JPL PUBLICATION 78-15, VOLUME I

# Characterization of Solar Cells for Space Applications

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




National Aeronautics and
Space Administration

**Jet Propulsion Laboratory**
California Institute of Technology
Pasadena, California

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

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R. G. Downing
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March 15, 1978

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## PREFACE

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

## 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.

## ABSTRACT

Electrical characteristics of OCLI violet N/P silicon solar cells are presented in graphical and tabular format as a function of solar illumination intensity and temperature.

CONTENTS

Tables

## SECTION I

## INTRODUCTION

This report, which is the first of a series, contains a set of parametric data on the OCLI violet cell that was obtained under a variety of intensity-temperature combinations of the type encountered in typical space applications. The purpose of this series of reports is to provide engineering data on the electrical characteristics of devices of interest to the photovoltaic community. The report series consists primarily of working graphs and tables and does not address itself to interpretive conclusions. The formatting of these 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 reported here were manufactured by Optical Coating Laboratories Inc. (OCLI) and are available as off-the-shelf, space-qualified solar cells. 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 0.025 cm (10 mils) thick. An antireflectance coating of tantalum pentoxide is applied to the top surface. The electrical contact on the top surface consist of solderless Cr-Au-Aq in a 3 x 11 finger grid pattern with a bus bar running the length of one side. The rear contact is a picture frame contact.

In order to obtain parametric test data consistent with typical space applications, cover slides were mounted on the cells prior to testing. The cover slides were 7940 fused silica 0.038 cm (15 mils) thick with a 0.35-micrometer cut-on dielectric interference filter. The cover slides were bonded to the surface of the cells with Dow Corning 182 silicone adhesive.

## 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 x 10-6 torr.

The illumination source used throughout the test program 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 2.5-kW short-arc xenon lamp. A system of filters mollifies the spectral distribution so that it approximates that of space sunlight. The light beam provides a pattern having a uniformity of ±1% over a square 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 in conjunction with the NASA/JPL solar cell standardization program. Photographs of the solar cell, the assembled plate, and the experimental characterization test facility are shown in an appendix.

## 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, 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 of 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 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 parameters, as shown in Figures 15 to 18.

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 $^oC$.
(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 m (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 (Figures 7 and 14) 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: $I_{sc}$, $V_{oc}$, $I_{Pmax}$, $V_{Pmax}$, $P_{max}$, CF, and efficiency at each intensity-temperature combination address. For 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 Figures 1 to 14 and Tables 1 to 7, it is possible to determine electrical parameters of import ($I_{sc}$, $V_{oc}$, $V_{mp}$, $P_{max}$, CF, and efficiency) for any arbitrary orbit profile within the confines of extremes of intensity

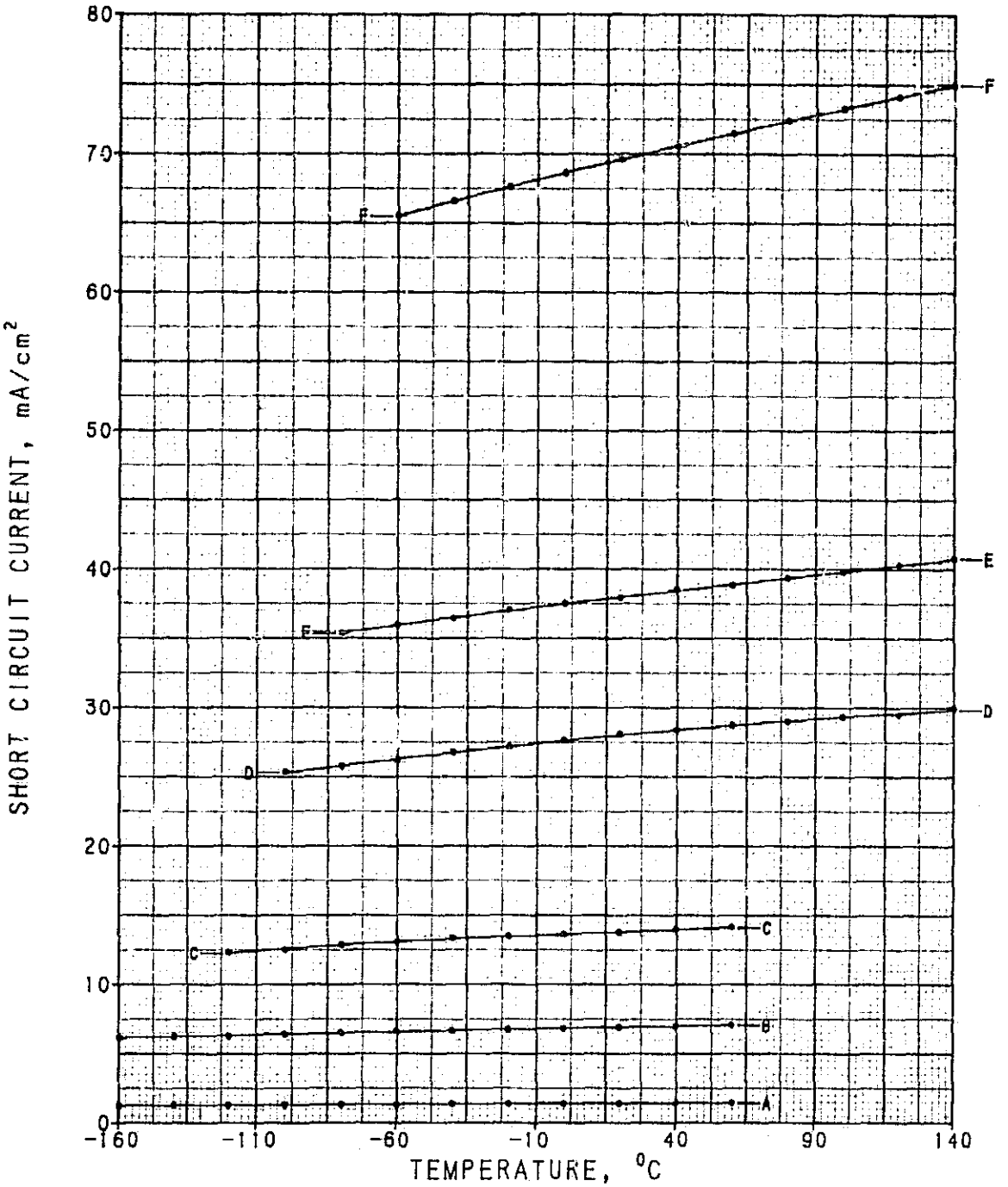
---

[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.

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 Figures 15 to 18 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.

