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JPL PUBLICATION 77-27, REVISION 1

Electrical Characteristics of 2-Ω-cm 0.046-cm-Thick Silicon Solar Cells as a Function of Intensity and Temperature

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California 91103

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B. E. Anspaugh

August 15, 1977

National Aeronautics and
Space Administration

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California Institute of Technology
Pasadena, California 91103

PREFACE

The work described in this report was performed by the Control and Energy Conversion Division of the Jet Propulsion Laboratory.

This document contains updated and more accurate data than was included in JPL Publication 77-27 and therefore supersedes the previously released document.

ACKNOWLEDGEMENT

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.

ABSTRACT

Electrical characteristics of Mariner '71 type of silicon solar cells are presented in graphical and tabular format as a function of intensity and temperature.

CONTENTS

Tables

SECTION I

INTRODUCTION

This is the first in a series of parametric data reports obtained on silicon photovoltaic devices under a variety of intensity-temperature combinations. The purpose of this series is to provide engineering data on the electrical characteristics of devices of interest to the photovoltaic community. The report consists primarily of working graphs and tables and does not address itself to interpretive conclusions. The formatting of this series of reports will be relatively invariant to facilitate comparisons between the characteristics of any two (or more) cell types considered in the series.

SECTION II

CELL DESCRIPTION

The cells were manufactured by Heliotek, Division of Textron (now Spectrolab Subsidiary of Hughes Aircraft Company) and are commonly referred to as Mariner '71 solar cells. The cells were received at JPL in 1969. They are fabricated from crucible grown P-type silicon, boron doped to a nominal resistivity of 2 Ω-cm. The N/P junction was formed by means of phosphorus vapor diffusion to a depth of approximately 0.3 μm. The cells have areal dimensions of 2 cm 2 cm and a thickness of approximately 0.046 cm. The cells have an antireflectance coating of SiO_x applied to the active (top) surface. The electrical contacts consist of Ti-Ag with an overlayer of solder. The front contact consists of a solid busbar along one edge with six equidistant "fingers" running perpendicular to the busbar. The rear contact is a solid area contact.

The cells are representative of those flown on the Mariner '69 and '71 flight programs and, although not representative of present-day silicon solar cell technology, are of interest historically and for comparative purposes with regard to currently available solar cells.

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 vacuum at a pressure of less than 1×10^{-6} torr.

The illumination source used throughout this test program was an Aerospace Control Corporation Model 302 filtered solar simulator. This simulator uses an optical integrator lens in the optical system. The lenses uniformly distribute 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. At an illumination intensity of 135.3 mW/cm^2, the light beam provides a pattern having a uniformity of approximately $\pm 2\%$ over a square area of 225 cm^2 (15 cm/side) at the test plane. The solar simulator beam was introduced into the vacuum chamber through a window of 7940 fused silica. The solar intensity and spectral integrity of the solar simulator were constantly monitored and maintained in conjunction with the NASA/JPL solar cell standardization program. The intensity of the incoming light was varied primarily by means of neutral density filters. A diagram of the test setup is shown in Fig. 1.

SECTION IV

FIGURES AND TABLES

The 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 computer then produces plots of the various electrical parameters of interest, with either incident intensity or cell temperature as the independent variable, as shown in Figs. 2 to 15. Least square fits to the data points are then made automatically to the measured data points using a second-degree polynomial for all parameters except for V_{oc} and V_{mp} parameters. In the latter case, the data points are fit with a linear expression. The fits are shown as solid lines on the figures. In addition, the computer 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 Figs. 16 to 19.

The figures and graphs included herein 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 this end, the following information is supplied on each figure and graph:

(1) Cell manufacturer

(2) Cell generic name (if any)

(3) Cell polarity

(4) Silicon starting resistivity

(5) Silicon growth technique

(6) Solar cell geometric dimensions

(7) Contact composition

(8) Antireflectance coating composition

(9) Sample size tested

(10) Coverslide description (if any)

Furthermore, 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[1] are in dimensionless units

(5) All efficiencies are in percent and are based on total 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[2] spectrum

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

The graphs included in this report utilize complete grid patterns, and are of sufficient quality to allow their use as working graphs from which the engineer may derive needed relationships. All current and power outputs are on a unit area basis as arrived at by dividing the measured output by the total cell area. All solar cell efficiency curves (Figs. 8 and 15) are based on total cell area.

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}, VP_{max}, P_{max}, CF, and efficiency at each intensity-temperature combination addressed. For

---

[1] $CF = \dfrac{I_{mp} \times V_{mp}}{I_{sc} \times V_{oc}}$

[2] AMO = air mass zero, representative of the spectral distribution of the Sun in near-Earth space with respect to energy versus wavelength.

each such parameter at each such intensity-temperature combination, the standard deviation is presented to provide estimates of statistical validity. All current and power output data is on the basis of unit area derived by dividing measured output by total cell area. All solar cell efficiency numerical data are based on total cell area.

SECTION V

CONCLUSIONS

The data obtained appears to be well-behaved over the range of intensity-temperature combinations considered here. Current and power parameters are presented in terms of unit area outputs to facilitate comparisons independent of areal dimensions. Through interpolation of the Figs. 2 to 15 and Tables 1 to 7, it is possible to determine electrical parameters of import (I_{sc}, V_{oc}, I_{mp}, V_{mp}, P_{max}, CF, and efficiency) for any arbitrary orbit profile within the confines of the extremes of intensity temperature combinations presented, provided that the equivalent solar intensity and equilibrium temperature conditions are known or can be assumed. Conversely, if a minimum output for any or all of the parameters is required, the figures and tables may be used to determine the panel design that will meet or exceed this minimum for intensity temperature combinations within the bounds of the extremes. In addition to the electrical parameters discussed above, there are also included in Figs. 16 to 19 the temperature coefficients of the I_{sc}, V_{oc}, and P_{max} figures of merit with intensity as a parameter. These temperature coefficients are particularly useful in computer predictions of current, voltage, and power profiles as a function of mission profile (again, where the solar intensity and cell equilibrium temperature are known or can be assumed). Also, a measure of the statistical validity of all data points is provided in Tables 1 to 7 which indicate the standard deviation appropriate to each data point for each of the parameters addressed.

The objective of these reports is to facilitate comparisons among solar cell types treated in this and in future reports with respect to electrial characteristics as a function of intensity and temperature (i.e., for sets of anticipated cell equilibrium conditions representative of particular mission profiles). Thus, for a given set of intensity-temperature conditions, these reports will assist the design engineer in selecting the cell type most appropriate for his or her needs and in determining the cell electrical characteristics. While it is not the objective of these reports to draw conclusions with regard to which cell is best (as this, of necessity, depends upon the mission constraints and characteristics), it might be mentioned that preliminary measurements on more recently manufactured silicon solar cells indicate that the parameters of I_{sc}, I_{mp}, V_{mp}, P_{max}, CF, and efficiency of the more recently acquired cells are significantly in excess of those reported here (for the Mariner '69/'71 cells tested) for most intensity-temperature combinations addressed.

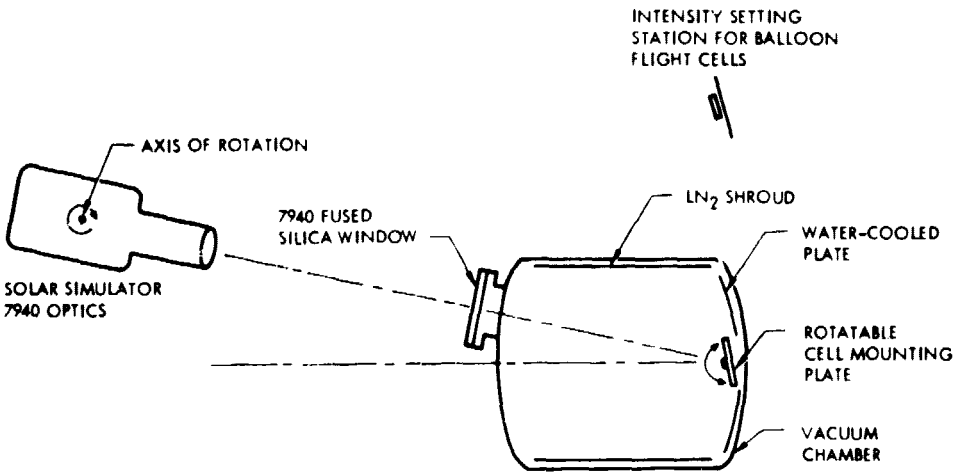
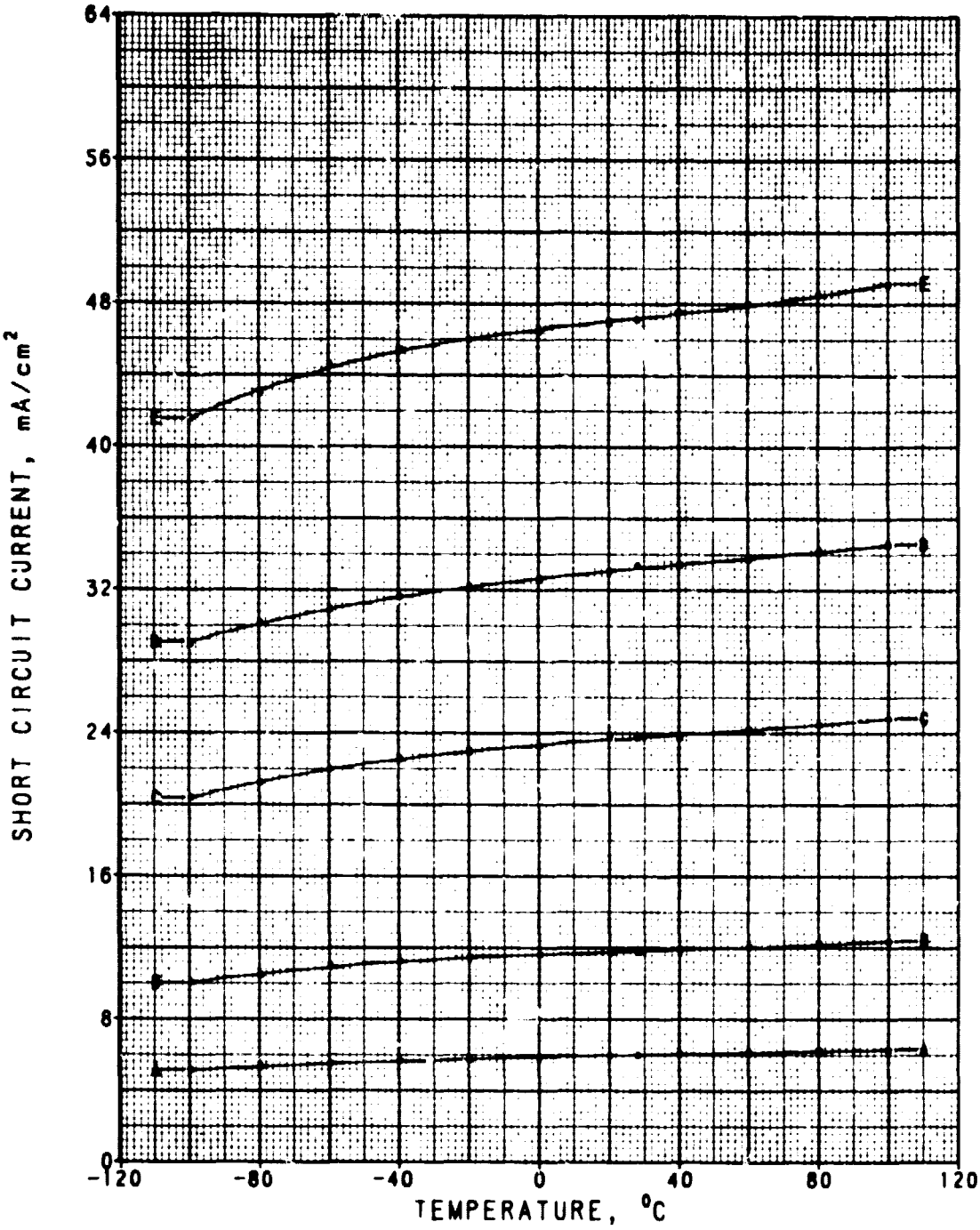


