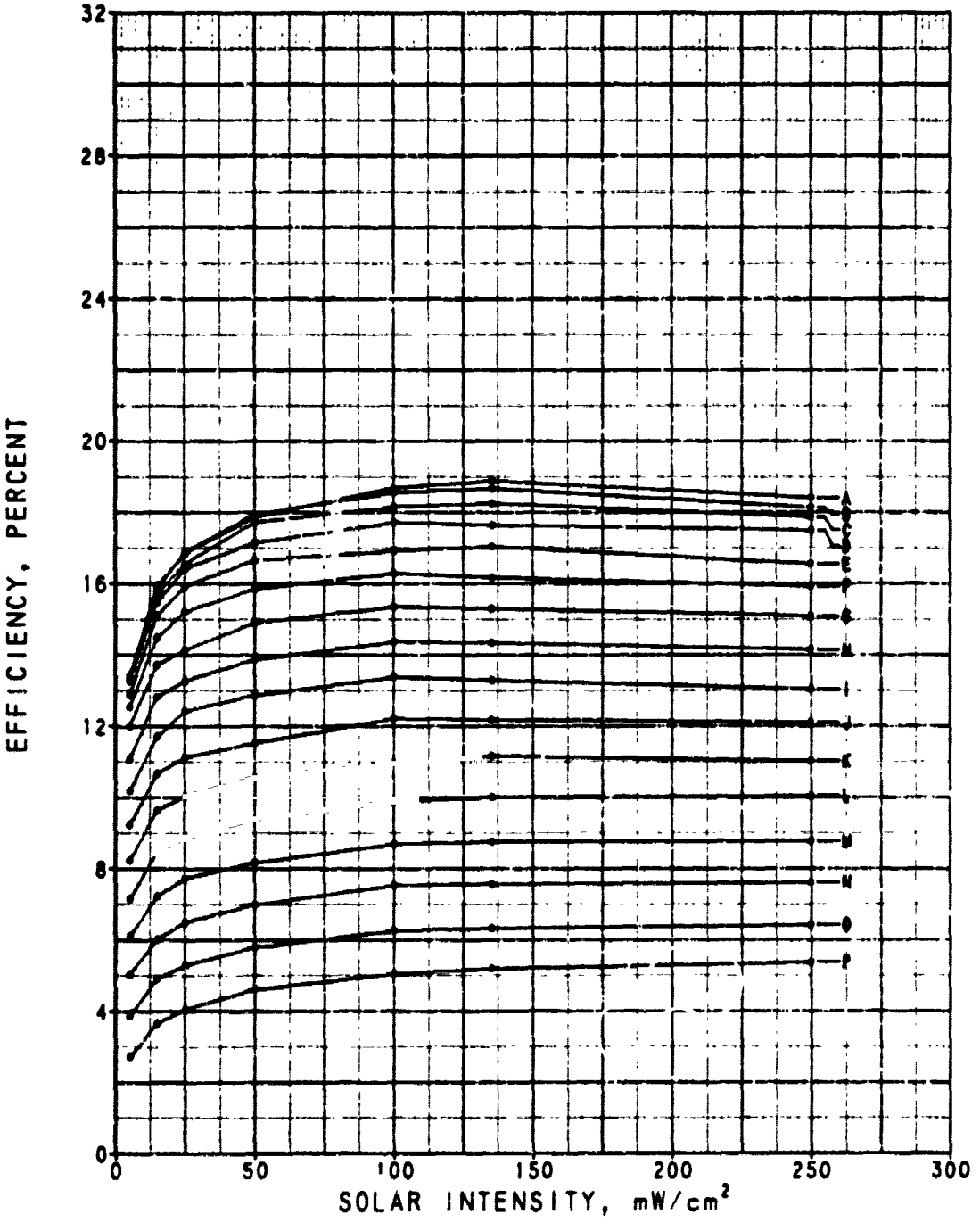
B	-140.0	J	20.0
C	-120.0	K	40.0
D	-100.0	L	60.0
E	-80.0	M	80.0
F	-60.0	N	100.0
G	-40.0	O	120.0
H	-20.0	P	140.0

SOLAREX OAST BSF THIN CELLS
1978 PILOT LINE
N/P 2 OHM-CM CG SILICON
2 X 2 X .005 CM
TI-PD-AG CONTACTS 3X19 LINES
TA2O5 AR COATING
NO COVERSLIDE
SAMPLE SIZE 13

Figure 13. Average Curve Factor as a Function of Intensity



ID	°C	ID	°C
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B	-140.0	J	20.0
C	-120.0	K	40.0
D	-100.0	L	60.0
E	-80.0	M	80.0
F	-60.0	N	100.0
G	-40.0	O	120.0
H	-20.0	P	140.0

SOLAREX OAST BSF THIN CELLS
1978 PILOT LINE
N/P 2 OHM-CM CG SILICON
2 X 2 X .005 CM
TI-PD-AG CONTACTS 3X10 LINES
TA2O5 AR COATING
NO COVERSLIDE
SAMPLE SIZE 13

