JPL PUBLICATION 78-15 VOLUME VII

Characterization of Solar Cells for Space Applications

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

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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 of Diane Engler who operates the program and produces the plots.

ABSTRACT

Electrical characteristics of Spectrolab HEWAC BSF, textured, 10 ohm-cm, 225 micron solar cells are presented in graphical and tabular format as a function of solar illumination intensity and temperature.

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Figures

Figures (contd)

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 the 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, identified by a volume number, each devoted to a particular type of solar cell. Previously published reports with their associated solar cell descriptions, are listed in the bibliography to this document. 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 Spectrolab HEWAC .0225 cm (9 mil) thick solar cell which is under development as a high-efficiency wraparound cell.

SECTION II

CELL DESCRIPTION

The cells reported here are advanced development cells manufactured by Spectrolab for NASA-Lewis Research Center Contract No. NAS3-20065. They were fabricated from crucible grown, P-type silicon, boron-doped to a nominal resistivity of 10 ohm-cm. The cells are 2 x 4 x 0.0225 cm (9 mils) thick. The front surfaces are textured and the junctions are formed by diffusion to a depth of 0.15 microns. A glass dielectric compound is screen printed on the edges of the cells and the front contacts are wrapped around this dielectric to connect with the contact pads on the rear cell surface. The front contacts are evaporated Cr-Pd-Ag, and the rear contacts are Al-Cr-Pd-Ag. The aluminum of the rear contact system is formed using a screen-printed paste which is then fired to form a back surface field (BSF). The subsequent Cr-Pd-Ag contacts are evaported.

SECTION III

TEST PROGRAM

The solar cells were mounted on a copper test plate using RTV 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 a 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 which uniformly distributes a relatively collimated light beam at specific distances from a 2.50-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 ±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 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 post test ambient measurements were performed daily to ensure that the accuracy and stability of the test equipment and the test specimens themselves were maintained within ±2% during the course of the testing program.

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 polynomial for most parameters. The curve factors, AMO efficiencies, V_{oc} and V_{mp} data points are not fit but are 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 the coefficients as a function of temperature, with intensity as a parameter, as shown in Figures 15 through 18.

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 ^oC.

(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 m (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}, I_{mp}, V_{mp}, P_{max}, CF, and efficiency at each intensity-temperature combination. For each parameter, at each intensity-temperature combination, the standard deviation is presented to provide estimates of statistical validity. All efficiency, current, and power output data are on the basis of unit area derived by dividing measured output by total cell area.

The Spectrolab HEWAC cells are experimental cells not currently in production. Since the time of fabrication of the cells reported here, NASA-Lewis Research Laboratory has continued to fund the development of similar, but much thinner, cells. As these thinner wraparound cells become available they will be tested and reported on in the future.

BIBLIOGRAPHY

PREVIOUS VOLUMES

Characterization of Solar Cells for Space Applications, JPL Publication 78-15

Volume I. Electrical Characteristics of OCLI Violet Solar Cells as a Function of Intensity and Temperature, March 1978.

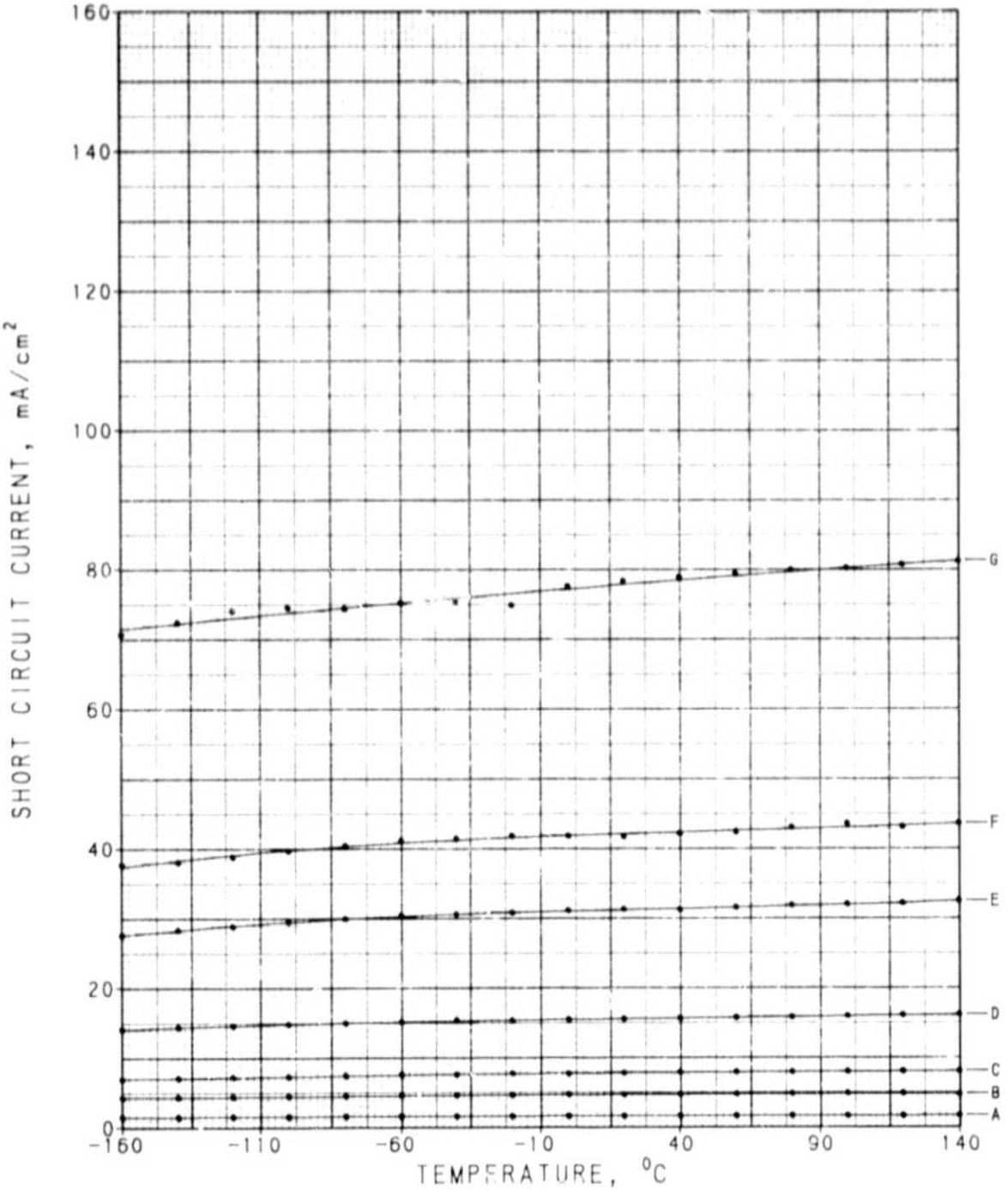
Volume II. Electrical Characteristics of Solarex 50 Micron Solar Cells as a Function of Intensity and Temperature, August 1978.

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, Nov. 1, 1978.

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

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.



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

SPECTROLAB HEWAC WRAPAROUND
N/P BSF 10 OHM-CM CG SILICON
TEXTURED SURFACE
2 X 4 X .0225 CM
CR-PD-AG CONTACTS
TA2O5 AR COATING
NO COVERSLIDE
SAMPLE SIZE 6

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

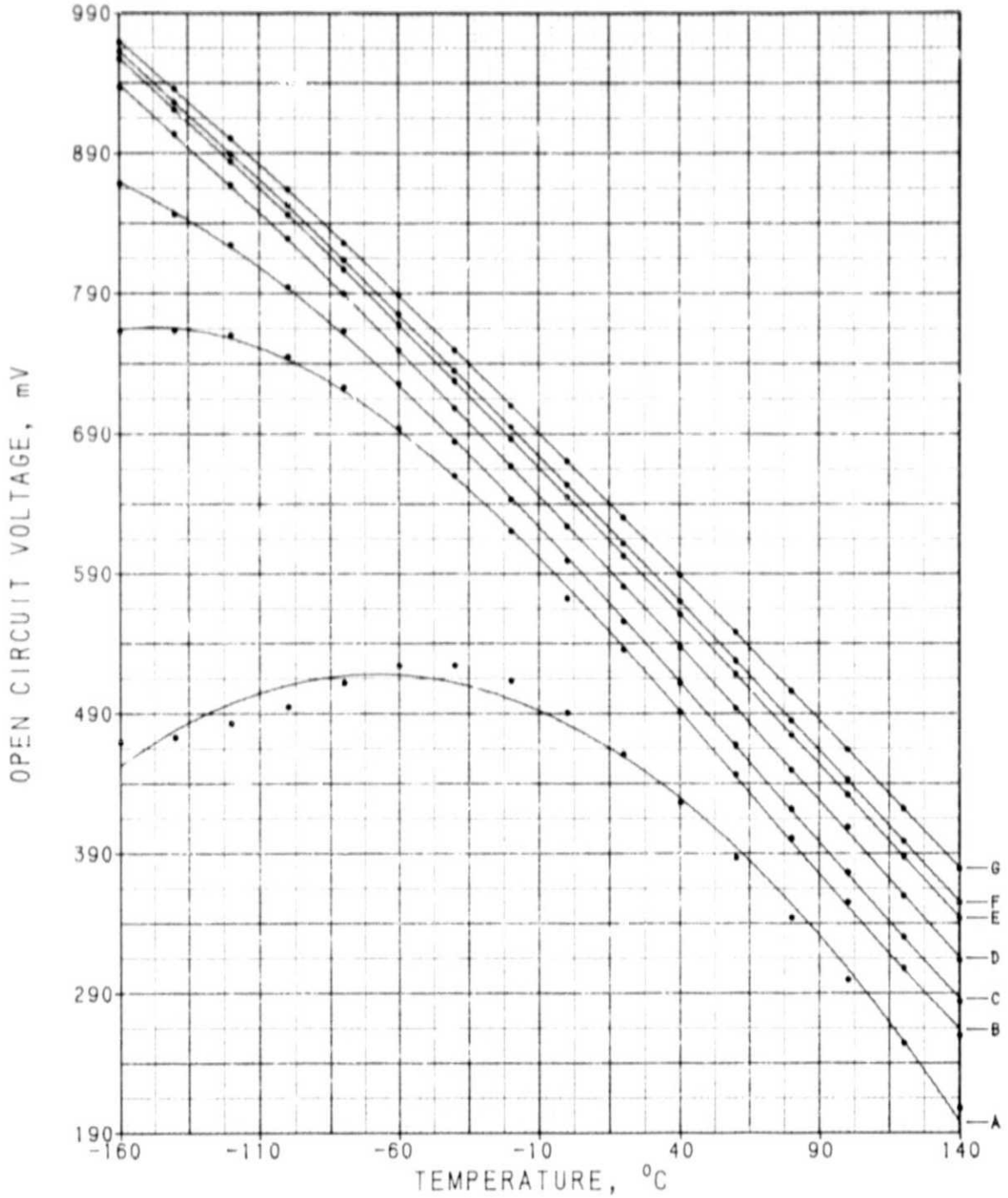
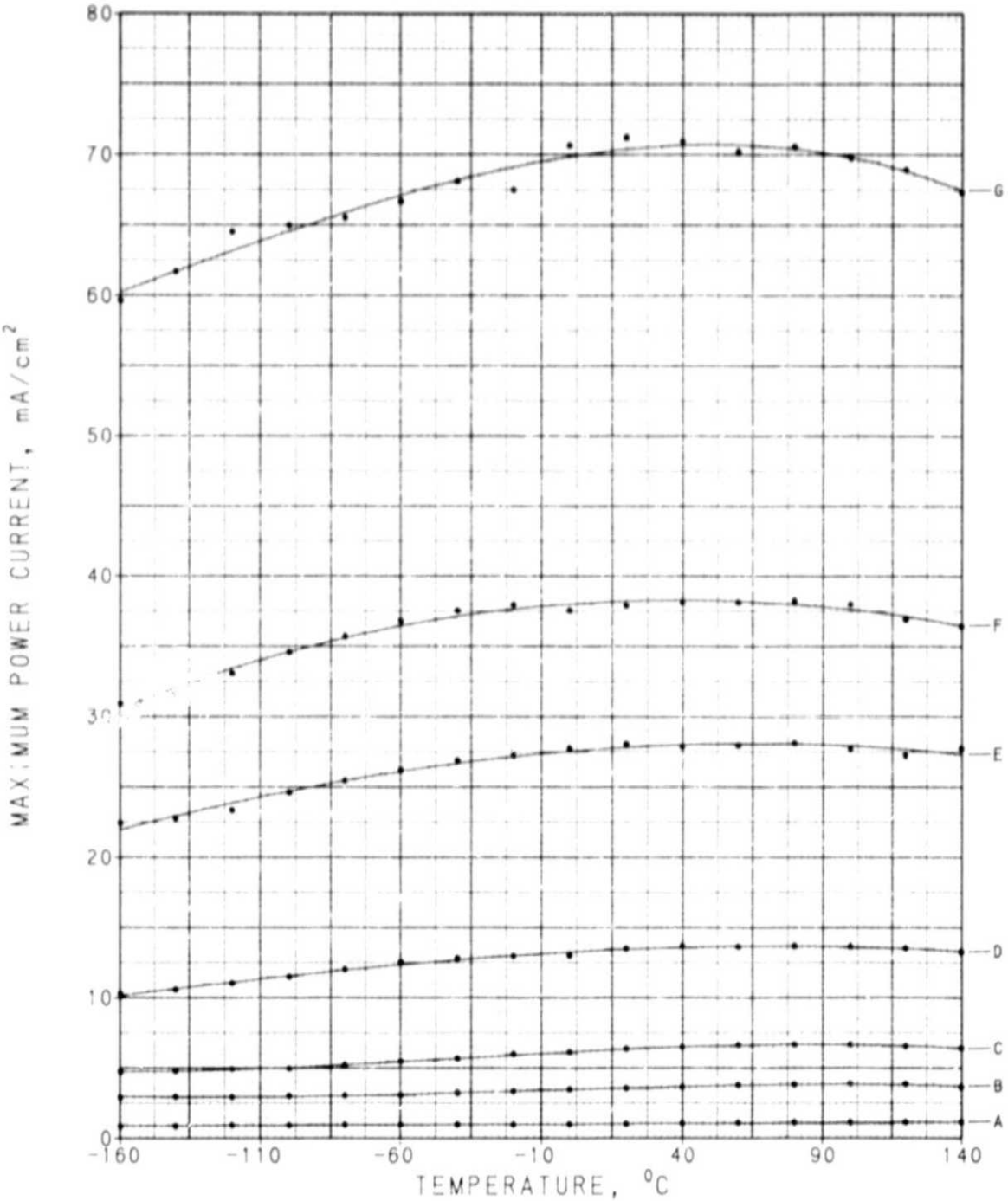