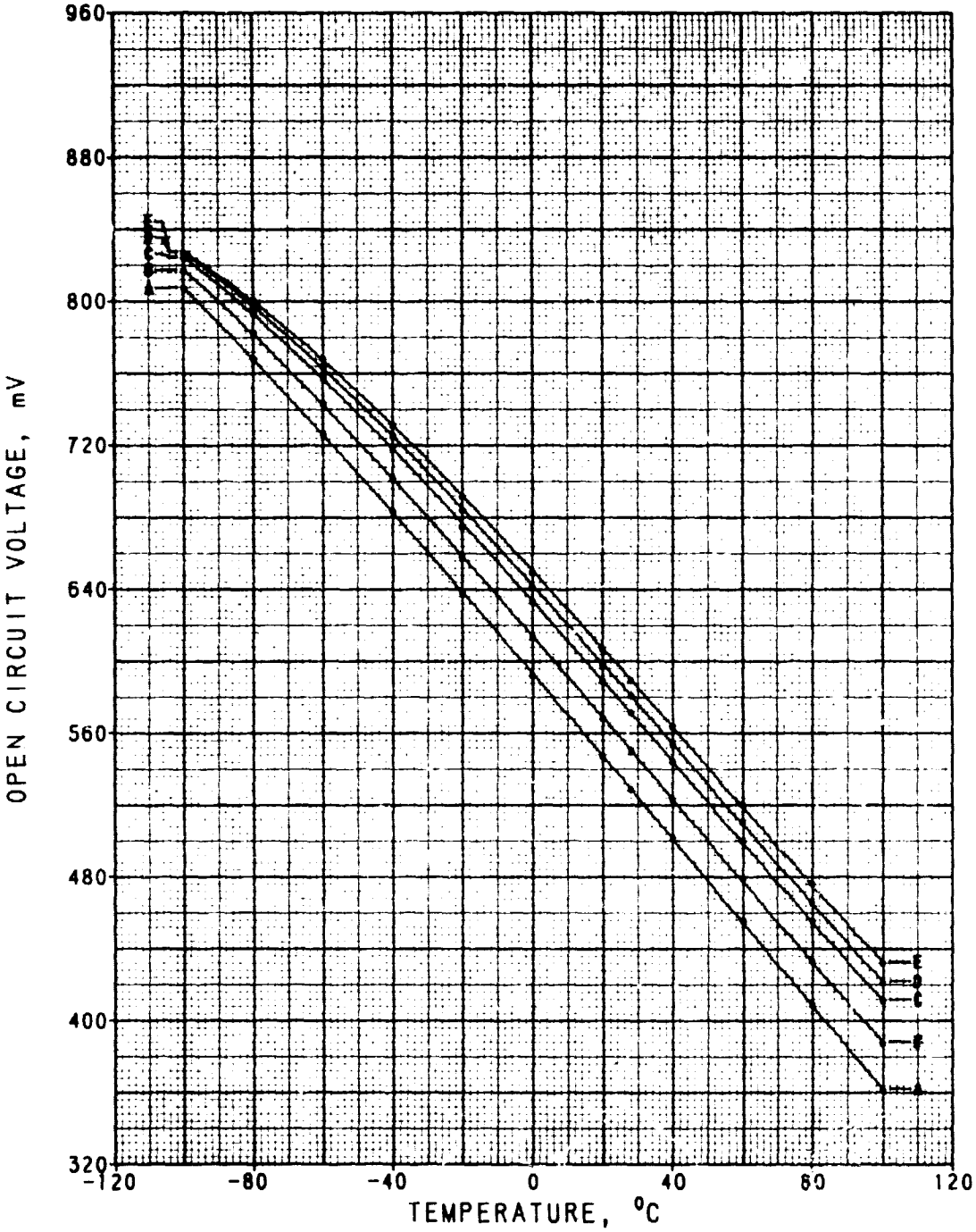
Figure 1. Solar Cell Measurement Geometry Schematic



ID	mW/cm²
A	24.2
B	48.3
C	96.8
D	135.3
E	193.3

HELIOTEK (HIO/MARINER 71)
N/P 2 OHM-CM CG SILICON
2 X 2 X .046 CM
AG-TI-SOLDER CONTACTS
SI-O AR COATING
SAMPLE SIZE 7
NO COVERSLIDE

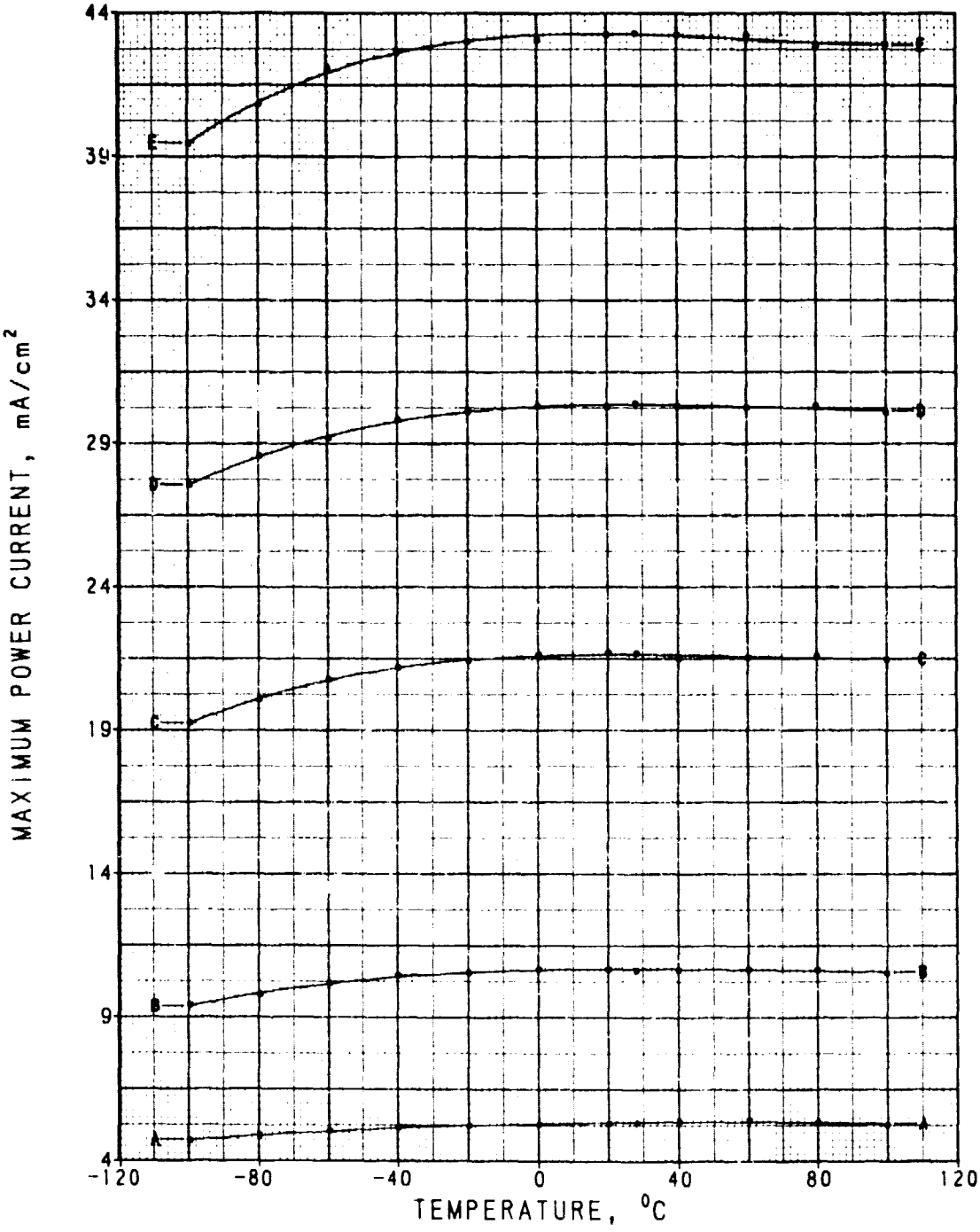
Figure 2. Average I_{sc}/cm^2 As a Function of Temperature (Intensity As a Parameter)



ID	mW/cm²
A	24.2
B	48.3
C	96.6
D	135.3
E	193.3

HELIOTEK (HIO/MARINER 71)
N/P 2 OHM-CM CG SILICON
2 X 2 X .046 CM
AG-TI-SOLDER CONTACTS
SI-O AR COATING
SAMPLE SIZE 7
NO COVERSLIDE

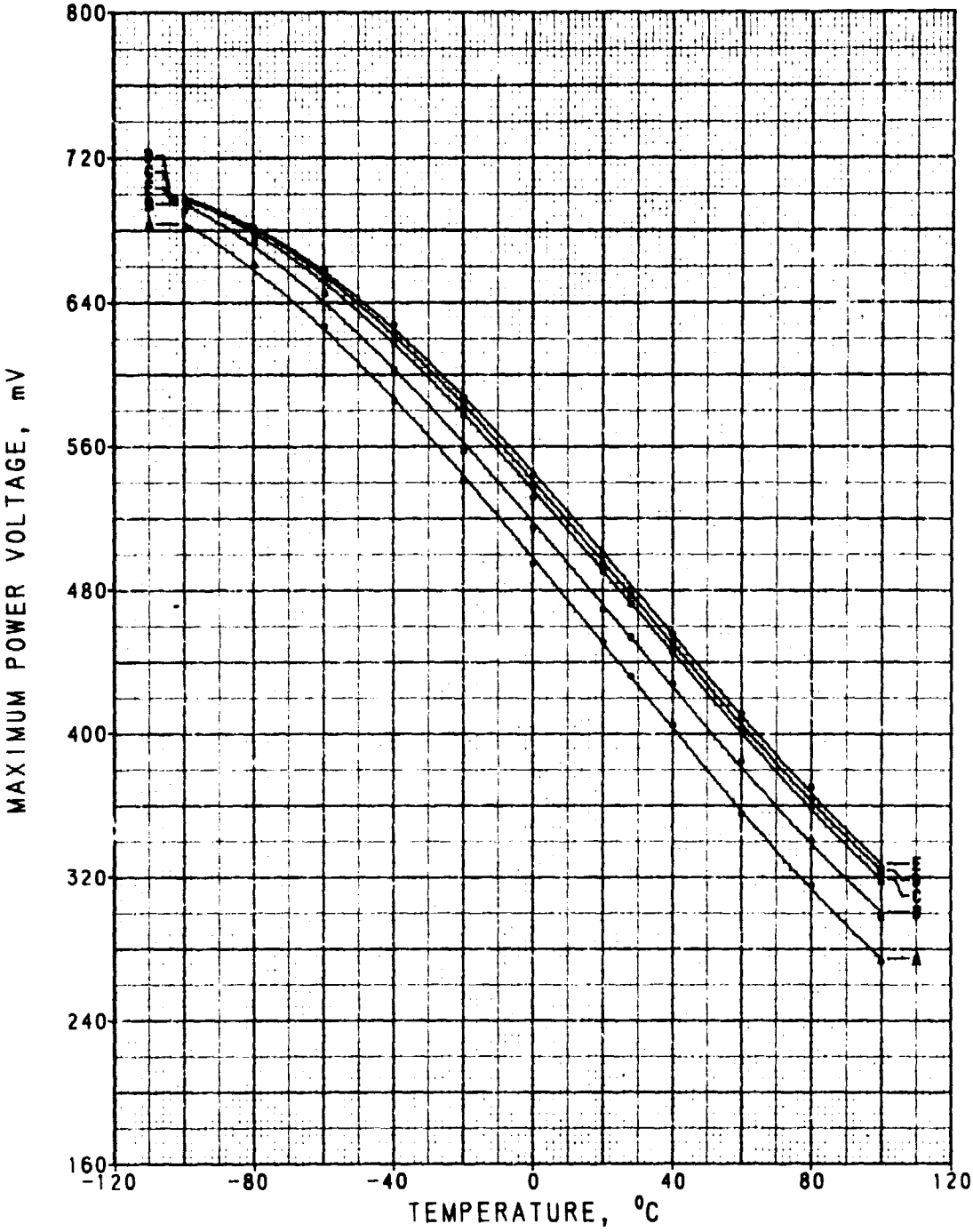
Figure 3. Average V_{OC} As a Function of Temperature (Intensity As a Parameter)



ID	mW/cm²
A	24.2
B	48.3
C	96.6
D	135.3
E	193.3

HELIOTEK (HIO/MARINER 71)
N/P 2 OHM-CM CG SILICON
2 X 2 X .046 CM
AG-TI-SOLDER CONTACTS
SI-O AR COATING
SAMPLE SIZE 7
NO COVERSLIDE