Figure 14. Average AMO Efficiency as a Function of Intensity

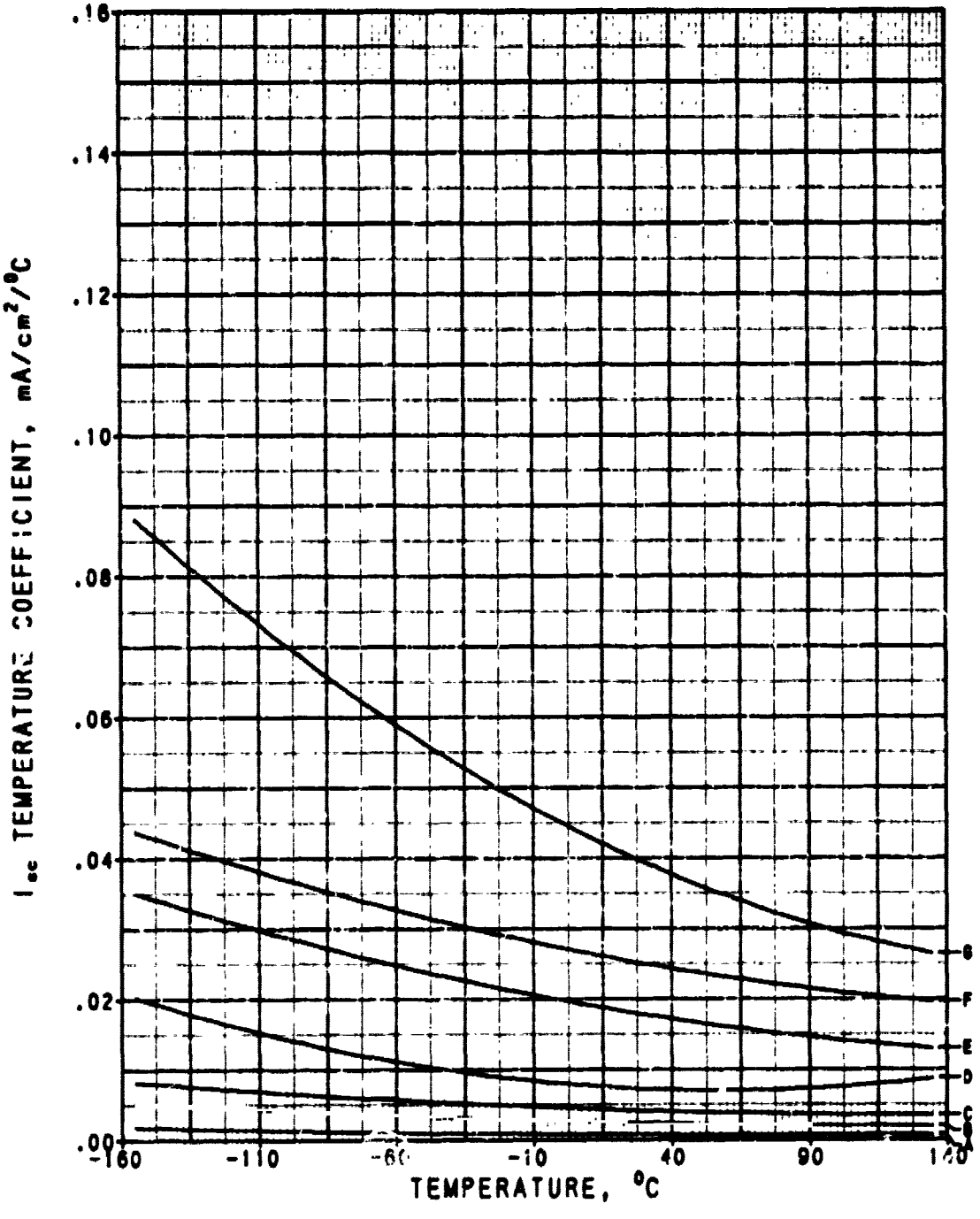


Figure 15. I_{sc} Temperature Coefficient

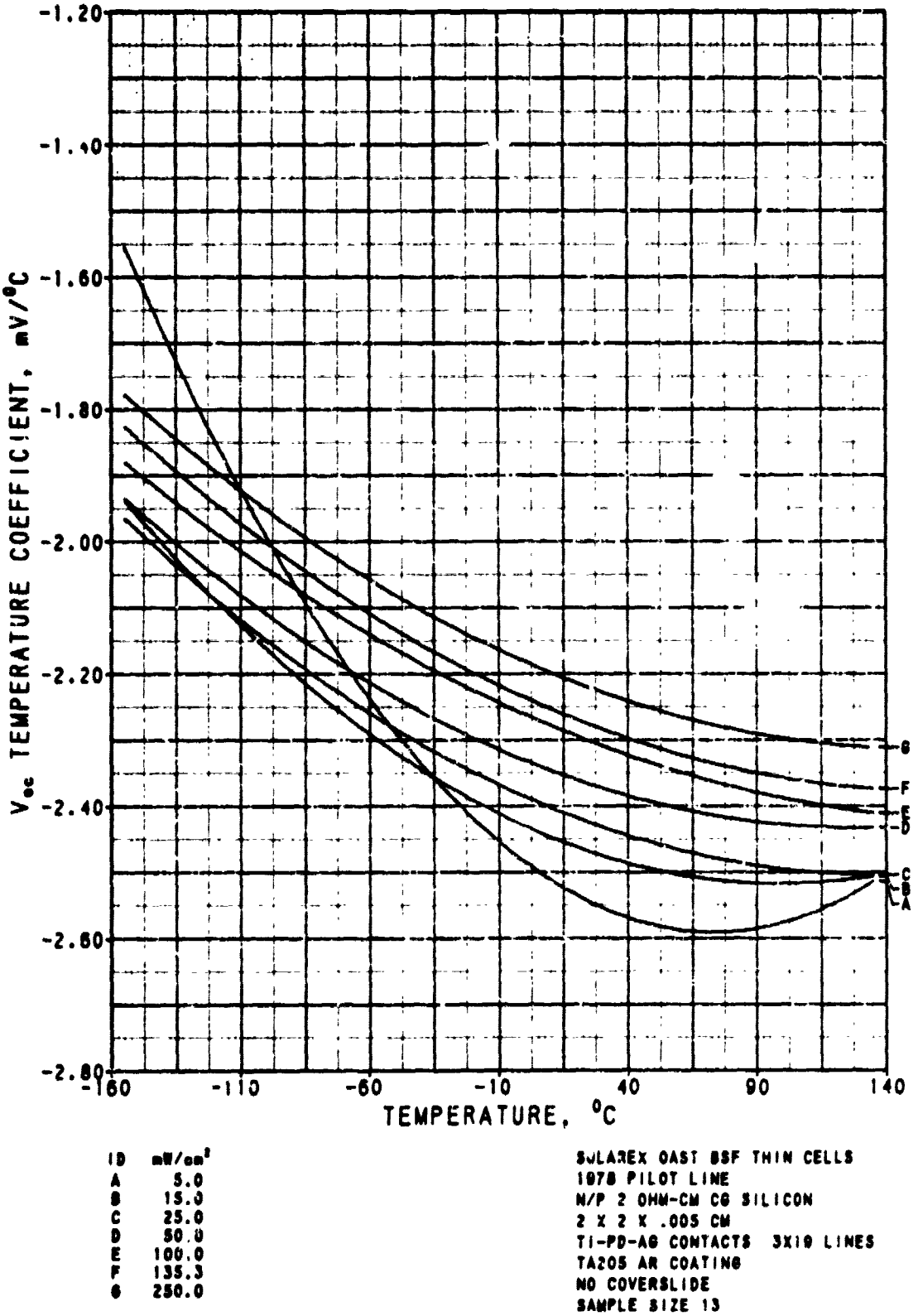
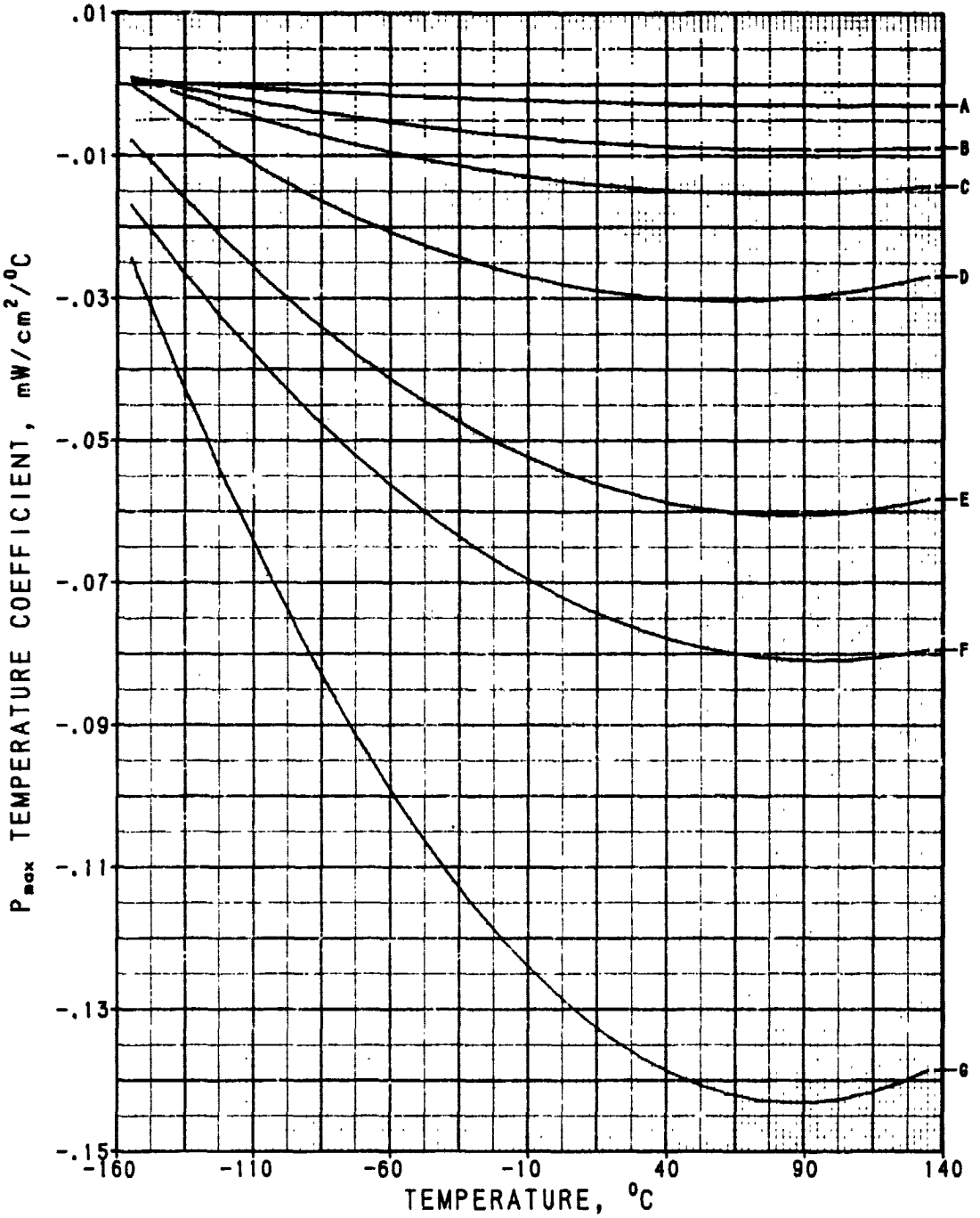


Figure 16. V_{oc} Temperature Coefficient



ID	mW/cm²
A	5.0
B	15.0
C	25.0
D	50.0
E	100.0
F	135.3
G	250.0

SOLAREX OAST BSF THIN CELLS
1978 PILOT LINE
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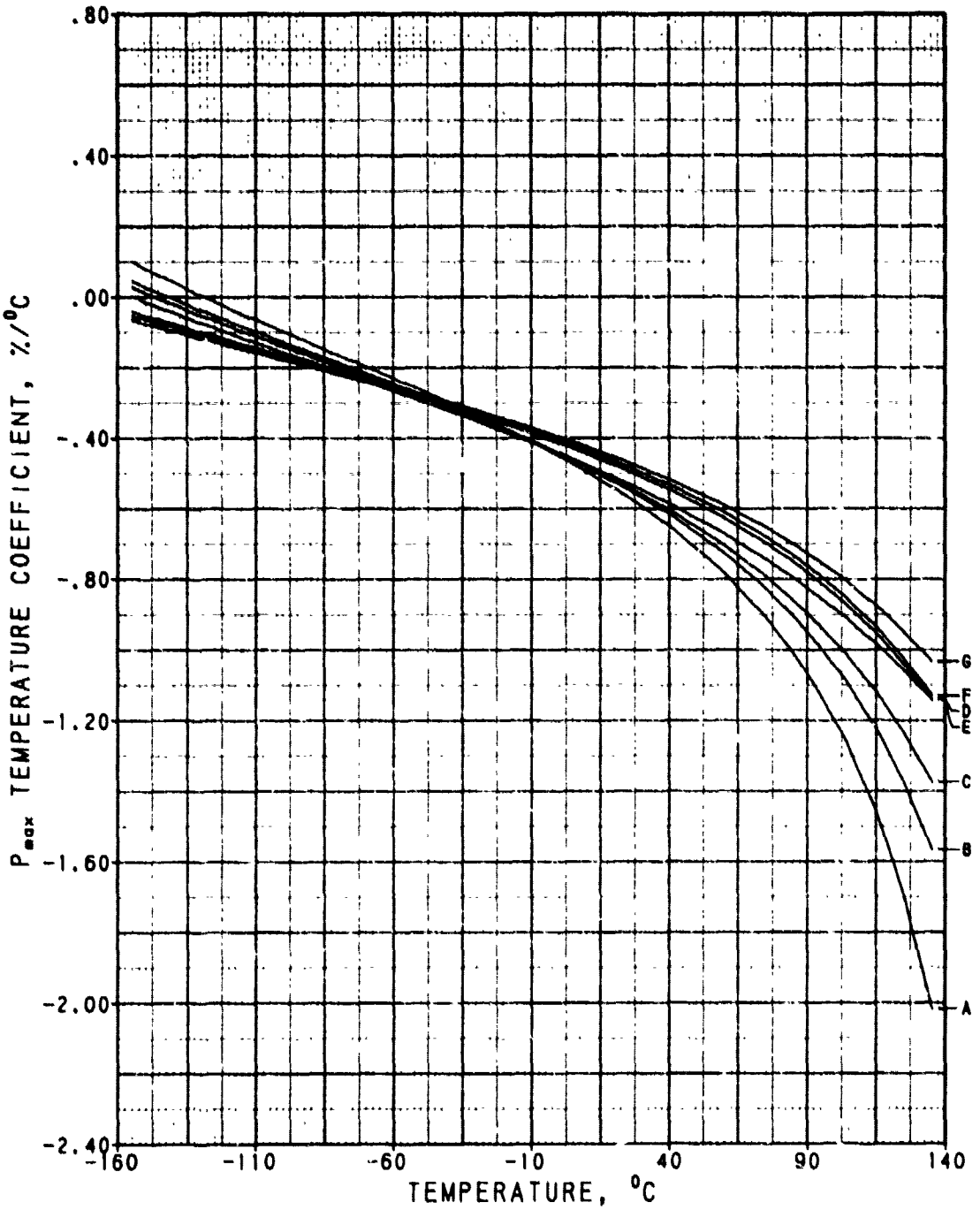
TA2O5 AR COATING
NO COVERSLIDE
SAMPLE SIZE 13