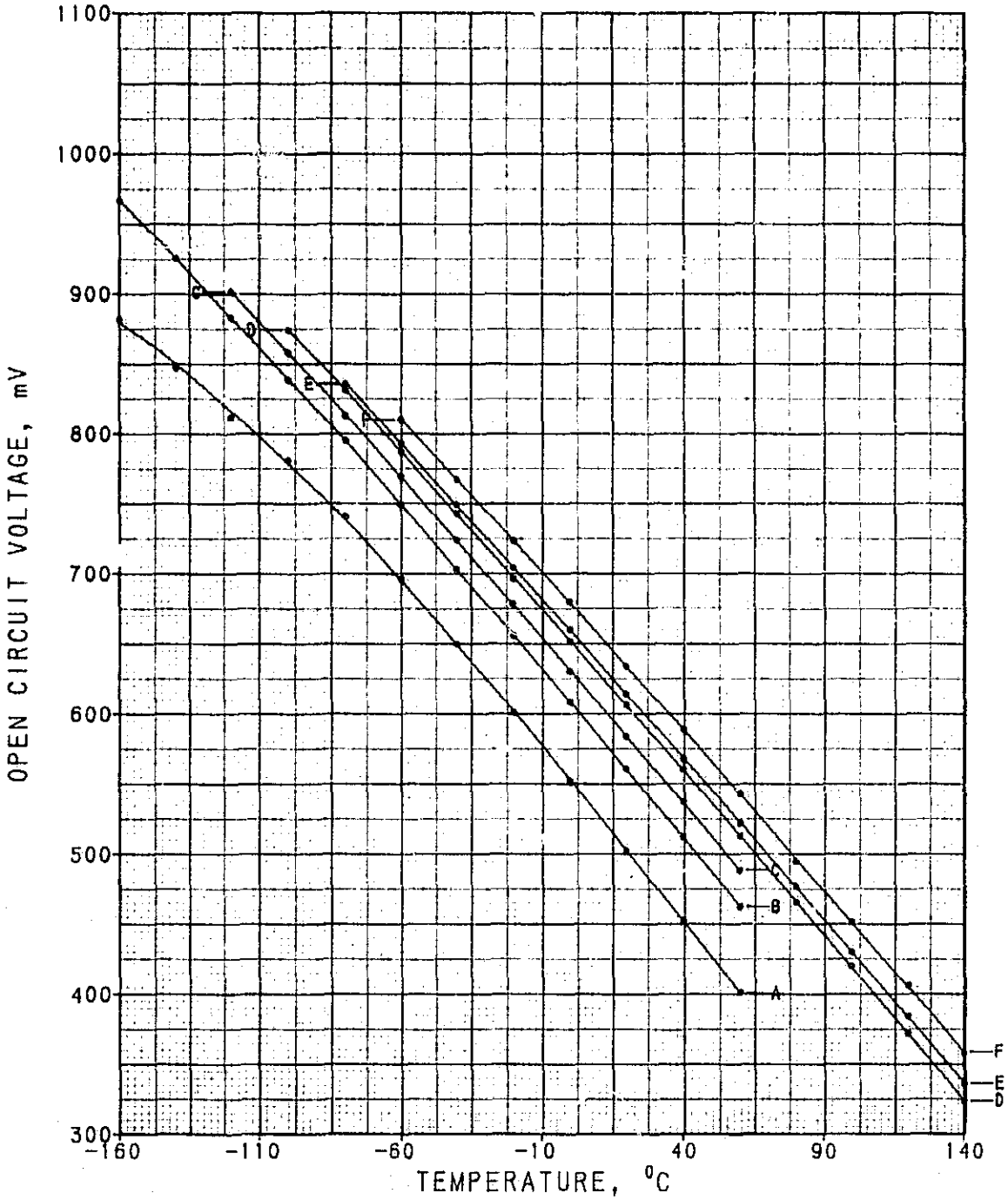
The objective of these reports is to facilitate comparisons among solar cell types treated in this and in future reports with respect to electrical characteristics as a function of intensity and temperature (i.e., for sets of anticipated cell equilibrium conditions representative of particular mission 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 an application and in determining the cell electrical characteristics.




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

OCLI VIOLET
N/P 2 OHM-CM CG SILICON
2 X 2 X .025 CM
CR-AU-AG 3 X 19 GRID LINES
TA2O5 AR COATING
7940 COVER .35 MICRON CUT-ON
.038 CM THICK
SAMPLE SIZE 14

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




| ID | mW/cm² |
|---|---|
| A | 5.0 |
| B | 25.0 |
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| D | 100.0 |
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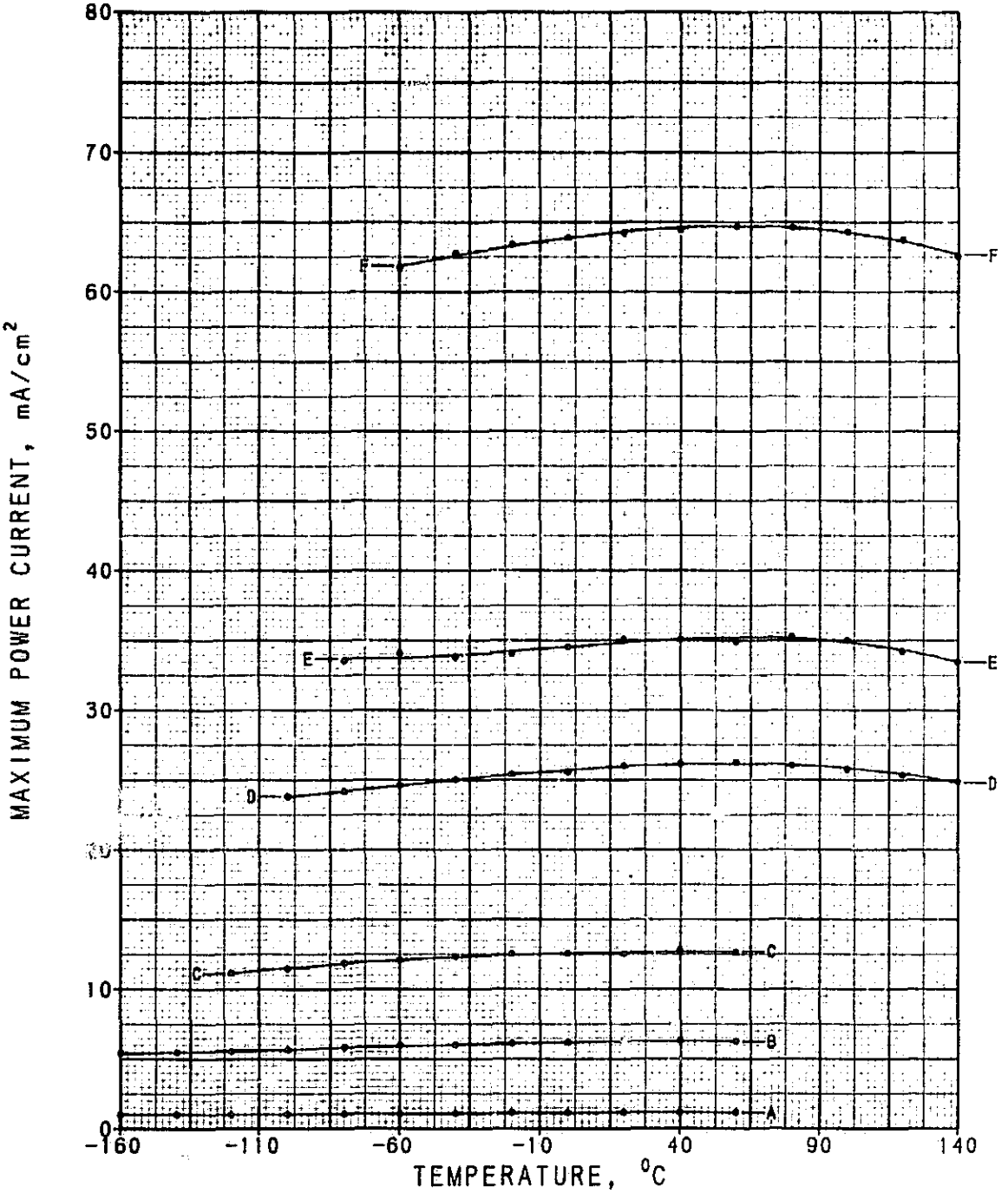
Figure 2. Average $V_{OC}$ as a Function of Temperature