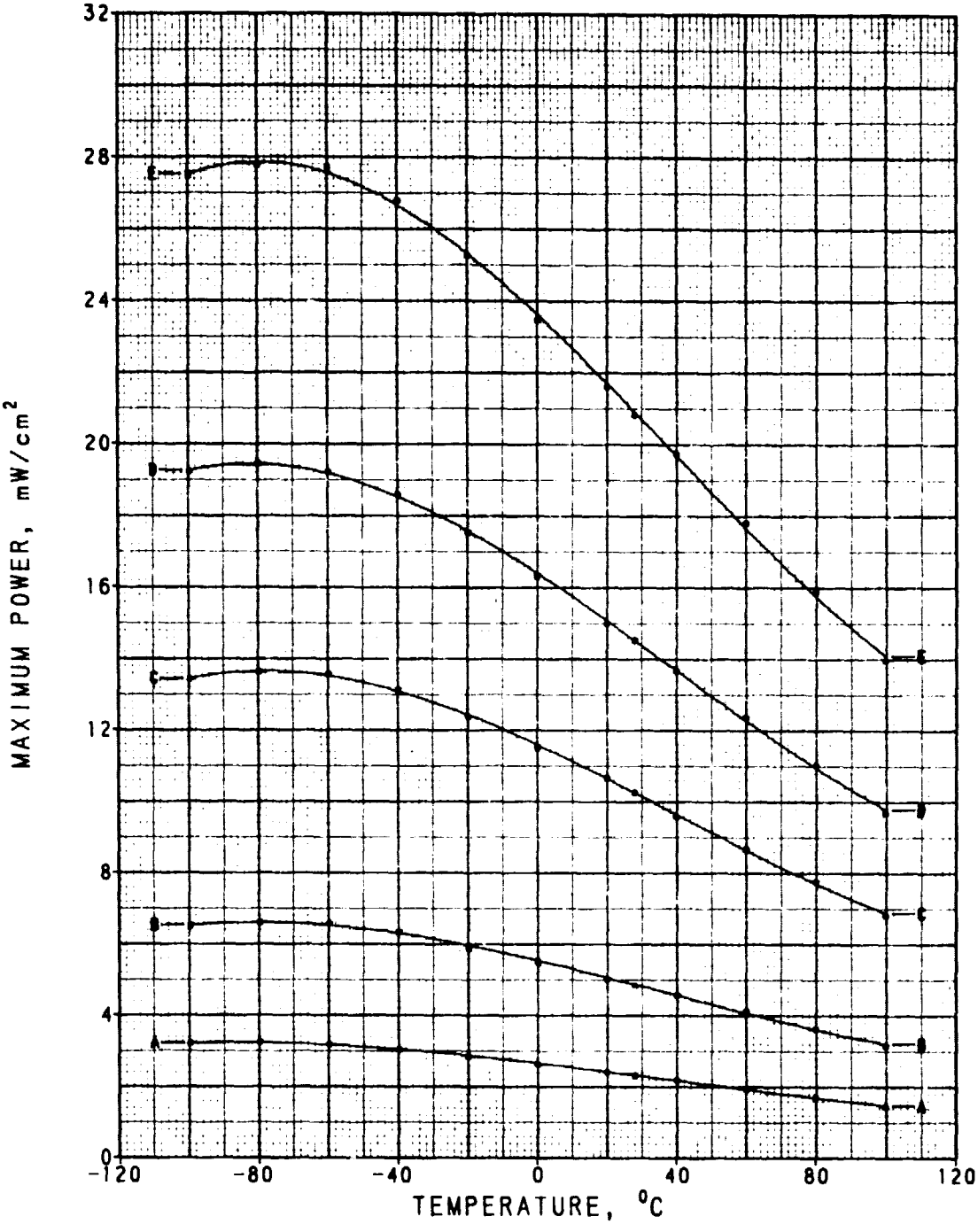
Figure 4. Average I_{mp}/cm^2 As a Function of Temperature (Intensity As a Parameter)



ID	mW/cm²
A	24.2
B	48.3
C	96.6
D	135.3
E	193.3

HELIOTEK (H10/MARINER 71)
N/P 2 OHM-CM CG SILICON
2 X 2 X .046 CM
AG-TI-SOLDER CONTACTS
SI-O AR COATING
SAMPLE SIZE 7
NO COVERSLIDE

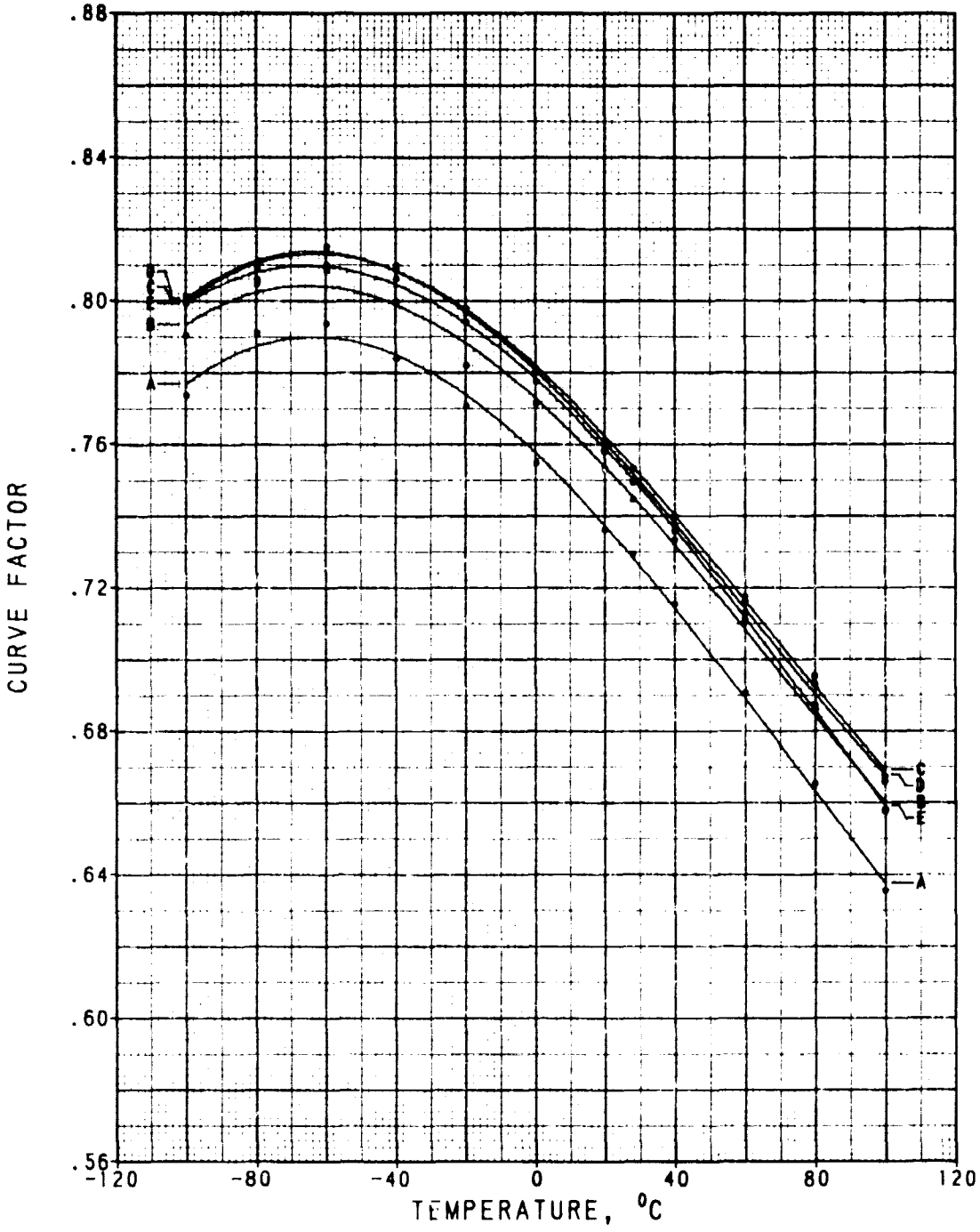
Figure 5. Average V_{mp} As a Function of Temperature (Intensity As a Parameter)



ID	mW/cm²
A	24.2
B	48.3
C	96.6
D	135.3
E	193.3

HELIOTEK (HIO/MARINER 71)
N/P 2 OHM-CM CG SILICON
2 X 2 X .046 CM
AG-TI-SOLDER CONTACTS
SI-O AR COATING
SAMPLE SIZE 7
NO COVERSLIDE

Figure 6. Average P_{max}/cm^2 As a Function of Temperature (Intensity As a Parameter)



ID	mW/cm²
A	24.2
B	48.3
C	96.6
D	135.3
E	193.3

HELIOTEK (HIO/MARINER 71)
N/P 2 OHM-CM CG SILICON
2 X 2 X .046 CM
AG-TI-SOLDER CONTACTS
SI-O AR COATING
SAMPLE SIZE 7
NO COVERSLIDE

Figure 7. Average Curve Factor As a Function of Temperature (Intensity As a Parameter)