Figure 2. Average V_{oc} as a Function of Temperature



ID	mW/cm²
A	5.0
B	15.0
C	25.0
D	50.0
E	100.0
F	13..3
G	250.0

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TA2O5 AR COATING
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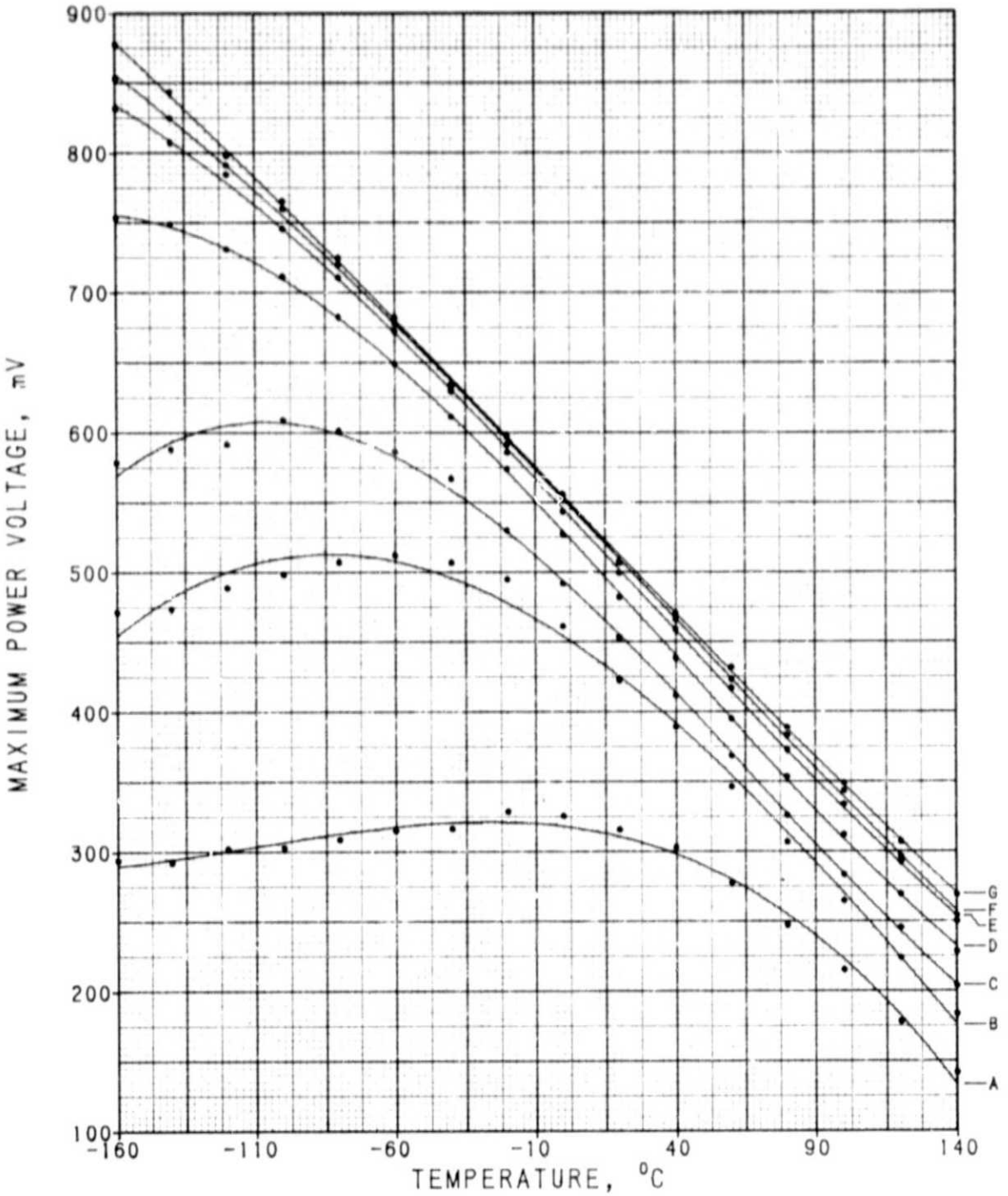
SAMPLE SIZE 6

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



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

SPECTROLAB HEWAC WRAPAROUND
N/P BSF 10 OHM-CM CG SILICON
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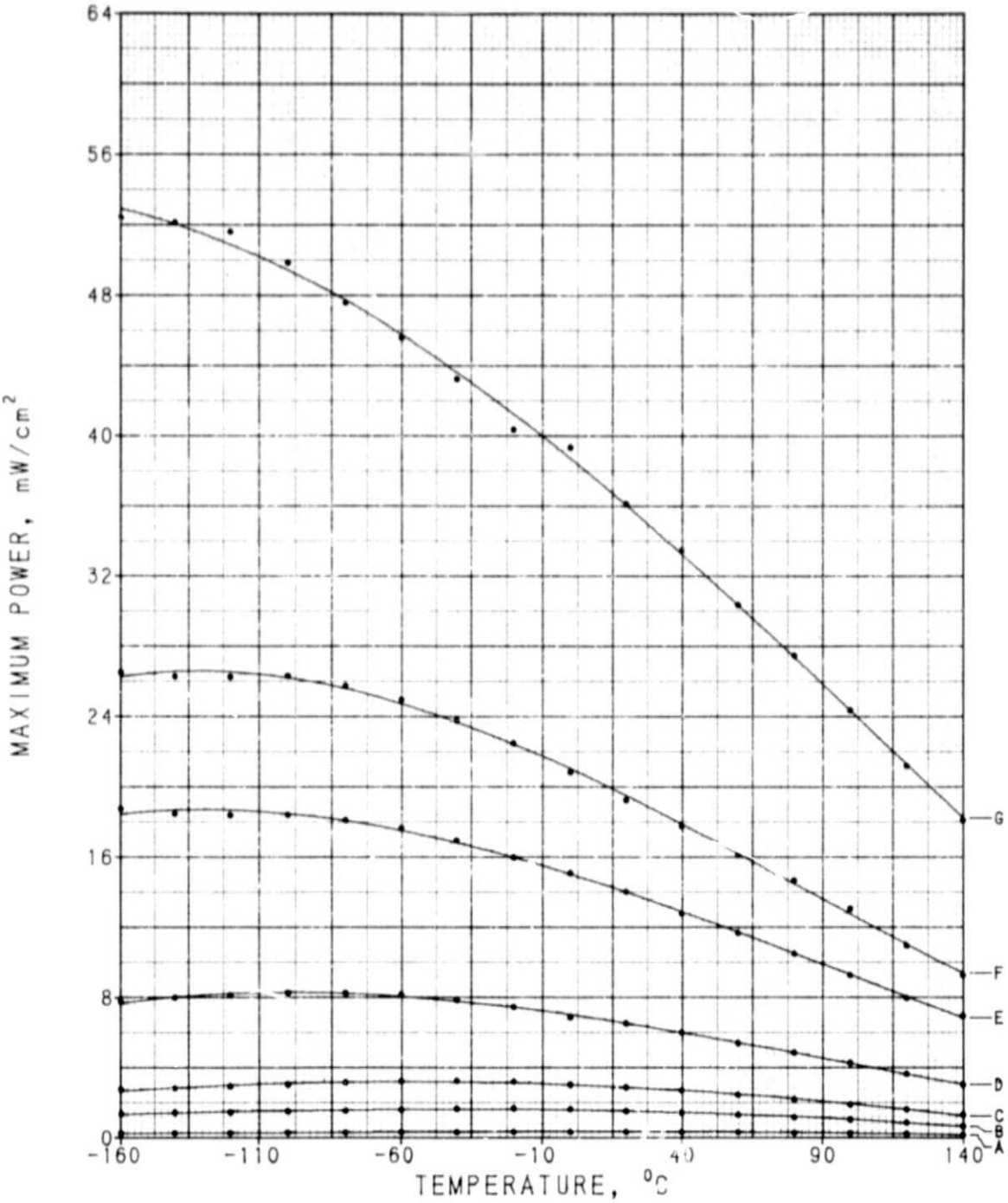
2 X 4 X .0225 CM
CR-PD-AG CONTACTS
TA205 AR COATING
NO COVERSLIDE
SAMPLE SIZE 6