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

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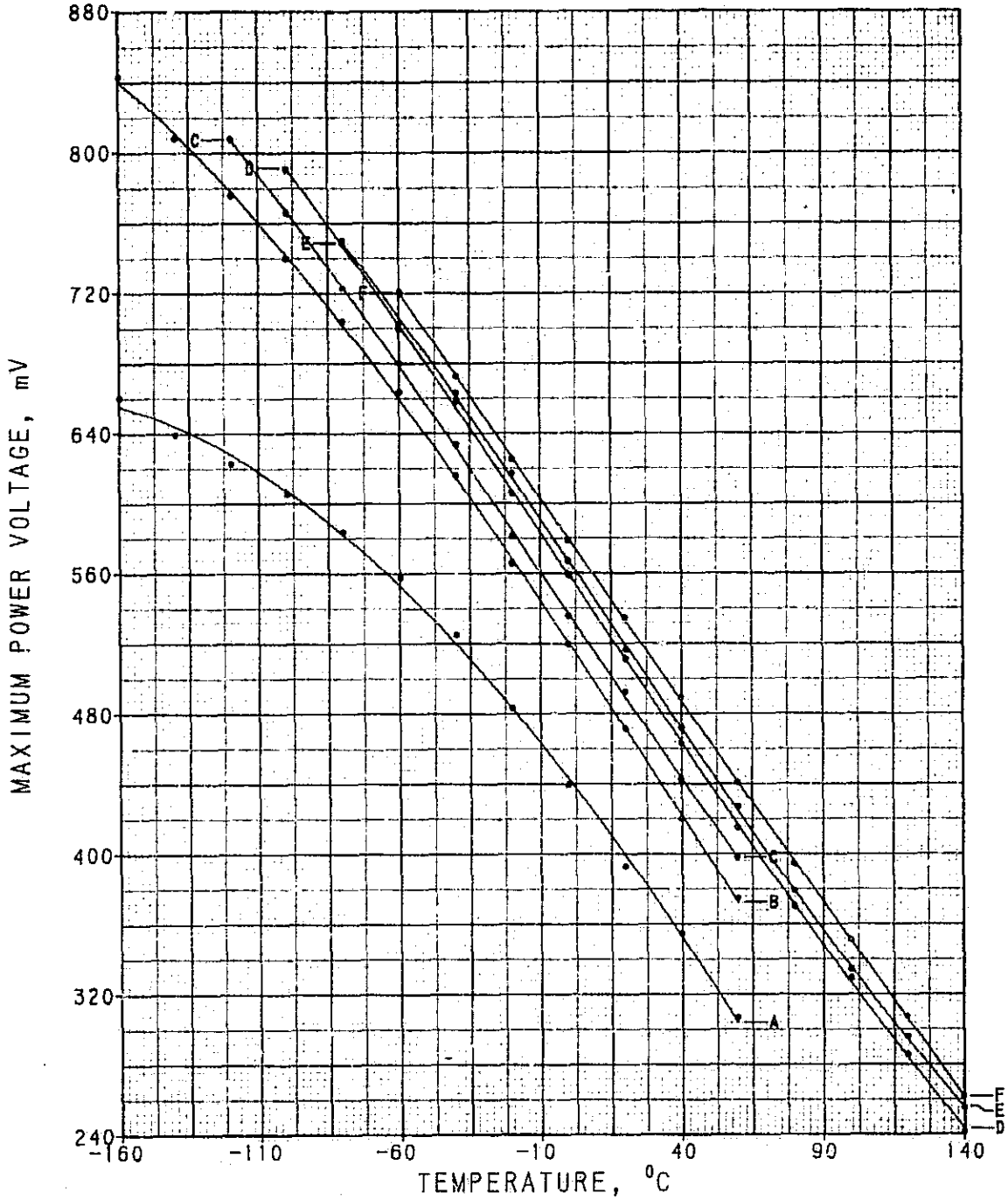
.038 CM THICK
SAMPLE SIZE 14

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




| ID | mW/cm² |
|---|---|
| A | 5.0 |
| B | 25.0 |
| C | 50.0 |
| D | 100.0 |
| E | 135.3 |
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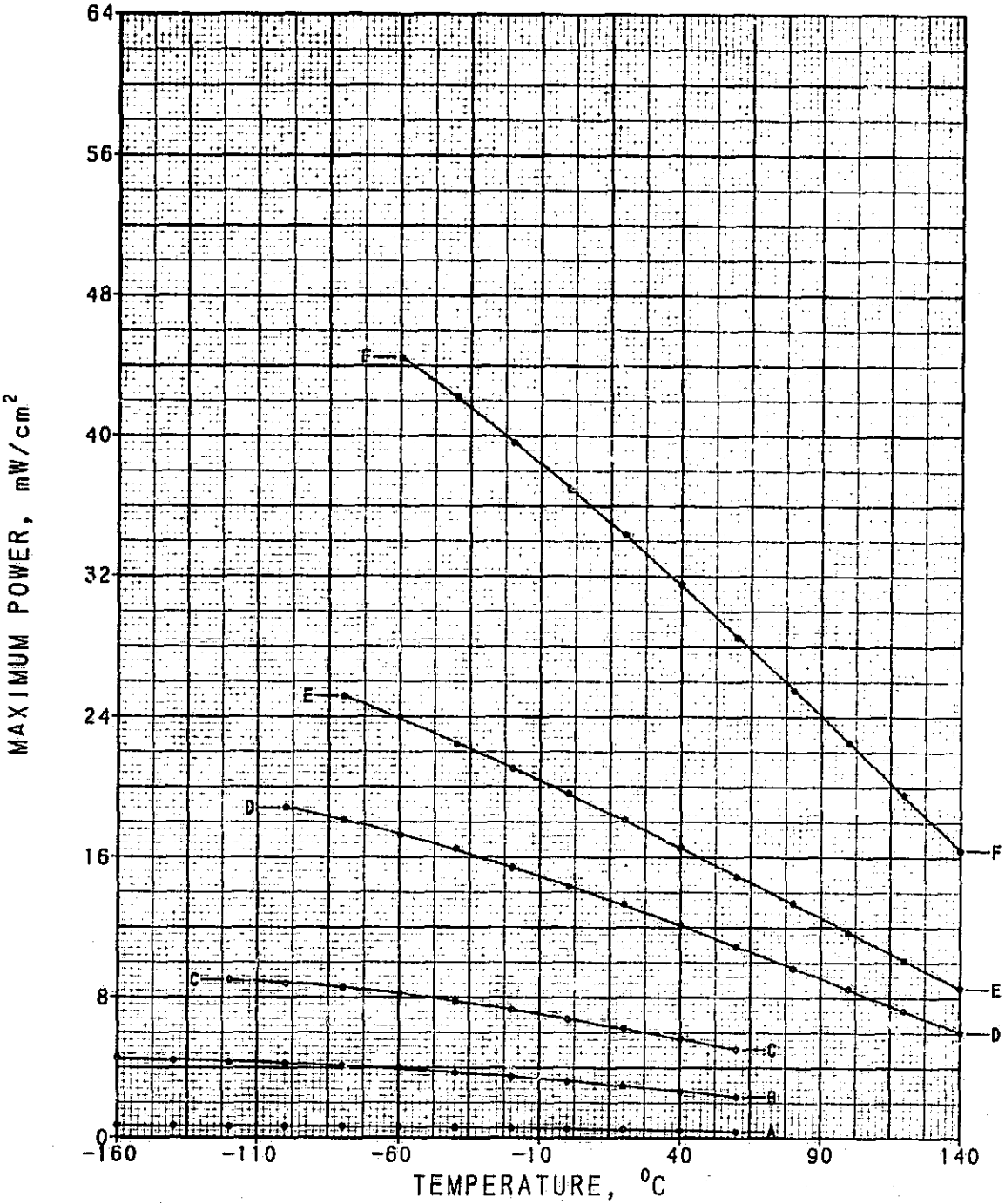
Figure 4. Average $V_{mp}$ as a Function of Temperature