Figure 17. Absolute P_{max} Temperature Coefficient



ID	mW/cm²
A	5.0
B	15.0
C	25.0
D	50.0
E	100.0
F	135.3
G	250.0

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TA2O5 AR COATING
NO COVERSLIDE
SAMPLE SIZE 13

Figure 18. Percent P_{max} Temperature Coefficient

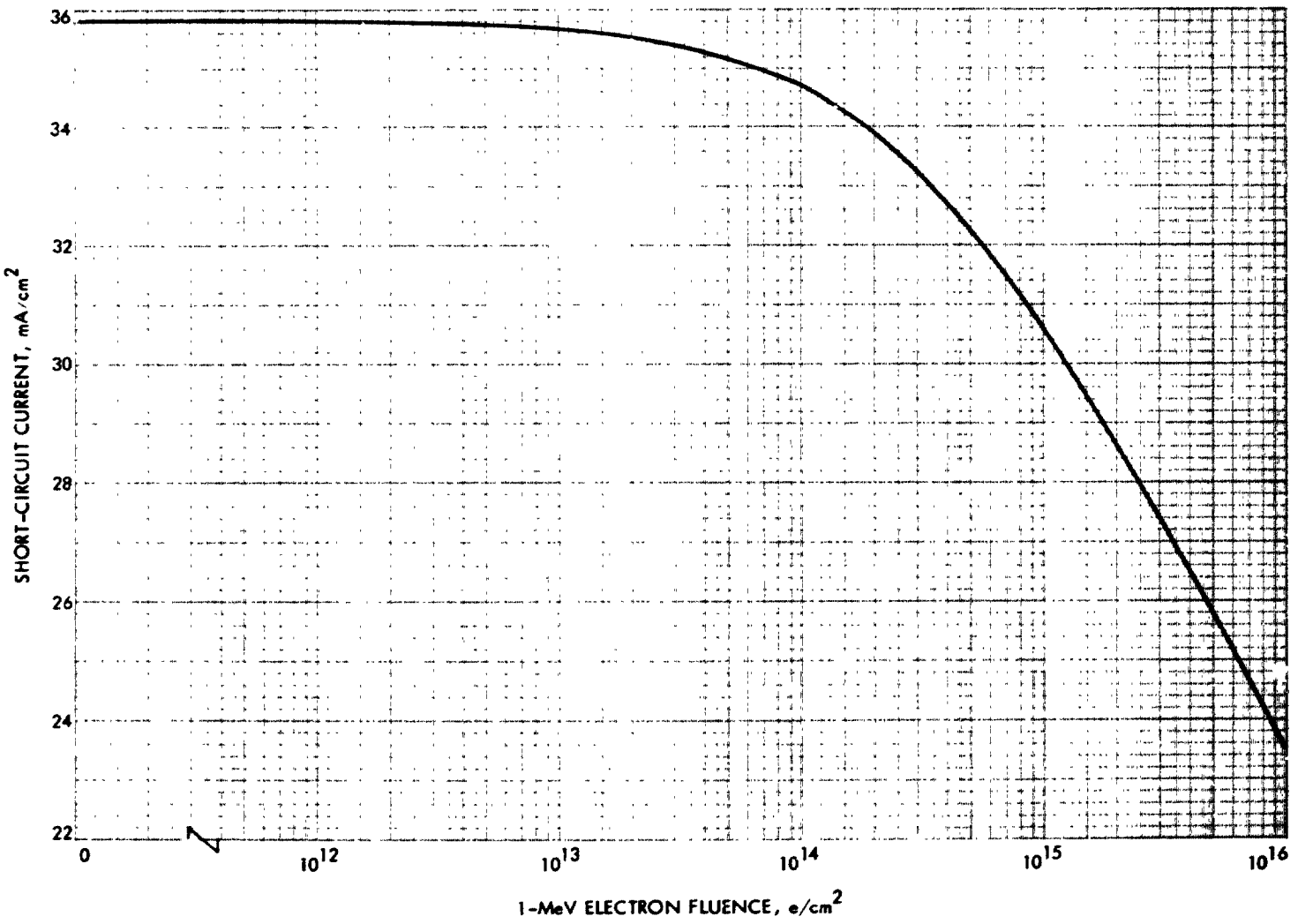

Figure 19. Short-Circuit Current Density vs 1-MeV Electron Fluence at 135.5-mW/cm^2 AMO Illumination, 28°C

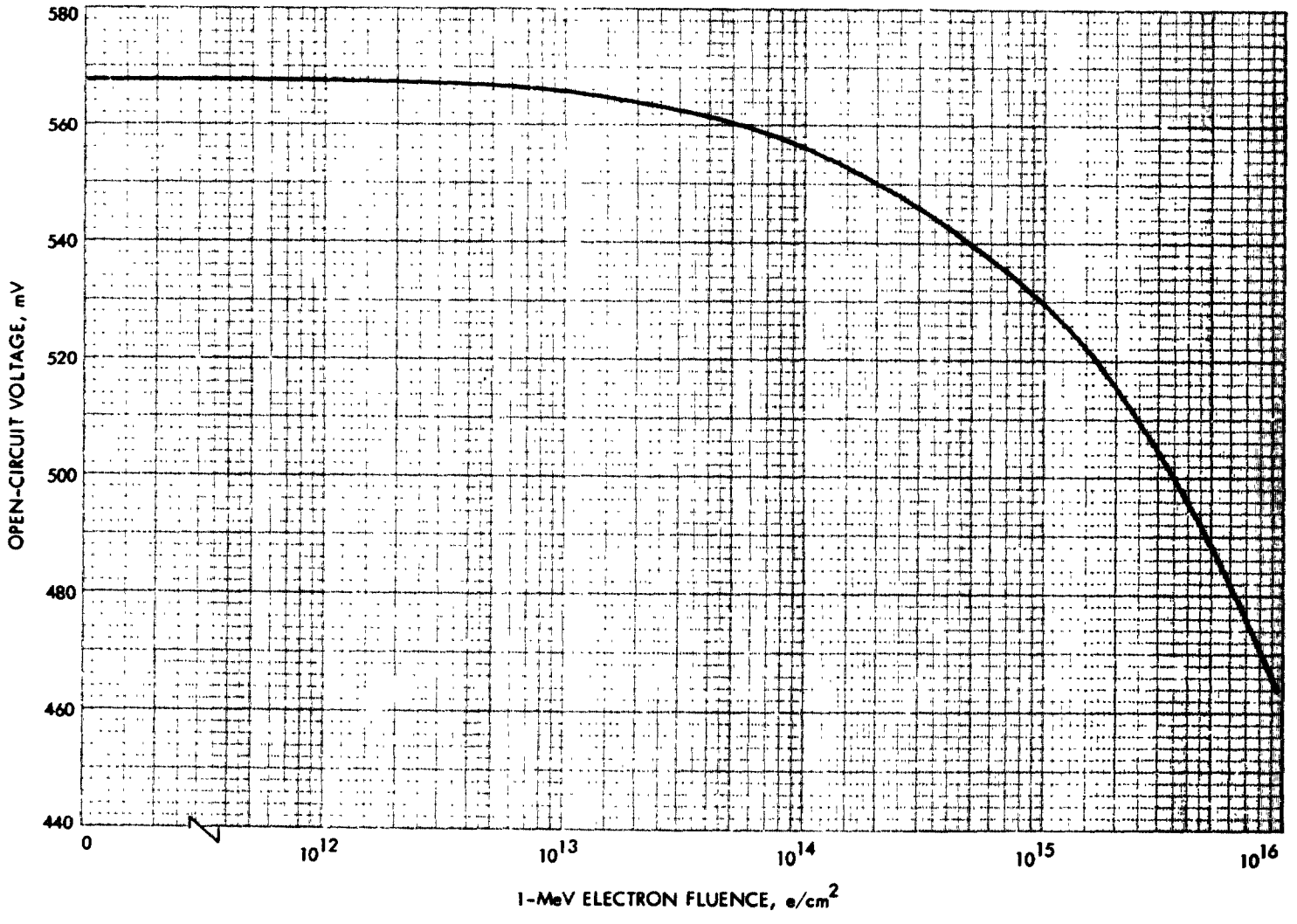

Figure 20. Open-Circuit Voltage vs 1-MeV Electron Fluence at 135.3-mW/cm^2 AMO Illumination, 28°C