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

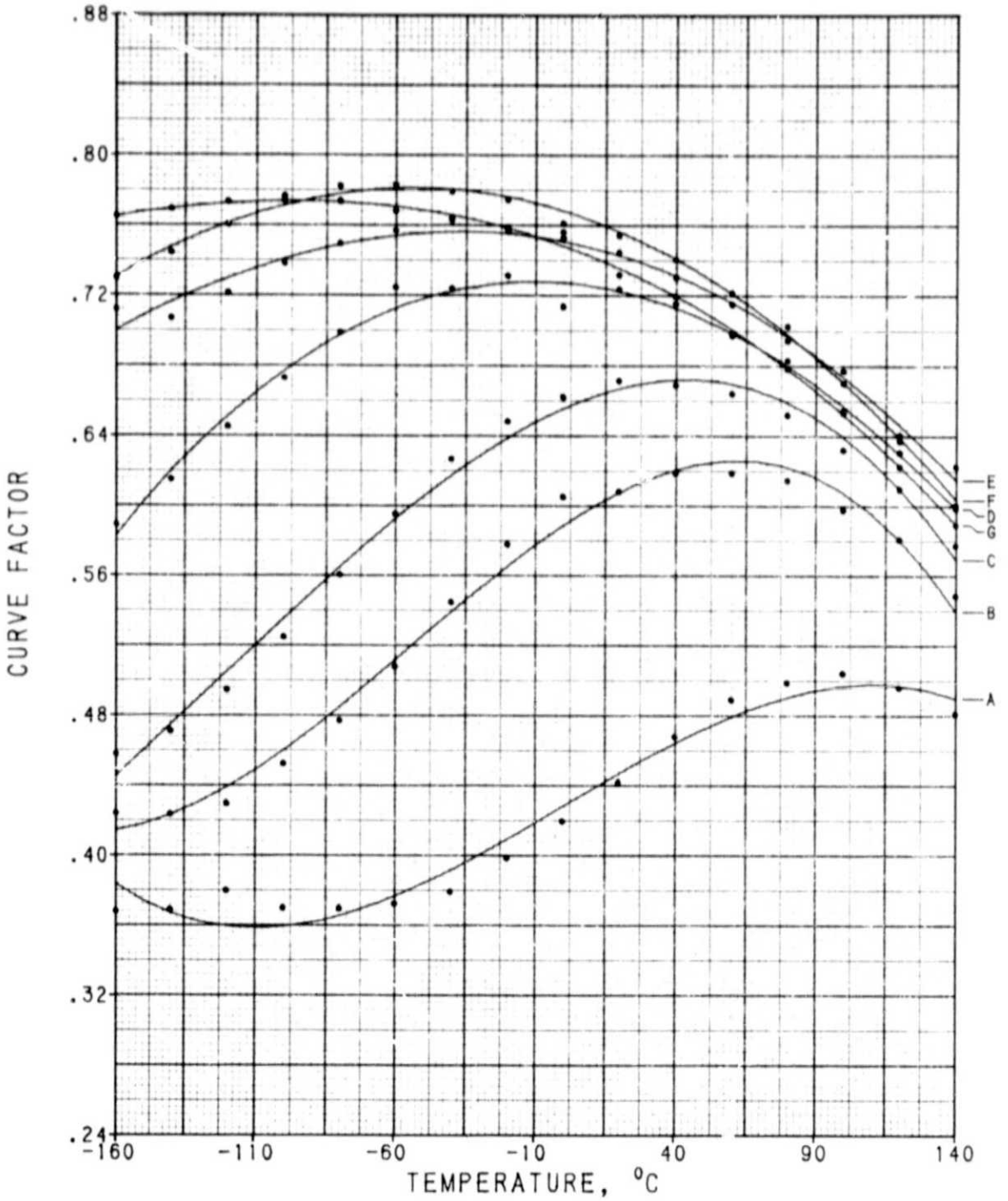


Figure 6. Average Curve Factor as a Function of Temperature

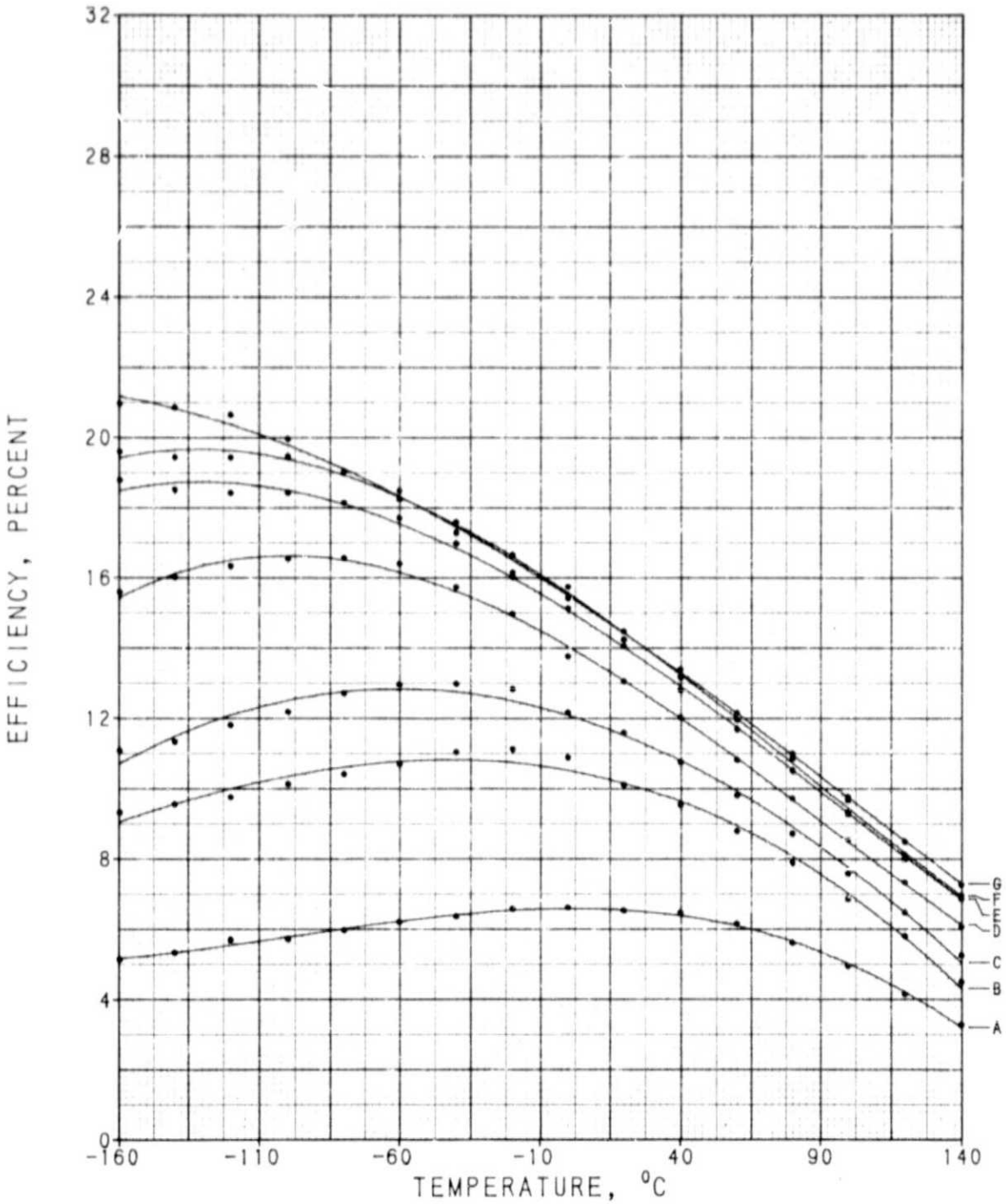


Figure 7. Average AMO Efficiency as a Function of Temperature

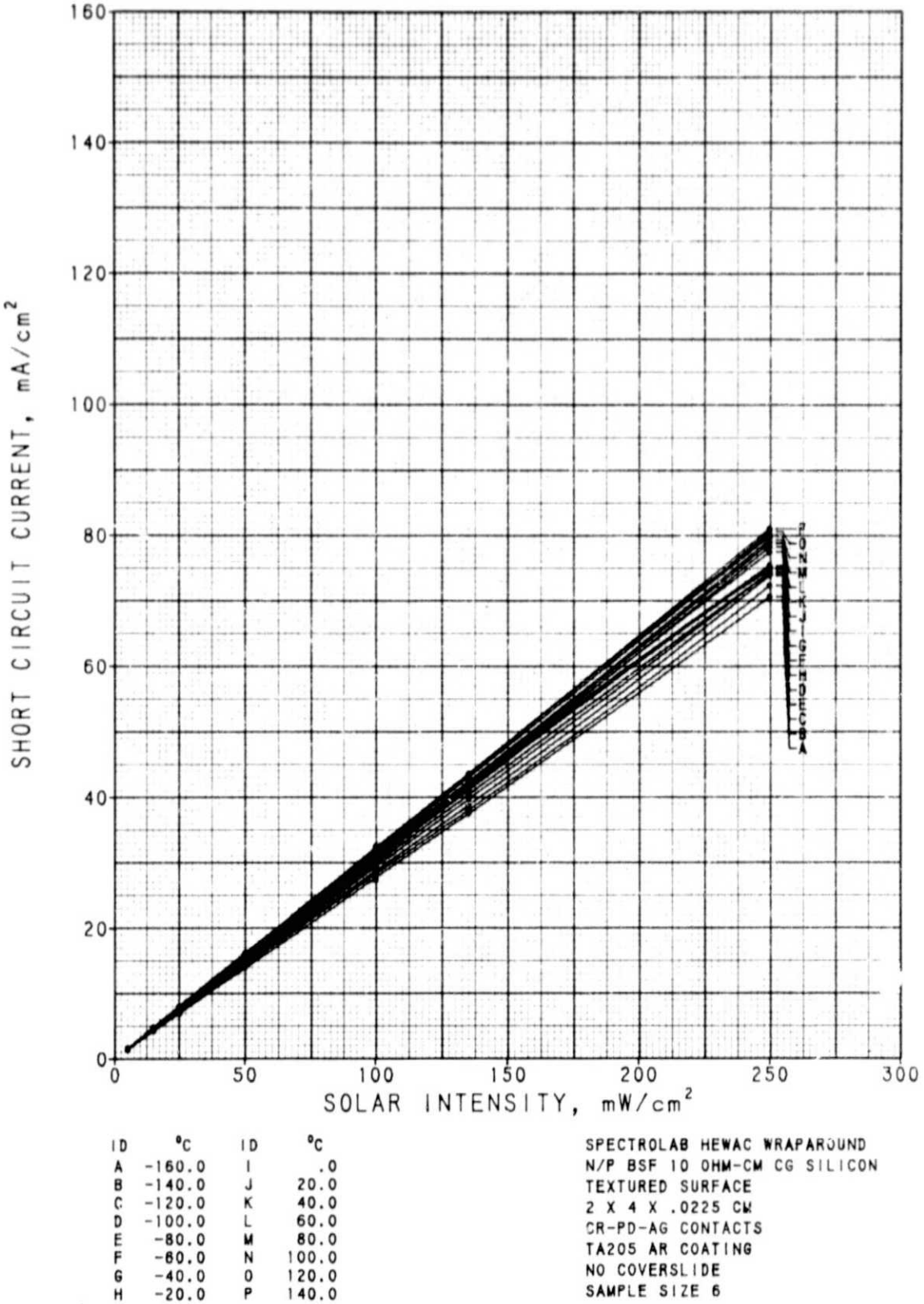
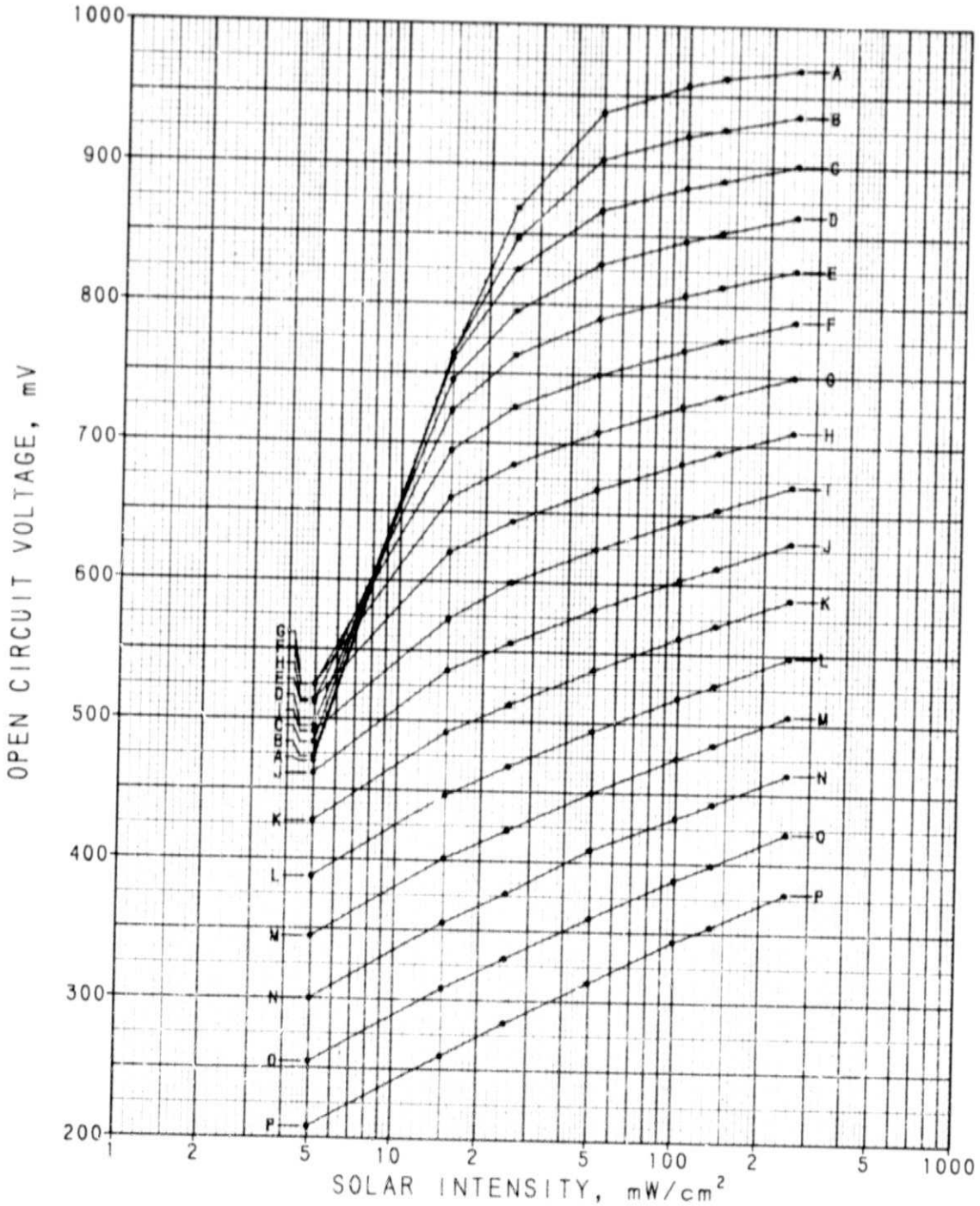


Figure 8. Average I_{sc}/cm^2 as a Function of Intensity



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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