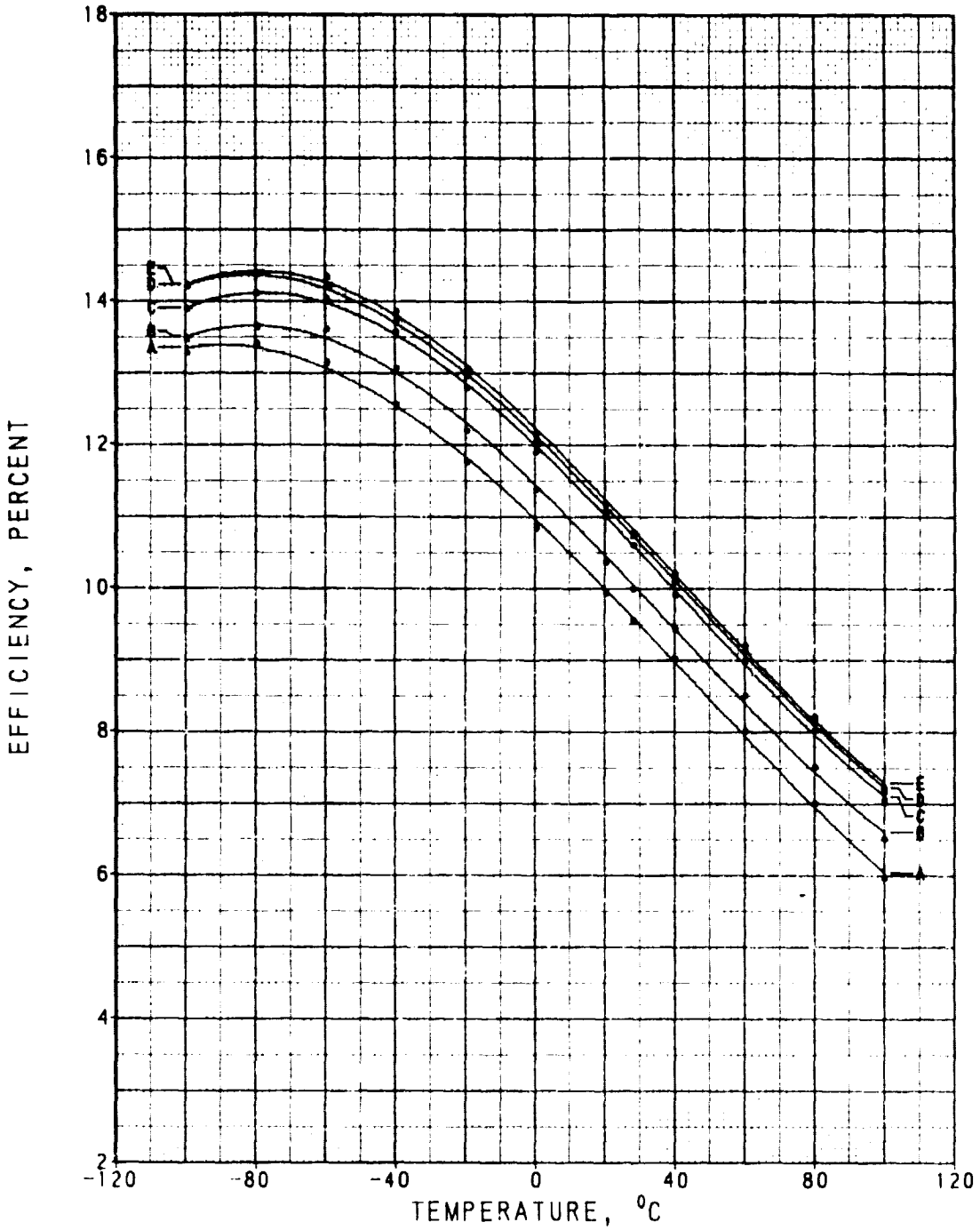
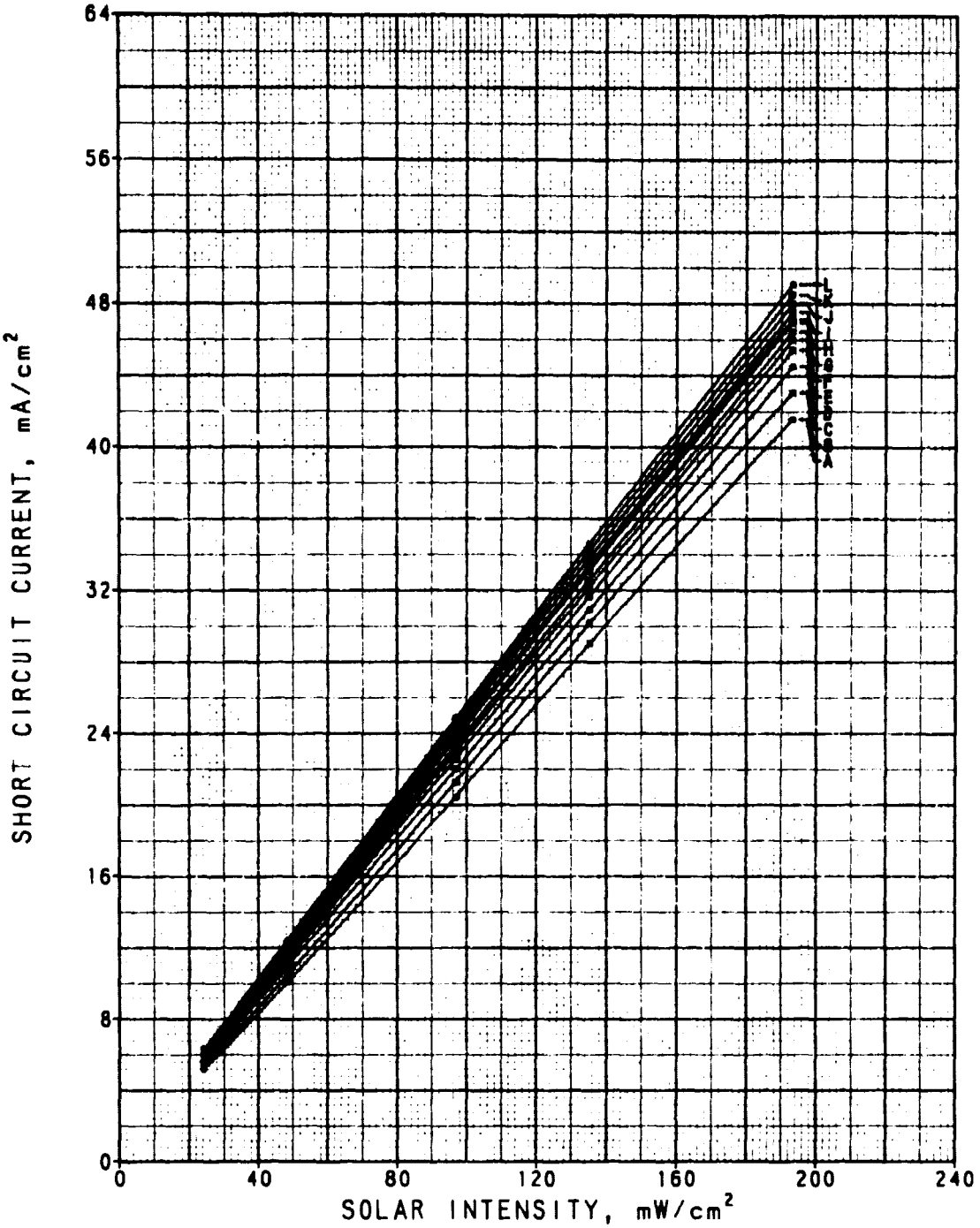


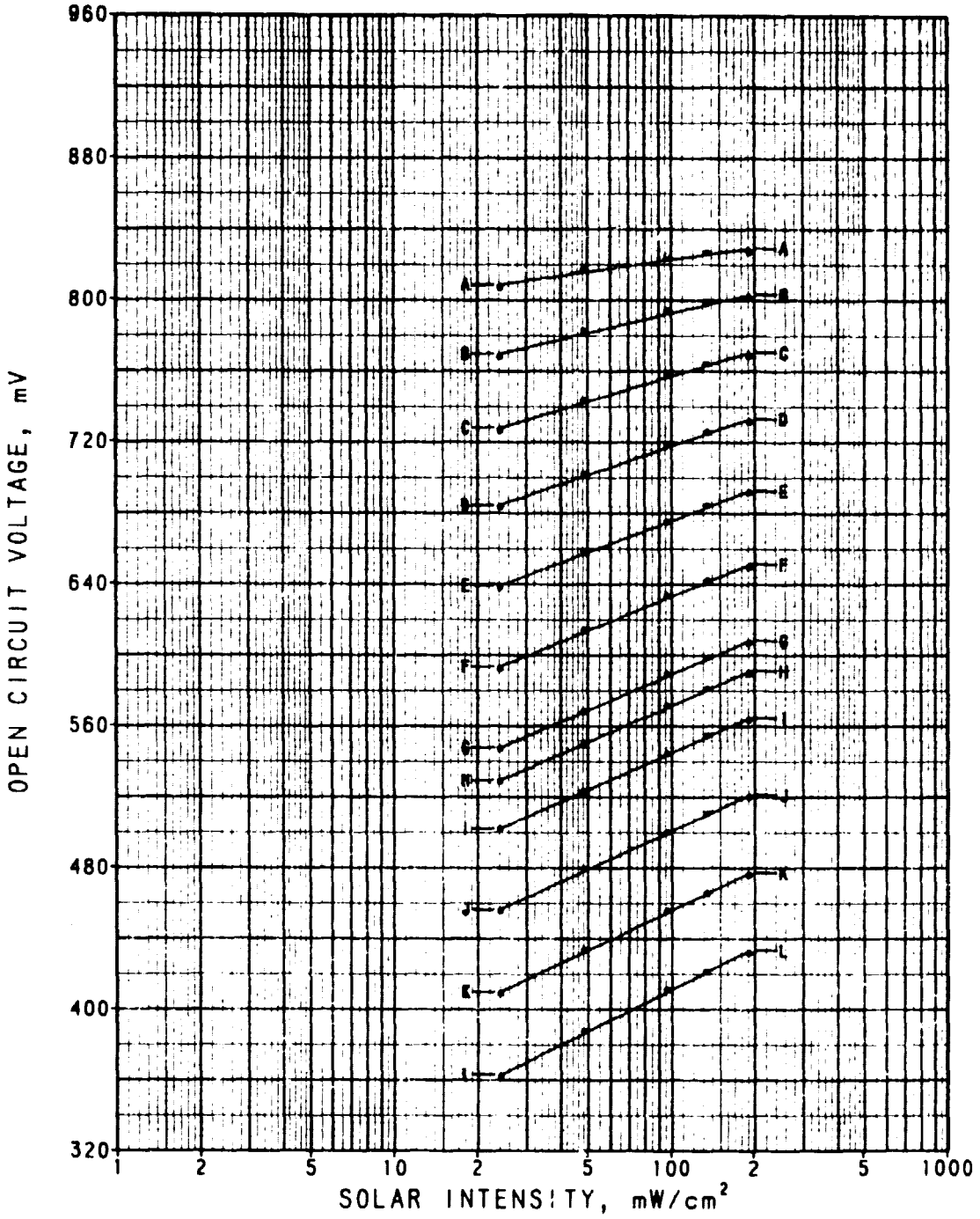
Figure 8. Average Efficiency As a Function of Temperature (Intensity As a Parameter)



ID	°C	ID	°C
A	-100.0	I	40.0
B	-80.0	J	60.0
C	-60.0	K	80.0
D	-40.0	L	100.0
E	-20.0		
F	.0		
G	20.0		
H	28.0		

HELIOTEK (H10/MARINER 71)
N/P 2 OHM-CM CG SILICON
2 X 2 X .046 CM
AG-TI-SOLDER CONTACTS
SI-O AR COATING
SAMPLE SIZE 7
NO COVERSLIDE

Figure 9. Average I_{sc}/cm^2 As a Function of Intensity (Temperature As a Parameter)



ID	°C	ID	°C
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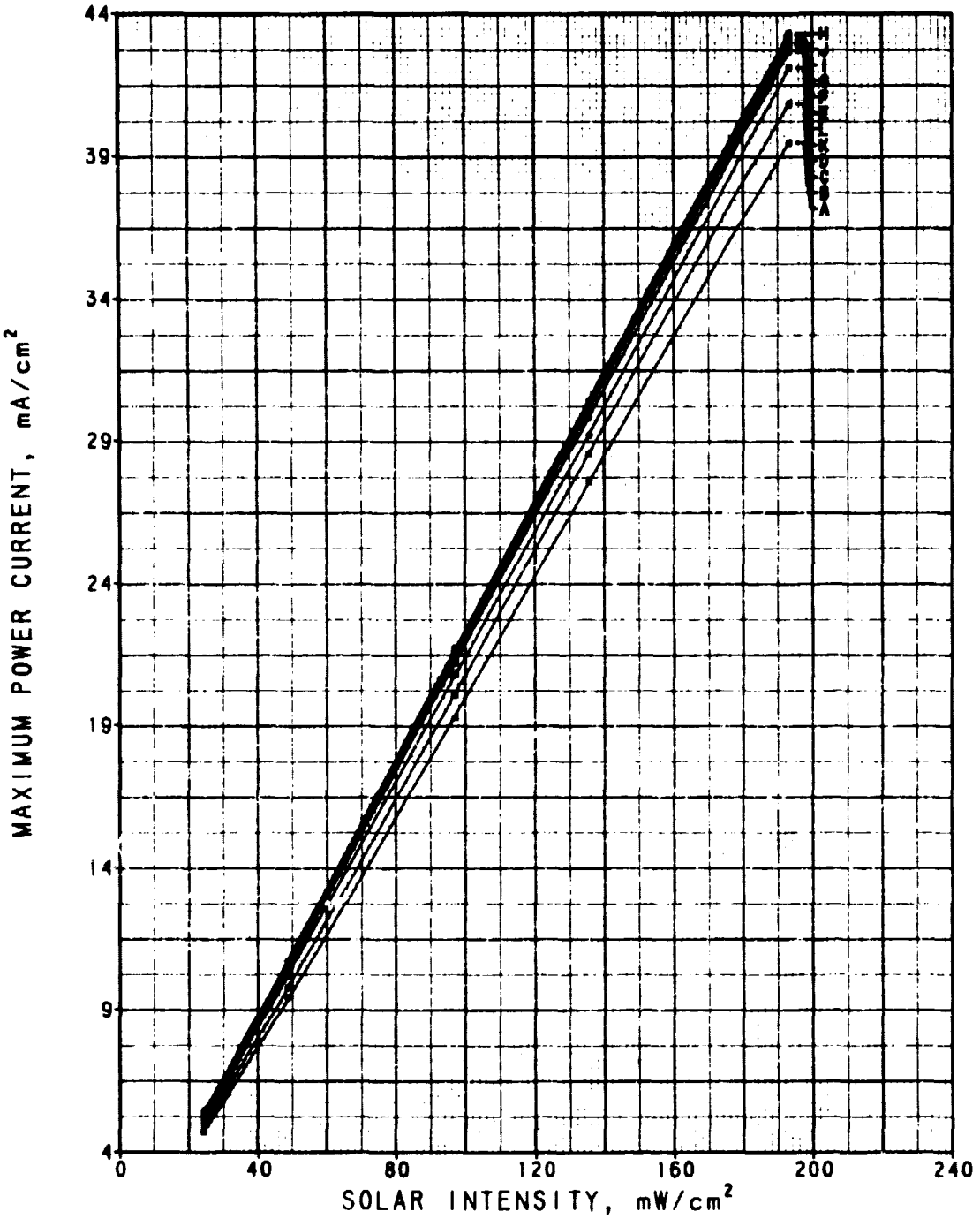
B	-80.0	J	60.0
C	-60.0	K	80.0
D	-40.0	L	100.0
E	-20.0		
F	.0		
G	20.0		
H	28.0		