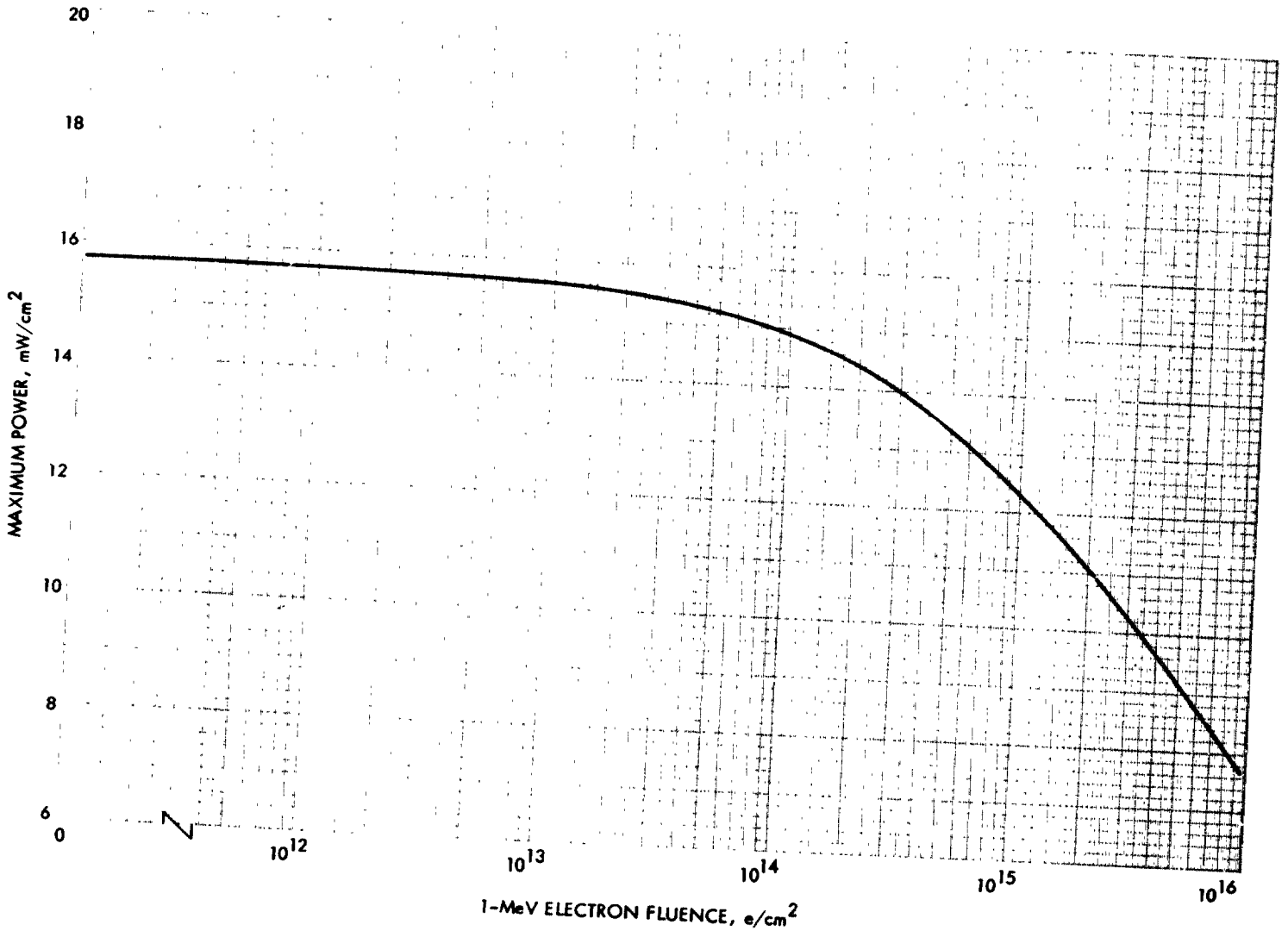

Figure 21. Maximum Power Density vs 1-MeV Electron Fluence at 135.3-mW/cm^2 AMO Illumination, 28°C

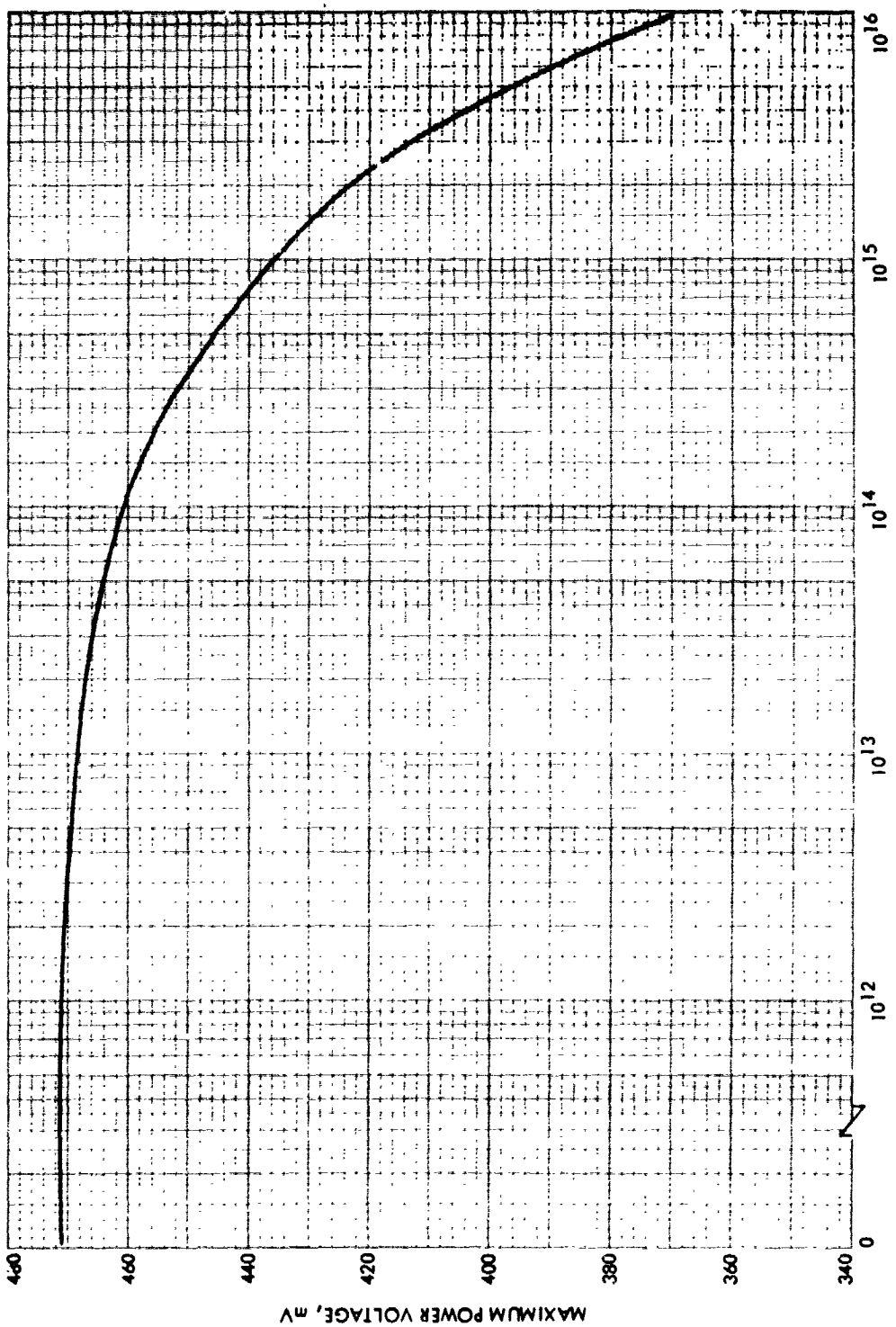

Figure 22. Voltage at Maximum Power vs 1-MeV Electron Fluence at 135.3-mW/cm^2 AMO Illumination, 28°C