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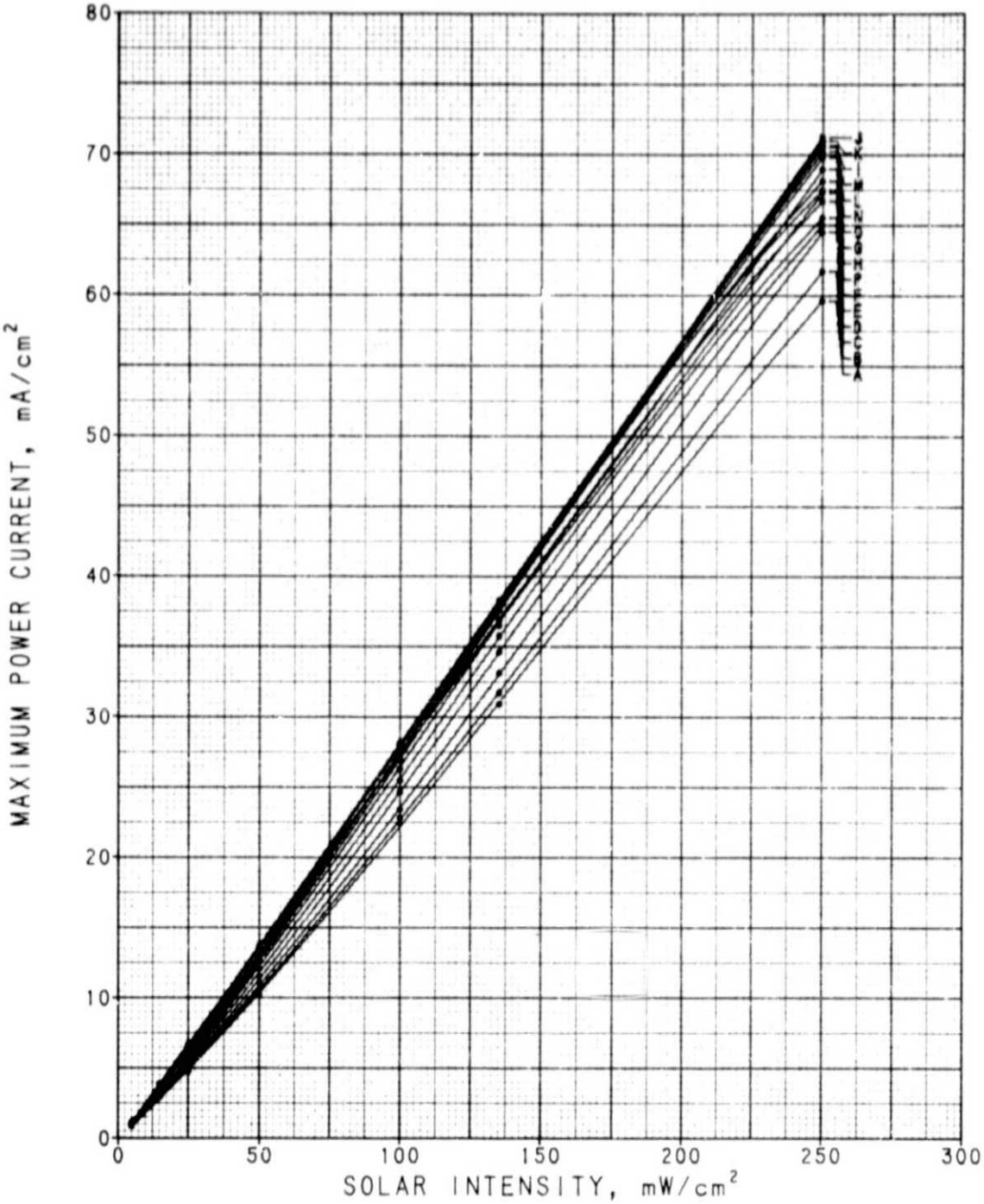
Figure 9. Average V_{oc} as a Function of Intensity



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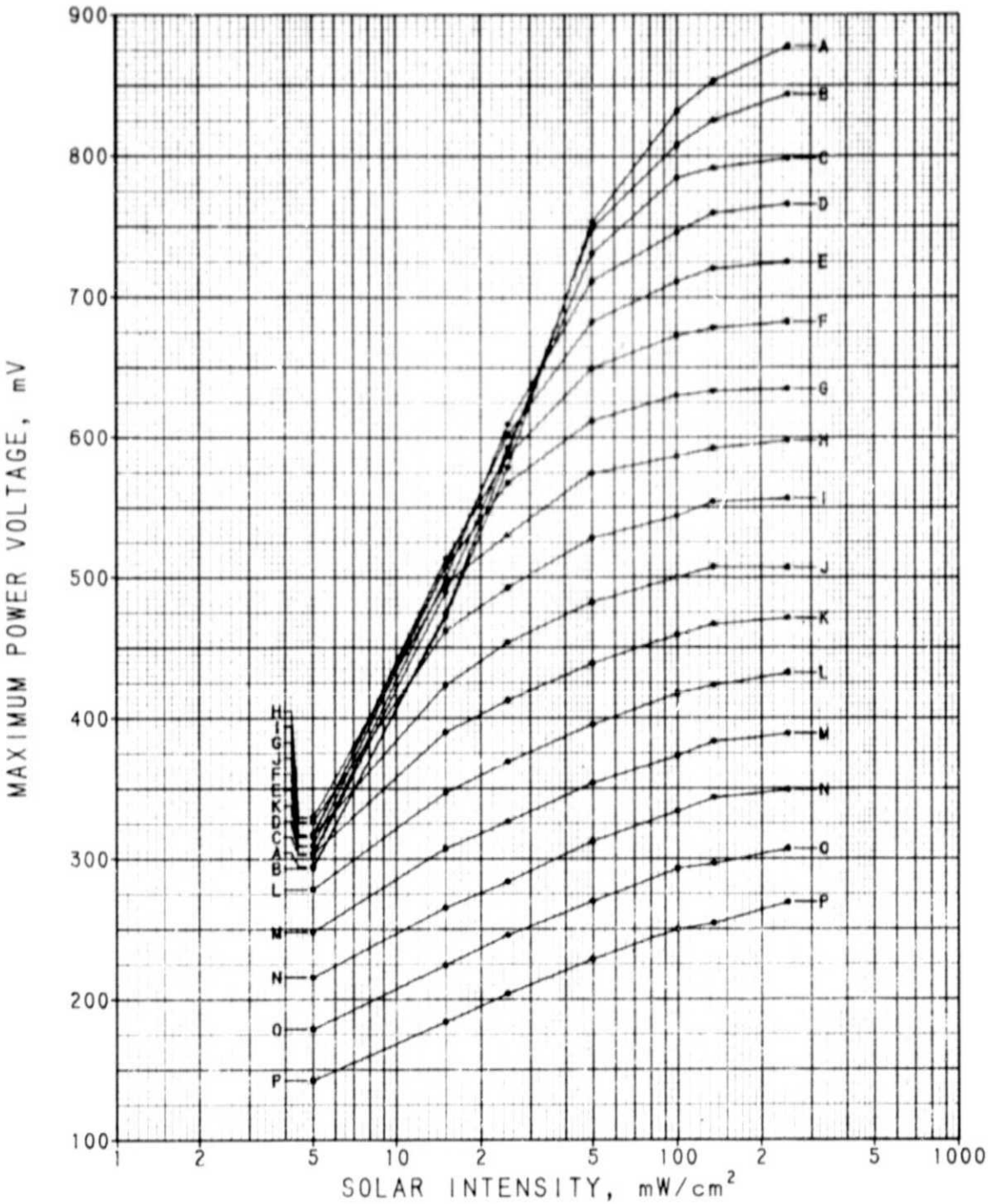
Figure 10. Average I_{mp}/cm^2 as a Function of Intensity



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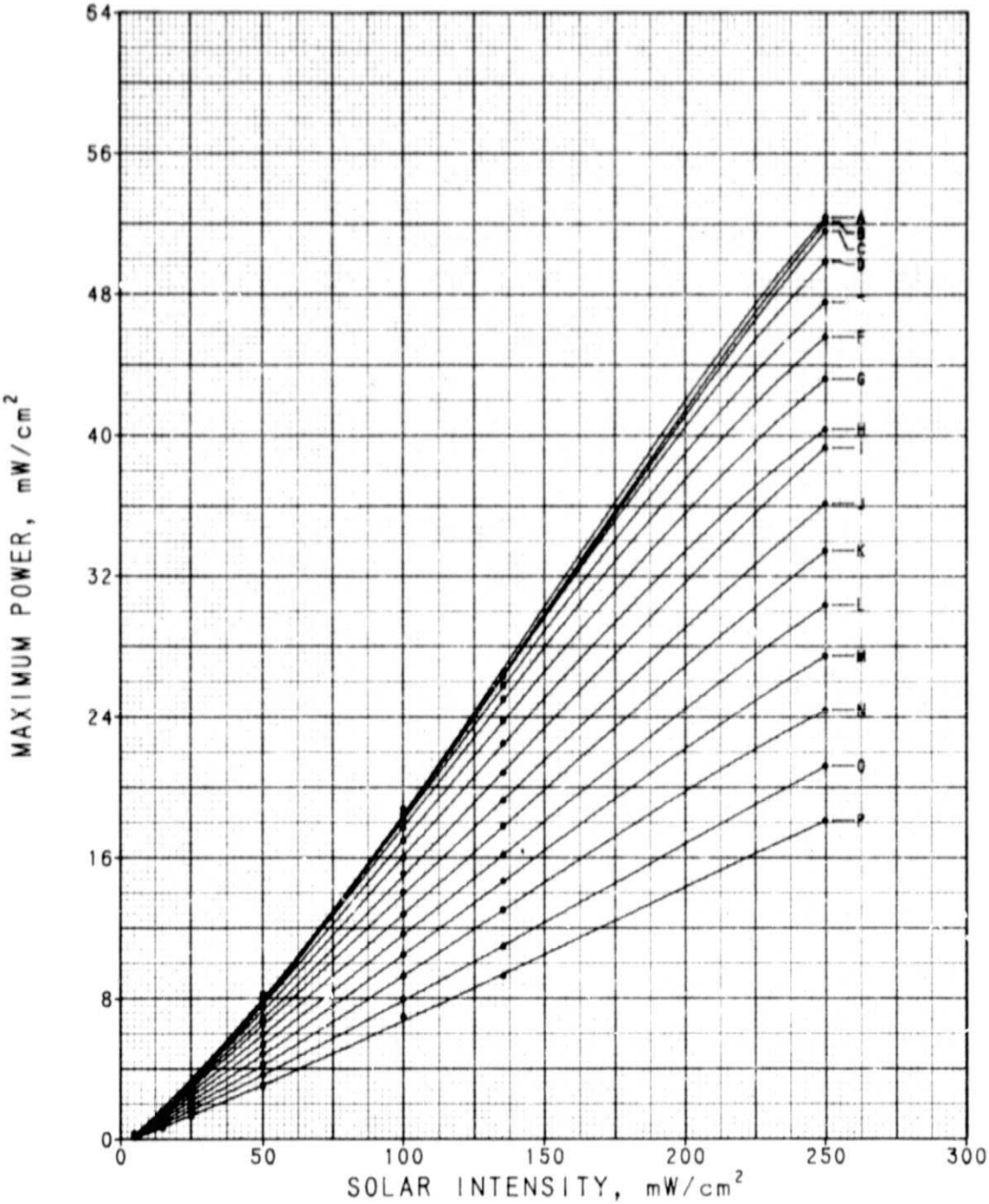
Figure 11. Average V_{mp} as a Function of Intensity



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

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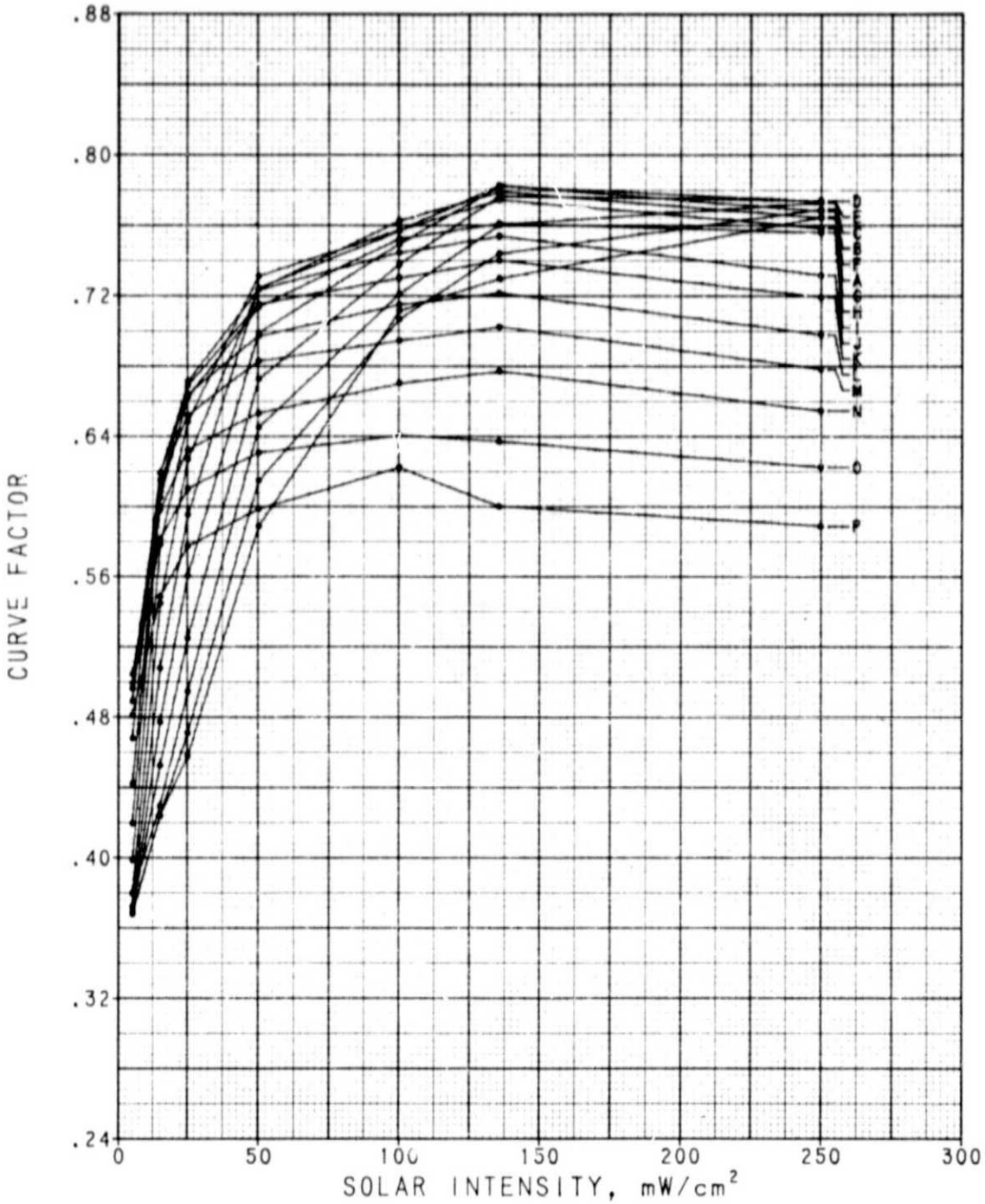
Figure 12. Average P_{max}/cm^2 as a Function of Intensity