HELIOTEK (HIO/MARINER 71)
N/P 2 OHM-CM CG SILICON
2 X 2 X .046 CM
AG-TI-SOLDER CONTACTS
SI-O AR COATING
SAMPLE SIZE 7
NO COVERSLIDE

Figure 10. Average V_{OC} As a Function of Intensity (Temperature As a Parameter)



ID	°C	ID	°C
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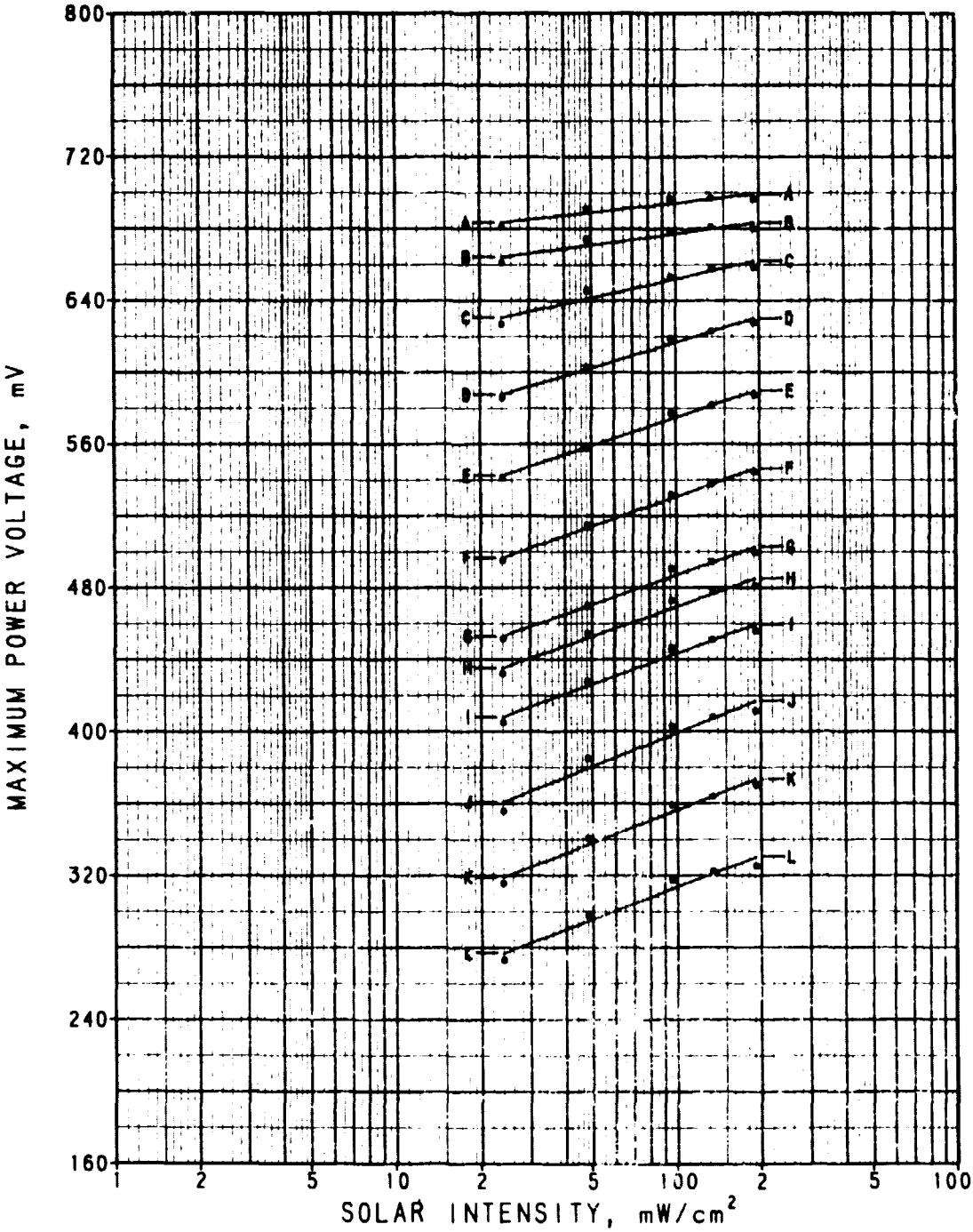
B	-80.0	J	60.0
C	-60.0	K	80.0
D	-40.0	L	100.0
E	-20.0		
F	.0		
G	20.0		
H	28.0		

HELIOTEK (HIO/MARINER 71)
N/P 2 OHM-CM CG SILICON
2 X 2 X .046 CM
AG-TI-SOLDER CONTACTS
SI-O AR COATING
SAMPLE SIZE 7
NO COVERSLIDE

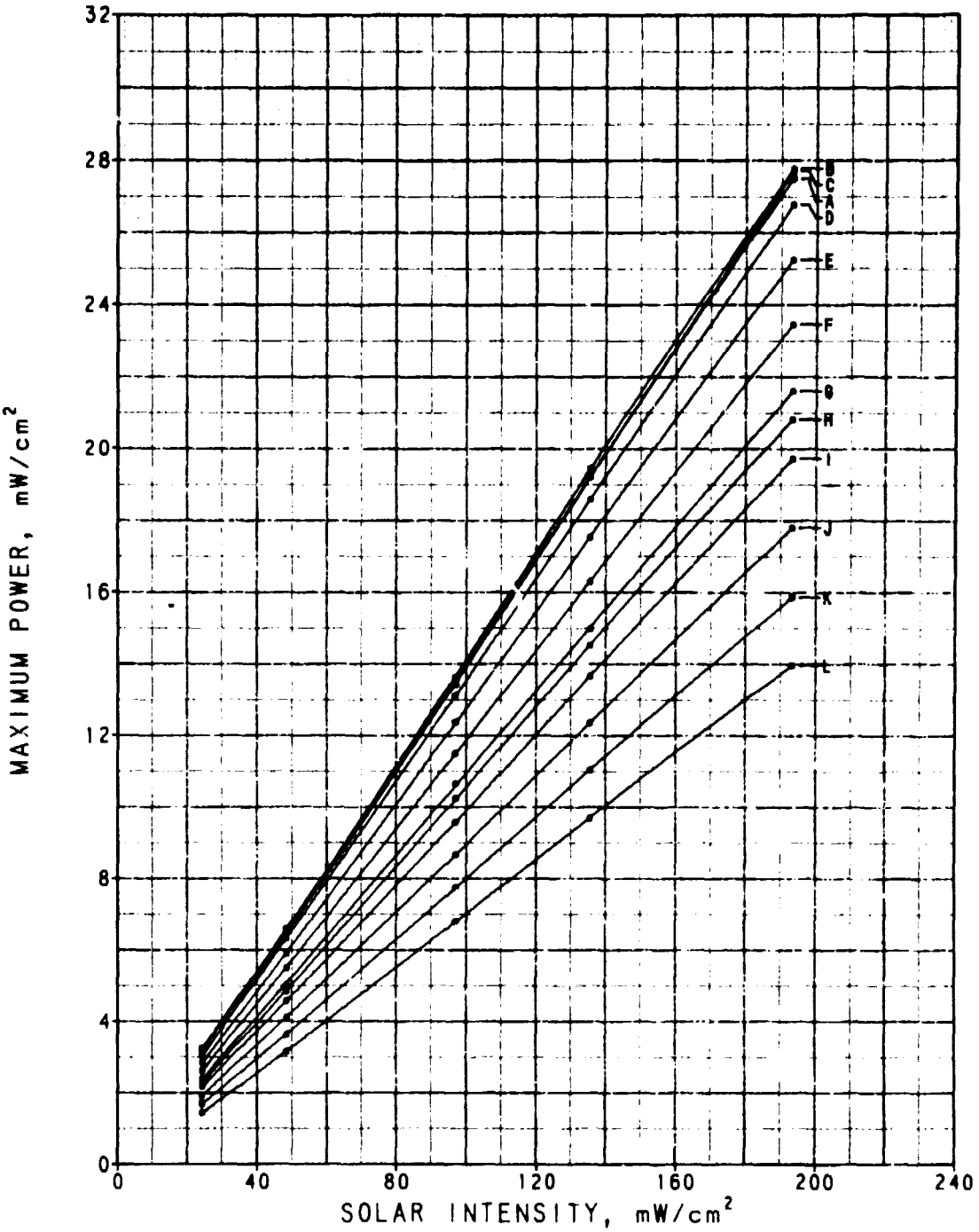
Figure 11. Average I_{mp}/cm^2 As a Function of Intensity (Temperature As a Parameter)



ID	°C	ID	°C
A	-100.0	I	40.0
B	-80.0	J	60.0
C	-60.0	K	80.0
D	-40.0	L	100.0
E	-20.0		
F	.0		
G	20.0		
H	28.0		

HELIOTEK (HIO/MARINER 71)
N/P 2 OHM-CM CG SILICON
2 X 2 X .046 CM
AG-TI-SOLDER CONTACTS
SI-O AR COATING
SAMPLE SIZE 7
NO COVERSLIDE

Figure 12. Average V_{mp} As a Function of Intensity (Temperature As a Parameter)



ID	°C	ID	°C
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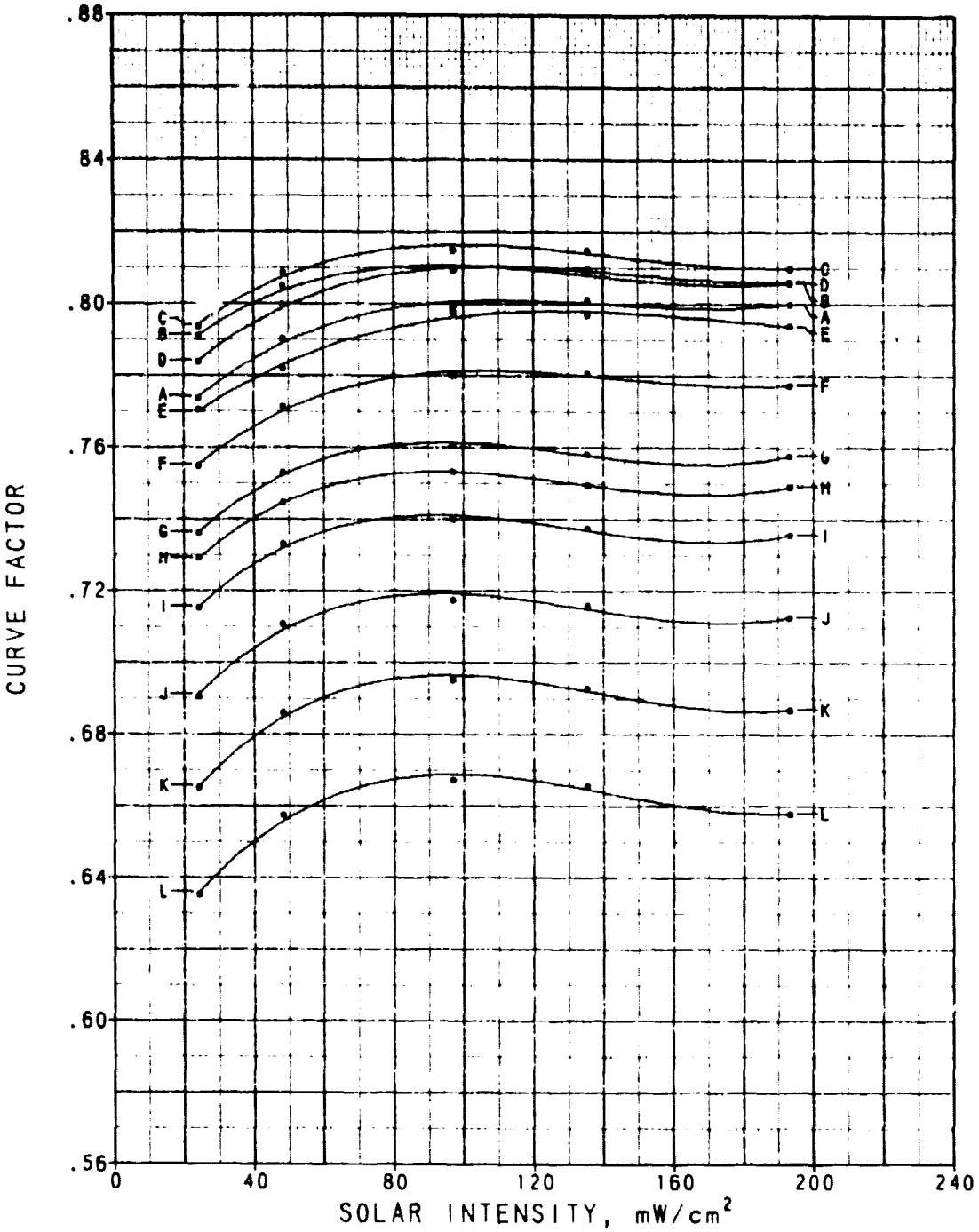
B	-80.0	J	60.0
C	-60.0	K	80.0
D	-40.0	L	100.0
E	-20.0		
F	.0		
G	20.0		
H	28.0		