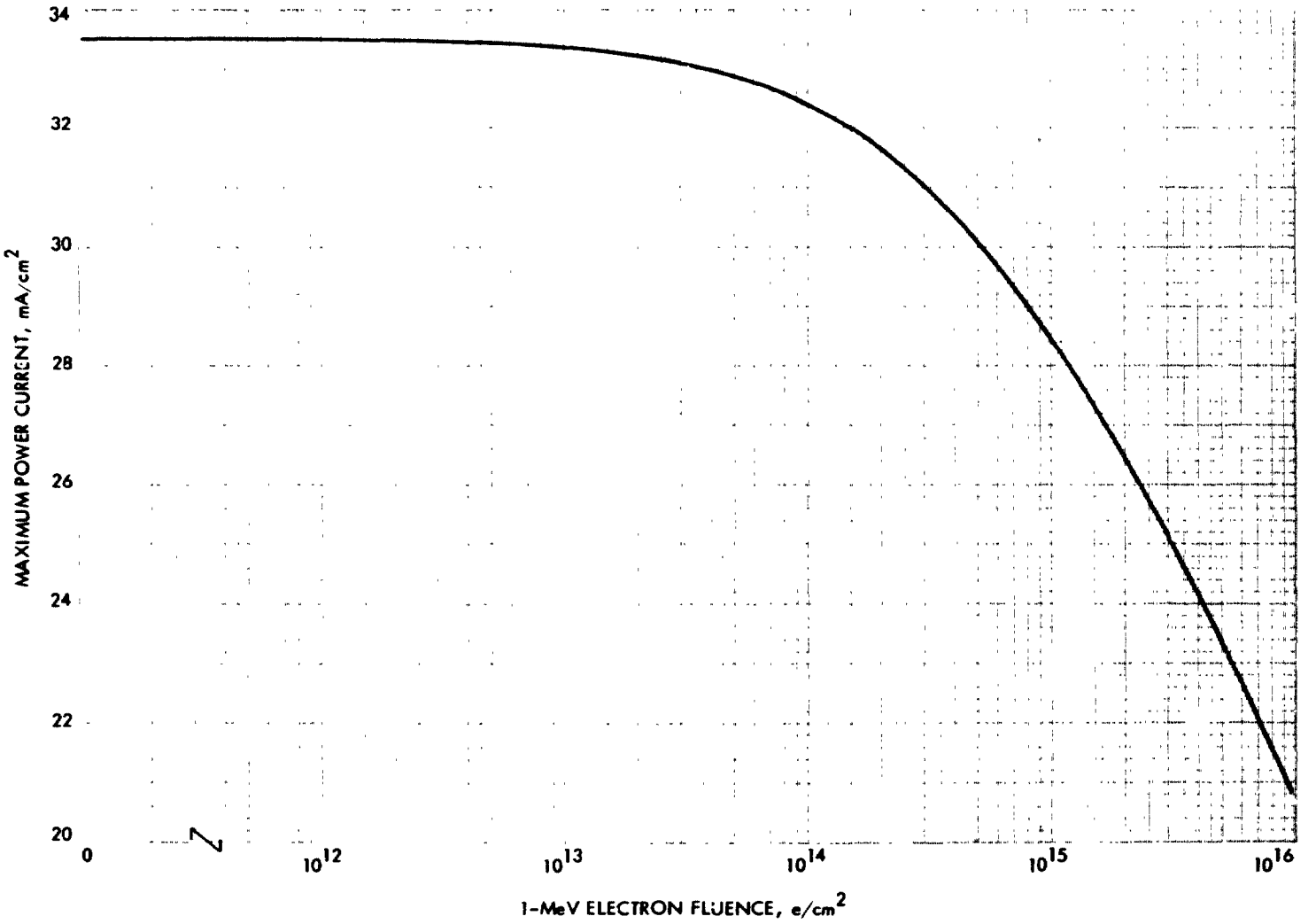

Figure 23. Maximum Power Current Density vs 1-MeV Electron Fluence at 135.3-mW/cm^2 AMO Illumination, 28°C

Table 1. Average Short-Circuit Current, mA/cm^2

SOLAREX OAST BSF THIN CELLS
1978 PILOT LINE
N/P 2 OHM-CM CG SILICON
2 X 2 X .005 CM
TI-PD-AG CONTACTS 3X19 LINES
TA205 AR COATING
NO COVERSLIDE
SAMPLE SIZE 13 TM-47

CELL TEMP. (DEG. C)	SOLAR INTENSITY (MW/CM**2) 5.00	15.00	25.00	50.00	100.00	135.30	250.00
-160.00	1.12	3.37	5.58	11.07	22.16	29.94	55.69
	(.03)	(.07)	(.13)	(.24)	(.53)	(.71)	(1.29)
-140.00	1.15	3.48	5.79	11.55	22.91	30.97	57.70
	(.02)	(.07)	(.13)	(.24)	(.52)	(.61)	(1.32)
-120.00	1.19	3.57	5.89	11.94	23.32	31.63	59.52
	(.02)	(.07)	(.10)	(.22)	(.67)	(.53)	(1.11)
-100.00	1.22	3.65	6.11	12.12	24.22	32.36	61.25
	(.02)	(.06)	(.10)	(.20)	(.47)	(.54)	(1.03)
-80.00	1.24	3.73	6.23	12.44	24.66	33.17	61.60
	(.02)	(.06)	(.10)	(.19)	(.47)	(.50)	(1.13)
-60.00	1.26	3.80	6.31	12.70	25.22	33.74	63.33
	(.02)	(.07)	(.09)	(.20)	(.42)	(.50)	(1.09)
-40.00	1.29	3.89	6.36	12.87	25.63	34.47	64.42
	(.02)	(.06)	(.10)	(.19)	(.49)	(.50)	(.91)
-20.00	1.30	3.94	6.48	13.07	26.01	35.09	65.49
	(.02)	(.06)	(.11)	(.16)	(.46)	(.58)	(1.09)
.00	1.32	4.00	6.64	13.29	26.62	35.71	66.09
	(.02)	(.06)	(.09)	(.19)	(.44)	(.52)	(.80)
20.00	1.34	4.05	6.70	13.27	26.93	36.02	67.13
	(.02)	(.06)	(.10)	(.21)	(.42)	(.51)	(1.04)
40.00	1.36	4.12	6.78	13.57	27.07	36.72	68.17
	(.02)	(.06)	(.11)	(.19)	(.43)	(.54)	(1.10)
60.00	1.37	4.16	6.85	13.75	27.55	37.20	68.79
	(.02)	(.06)	(.11)	(.18)	(.37)	(.49)	(1.05)
80.00	1.39	4.19	6.98	13.83	27.95	37.53	69.72
	(.02)	(.05)	(.10)	(.20)	(.43)	(.47)	(.92)
100.00	1.41	4.21	7.05	14.01	28.24	37.99	70.42
	(.02)	(.05)	(.11)	(.20)	(.43)	(.48)	(1.15)
120.00	1.42	4.28	7.11	14.16	28.57	38.32	70.32
	(.02)	(.06)	(.12)	(.17)	(.42)	(.54)	(1.23)
140.00	1.43	4.33	7.13	14.28	28.65	38.90	71.14
	(.02)	(.06)	(.11)	(.20)	(.50)	(.56)	(1.28)

NOTE: STANDARD DEVIATIONS ARE GIVEN IN PARENTHESES.

Table 2. Average Open-Circuit Voltage, mV

SOLAREX OAST BSF THIN CELLS
1978 PILOT LINE
N/P 2 OHM-CM CG SILICON
2 X 2 X .005 CM
TI-PD-AG CONTACTS 3X19 LINES
TA205 AR COATING
NO COVERSLIDE
SAMPLE SIZE 13 TM-47

CELL TEMP. (DEG. C)	SOLAR INTENSITY (MW/CM**2) 5.00	15.00	25.00	50.00	100.00	135.30	250.00
-160.00	873.89	927.21	939.28	949.71	957.62	959.99	967.60
	(86.70)	(23.88)	(5.43)	(2.84)	(2.97)	(2.65)	(2.62)
-140.00	841.56	887.62	900.25	911.27	920.89	923.79	933.38
	(73.50)	(15.23)	(5.66)	(3.37)	(2.91)	(2.76)	(2.74)
-120.00	808.01	848.89	858.84	871.09	881.41	885.86	896.51
	(57.57)	(9.67)	(5.55)	(3.54)	(3.26)	(2.91)	(2.85)
-100.00	769.79	806.91	816.00	830.48	841.04	846.47	857.47
	(42.09)	(7.17)	(4.70)	(3.56)	(3.31)	(3.55)	(3.17)
-80.00	727.47	762.36	773.48	786.78	799.42	805.65	816.95
	(27.01)	(5.92)	(4.44)	(3.60)	(3.41)	(3.48)	(3.23)
-60.00	684.67	715.75	729.54	742.92	757.75	764.58	776.91
	(16.55)	(5.43)	(4.54)	(3.90)	(3.47)	(3.57)	(3.50)
-40.00	638.80	668.59	682.85	698.15	713.99	720.45	735.20
	(10.88)	(5.05)	(4.66)	(4.22)	(3.79)	(3.85)	(3.69)
-20.00	590.42	621.19	635.27	651.48	668.77	676.81	691.92
	(8.73)	(5.08)	(4.53)	(4.57)	(4.19)	(4.07)	(4.13)
.00	539.28	572.45	588.13	605.68	624.98	632.47	648.80
	(7.00)	(5.03)	(4.73)	(4.46)	(4.39)	(4.16)	(4.52)
20.00	488.86	524.42	540.15	558.19	579.62	587.78	605.18
	(6.97)	(5.10)	(5.06)	(4.90)	(4.72)	(4.71)	(4.80)
40.00	439.76	476.53	491.68	512.15	533.30	542.98	561.54
	(6.24)	(5.37)	(5.08)	(5.03)	(4.89)	(5.08)	(5.18)
60.00	389.04	427.41	443.24	464.57	486.91	496.81	516.48
	(6.60)	(5.52)	(5.70)	(5.44)	(5.58)	(5.42)	(5.71)
80.00	338.32	376.18	393.91	416.29	438.96	449.74	470.87
	(6.89)	(6.11)	(6.12)	(5.81)	(5.84)	(5.70)	(5.99)
100.00	287.05	324.94	344.62	368.44	392.92	403.12	424.66
	(7.08)	(6.68)	(6.24)	(6.20)	(6.03)	(6.11)	(6.22)
120.00	234.74	275.36	293.88	318.47	343.53	355.64	378.05
	(7.17)	(6.59)	(7.14)	(6.64)	(7.08)	(6.62)	(6.76)
140.00	181.13	223.84	242.85	269.28	295.49	307.30	332.21
	(7.56)	(7.59)	(7.04)	(6.66)	(6.81)	(7.13)	(7.08)

NOTE: STANDARD DEVIATIONS ARE GIVEN IN PARENTHESES.