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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
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G	-40.0	O	120.0
H	-20.0	P	140.0

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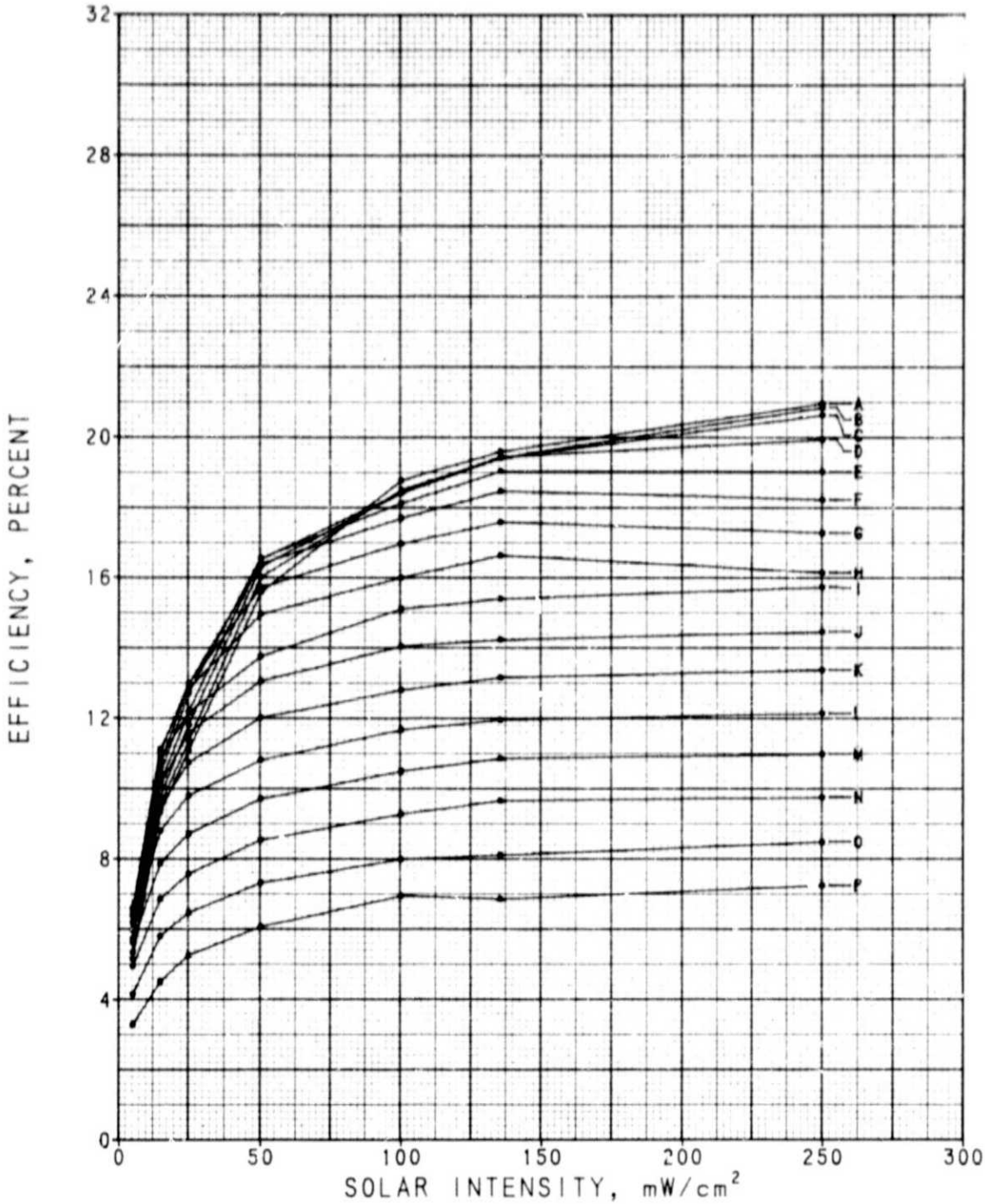
Figure 13. Average Curve Factor as a Function of Intensity



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B	-140.0	J	20.0
C	-120.0	K	40.0
D	-100.0	L	60.0
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G	-40.0	O	120.0
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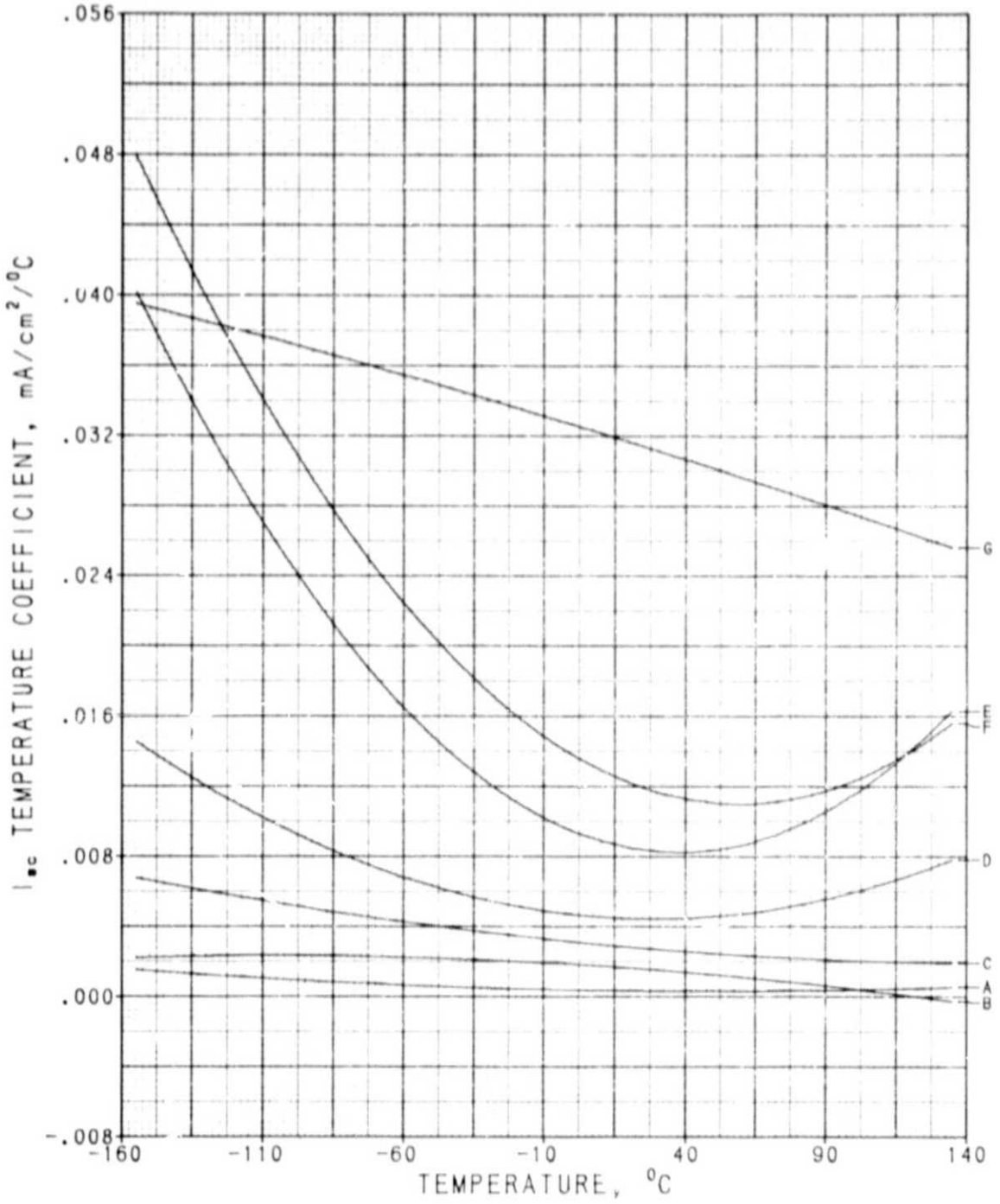
Figure 14. Average AMO Efficiency as a Function of Intensity



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D	50.0
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G	250.0

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Figure 15. I_{sc} Temperature Coefficient