HELIOTEK (HIO/MARINER 71)
N/P 2 OHM-CM CG SILICON
2 X 2 X .046 CM
AG-TI-SOLDER CONTACTS
SI-O AR COATING
SAMPLE SIZE 7
NO COVERSLIDE

Figure 13. Average P_{max}/cm^2 As a Function of Intensity (Temperature As a Parameter)



ID	°C	ID	°C
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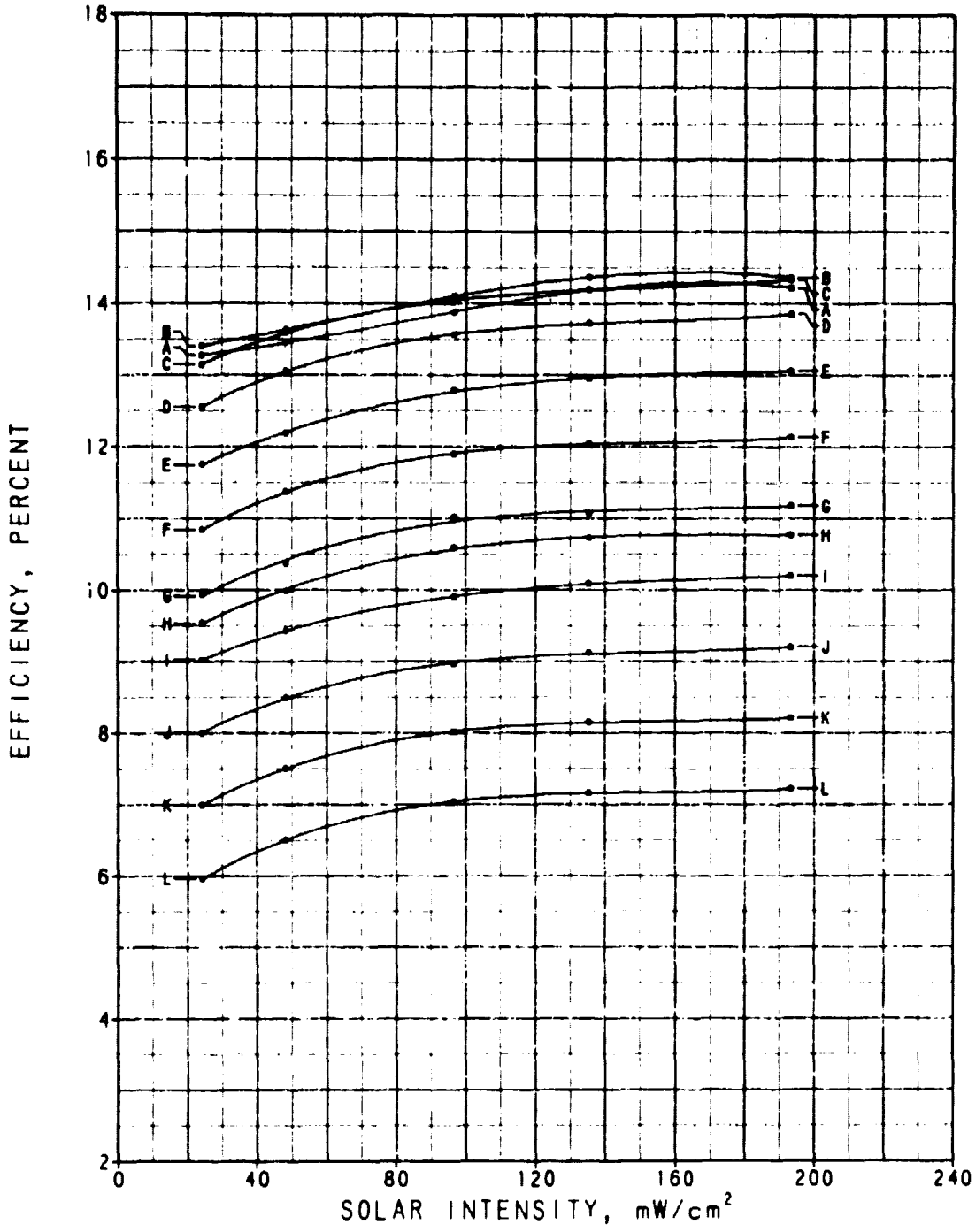
B	-80.0	J	60.0
C	-60.0	K	80.0
D	-40.0	L	100.0
E	-20.0		
F	.0		
G	20.0		
H	28.0		

HELIOTEK (MIO/MARINER 71)
N/P 2 OHM-CM CG SILICON
2 X 2 X .046 CM
AG-TI-SOLDER CONTACTS
SI-O AR COATING
SAMPLE SIZE 7
NO COVERSLIDE

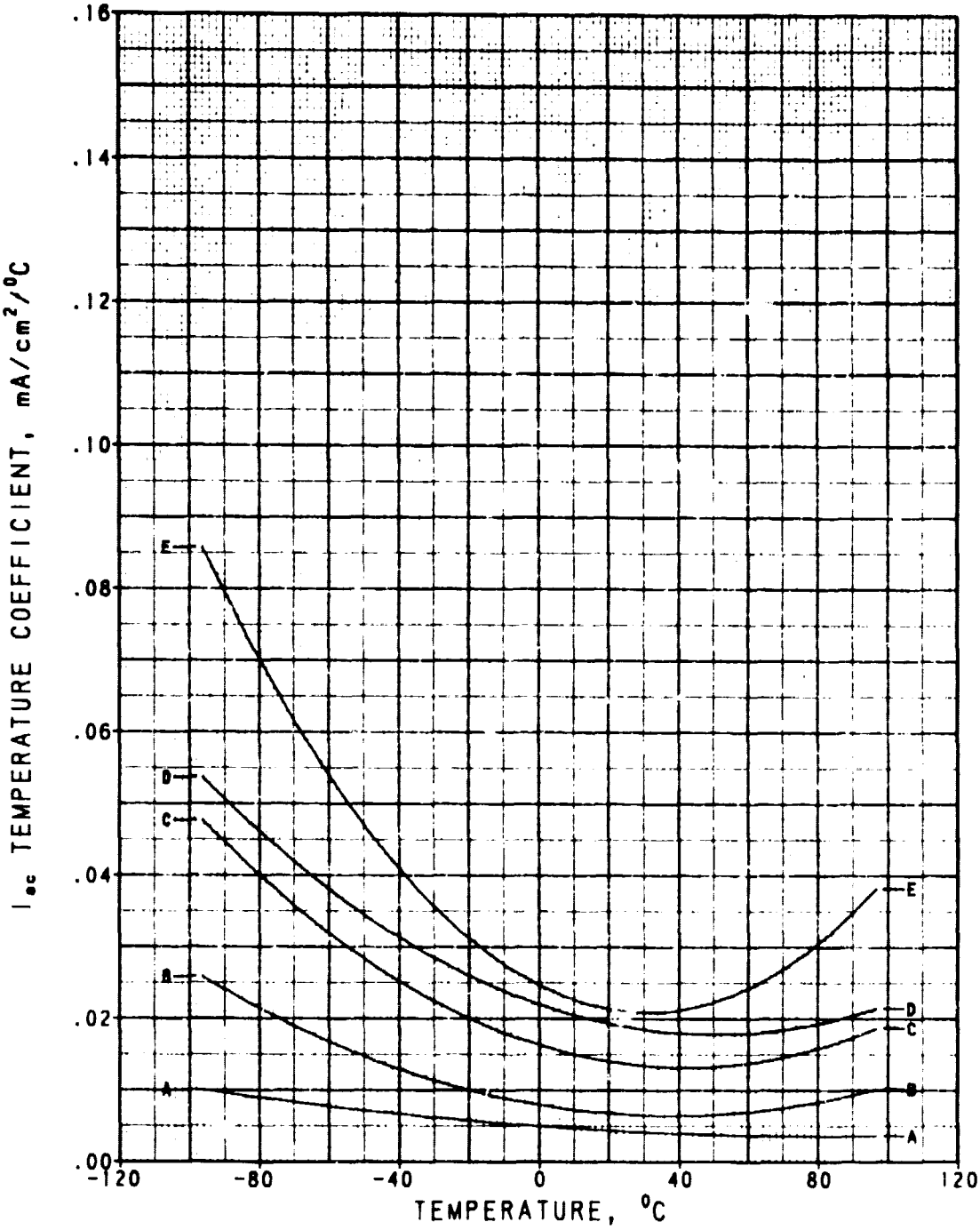
Figure 14. Average Curve Factor As a Function of Intensity (Temperature As a Parameter)



ID	°C	ID	°C
A	-100.0	I	40.0
B	-80.0	J	60.0
C	-60.0	K	80.0
D	-40.0	L	100.0
E	-20.0		
F	.0		
G	20.0		
H	28.0		

HELIOTEK (HIO/MARINER 71)
N/P 2 OHM-CM CG SILICON
2 X 2 X .046 CM
AG-TI-SOLDER CONTACTS
SI-O AR COATING
SAMPLE SIZE 7
NO COVERSLIDE

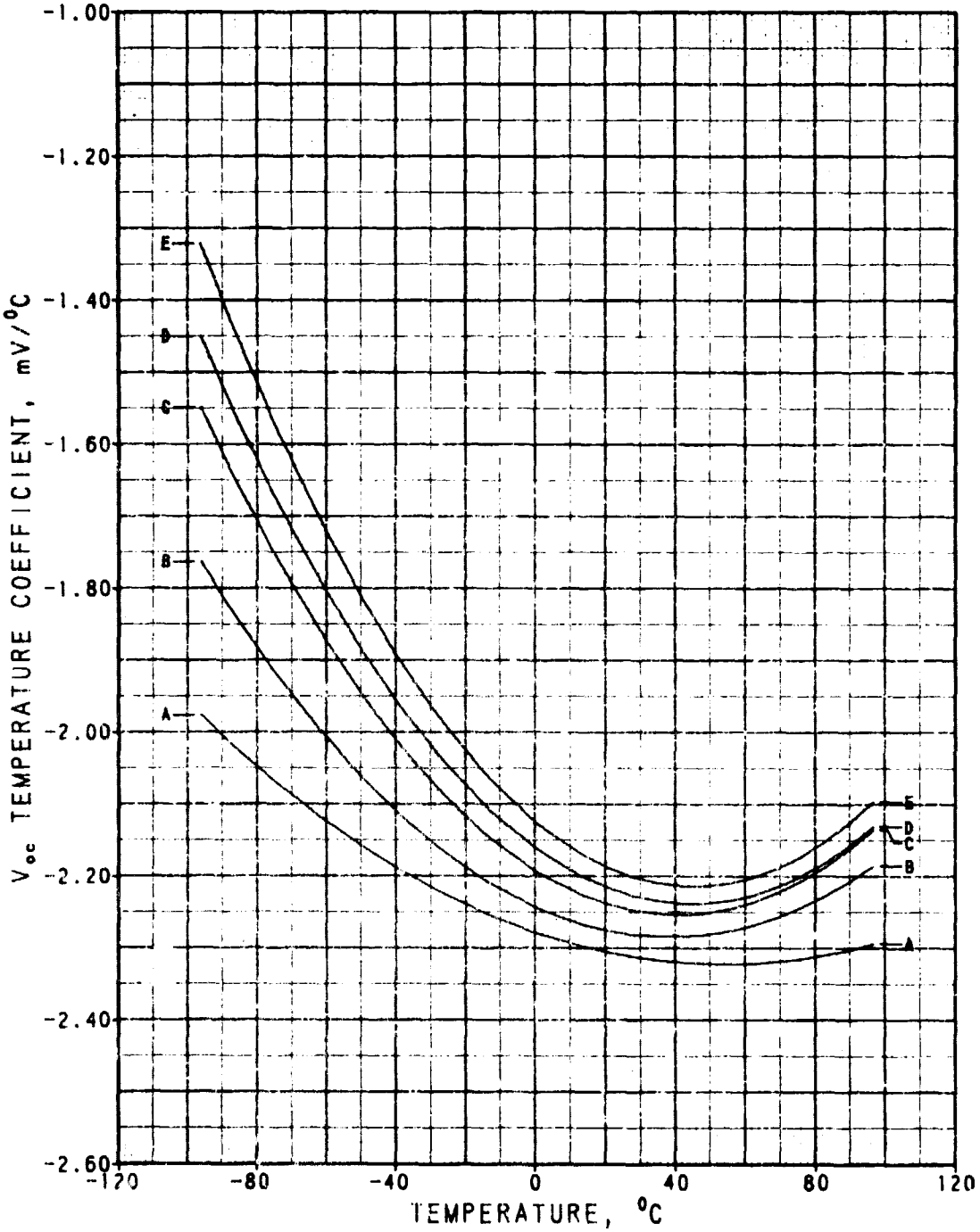
Figure 15. Average Efficiency As a Function of Intensity (Temperature As a Parameter)