Table 3. Average Maximum Power Current, mA/cm^2

SOLAREX OAST BSF THIN CELLS
1978 PILOT LINE
N/P 2 OHM-CM CG SILICON
2 X 2 X .005 CM
TI-PD-AG CONTACTS 3X19 LINES
TA205 AR COATING
NO COVERSLIDE
SAMPLE SIZE 13 TM-47

CELL TEMP. (DEG. C)	SOLAR INTENSITY (MW/CM**2) 5.00	15.00	25.00	50.00	100.00	135.30	250.00
-160.00	.94	2.98	4.99	10.10	20.75	28.44	51.65
	(.09)	(.13)	(.26)	(.58)	(1.07)	(1.13)	(1.74)
-140.00	.97	3.11	5.20	10.61	21.57	29.46	53.25
	(.09)	(.11)	(.29)	(.65)	(1.08)	(1.12)	(1.54)
-120.00	1.00	3.19	5.30	11.02	22.30	30.28	55.21
	(.08)	(.12)	(.29)	(.54)	(.93)	(1.01)	(1.37)
-100.00	1.04	3.28	5.57	11.31	23.04	30.90	56.92
	(.07)	(.12)	(.29)	(.48)	(.80)	(.85)	(1.59)
-80.00	1.07	3.39	5.70	11.68	23.33	31.79	57.33
	(.06)	(.12)	(.32)	(.38)	(.93)	(.86)	(1.62)
-60.00	1.10	3.47	5.82	11.98	24.00	32.25	58.69
	(.04)	(.13)	(.25)	(.31)	(.64)	(.85)	(1.25)
-40.00	1.12	3.57	5.87	12.08	24.36	32.77	59.50
	(.04)	(.11)	(.21)	(.30)	(.63)	(.79)	(1.36)
-20.00	1.13	3.59	5.99	12.20	24.73	33.24	60.37
	(.04)	(.12)	(.20)	(.26)	(.95)	(.75)	(1.43)
.00	1.15	3.63	6.17	12.34	25.05	33.64	60.17
	(.04)	(.10)	(.11)	(.23)	(.63)	(.75)	(1.45)
20.00	1.16	3.66	6.11	12.20	25.03	33.57	60.83
	(.04)	(.09)	(.19)	(.25)	(.54)	(.65)	(1.48)
40.00	1.17	3.68	6.15	12.45	25.03	34.14	61.19
	(.03)	(.09)	(.15)	(.17)	(.51)	(.64)	(1.69)
60.00	1.17	3.68	6.15	12.45	25.16	34.01	61.81
	(.03)	(.08)	(.13)	(.19)	(.52)	(.76)	(4.14)
80.00	1.17	3.67	6.19	12.36	25.17	33.47	60.83
	(.04)	(.08)	(.14)	(.20)	(.67)	(.71)	(1.87)
100.00	1.17	3.61	6.14	12.25	24.91	33.29	60.23
	(.03)	(.07)	(.12)	(.19)	(.49)	(.80)	(2.20)
120.00	1.13	3.56	6.05	12.07	24.69	33.09	58.98
	(.03)	(.08)	(.15)	(.26)	(.66)	(.97)	(1.52)
140.00	1.09	3.42	5.77	11.79	23.71	32.18	58.29
	(.03)	(.07)	(.12)	(.26)	(.72)	(1.05)	(2.35)

NOTE: STANDARD DEVIATIONS ARE GIVEN IN PARENTHESES.

Table 4. Average Maximum Power Voltage, mV

SOLAREX OAST BSF THIN CELLS
1978 PILOT LINE
N/P 2 OHM-CM CG SILICON
2 X 2 X .005 CM
TI-PD-AG CONTACTS 3X19 LINES
TA205 AR COATING
NO COVERSLIDE
SAMPLE SIZE 13 TM-47

CELL TEMP. (DEG. C)	SOLAR INTENSITY (MW/CM**2) 5.00	15.00	25.00	50.00	100.00	135.30	250.00
-160.00	712.54	802.92	842.15	882.54	900.77	898.00	890.31
	(121.33)	(114.69)	(87.43)	(37.86)	(15.99)	(17.19)	(13.96)
-140.00	694.38	766.62	808.85	844.15	859.85	857.08	850.69
	(112.53)	(99.18)	(70.24)	(22.35)	(13.11)	(13.25)	(15.10)
-120.00	669.69	740.08	778.00	803.54	813.54	814.62	808.77
	(101.78)	(79.57)	(52.28)	(18.21)	(13.07)	(11.44)	(16.15)
-100.00	640.77	706.15	734.85	757.00	768.77	772.15	767.62
	(87.89)	(59.77)	(35.53)	(13.48)	(10.91)	(12.85)	(15.62)
-80.00	605.77	666.62	697.46	712.92	724.62	724.85	721.08
	(72.37)	(43.59)	(17.37)	(11.18)	(10.16)	(12.52)	(12.89)
-60.00	571.00	625.46	652.38	661.46	678.23	678.08	677.92
	(53.90)	(26.73)	(13.05)	(10.81)	(9.54)	(10.16)	(13.77)
-40.00	533.15	576.62	601.92	616.54	630.15	631.54	633.77
	(37.69)	(19.41)	(10.50)	(9.71)	(10.07)	(11.11)	(12.56)
-20.00	489.23	535.00	553.92	568.46	581.31	583.85	585.77
	(26.18)	(10.43)	(7.79)	(7.75)	(8.73)	(10.74)	(11.26)
.00	443.38	483.15	503.69	521.31	534.23	534.62	541.54
	(16.53)	(8.72)	(8.10)	(7.77)	(6.76)	(9.73)	(12.40)
20.00	398.08	436.85	455.23	472.69	488.23	490.92	497.38
	(11.89)	(8.60)	(6.71)	(6.92)	(8.36)	(9.53)	(13.60)
40.00	353.38	392.69	407.85	424.77	438.00	442.46	450.31
	(9.12)	(6.61)	(7.90)	(7.07)	(8.82)	(9.03)	(11.79)
60.00	305.31	345.23	360.77	377.31	393.23	398.08	405.92
	(10.56)	(7.99)	(7.14)	(6.87)	(6.48)	(8.04)	(10.12)
80.00	260.15	295.77	312.00	330.92	345.46	354.23	360.46
	(7.46)	(6.87)	(7.22)	(8.04)	(6.54)	(8.85)	(9.94)
100.00	215.08	250.15	265.00	285.54	302.46	307.77	315.92
	(7.23)	(7.65)	(8.69)	(7.49)	(9.11)	(8.07)	(9.36)
120.00	171.15	206.92	218.69	240.46	254.08	258.85	272.23
	(6.78)	(11.32)	(6.52)	(6.96)	(6.61)	(7.38)	(9.13)
140.00	125.77	161.31	176.00	195.92	213.46	218.62	230.31
	(6.04)	(7.22)	(7.52)	(6.01)	(6.94)	(6.75)	(7.99)

NOTE: STANDARD DEVIATIONS ARE GIVEN IN PARENTHESES.

Table 5. Average Maximum Power, mW/cm^2

SOLAREX OAST BSF THIN CELLS
1978 PILOT LINE
N/P 2 OHM-CM CG SILICON
2 X 2 X .005 CM
TI-PD-AG CONTACTS 3X19 LINES
TA205 AR COATING
NO COVERSLIDE
SAMPLE SIZE 13 TM-47

CELL TEMP. (DEG. C)	SOLAR INTENSITY (MW/CM**2) 5.00	15.00	25.00	50.00	100.00	135.30	250.00
-160.00	.67	2.39	4.21	8.93	18.70	25.55	46.00
	(.10)	(.34)	(.55)	(.85)	(1.18)	(1.32)	(2.01)
-140.00	.67	2.38	4.22	8.97	18.55	25.25	45.31
	(.10)	(.32)	(.53)	(.74)	(1.08)	(1.20)	(1.79)
-120.00	.67	2.36	4.14	8.86	18.15	24.68	44.67
	(.10)	(.29)	(.45)	(.60)	(.94)	(1.08)	(1.77)
-100.00	.66	2.32	4.10	8.57	17.72	23.87	43.71
	(.09)	(.26)	(.38)	(.49)	(.75)	(.91)	(1.78)
-80.00	.64	2.26	3.98	8.33	16.91	23.05	41.35
	(.08)	(.21)	(.30)	(.36)	(.75)	(.89)	(1.68)
-60.00	.63	2.17	3.80	7.93	16.28	21.87	39.80
	(.07)	(.16)	(.23)	(.29)	(.56)	(.84)	(1.45)
-40.00	.60	2.06	3.54	7.45	15.35	20.79	37.72
	(.05)	(.12)	(.18)	(.25)	(.53)	(.73)	(1.34)
-20.00	.55	1.92	3.32	6.94	14.38	19.41	35.37
	(.04)	(.09)	(.14)	(.20)	(.63)	(.72)	(1.38)
.00	.51	1.76	3.11	6.43	13.39	17.99	32.59
	(.03)	(.07)	(.08)	(.18)	(.46)	(.65)	(1.31)
20.00	.46	1.60	2.78	5.77	12.22	16.48	30.26
	(.03)	(.06)	(.10)	(.17)	(.43)	(.57)	(1.35)
40.00	.41	1.45	2.51	5.29	10.97	15.11	27.56
	(.02)	(.05)	(.09)	(.14)	(.40)	(.51)	(1.26)
60.00	.36	1.27	2.22	4.70	9.89	13.54	25.10
	(.02)	(.05)	(.08)	(.14)	(.33)	(.53)	(1.97)
80.00	.30	1.09	1.93	4.09	8.70	11.86	21.94
	(.02)	(.04)	(.08)	(.14)	(.35)	(.49)	(1.18)
100.00	.25	.90	1.63	3.50	7.54	10.25	19.04
	(.01)	(.04)	(.07)	(.13)	(.34)	(.47)	(1.13)
120.00	.19	.74	1.32	2.90	6.28	8.57	16.07
	(.01)	(.05)	(.06)	(.13)	(.30)	(.44)	(.88)
140.00	.14	.55	1.02	2.31	5.06	7.04	13.44
	(.01)	(.03)	(.06)	(.12)	(.29)	(.40)	(.90)