| ID | mW/cm² |
|---|---|
| A | 5.0 |
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| D | 100.0 |
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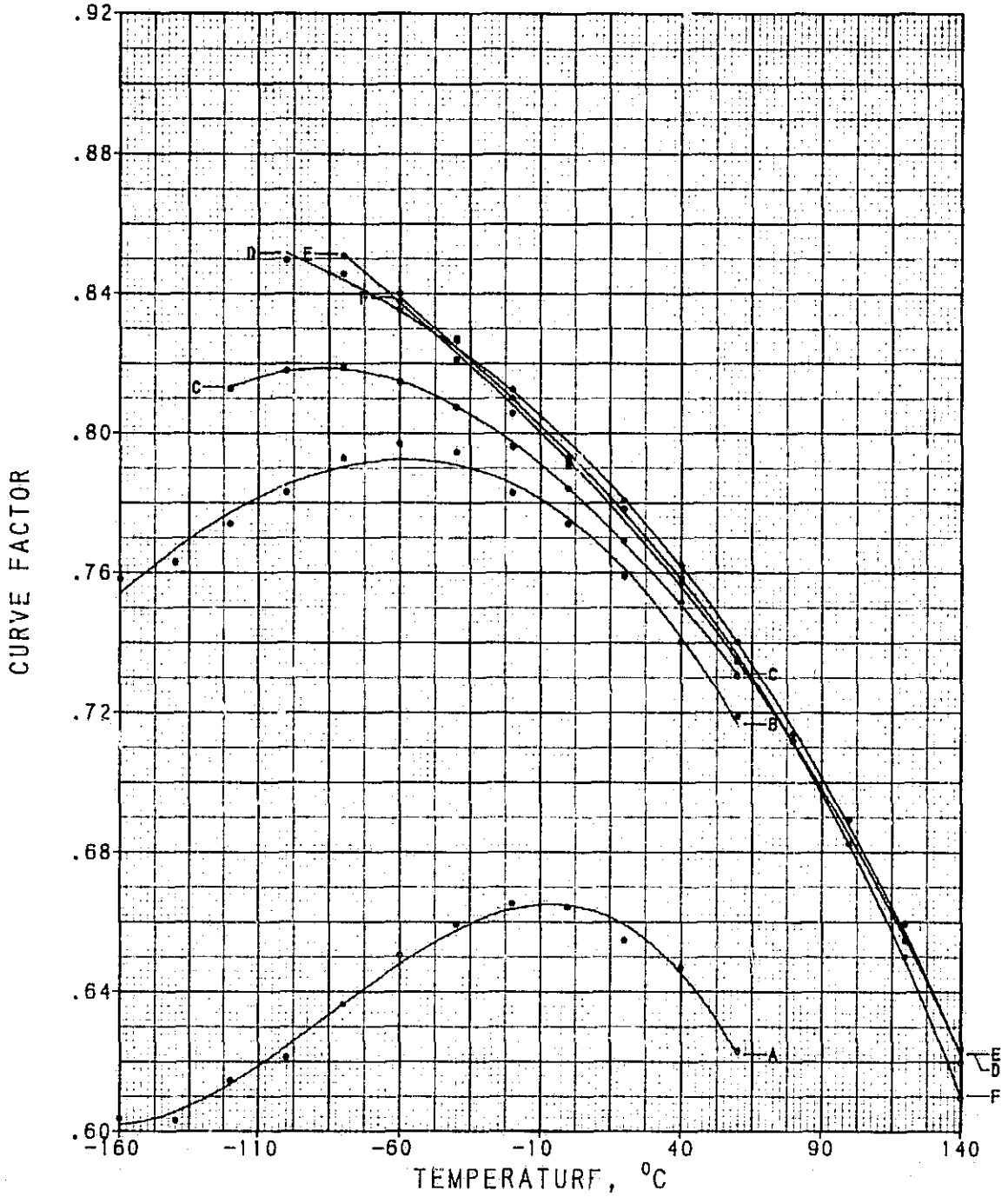
Figure 5. Average $P_{max}/cm^2$ as a Function of Temperature




| ID | mW/cm² |
|---|---|
| A | 5.0 |
| B | 25.0 |
| C | 50.0 |
| D | 100.0 |
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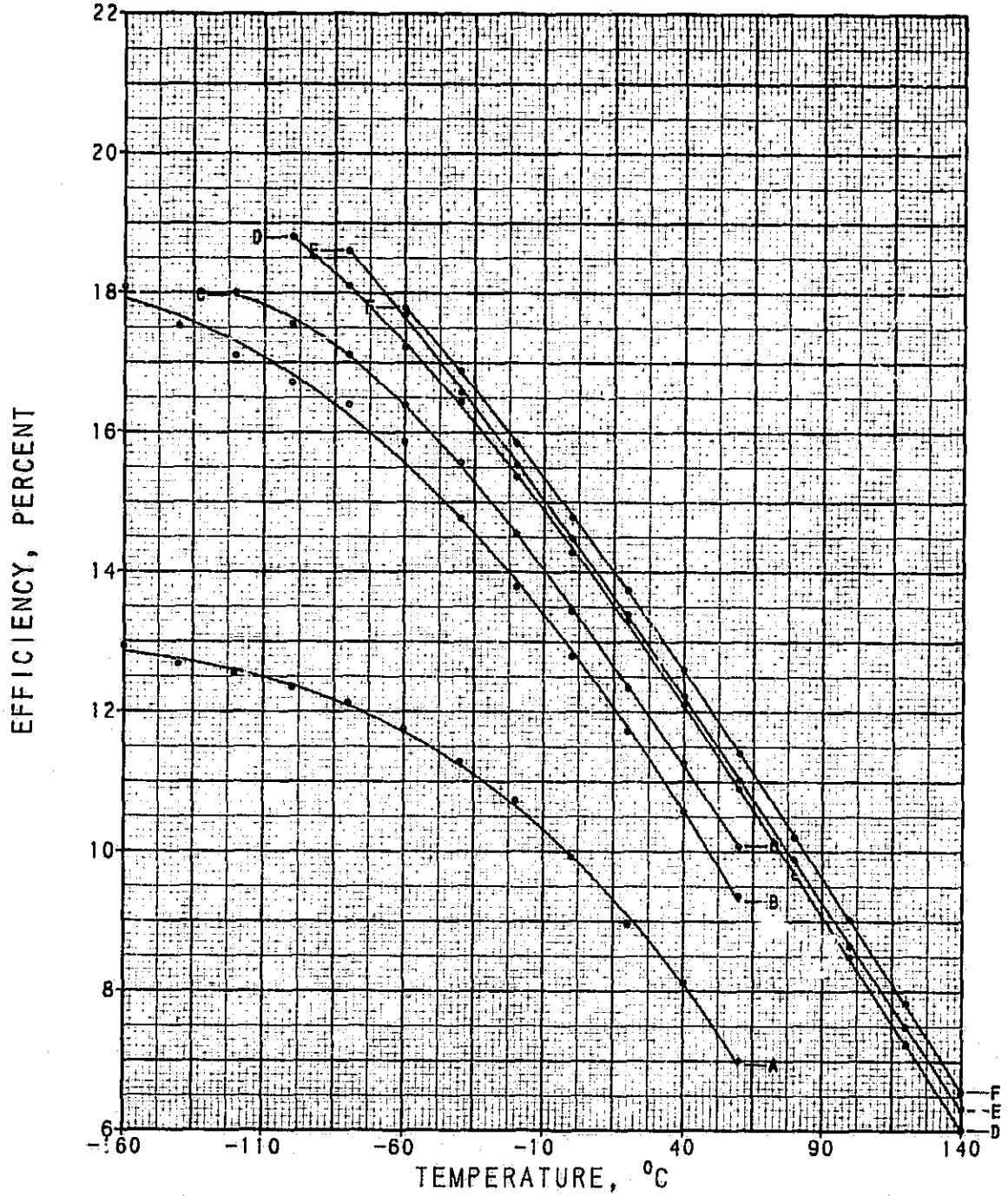
.038 CM THICK
SAMPLE SIZE 14