ID	mW/cm²
A	24.2
B	48.3
C	96.6
D	135.3
E	193.3

HELIOTEK (HIO/MARINER 71)
N/P 2 OHM-CM CG SILICON
2 X 2 X .046 CM
AG-TI-SOLDER CONTACTS
SI-O AR COATING
SAMPLE SIZE 7
NO COVERSLIDE

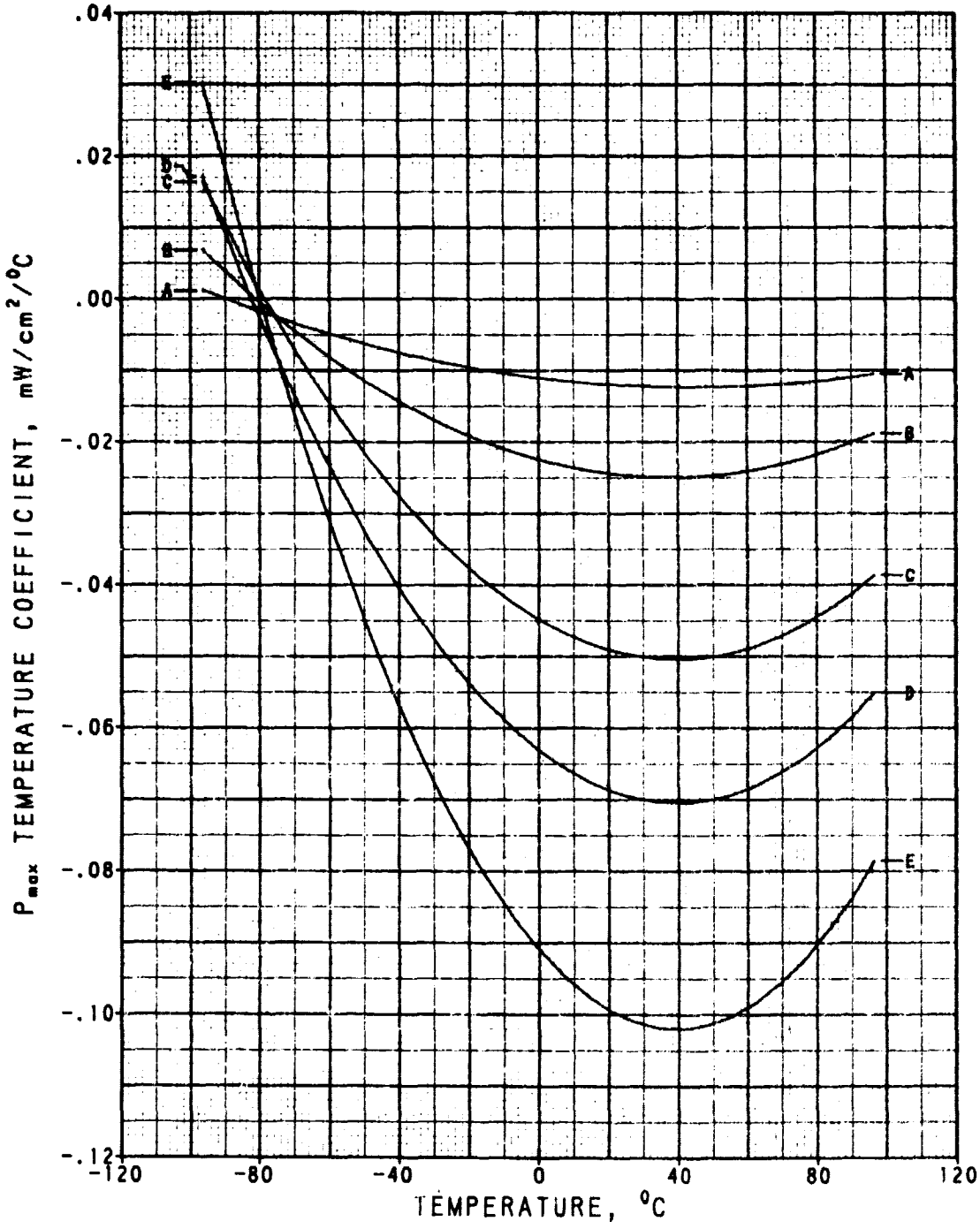
Figure 16. I_{SC} Temperature Coefficient (Intensity As a Parameter)



ID	mW/cm²
A	24.2
B	48.3
C	98.6
D	135.3
E	195.3

HELIOTEK (HIO/MARINER 71)
N/P 2 OHM-CM CG SILICON
2 X 2 X .046 CM
AG-TI-SOLDER CONTACTS
SI-O AR COATING
SAMPLE SIZE 7
NO COVERSLIDE

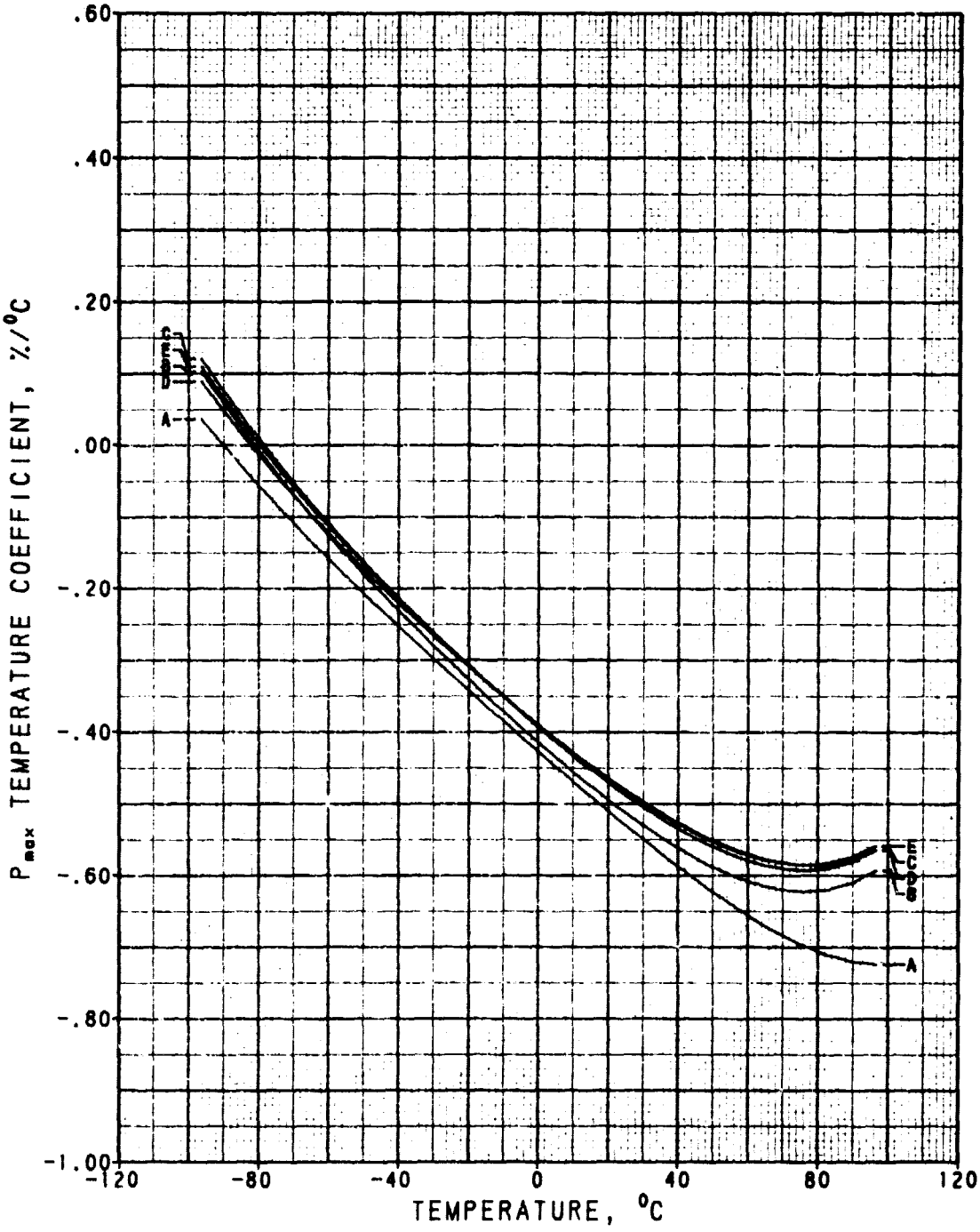
Figure 17. V_{oc} Temperature Coefficient (Intensity As a Parameter)



ID	mW/cm²
A	24.2
B	48.3
C	96.6
D	135.3
E	193.3

HELIOTEK (HIO/MARINER 71)
N/P 2 OHM-CM CG SILICON
2 X 2 X .046 CM
AG-TI-SOLDER CONTACTS
SI-O AR COATING
SAMPLE SIZE 7
NO COVERSLIDE

Figure 18. P_{max} Temperature Coefficient (Intensity As a Parameter)



ID	mW/cm²
A	24.2
B	48.3
C	96.6
D	135.3
E	193.3

HELIOTEK (HIO/MARINER 71)
N/P 2 OHM-CM CG SILICON
2 X 2 X .046 CM
AG-TI-SOLDER CONTACTS
SI-O AR COATING
SAMPLE SIZE 7
NO COVERSLIDE

Figure 19. P_{max} Temperature Coefficient (Intensity As a Parameter)

Table 1. Average Short Circuit Current, I_{sc} (mA/cm^2)

HELIOTEK (H10/MARINER 71)
N/P 2 OHM-CM CG SILICON
2 X 2 X .046 CM
AG-TI-SOLDER CONTACTS
SI-O AR COATING
SAMPLE SIZE 7
NO COVERSLIDE

CELL TEMP. (DEG. C)	SOLAR INTENSITY (MW/CM**2) 24.16	48.32	96.64	135.30	193.29
-100.00	5.14	10.07	20.36	29.01	41.55
	(.09)	(.17)	(.35)	(.49)	(.66)
-80.00	5.33	10.46	21.21	30.12	43.03
	(.10)	(.17)	(.30)	(.43)	(.48)
-60.00	5.51	10.93	21.95	30.87	44.51
	(.10)	(.17)	(.26)	(.36)	(.36)
-40.00	5.66	11.25	22.55	31.63	45.42
	(.11)	(.19)	(.27)	(.37)	(.32)
-20.00	5.77	11.45	22.96	32.15	45.99
	(.11)	(.19)	(.28)	(.38)	(.38)
.00	5.86	11.61	23.27	32.53	46.45
	(.10)	(.20)	(.30)	(.40)	(.41)
20.00	5.96	11.71	23.76	33.02	46.97
	(.10)	(.22)	(.29)	(.43)	(.44)
28.00	5.98	11.78	23.80	33.33	47.13
	(.10)	(.21)	(.28)	(.43)	(.45)
40.00	6.07	11.89	23.78	33.39	47.53
	(.09)	(.21)	(.27)	(.43)	(.42)
60.00	6.15	12.06	24.16	33.77	48.01
	(.08)	(.20)	(.28)	(.37)	(.40)
80.00	6.21	12.20	24.47	34.16	48.50
	(.09)	(.21)	(.22)	(.39)	(.37)
100.00	6.26	12.34	24.82	34.55	49.08
	(.09)	(.22)	(.22)	(.33)	(.34)

NOTE: STANDARD DEVIATIONS ARE GIVEN IN PARENTHESES.