NOTE: STANDARD DEVIATIONS ARE GIVEN IN PARENTHESES.

Table 6. Average Curve Factor

SOLAREX OAST BSF THIN CELLS
1978 PILOT LINE
N/P 2 OHM-CM CG SILICON
2 X 2 X .005 CM
TI-PD-AG CONTACTS 3X19 LINES
TA205 AR COATING
NO COVERSLIDE
SAMPLE SIZE 13 TM-47

CELL TEMP. (DEG. C)	SOLAR INTENSITY (MW/CM**2) 5.00	15.00	25.00	50.00	100.00	135.30	250.00
-160.00	.6832	.7655	.8028	.8495	.8810	.8892	.8537
	(.0846)	(.1026)	(.1037)	(.0796)	(.0506)	(.0435)	(.0317)
-140.00	.6914	.7704	.8085	.8524	.8790	.8827	.8414
	(.0845)	(.1018)	(.0983)	(.0726)	(.0444)	(.0370)	(.0285)
-120.00	.6957	.7791	.8176	.8524	.8830	.8805	.8370
	(.0833)	(.0954)	(.0850)	(.0577)	(.0459)	(.0342)	(.0284)
-100.00	.7064	.7870	.8229	.8512	.8697	.8713	.8320
	(.0815)	(.0837)	(.0701)	(.0450)	(.0278)	(.0283)	(.0275)
-80.00	.7126	.7957	.8255	.8510	.8577	.8623	.8216
	(.0752)	(.0727)	(.0574)	(.0351)	(.0274)	(.0263)	(.0281)
-60.00	.7231	.7980	.8253	.8402	.8517	.8478	.8088
	(.0676)	(.0564)	(.0421)	(.0266)	(.0221)	(.0247)	(.0249)
-40.00	.7261	.7903	.8139	.8229	.8387	.8334	.7963
	(.0582)	(.0424)	(.0320)	(.0213)	(.0194)	(.0218)	(.0262)
-20.00	.7196	.7851	.8057	.8142	.8264	.8171	.7805
	(.0483)	(.0321)	(.0239)	(.0168)	(.0260)	(.0212)	(.0259)
.00	.7143	.7676	.7957	.7990	.8043	.7964	.7601
	(.0379)	(.0237)	(.0186)	(.0146)	(.0169)	(.0223)	(.0274)
20.00	.7046	.7540	.7691	.7783	.7829	.7785	.7448
	(.0308)	(.0206)	(.0179)	(.0125)	(.0181)	(.0211)	(.0280)
40.00	.6900	.7365	.7523	.7610	.7597	.7578	.7199
	(.0276)	(.0170)	(.0159)	(.0129)	(.0178)	(.0202)	(.0279)
60.00	.6707	.7146	.7309	.7357	.7376	.7325	.7066
	(.0239)	(.0163)	(.0119)	(.0132)	(.0187)	(.0233)	(.0558)
80.00	.6493	.6883	.7027	.7103	.7089	.7025	.6681
	(.0198)	(.0154)	(.0128)	(.0141)	(.0193)	(.0218)	(.0290)
100.00	.6241	.6601	.6694	.6776	.6791	.6692	.6364
	(.0152)	(.0138)	(.0139)	(.0122)	(.0201)	(.0231)	(.0292)
120.00	.5826	.6258	.6330	.6432	.6393	.6285	.6041
	(.0151)	(.0262)	(.0107)	(.0134)	(.0209)	(.0230)	(.0227)
140.00	.5269	.5683	.5867	.6006	.5980	.5885	.5681
	(.0177)	(.0111)	(.0153)	(.0163)	(.0211)	(.0226)	(.0263)

NOTE: STANDARD DEVIATIONS ARE GIVEN IN PARENTHESES.

Table 7. Average AMO Efficiency, Percent

SOLAREX OAST BSF THIN CELLS
1978 PILOT LINE
N/P 2 OHM-CM CG SILICON
2 X 2 X .005 CM
TI-PD-AG CONTACTS 3X19 LINES
TA205 AR COATING
NO COVERSLIDE
SAMPLE SIZE 13 TM-47

CELL TEMP. (DEG. C)	SOLAR INTENSITY (MW/CM**2) 5.00	15.00	25.00	50.00	100.00	135.30	250.00
-160.00	13.30 (2.06)	15.94 (2.26)	16.83 (2.21)	17.86 (1.67)	18.70 (1.18)	18.88 (.97)	18.40 (.80)
-140.00	13.40 (2.03)	15.87 (2.14)	16.87 (2.11)	17.94 (1.48)	18.55 (1.08)	18.67 (.89)	18.12 (.72)
-120.00	13.34 (1.94)	15.75 (1.96)	16.55 (1.80)	17.72 (1.19)	18.15 (.94)	18.24 (.80)	17.87 (.71)
-100.00	13.26 (1.86)	15.48 (1.70)	16.41 (1.51)	17.14 (.99)	17.72 (.75)	17.64 (.67)	17.48 (.71)
-80.00	12.88 (1.60)	15.10 (1.41)	15.92 (1.20)	16.66 (.73)	16.91 (.75)	17.04 (.66)	16.54 (.67)
-60.00	12.52 (1.34)	14.48 (1.08)	15.21 (.90)	15.85 (.59)	16.28 (.56)	16.17 (.62)	15.92 (.53)
-40.00	11.99 (1.09)	13.72 (.81)	14.14 (.70)	14.90 (.50)	15.35 (.53)	15.30 (.54)	15.09 (.54)
-20.00	11.08 (.88)	12.82 (.63)	13.27 (.57)	13.87 (.40)	14.38 (.63)	14.35 (.53)	14.15 (.55)
.00	10.18 (.66)	11.71 (.47)	12.43 (.31)	12.87 (.37)	13.39 (.46)	13.30 (.48)	13.04 (.53)
20.00	9.22 (.52)	10.67 (.41)	11.13 (.38)	11.53 (.34)	12.22 (.43)	12.18 (.42)	12.11 (.54)
40.00	8.24 (.41)	9.65 (.35)	10.04 (.37)	10.58 (.27)	10.97 (.40)	11.17 (.38)	11.03 (.50)
60.00	7.16 (.36)	8.47 (.32)	8.88 (.31)	9.40 (.29)	9.89 (.33)	10.01 (.39)	10.04 (.79)
80.00	6.10 (.31)	7.24 (.28)	7.73 (.31)	8.18 (.28)	8.70 (.35)	8.77 (.36)	8.78 (.47)
100.00	5.04 (.26)	6.03 (.27)	6.51 (.29)	7.00 (.25)	7.54 (.34)	7.58 (.35)	7.62 (.45)
120.00	3.88 (.23)	4.92 (.34)	5.29 (.26)	5.80 (.25)	6.28 (.30)	6.33 (.33)	6.43 (.35)
140.00	2.73 (.16)	3.68 (.21)	4.07 (.24)	4.62 (.23)	5.06 (.29)	5.20 (.30)	5.37 (.36)

NOTE: STANDARD DEVIATIONS ARE GIVEN IN PARENTHESES.