Figure 6. Average Curve Factor as a Function of Temperature




| ID | mW/cm² |
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| A | 5.0 |
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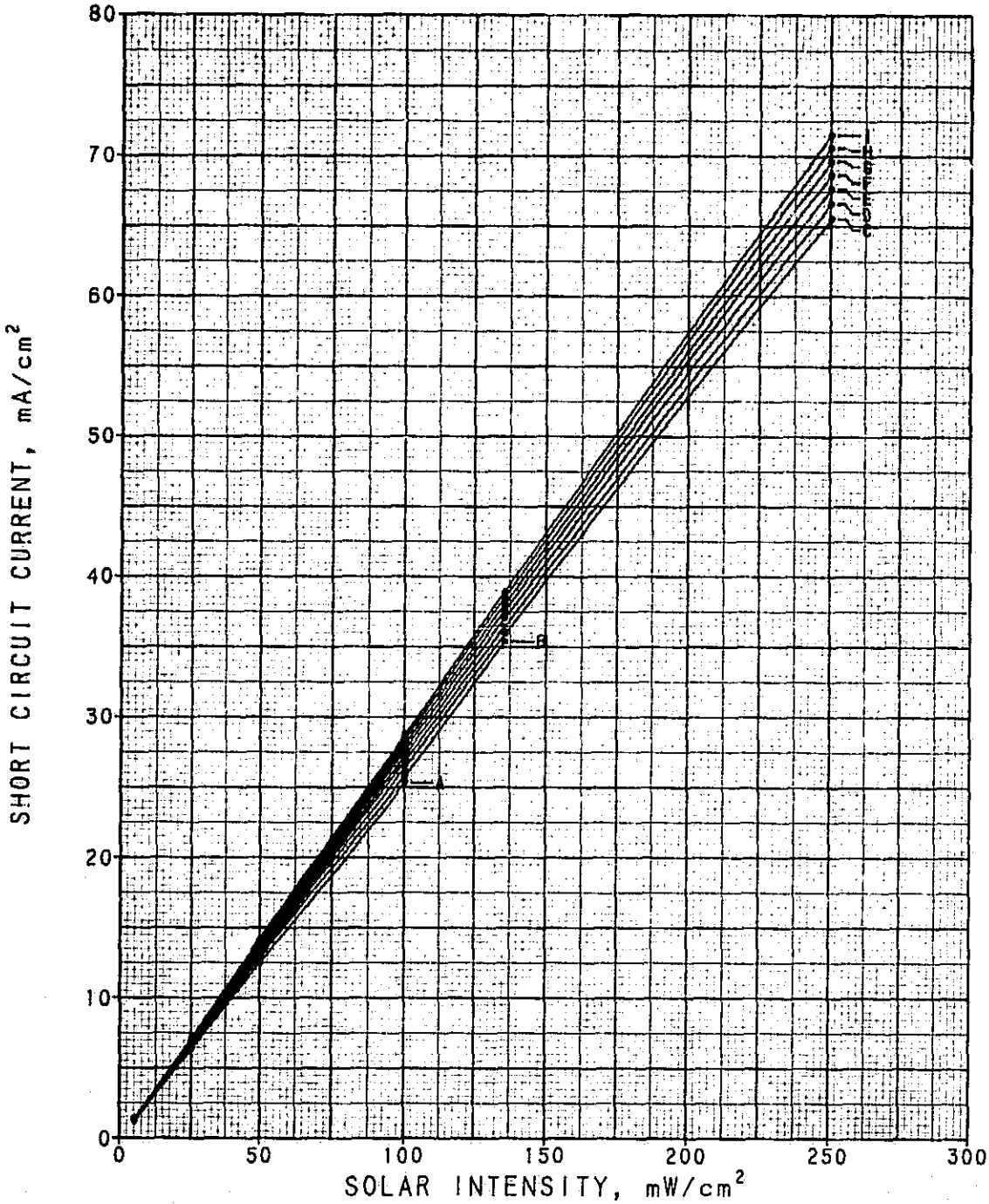
Figure 7. Average AMO Efficiency as a Function of Temperature




| ID | °C | ID | °C |
|---|---|---|---|
| A | -100.0 | I | 60.0 |
| B | -80.0 | | |
| C | -60.0 | | |
| D | -40.0 | | |
| E | -20.0 | | |
| F | .0 | | |
| G | 20.0 | | |
| H | 40.0 | | |

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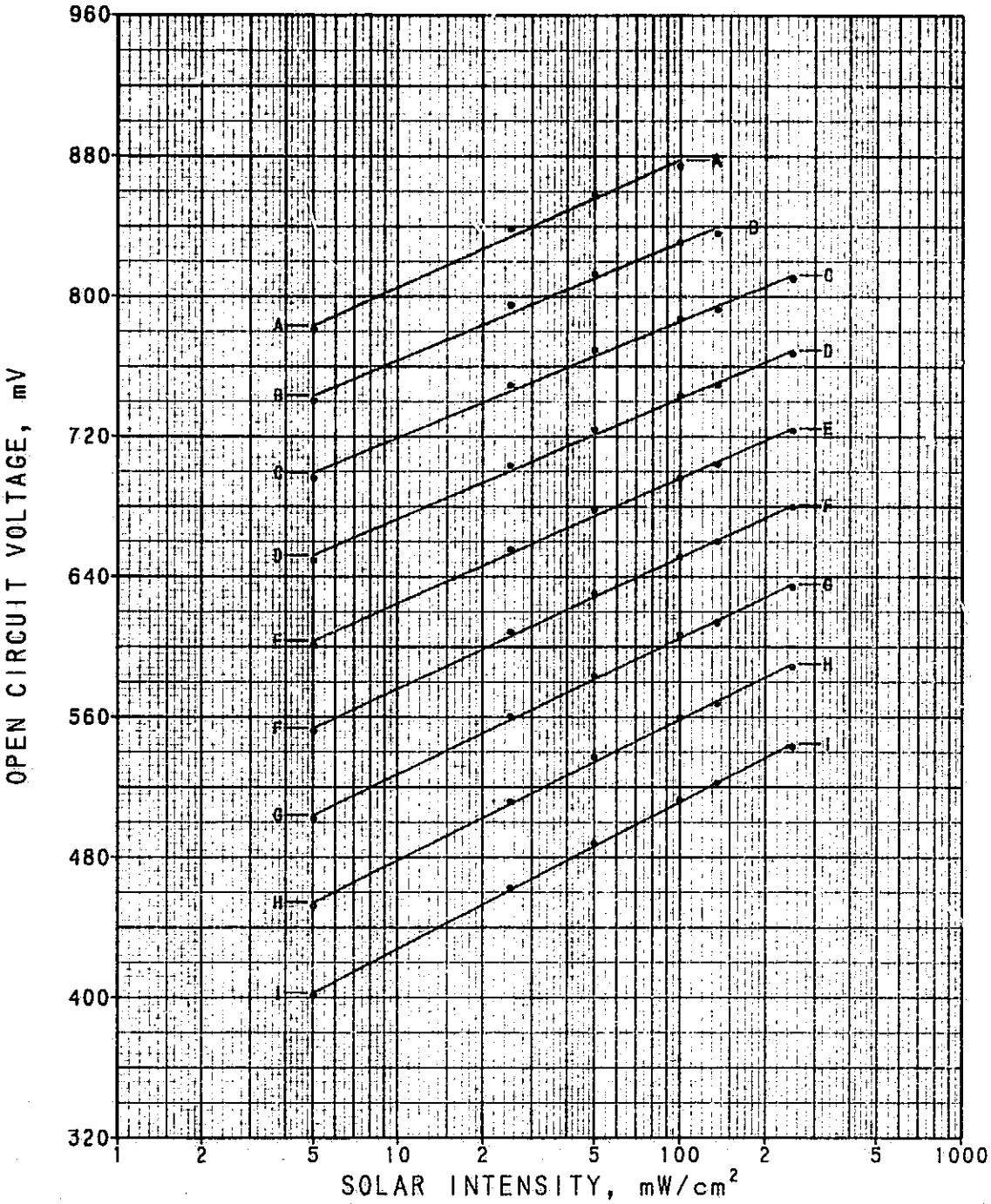
SAMPLE SIZE 14

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




| ID | °C | ID | °C |
|---|---|---|---|
| A | -100.0 | I | 60.0 |
| B | -80.0 | | |
| C | -60.0 | | |
| D | -40.0 | | |
| E | -20.0 | | |
| F | .0 | | |
| G | 20.0 | | |
| H | 40.0 | | |