Table 2. Average Open Circuit Voltage, V_{oc} (mV)

HELIOTEK (H10/MARINER 71)
N/P 2 OHM-CM CG SILICON
2 X 2 X .046 CM
AG-TI-SOLDER CONTACTS
SI-O AR COATING
SAMPLE SIZE 7
NO COVERSLIDE

CELL TEMP. (DEG. C)	SOLAR INTENSITY (MW/CM**2) 24.16	48.32	96.64	135.30	193.29
-100.00	807.01 (3.57)	816.99 (3.17)	824.10 (4.45)	826.63 (5.42)	826.96 (6.04)
-80.00	763.07 (4.10)	782.21 (2.96)	793.44 (2.95)	798.14 (3.01)	800.79 (3.66)
-60.00	726.30 (4.67)	743.27 (3.46)	757.99 (2.95)	763.74 (2.85)	768.47 (2.88)
-40.00	683.09 (4.88)	701.44 (3.57)	719.27 (3.01)	725.17 (2.89)	731.26 (2.67)
-20.00	638.04 (5.14)	658.07 (3.79)	674.81 (4.34)	683.39 (2.89)	691.40 (2.69)
.00	592.13 (5.29)	613.54 (4.10)	633.34 (3.29)	641.51 (3.09)	649.51 (2.75)
20.00	546.99 (4.56)	568.09 (3.92)	588.99 (3.30)	598.14 (2.76)	606.91 (2.92)
28.00	529.47 (4.88)	550.04 (3.82)	571.27 (3.33)	580.99 (2.89)	589.49 (2.94)
40.00	501.56 (4.28)	523.06 (3.73)	544.21 (3.42)	554.23 (3.03)	563.64 (3.07)
60.00	455.39 (4.19)	479.07 (3.50)	499.94 (3.39)	510.37 (3.15)	519.97 (3.20)
80.00	408.84 (4.12)	433.24 (3.46)	455.37 (3.13)	465.66 (3.19)	476.07 (3.28)
100.00	361.63 (4.07)	387.54 (3.41)	410.97 (3.16)	421.23 (3.29)	432.06 (3.18)

NOTE: STANDARD DEVIATIONS ARE GIVEN IN PARENTHESES.

Table 3. Average Maximum Power Current, I_{mp} (mA/cm^2)

HELIOTEK (H10/MARINER 71)
N/P 2 OHM-CM CG SILICON
2 X 2 X .046 CM
AG-TI-SOLDER CONTACTS
SI-O AR COATING
SAMPLE SIZE 7
NO COVERSLIDE

CELL TEMP. (DEG. C)	SOLAR INTENSITY (MW/CM**2) 24.16	48.32	96.64	135.30	193.29
-100.00	4.71	9.41	19.25	27.56	39.47
	(.17)	(.20)	(.32)	(.48)	(.59)
-80.00	4.90	9.77	20.07	28.56	40.84
	(.19)	(.20)	(.38)	(.52)	(.57)
-60.00	5.06	10.19	20.77	29.20	42.10
	(.17)	(.24)	(.36)	(.48)	(.40)
-40.00	5.17	10.47	21.19	29.84	42.67
	(.16)	(.23)	(.32)	(.49)	(.42)
-20.00	5.24	10.56	21.40	30.13	43.01
	(.14)	(.21)	(.26)	(.48)	(.43)
.00	5.29	10.68	21.63	30.30	43.09
	(.16)	(.22)	(.40)	(.49)	(.42)
20.00	5.32	10.67	21.71	30.30	43.26
	(.15)	(.19)	(.39)	(.50)	(.49)
28.00	5.33	10.63	21.68	30.41	43.31
	(.13)	(.21)	(.31)	(.56)	(.38)
40.00	5.38	10.66	21.46	30.28	43.25
	(.15)	(.22)	(.37)	(.39)	(.32)
60.00	5.44	10.67	21.52	30.25	43.27
	(.16)	(.17)	(.27)	(.45)	(.38)
80.00	5.36	10.65	21.59	30.31	42.86
	(.11)	(.17)	(.24)	(.32)	(.32)
100.00	5.27	10.56	21.45	30.09	42.91
	(.09)	(.18)	(.23)	(.46)	(.49)

NOTE: STANDARD DEVIATIONS ARE GIVEN IN PARENTHESES.

Table 4. Average Maximum Power Voltage, V_{mp} (mV)

HELIOTEK (H10/MARINER 71)
N/P 2 OHM-CM CG SILICON
2 X 2 X .046 CM
AG-TI-SOLDER CONTACTS
SI-O AR COATING
SAMPLE SIZE 7
NO COVERSLIDE

CELL TEMP. (DEG. C)	SOLAR INTENSITY (MW/CM**2) 24.16	48.32	96.64	135.30	193.20
-100.00	660.91	690.79	696.70	696.06	696.37
	(12.17)	(10.37)	(9.85)	(8.90)	(8.06)
-80.00	660.96	674.14	678.70	680.34	679.89
	(11.06)	(9.60)	(9.23)	(8.24)	(8.11)
-60.00	626.74	645.17	652.80	657.06	658.09
	(11.13)	(5.96)	(5.60)	(5.58)	(6.74)
-40.00	585.71	602.69	618.74	622.53	627.54
	(11.02)	(8.71)	(6.54)	(4.10)	(4.49)
-20.00	541.21	557.64	577.33	581.74	587.01
	(12.10)	(11.77)	(7.77)	(4.67)	(2.72)
.00	494.94	514.63	531.53	537.60	544.30
	(8.81)	(7.80)	(4.78)	(5.24)	(4.96)
20.00	451.33	469.21	490.21	494.29	499.37
	(7.57)	(7.21)	(2.95)	(3.23)	(3.24)
28.00	432.06	453.80	472.43	477.90	480.64
	(7.93)	(4.90)	(4.55)	(4.71)	(3.92)
40.00	404.90	427.61	446.07	450.71	455.67
	(5.70)	(3.98)	(3.39)	(4.44)	(3.06)
60.00	355.37	384.64	402.54	407.94	411.13
	(5.01)	(3.91)	(3.28)	(3.86)	(2.94)
80.00	315.39	340.44	358.89	363.59	370.03
	(6.58)	(4.78)	(3.27)	(3.28)	(3.77)
100.00	272.99	297.77	317.26	321.96	325.10
	(7.22)	(3.06)	(3.23)	(3.51)	(4.19)

NOTE: STANDARD DEVIATIONS ARE GIVEN IN PARENTHESES.

Table 5. Average Maximum Power, P_{max} (mW/cm^2)

HELIOTEK (H10/MARINER 71)
N/P 2 OHM-CM CG SILICON
2 X 2 X .046 CM
AG-TI-SOLDER CONTACTS
SI-O AR COATING
SAMPLE SIZE 7
NO COVERSLIDE

CELL TEMP. (DEG. C)	SOLAR INTENSITY (MW/CM**2)				
	24.16	48.32	96.64	135.30	193.29
-100.00	3.21	6.50	13.42	19.01	27.49
	(.16)	(.21)	(.35)	(.46)	(.57)
-80.00	3.24	6.59	13.63	19.44	27.77
	(.17)	(.22)	(.37)	(.51)	(.56)
-60.00	3.18	6.57	13.56	19.22	27.71
	(.16)	(.21)	(.34)	(.45)	(.64)
-40.00	3.03	6.31	13.11	18.58	26.78
	(.15)	(.20)	(.32)	(.39)	(.36)
-20.00	2.84	5.89	12.36	17.53	25.25
	(.13)	(.20)	(.30)	(.36)	(.32)
.00	2.62	5.50	11.50	16.29	23.46
	(.12)	(.17)	(.27)	(.33)	(.30)
20.00	2.40	5.01	10.65	14.98	21.60
	(.10)	(.15)	(.24)	(.30)	(.28)
28.00	2.30	4.83	10.24	14.51	20.82
	(.09)	(.14)	(.22)	(.29)	(.27)
40.00	2.18	4.56	9.58	13.65	19.71
	(.09)	(.12)	(.21)	(.27)	(.24)
60.00	1.93	4.11	8.67	12.34	17.79
	(.08)	(.10)	(.16)	(.21)	(.21)
80.00	1.69	3.63	7.75	11.02	15.86
	(.07)	(.09)	(.12)	(.17)	(.16)
100.00	1.44	3.14	6.81	9.69	13.95
	(.06)	(.08)	(.10)	(.13)	(.13)

NOTE: STANDARD DEVIATIONS ARE GIVEN IN PARENTHESES.

Table 6. Average Curve Factor

HELIOTEK (H10/MARINER 71)
N/P 2 OHM-CM CG SILICON
2 X 2 X .046 CM
AG-TI-SOLDER CONTACTS
SI-O AR COATING
SAMPLE SIZE 7
NO COVERSLIDE

CELL TEMP. (DEG. C)	SOLAR INTENSITY (MW/CM**2) 24.16	48.32	96.64	135.30	193.20
-100.00	.7736	.7902	.7993	.8010	.8000
	(.0341)	(.0221)	(.0130)	(.0098)	(.0088)
-80.00	.7908	.8048	.8094	.8088	.8059
	(.0313)	(.0193)	(.0120)	(.0090)	(.0085)
-60.00	.7935	.8088	.8150	.8149	.8100
	(.0242)	(.0167)	(.0108)	(.0087)	(.0076)
-40.00	.7839	.7997	.8093	.8098	.8062
	(.0221)	(.0152)	(.0099)	(.0077)	(.0068)
-20.00	.7705	.7818	.7977	.7970	.7940
	(.0192)	(.0172)	(.0116)	(.0083)	(.0069)
.00	.7547	.7712	.7800	.7807	.7774
	(.0183)	(.0132)	(.0090)	(.0078)	(.0061)
20.00	.7361	.7529	.7606	.7592	.7578
	(.0180)	(.0122)	(.0088)	(.0079)	(.0068)
28.00	.7291	.7445	.7532	.7495	.7493
	(.0138)	(.0124)	(.0091)	(.0074)	(.0070)
40.00	.7152	.7331	.7399	.7375	.7357
	(.0165)	(.0113)	(.0083)	(.0074)	(.0066)
60.00	.6905	.7107	.7174	.7159	.7126
	(.0155)	(.0113)	(.0092)	(.0069)	(.0068)
80.00	.6650	.6860	.6951	.6928	.6869
	(.0154)	(.0111)	(.0069)	(.0067)	(.0072)
100.00	.6352	.6575	.6670	.6656	.6579
	(.0146)	(.0105)	(.0070)	(.0064)	(.0077)

NOTE: STANDARD DEVIATIONS ARE GIVEN IN PARENTHESES.

Table 7. Average Efficiency (%)

HELIOTEK (H10/MARINER 71)
N/P 2 OHM-CM CG SILICON
2 X 2 X .046 CM
AG-TI-SOLDER CONTACTS
SI-O AR COATING
SAMPLE SIZE 7
NO COVERSLIDE

CELL TEMP. (DEG. C)	SOLAR INTENSITY (MW/CM**2) 24.16	48.32	96.64	135.30	193.29
-100.00	13.27	13.46	13.89	14.30	14.22
	(.68)	(.43)	(.36)	(.34)	(.29)
-80.00	13.40	13.64	14.10	14.47	14.37
	(.71)	(.46)	(.39)	(.36)	(.29)
-60.00	13.14	13.60	14.03	14.30	14.33
	(.66)	(.44)	(.35)	(.34)	(.23)
-40.00	12.55	13.06	13.57	13.73	13.85
	(.61)	(.42)	(.33)	(.29)	(.19)
-20.00	11.75	12.19	12.79	12.96	13.06
	(.56)	(.41)	(.31)	(.27)	(.16)
.00	10.84	11.37	11.90	12.04	12.14
	(.50)	(.35)	(.28)	(.24)	(.16)
20.00	9.94	10.37	11.02	11.07	11.18
	(.43)	(.31)	(.24)	(.20)	(.14)
28.00	9.54	9.99	10.60	10.72	10.77
	(.38)	(.28)	(.23)	(.20)	(.14)
40.00	9.02	9.43	9.91	10.09	10.20
	(.36)	(.25)	(.21)	(.20)	(.13)
60.00	8.00	8.50	8.97	9.12	9.20
	(.32)	(.21)	(.17)	(.16)	(.11)
80.00	7.00	7.51	8.02	8.15	8.21
	(.28)	(.18)	(.13)	(.12)	(.09)
100.00	5.96	6.51	7.04	7.16	7.22
	(.24)	(.16)	(.10)	(.09)	(.07)

NOTE: STANDARD DEVIATIONS ARE GIVEN IN PARENTHESES.