APPENDIX

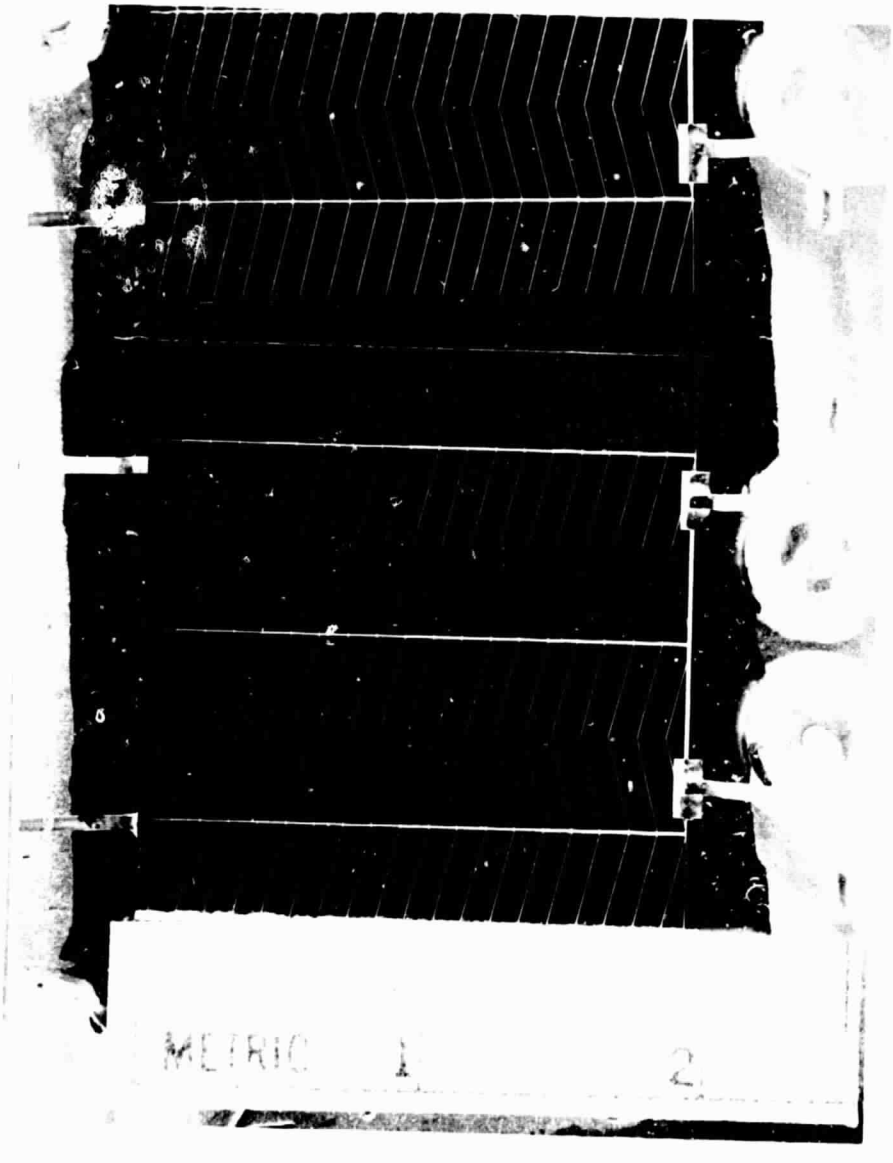

Figure A-1. Solar Cell

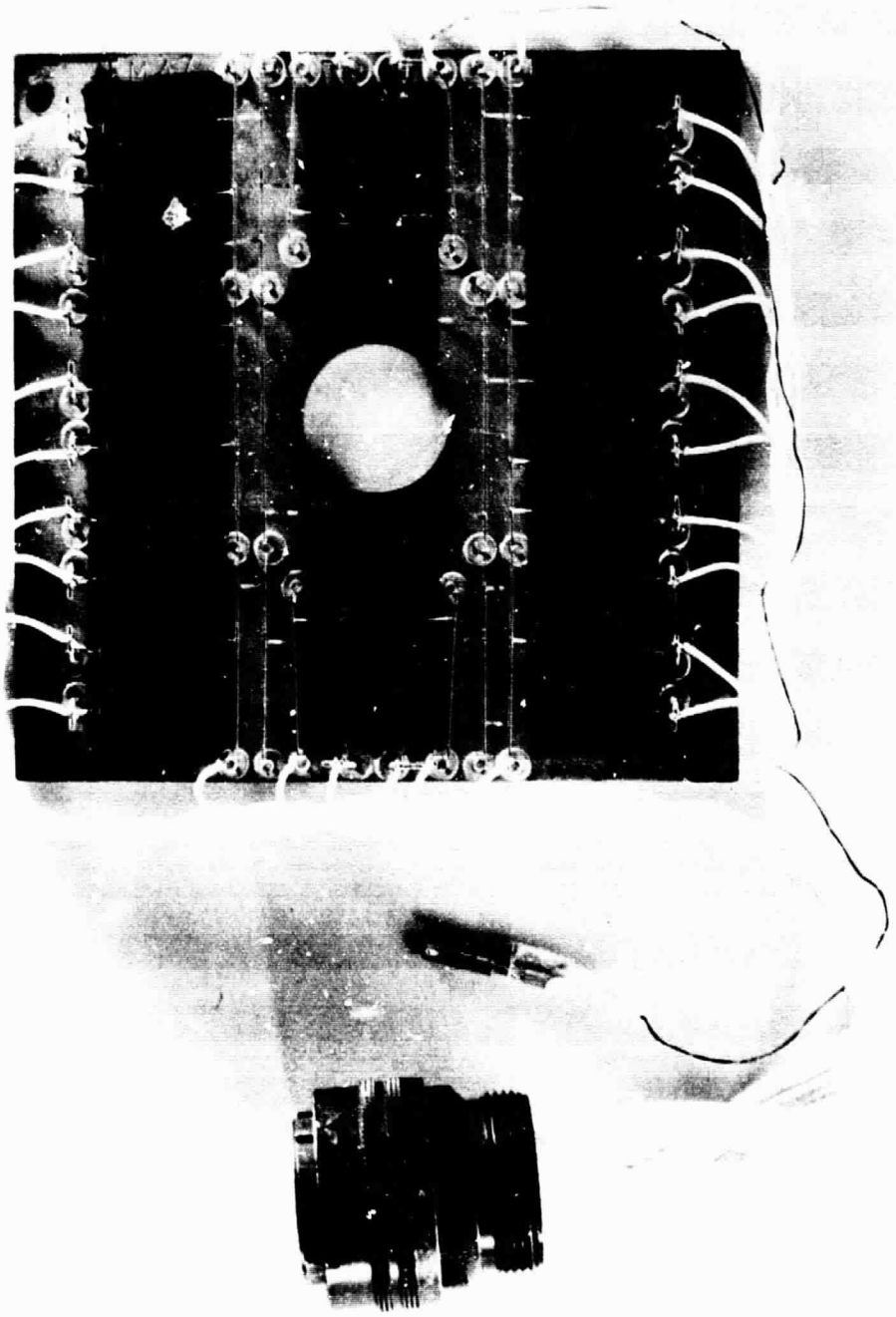

Figure A-2. Test Plate

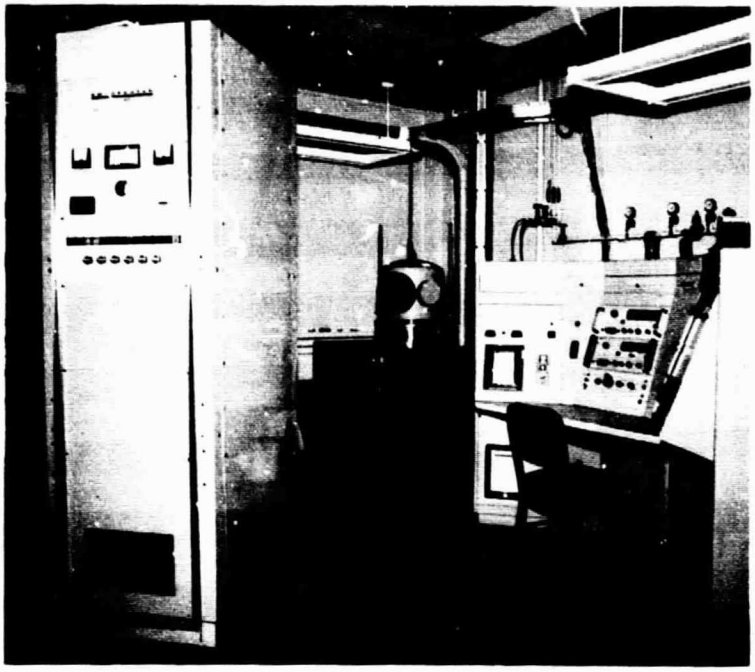

Figure A-3. Solar Cell Characterization Facility

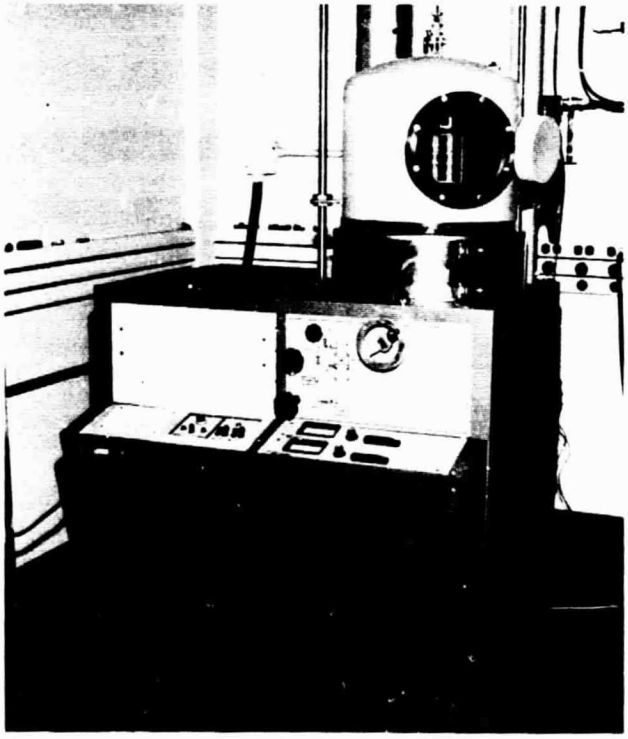

Figure A-4. Solar Cell Environmental Test Chamber