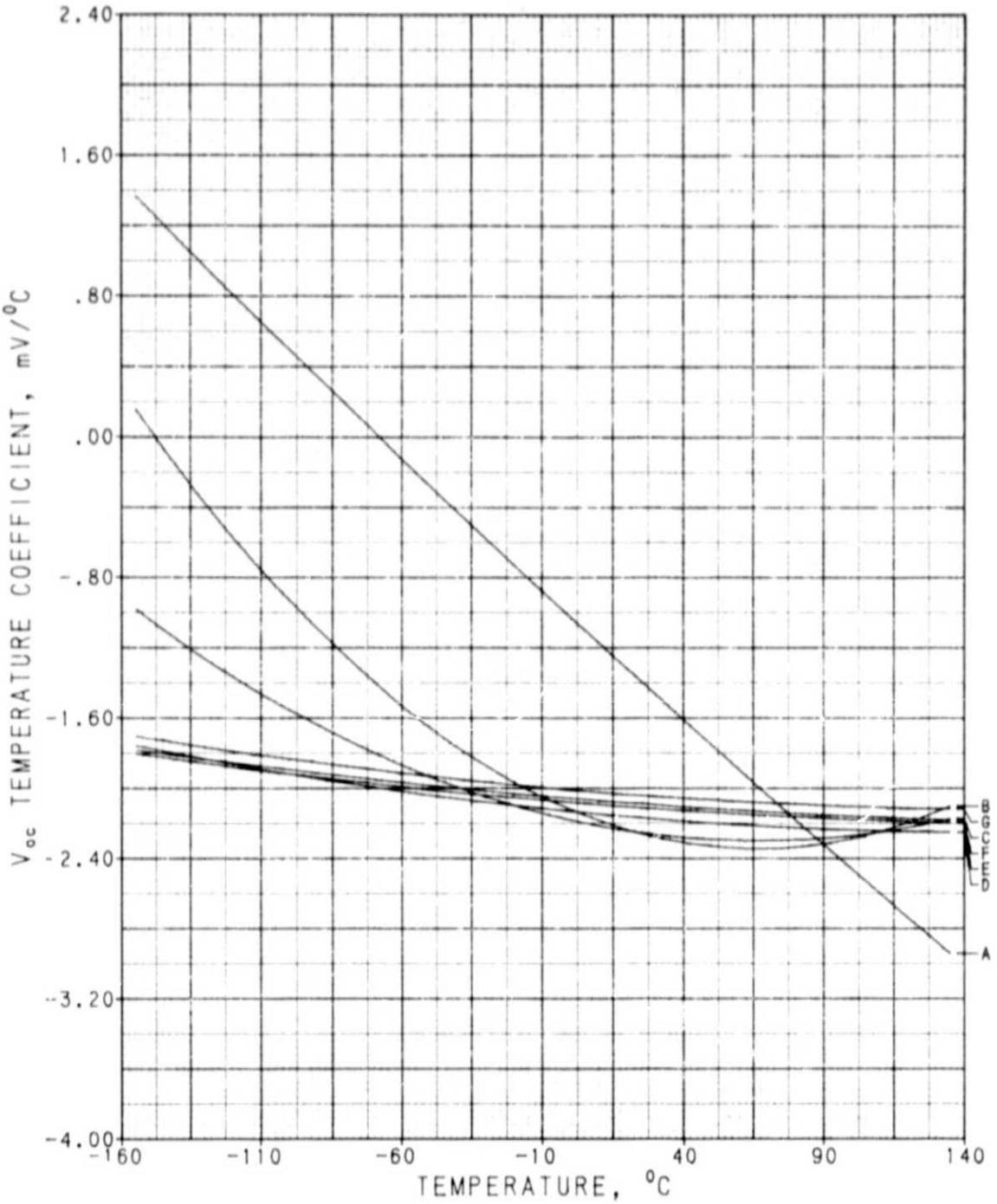

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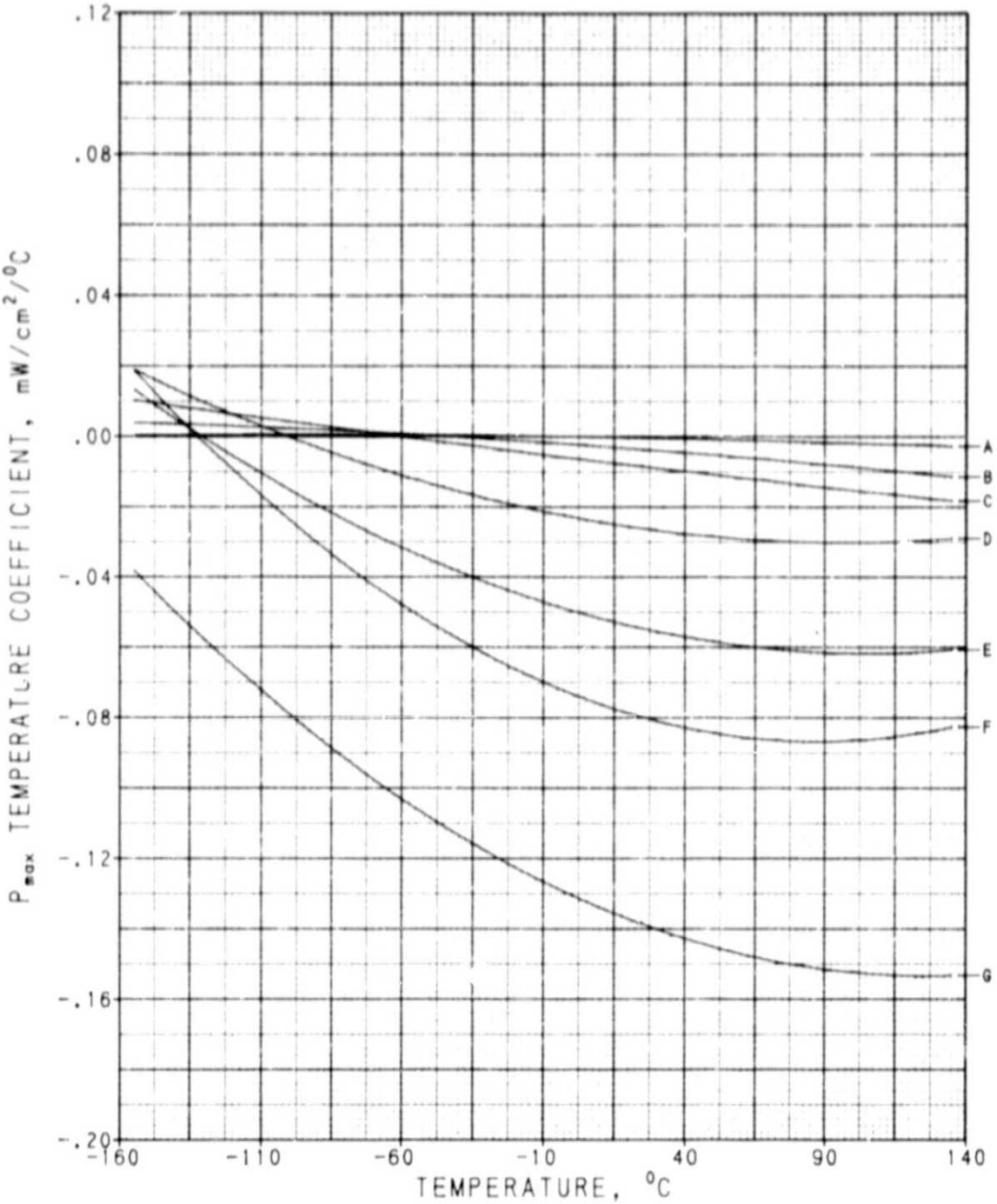
Figure 16. V_{oc} Temperature Coefficient



ID	mW/cm²
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D	50.0
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G	250.0

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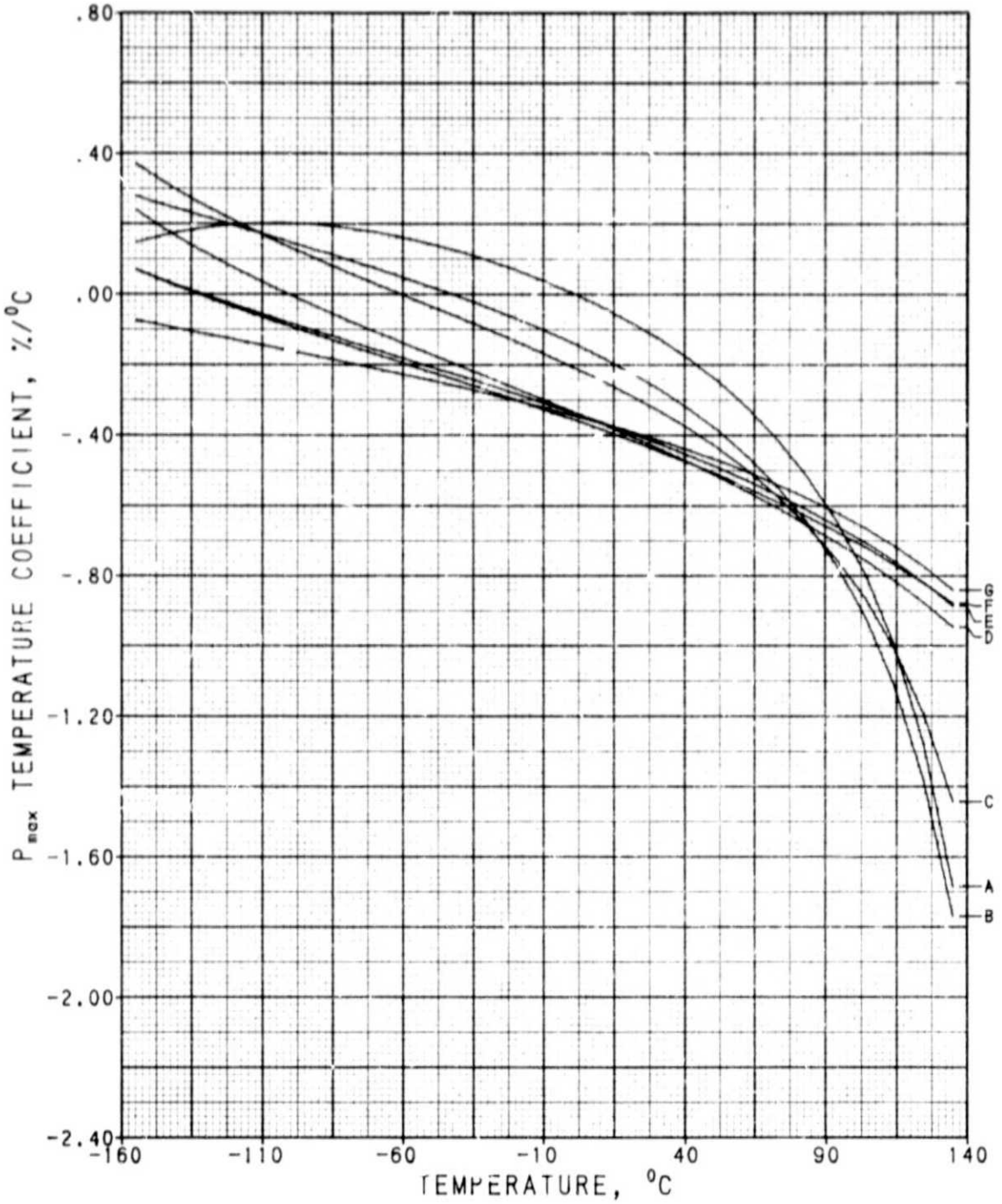
SAMPLE SIZE 6

Figure 17. Absolute P_{max} Temperature Coefficient



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SAMPLE SIZE 6

Figure 18. Percent P_{max} Temperature Coefficient

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

SPECTROLAB HEMAC WRAPAROUND
N/P BSF 10 OHM•CM CG SILICON
TEXTURED SURFACE
2 X ~ X .0225 CM
CR•PD•AG CONTACTS
TA2O5 AR COATING
NO COVERSLIDE
SAMPLE SIZE 6

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	1.45	4.28	6.94	14.07	27.54	37.70	70.67
	(.02)	(.04)	(.12)	(.20)	(.29)	(.59)	(1.23)
-140.00	1.48	4.38	7.07	14.37	28.39	38.08	72.38
	(.02)	(.04)	(.14)	(.22)	(.20)	(.68)	(.74)
-120.00	1.52	4.44	7.21	14.56	28.87	38.80	74.01
	(.02)	(.05)	(.14)	(.21)	(.28)	(.55)	(1.25)
-100.00	1.52	4.47	7.29	14.80	29.51	39.72	74.47
	(.01)	(.04)	(.12)	(.20)	(.26)	(.60)	(1.11)
-80.00	1.54	4.50	7.42	14.98	29.95	40.45	74.35
	(.02)	(.05)	(.14)	(.19)	(.26)	(.36)	(1.55)
-60.00	1.56	4.52	7.50	15.09	30.44	41.18	75.16
	(.02)	(.04)	(.13)	(.15)	(.27)	(.35)	(1.28)
-40.00	1.58	4.59	7.56	15.34	30.59	41.53	75.43
	(.01)	(.05)	(.12)	(.17)	(.32)	(.46)	(1.20)
-20.00	1.58	4.64	7.69	15.33	30.79	41.84	74.87
	(.02)	(.04)	(.13)	(.20)	(.26)	(.50)	(1.43)
.00	1.58	4.70	7.66	15.44	31.12	41.86	77.56
	(.02)	(.04)	(.11)	(.20)	(.31)	(.39)	(.89)
20.00	1.59	4.65	7.76	15.53	31.30	41.74	78.34
	(.02)	(.07)	(.17)	(.19)	(.21)	(.38)	(.95)
40.00	1.60	4.70	7.84	15.63	31.25	42.19	78.90
	(.02)	(.04)	(.13)	(.20)	(.28)	(.58)	(.90)
60.00	1.61	4.77	7.89	15.69	31.54	42.45	79.37
	(.02)	(.05)	(.1	(.20)	(.22)	(.58)	(.93)
80.00	1.62	4.79	7.9	15.81	31.84	43.09	79.97
	(.02)	(.06)	(.14)	(.24)	(.19)	(.51)	(1.06)
100.00	1.63	4.84	7.95	15.99	32.03	43.58	80.23
	(.02)	(.05)	(.14)	(.24)	(.28)	(.35)	(.84)
120.00	1.64	4.86	8.03	16.13	32.19	43.15	80.69
	(.02)	(.03)	(.14)	(.21)	(.44)	(.85)	(1.22)
140.00	1.64	4.73	8.03	16.16	32.52	43.59	81.16
	(.02)	(.04)	(.13)	(.20)	(.32)	(.89)	(1.31)

NOTE: STANDARD DEVIATIONS ARE GIVEN IN PARENTHESES.

Table 2. Average Open-Circuit Voltage, mV

SPECTROLAB MEWAC WRAPAROUND
N/P BSF 10 OHM-CM CG SILICON
TEXTURED SURFACE
2 X 4 X .0225 CM
CR-PD-AG CONTACTS
TA2O5 AR COATING
NO COVERSLIDE
SAMPLE SIZE 6

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	469.83	763.13	868.37	937.25	957.55	962.85	969.20
	(101.96)	(111.26)	(86.22)	(18.52)	(3.02)	(1.26)	(2.91)
-140.00	473.10	763.98	846.77	904.05	921.35	926.37	936.16
	(101.11)	(106.64)	(67.46)	(11.19)	(2.70)	(1.82)	(1.45)
-120.00	483.18	760.23	824.60	867.35	884.37	889.67	901.02
	(102.21)	(91.46)	(48.11)	(8.13)	(2.51)	(1.60)	(1.68)
-100.00	495.20	744.97	794.80	829.13	846.10	852.90	864.54
	(103.30)	(71.43)	(29.90)	(5.77)	(2.12)	(1.67)	(1.94)
-80.00	512.15	723.12	763.08	790.05	807.48	813.97	826.30
	(104.94)	(49.81)	(16.42)	(4.23)	(2.08)	(1.77)	(2.50)
-60.00	524.87	694.25	725.82	749.57	768.05	775.35	789.24
	(101.25)	(32.55)	(10.65)	(3.76)	(1.82)	(2.12)	(2.30)
-40.00	524.65	660.25	684.58	708.32	727.62	735.22	749.62
	(89.34)	(19.54)	(7.34)	(3.16)	(1.90)	(1.88)	(2.23)
-20.00	513.65	620.87	643.37	667.08	686.58	694.98	710.20
	(72.61)	(12.91)	(5.69)	(2.91)	(1.69)	(2.06)	(2.67)
.00	491.00	572.62	599.73	624.20	645.17	653.92	670.86
	(56.24)	(21.58)	(4.90)	(2.65)	(1.89)	(1.87)	(2.58)
20.00	461.22	535.98	556.25	580.95	602.90	611.93	630.40
	(40.24)	(7.66)	(4.37)	(2.50)	(1.48)	(2.07)	(2.96)
40.00	426.85	491.70	512.17	537.53	561.25	570.33	589.50
	(27.42)	(6.68)	(3.80)	(2.72)	(2.05)	(2.28)	(2.96)
60.00	387.38	446.65	467.97	494.05	518.18	528.00	548.22
	(19.12)	(5.50)	(3.54)	(2.88)	(2.03)	(2.35)	(3.18)
80.00	344.53	401.38	422.23	449.82	475.08	485.30	506.52
	(13.88)	(4.99)	(3.49)	(2.86)	(2.03)	(2.34)	(3.18)
100.00	300.05	355.52	376.83	409.20	432.20	442.87	464.38
	(10.64)	(4.66)	(3.60)	(9.82)	(2.20)	(2.42)	(3.49)
120.00	254.48	308.13	330.37	359.82	387.97	399.00	422.26
	(8.54)	(4.44)	(2.80)	(3.30)	(2.44)	(2.25)	(3.41)
140.00	208.02	259.97	283.88	313.77	343.62	354.90	379.26
	(6.22)	(4.00)	(3.36)	(2.65)	(1.94)	(2.39)	(2.43)

NOTE: STANDARD DEVIATIONS ARE GIVEN IN PARENTHESES.