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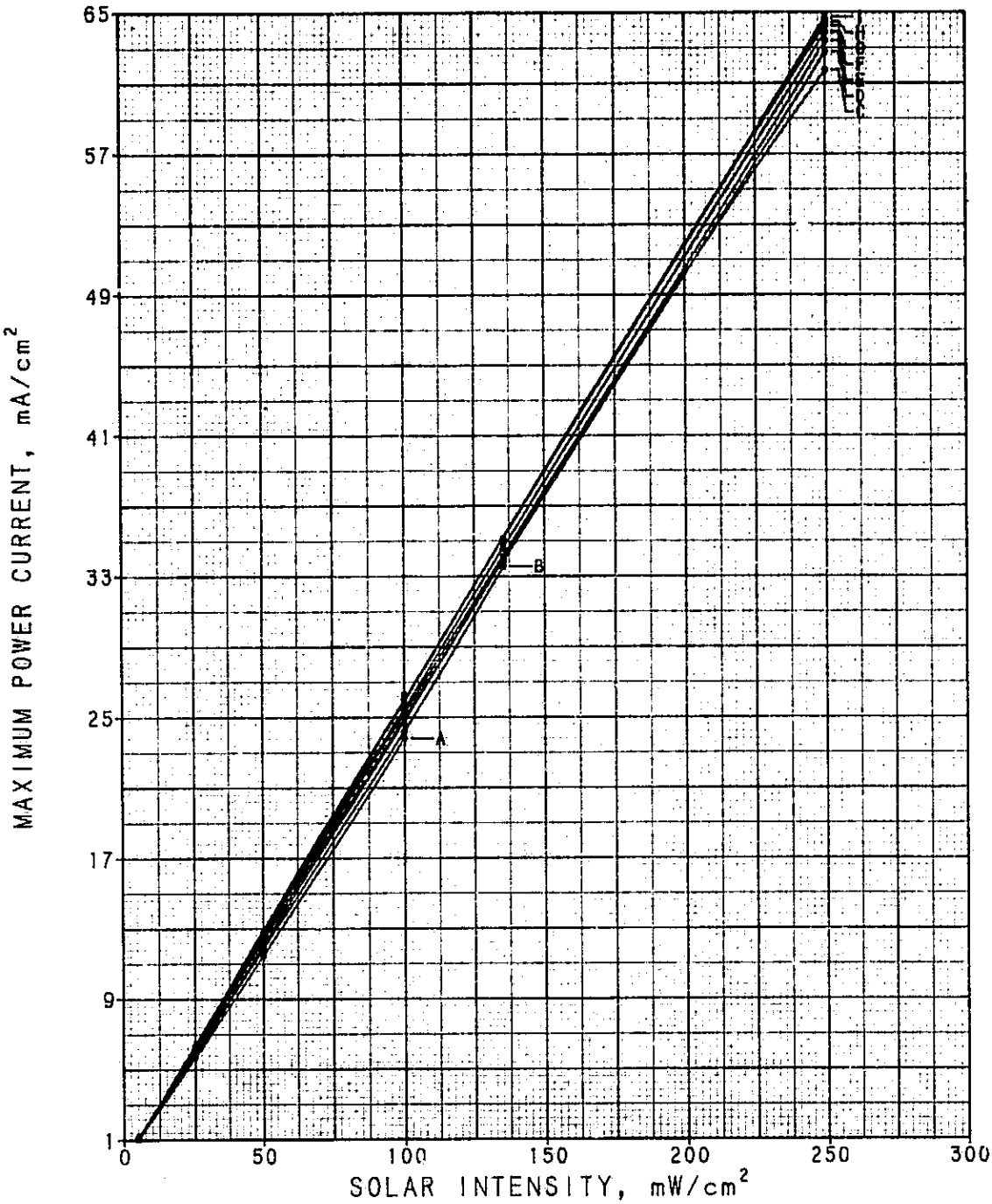
SAMPLE SIZE 14

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




| ID | °C | ID | °C |
|---|---|---|---|
| A | -100.0 | I | 60.0 |
| B | -80.0 | | |
| C | -60.0 | | |
| D | -40.0 | | |
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| G | 20.0 | | |
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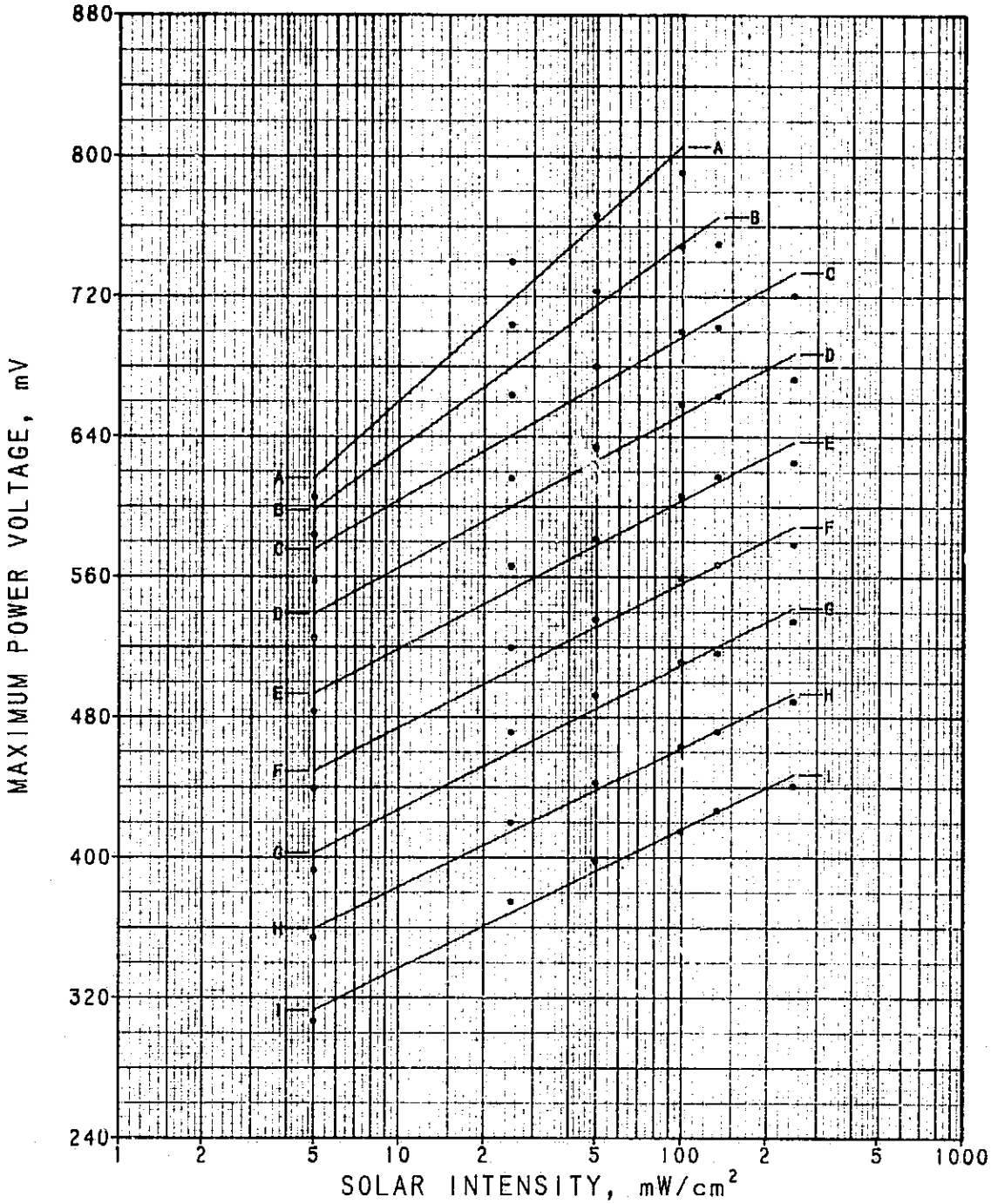
Figure 10. Average $I_{mp}/cm^2$ as a Function of Intensity




| ID | °C | ID | °C |
|---|---|---|---|
| A | -100.0 | I | 60.0 |
| B | -80.0 | | |
| C | -60.0 | | |
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| E | -20.0 | | |
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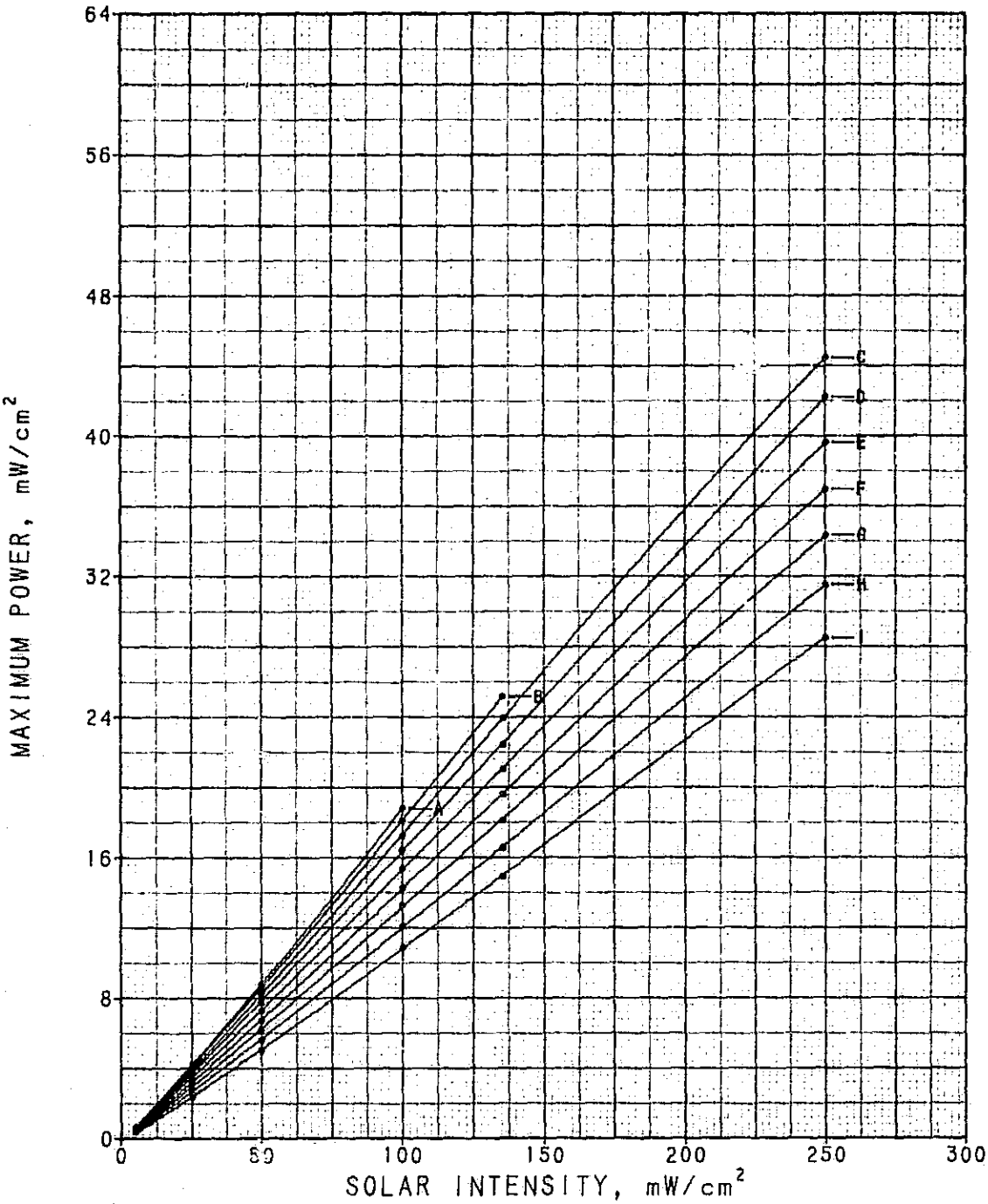
Figure 11. Average $V_{mp}$ as a Function of Intensity




| ID | °C | ID | °C |
|---|---|---|---|
| A | -100.0 | I | 60.0 |
| B | -80.0 | | |
| C | -60.0 | | |
| D | -40.0 | | |
| E | -20.0 | | |
| F | .0 | | |
| G | 20.0 | | |
| H | 40.0 | | |

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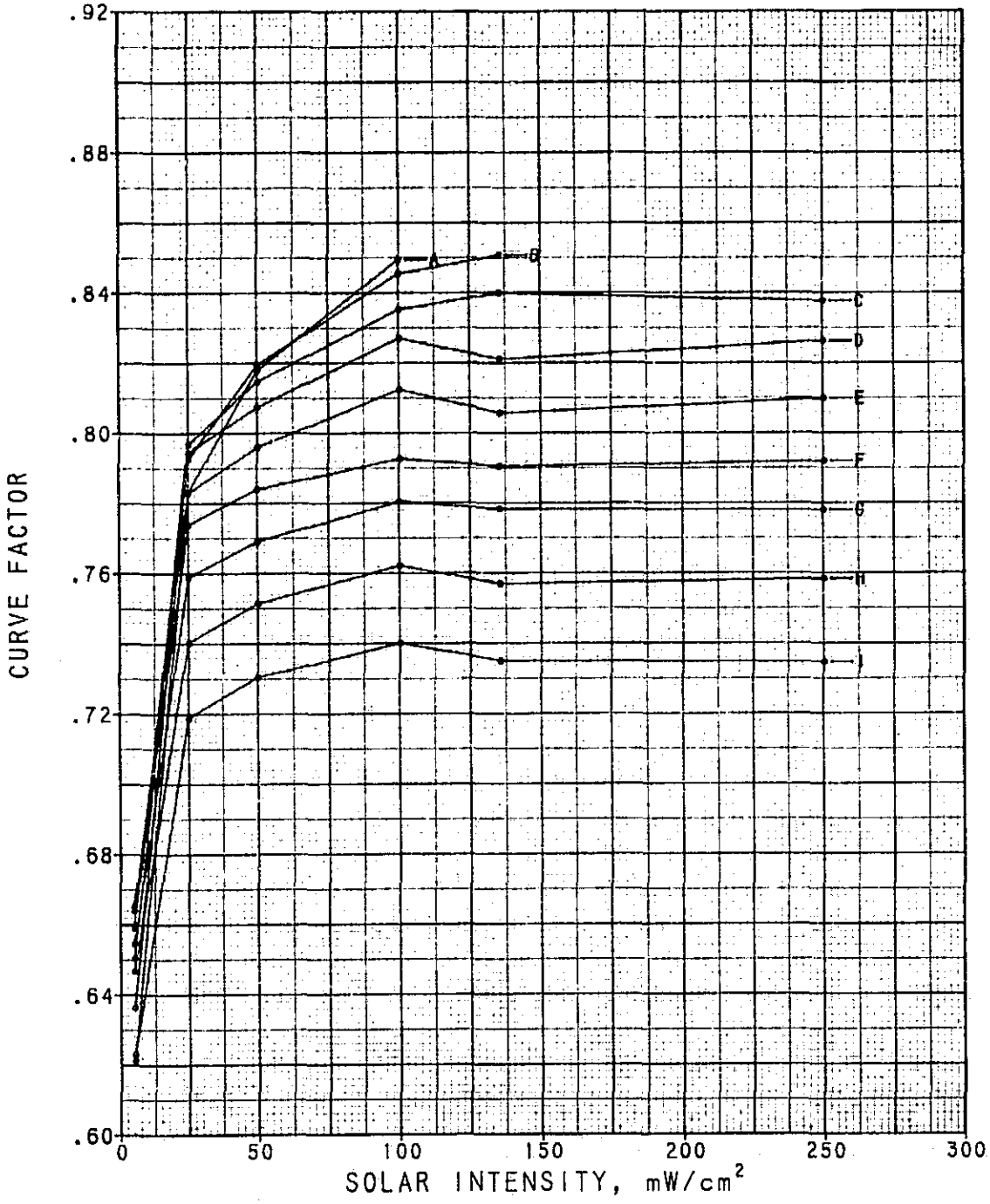
SAMPLE SIZE 14