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

SPECTROLAB HEWAC WRAPAROUND
N/P BSF 10 OHM-CM CG SILICON
TEXTURED SURFACE
2 X 4 X .0225 CM
CR-PD-AG CONTACTS
TA2O5 AR COATING
NO COVERSLIDE
SAMPLE SIZE 6

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	.85	2.93	4.77	10.27	22.44	30.94	59.65
	(.08)	(.26)	(.22)	(.84)	(2.60)	(3.22)	(5.34)
-140.00	.89	2.99	4.80	10.61	22.81	31.73	61.72
	(.08)	(.26)	(.22)	(1.00)	(1.69)	(3.46)	(5.00)
-120.00	.93	2.97	4.97	11.08	23.42	33.10	64.52
	(.08)	(.23)	(.23)	(1.04)	(1.91)	(3.30)	(4.60)
-100.00	.92	3.02	4.98	11.54	24.67	34.60	65.02
	(.08)	(.20)	(.26)	(1.10)	(1.65)	(3.06)	(5.82)
-80.00	.95	3.06	5.26	12.07	25.48	35.73	69.55
	(.09)	(.18)	(.26)	(1.11)	(1.69)	(2.58)	(5.65)
-60.00	.97	3.11	5.50	12.59	26.29	36.83	66.72
	(.08)	(.22)	(.37)	(.95)	(1.45)	(2.45)	(5.48)
-40.00	.99	3.25	5.70	12.83	26.94	37.56	68.15
	(.09)	(.27)	(.43)	(.93)	(1.37)	(2.28)	(5.23)
-20.00	.99	3.35	6.03	13.00	27.29	38.00	67.50
	(.08)	(.31)	(.46)	(.85)	(1.21)	(2.00)	(4.63)
.00	1.00	3.51	6.17	13.02	27.79	37.58	70.70
	(.10)	(.33)	(.45)	(.68)	(.85)	(2.01)	(3.39)
20.00	1.02	3.57	6.39	13.54	28.10	37.94	71.27
	(.10)	(.30)	(.39)	(.47)	(.77)	(1.10)	(3.10)
40.00	1.05	3.66	6.51	13.70	27.92	38.17	71.00
	(.11)	(.29)	(.35)	(.44)	(.64)	(.77)	(3.20)
60.00	1.09	3.80	6.65	13.67	28.00	38.19	70.25
	(.12)	(.21)	(.27)	(.38)	(.65)	(1.15)	(2.84)
80.00	1.12	3.84	6.68	13.72	28.15	38.29	70.62
	(.11)	(.21)	(.21)	(.39)	(.54)	(.76)	(2.21)
100.00	1.14	3.88	6.67	13.66	27.79	38.02	69.82
	(.09)	(.16)	(.21)	(.28)	(.38)	(.85)	(2.21)
120.00	1.16	3.88	6.59	13.56	27.29	36.94	68.97
	(.09)	(.13)	(.19)	(.38)	(.88)	(.81)	(2.25)
140.00	1.15	3.66	6.44	13.27	27.79	36.48	67.35
	(.07)	(.12)	(.16)	(.33)	(1.92)	(.80)	(3.99)

NOTE: STANDARD DEVIATIONS ARE GIVEN IN PARENTHESES.

Table 4. Average Maximum Power Voltage, mV

SPECTROLAB HEHAC WRAPAROUND
N/P 8SF 10 OHM-CM CG SILICON
TEXTURED SURFACE
2 X 4 X .0225 CM
CR-PD-AG CONTACTS
TA2O5 AR COATING
NO COVERSLIDE
SAMPLE SIZE 6

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	294.50	471.83	578.67	753.33	832.00	853.50	877.60
	(87.99)	(82.46)	(85.19)	(112.54)	(70.83)	(54.86)	(39.13)
-140.00	293.17	474.00	588.50	749.00	808.00	825.33	843.60
	(87.63)	(83.89)	(88.42)	(99.13)	(54.00)	(41.84)	(32.32)
-120.00	302.67	489.17	592.17	731.50	785.00	791.67	798.40
	(81.69)	(85.99)	(87.97)	(82.99)	(30.76)	(34.06)	(36.94)
-100.00	303.50	498.83	609.50	712.00	745.83	760.00	766.00
	(80.64)	(93.00)	(84.82)	(60.79)	(27.74)	(21.50)	(28.32)
-80.00	309.17	507.67	601.83	682.83	711.17	720.33	725.00
	(75.67)	(87.92)	(77.33)	(45.44)	(13.91)	(22.25)	(24.22)
-60.00	315.67	512.67	586.83	649.50	672.67	678.17	682.40
	(73.93)	(85.34)	(56.34)	(35.37)	(14.33)	(17.20)	(21.87)
-40.00	317.17	507.50	567.50	612.00	630.00	633.00	634.60
	(65.61)	(70.10)	(39.50)	(23.67)	(12.39)	(18.63)	(22.30)
-20.00	329.17	495.33	530.33	574.50	586.50	592.17	597.60
	(69.16)	(48.75)	(26.34)	(22.60)	(11.26)	(18.71)	(20.72)
.00	326.17	461.67	492.33	527.83	543.67	554.17	556.40
	(62.78)	(40.69)	(17.37)	(11.11)	(9.99)	(16.35)	(18.23)
20.00	316.50	423.17	453.33	482.17	500.00	507.50	507.00
	(55.57)	(23.46)	(14.76)	(8.54)	(8.81)	(18.49)	(23.16)
40.00	303.50	389.67	412.50	438.67	458.83	466.67	471.00
	(43.34)	(13.63)	(8.87)	(5.54)	(7.70)	(18.36)	(11.00)
60.00	278.17	346.83	369.00	395.50	417.33	423.50	432.20
	(34.63)	(12.25)	(7.18)	(6.92)	(7.63)	(15.93)	(13.77)
80.00	247.83	307.50	326.33	354.00	373.17	383.50	389.00
	(23.09)	(8.22)	(6.25)	(4.56)	(6.37)	(17.93)	(12.86)
100.00	215.67	265.17	284.00	312.67	333.83	343.67	349.20
	(16.13)	(6.52)	(5.14)	(6.89)	(7.36)	(18.38)	(11.21)
120.00	178.67	224.33	245.83	270.00	293.17	297.00	307.40
	(9.37)	(7.61)	(4.67)	(4.56)	(7.03)	(8.00)	(10.83)
140.00	142.17	184.00	204.17	228.67	250.17	254.50	269.20
	(5.12)	(4.15)	(4.40)	(5.75)	(6.01)	(10.43)	(6.06)

NOTE: STANDARD DEVIATIONS ARE GIVEN IN PARENTHESES.

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

SPECTROLAB HEMAC WRAPAROUND
N/P BSF 10 OHM-CM CG SILICON
TEXTURED SURFACE
2 X 4 X .0225 CM
CR-PD-AG CONTACTS
TA2O5 AR COATING
NO COVERSLIDE
SAMPLE SIZE 6

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	.26	1.40	2.77	7.79	18.78	26.53	52.42
	(.10)	(.37)	(.51)	(1.69)	(3.67)	(4.29)	(6.07)
-140.00	.27	1.43	2.84	8.01	18.50	26.30	52.15
	(.10)	(.37)	(.52)	(1.70)	(2.51)	(4.11)	(5.67)
-120.00	.28	1.46	2.95	8.16	18.42	26.28	51.63
	(.10)	(.35)	(.53)	(1.62)	(2.11)	(3.56)	(5.74)
-100.00	.29	1.52	3.05	8.27	18.43	26.34	49.88
	(.10)	(.37)	(.54)	(1.45)	(1.85)	(2.90)	(5.72)
-80.00	.30	1.56	3.18	8.28	18.14	25.76	47.59
	(.10)	(.34)	(.52)	(1.29)	(1.50)	(2.39)	(5.19)
-60.00	.31	1.60	3.24	8.20	17.70	25.00	45.60
	(.10)	(.36)	(.49)	(1.02)	(1.26)	(2.12)	(4.82)
-40.00	.32	1.66	3.25	7.87	16.98	23.80	43.23
	(.09)	(.33)	(.44)	(.83)	(1.08)	(1.93)	(3.39)
-20.00	.33	1.67	3.21	7.48	16.01	22.52	40.37
	(.09)	(.30)	(.39)	(.74)	(.94)	(1.73)	(3.63)
.00	.33	1.63	3.04	6.88	15.11	20.85	39.35
	(.09)	(.28)	(.31)	(.46)	(.65)	(1.58)	(2.54)
20.00	.33	1.52	2.90	6.53	14.06	19.26	36.16
	(.08)	(.20)	(.26)	(.33)	(.56)	(1.10)	(2.67)
40.00	.32	1.43	2.69	6.0'	12.81	17.82	33.46
	(.08)	(.16)	(.19)	(.25)	(.47)	(.89)	(2.17)
60.00	.31	1.32	2.45	5.41	11.69	16.18	30.38
	(.07)	(.12)	(.13)	(.23)	(.42)	(.92)	(1.99)
80.00	.28	1.18	2.18	4.86	10.51	14.69	27.49
	(.05)	(.09)	(.10)	(.19)	(.36)	(.90)	(1.62)
100.00	.25	1.03	1.90	4.27	9.28	13.07	24.40
	(.04)	(.07)	(.09)	(.17)	(.27)	(.90)	(1.49)
120.00	.21	.87	1.62	3.66	8.00	10.97	21.22
	(.03)	(.05)	(.07)	(.15)	(.33)	(.43)	(1.37)
140.00	.16	.67	1.32	3.04	6.96	9.28	18.14
	(.02)	(.04)	(.04)	(.13)	(.57)	(.39)	(1.30)

NOTE: STANDARD DEVIATIONS ARE GIVEN IN PARENTHESES.

Table 6. Average Curve Factor

SPECTROLAB HEWAC WRAPAROUND
N/P BSF 10 OHM-CM CG SILICON
TEXTURED SURFACE
2 X 4 X .0225 CM
CR-PD-AG CONTACTS
TA2O5 AR COATING
NO COVERSLIDE
SAMPLE SIZE 6

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	.3681	.4240	.4578	.5889	.7117	.7300	.7649
	(.0691)	(.0578)	(.0501)	(.1166)	(.1343)	(.1107)	(.0835)
-140.00	.3692	.4236	.4709	.6149	.7069	.7443	.7692
	(.0642)	(.0593)	(.0601)	(.1213)	(.0910)	(.1056)	(.0788)
-120.00	.3800	.4295	.4945	.6452	.7213	.7604	.7733
	(.0535)	(.0598)	(.0710)	(.1212)	(.0807)	(.0940)	(.0756)
-100.00	.3702	.4524	.5246	.6728	.7381	.7768	.7740
	(.0589)	(.0749)	(.0808)	(.1118)	(.0713)	(.0784)	(.0781)
-80.00	.3697	.4772	.5604	.6990	.7496	.7822	.7737
	(.0531)	(.0798)	(.0867)	(.1024)	(.0580)	(.0705)	(.0714)
-60.00	.3725	.5079	.5951	.7246	.7570	.7829	.7680
	(.0525)	(.0945)	(.0876)	(.0895)	(.0512)	(.0639)	(.0724)
-40.00	.3794	.5447	.6267	.7240	.7626	.7792	.7642
	(.0530)	(.0982)	(.0836)	(.0752)	(.0441)	(.0603)	(.0555)
-20.00	.3987	.5780	.6483	.7314	.7574	.7746	.7584
	(.0683)	(.0967)	(.0761)	(.0685)	(.0410)	(.0596)	(.0535)
.00	.4197	.6053	.6622	.7138	.7527	.7612	.7561
	(.0795)	(.0891)	(.0652)	(.0430)	(.0315)	(.0531)	(.0430)
20.00	.4420	.6084	.6713	.7238	.7447	.7541	.7318
	(.0846)	(.0744)	(.0548)	(.0312)	(.0269)	(.0421)	(.0472)
40.00	.4681	.6188	.6690	.7154	.7303	.7403	.7193
	(.0865)	(.0602)	(.0435)	(.0268)	(.0237)	(.0330)	(.0414)
60.00	.4893	.6188	.6641	.6973	.7150	.7216	.6980
	(.0907)	(.0485)	(.0331)	(.0209)	(.0207)	(.0371)	(.0383)
80.00	.4989	.6148	.6521	.6831	.6944	.7025	.6784
	(.0756)	(.0372)	(.0260)	(.0188)	(.0196)	(.0396)	(.0323)
100.00	.5044	.5980	.6324	.6535	.6701	.6773	.6546
	(.0605)	(.0303)	(.0236)	(.0281)	(.0170)	(.0430)	(.0326)
120.00	.4963	.5812	.6100	.6308	.6406	.6373	.6224
	(.0480)	(.0258)	(.0185)	(.0167)	(.0190)	(.0218)	(.0308)
140.00	.4811	.5485	.5773	.5986	.6223	.6001	.5890
	(.0333)	(.0219)	(.0137)	(.0167)	(.0466)	(.0232)	(.0338)

NOTE: STANDARD DEVIATIONS ARE GIVEN IN PARENTHESES.

Table 7. Average AMO Efficiency, Percent

SPECTROLAB HE-AC WRAPAROUND
N/P BSF 10 OHM-CM CG SILICON
TEXTURED SURFACE
2 X 4 X .0225 CM
CR-PD-AG CONTACTS
TA2O5 AR COATING
NO COVERSLIDE
SAMPLE SIZE 6

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	5.15	9.33	11.08	15.58	18.78	19.61	20.97
	(2.02)	(2.44)	(2.02)	(3.37)	(3.67)	(3.17)	(2.43)
-140.00	5.33	9.55	11.34	16.02	18.50	19.44	20.86
	(2.02)	(2.47)	(2.09)	(3.41)	(2.51)	(3.04)	(2.27)
-120.00	5.70	9.76	11.81	16.32	18.42	19.42	20.65
	(1.96)	(2.36)	(2.13)	(3.23)	(2.11)	(2.63)	(2.30)
-100.00	5.72	10.14	12.19	16.53	18.43	19.47	19.95
	(2.01)	(2.44)	(2.16)	(2.90)	(1.85)	(2.14)	(2.29)
-80.00	5.97	10.42	12.71	16.56	18.14	19.04	19.04
	(1.97)	(2.27)	(2.08)	(2.58)	(1.50)	(1.77)	(2.08)
-60.00	6.21	10.70	12.96	16.40	17.70	18.48	18.24
	(1.95)	(2.39)	(1.98)	(2.04)	(1.26)	(1.57)	(1.93)
-40.00	6.37	11.05	12.98	15.74	16.98	17.59	17.29
	(1.83)	(2.22)	(1.78)	(1.66)	(1.08)	(1.43)	(1.36)
-20.00	6.58	11.13	12.84	14.96	16.01	16.65	16.15
	(1.87)	(2.02)	(1.56)	(1.48)	(.94)	(1.28)	(1.45)
.00	6.62	10.88	12.17	13.76	15.11	15.41	15.74
	(1.82)	(1.89)	(1.25)	(.93)	(.65)	(1.17)	(1.02)
20.00	6.54	10.12	11.60	13.06	14.06	14.24	14.46
	(1.69)	(1.35)	(1.05)	(.65)	(.56)	(.82)	(1.07)
40.00	6.47	9.53	10.75	12.02	12.81	13.17	13.39
	(1.53)	(1.04)	(.75)	(.50)	(.47)	(.66)	(.87)
60.00	6.16	8.80	9.81	10.82	11.69	11.96	12.15
	(1.38)	(.78)	(.53)	(.46)	(.42)	(.68)	(.80)
80.00	5.61	7.89	8.72	9.72	10.51	10.86	11.00
	(1.05)	(.60)	(.39)	(.38)	(.36)	(.66)	(.65)
100.00	4.95	6.86	7.58	8.55	9.28	9.66	9.76
	(.74)	(.44)	(.36)	(.34)	(.27)	(.66)	(.59)
120.00	4.14	5.80	6.48	7.33	8.00	8.11	8.49
	(.52)	(.33)	(.27)	(.31)	(.33)	(.31)	(.55)
140.00	3.28	4.50	5.26	6.07	6.96	6.86	7.26
	(.31)	(.25)	(.17)	(.26)	(.57)	(.29)	(.52)

NOTE: STANDARD DEVIATIONS ARE GIVEN IN PARENTHESES.

APPENDIX

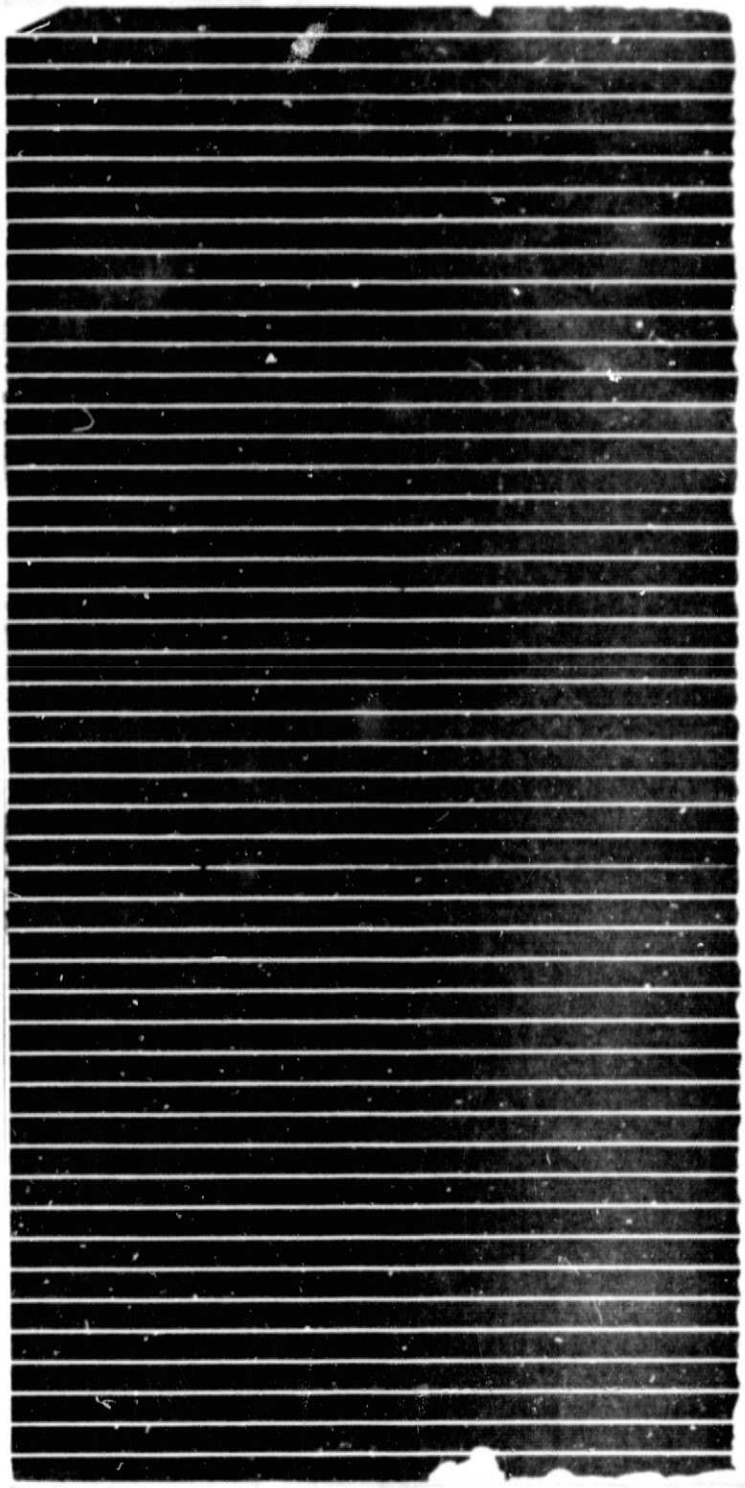

Figure A-1. Solar Cell

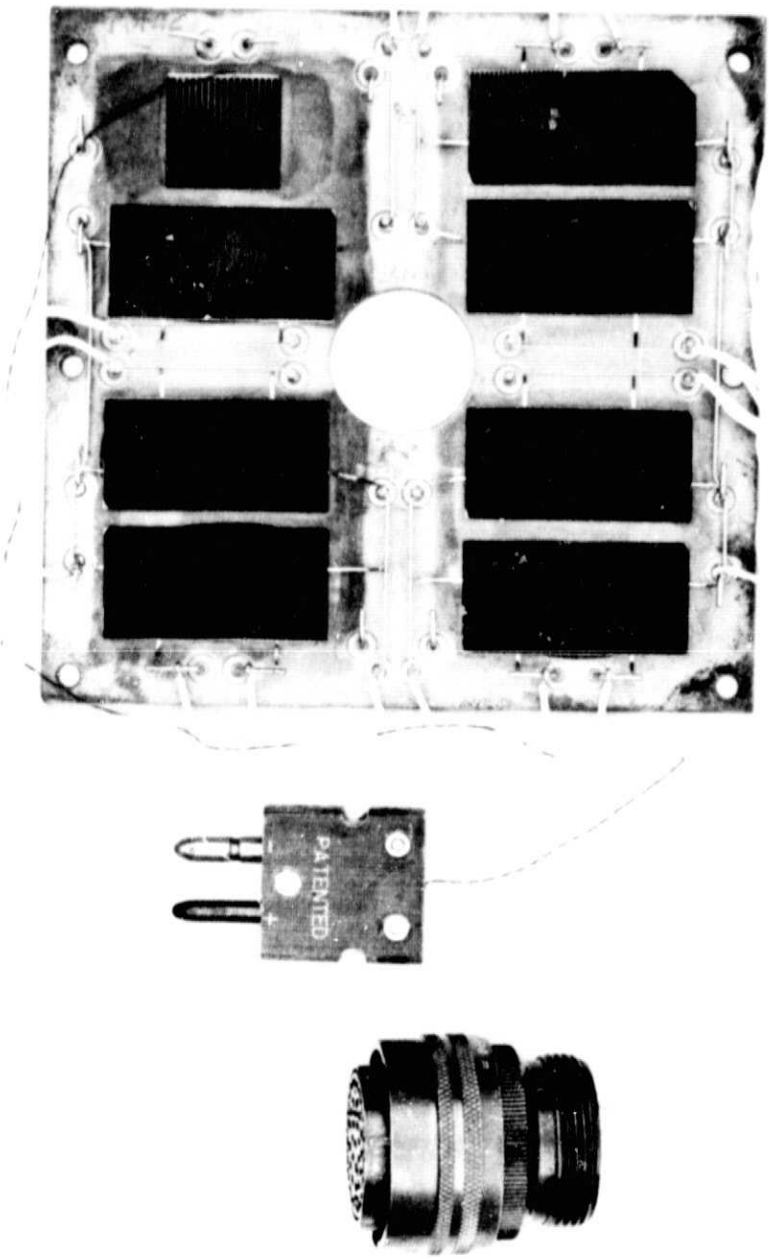

Figure A-2. Test Plate

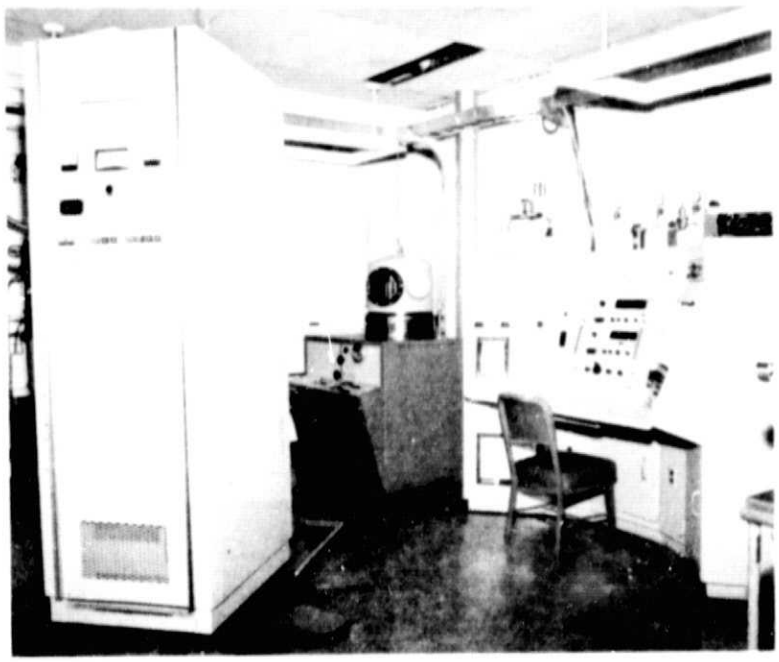

Figure A-3. Solar Cell Characterization Facility

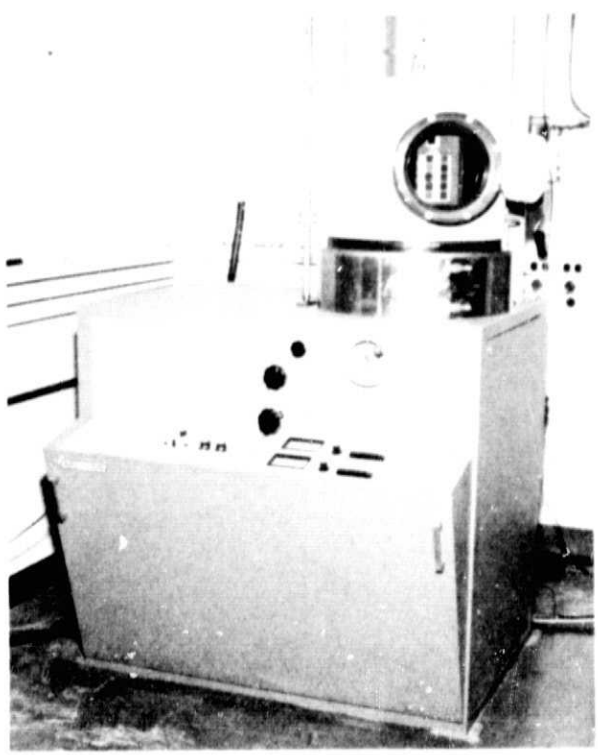

Figure A-4. Solar Cell Environmental Test Chamber