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




| ID | °C | ID | °C |
|---|---|---|---|
| A | -100.0 | I | 60.0 |
| B | -80.0 | | |
| C | -60.0 | | |
| D | -40.0 | | |
| E | -20.0 | | |
| F | .0 | | |
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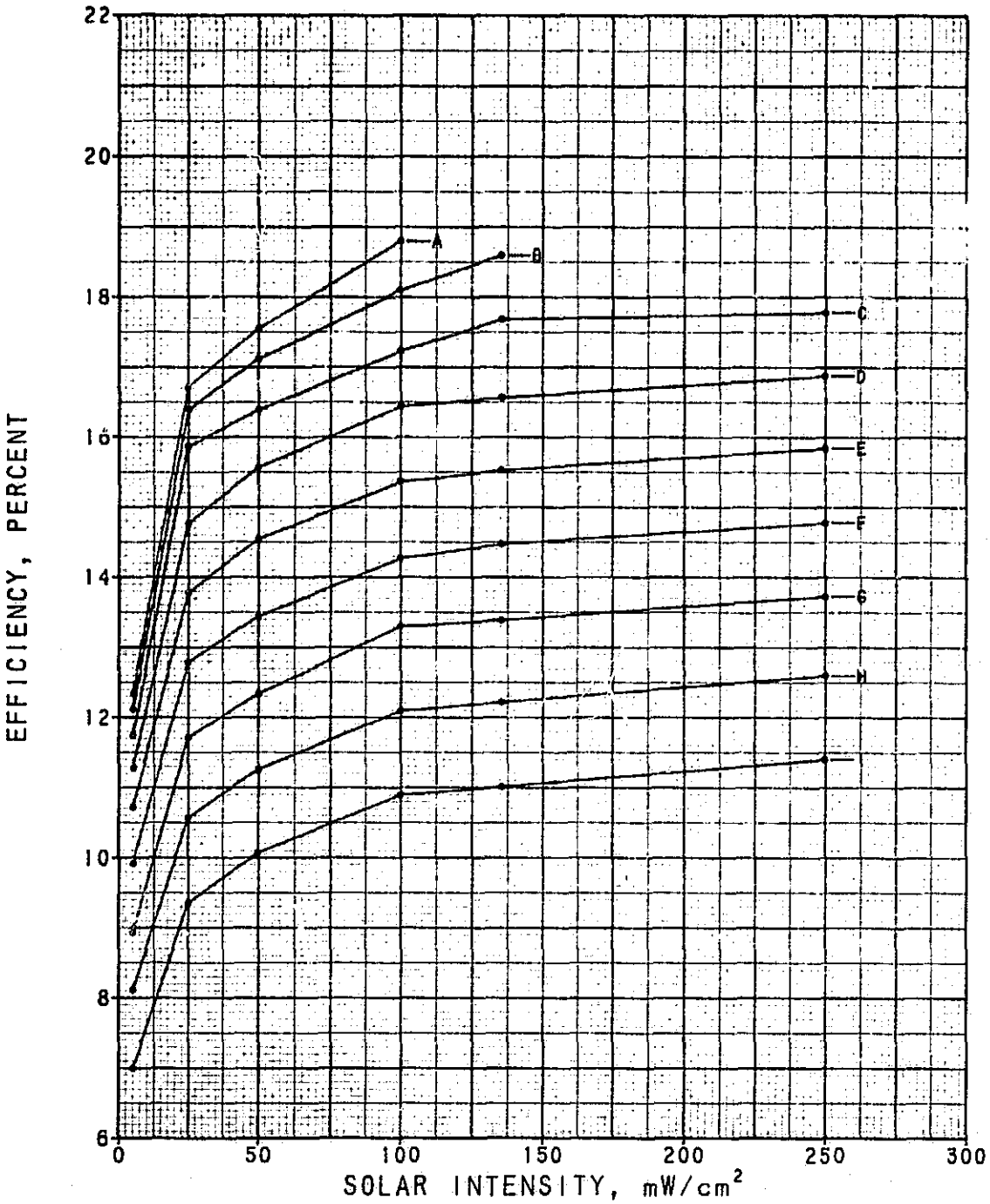
Figure 13. Average Curve Factor as a Function of Intensity




| ID | °C | ID | °C |
|---|---|---|---|
| A | -100.0 | I | 60.0 |
| B | -80.0 | | |
| C | -60.0 | | |
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| E | -20.0 | | |
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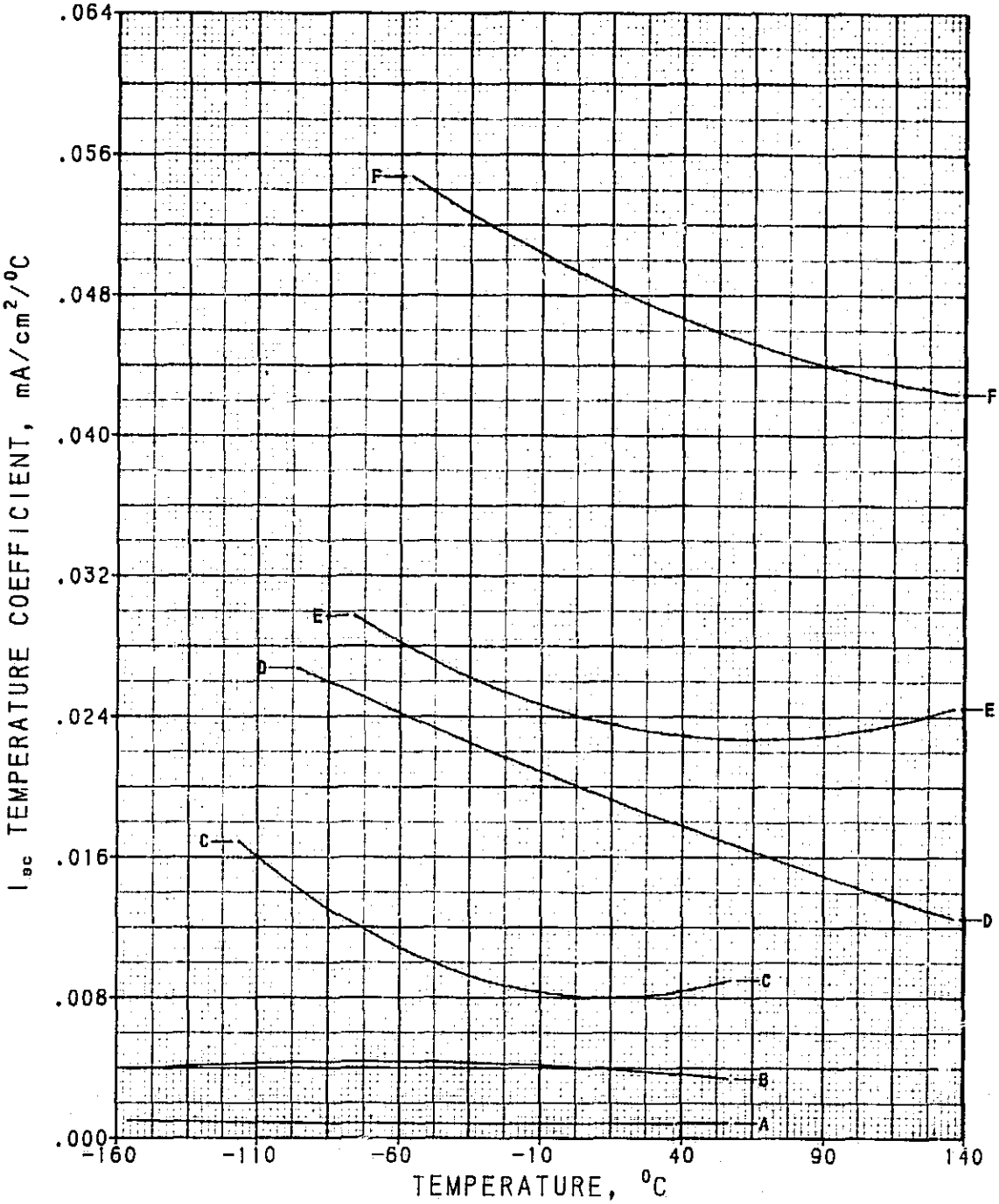
Figure 14. Average AMO Efficiency as a Function of Intensity




| ID | mW/cm$^2$ |
|---|---|
| A | 5.0 |
| B | 25.0 |
| C | 50.0 |
| D | 100.0 |
| E | 135.3 |
| F | 250.0 |

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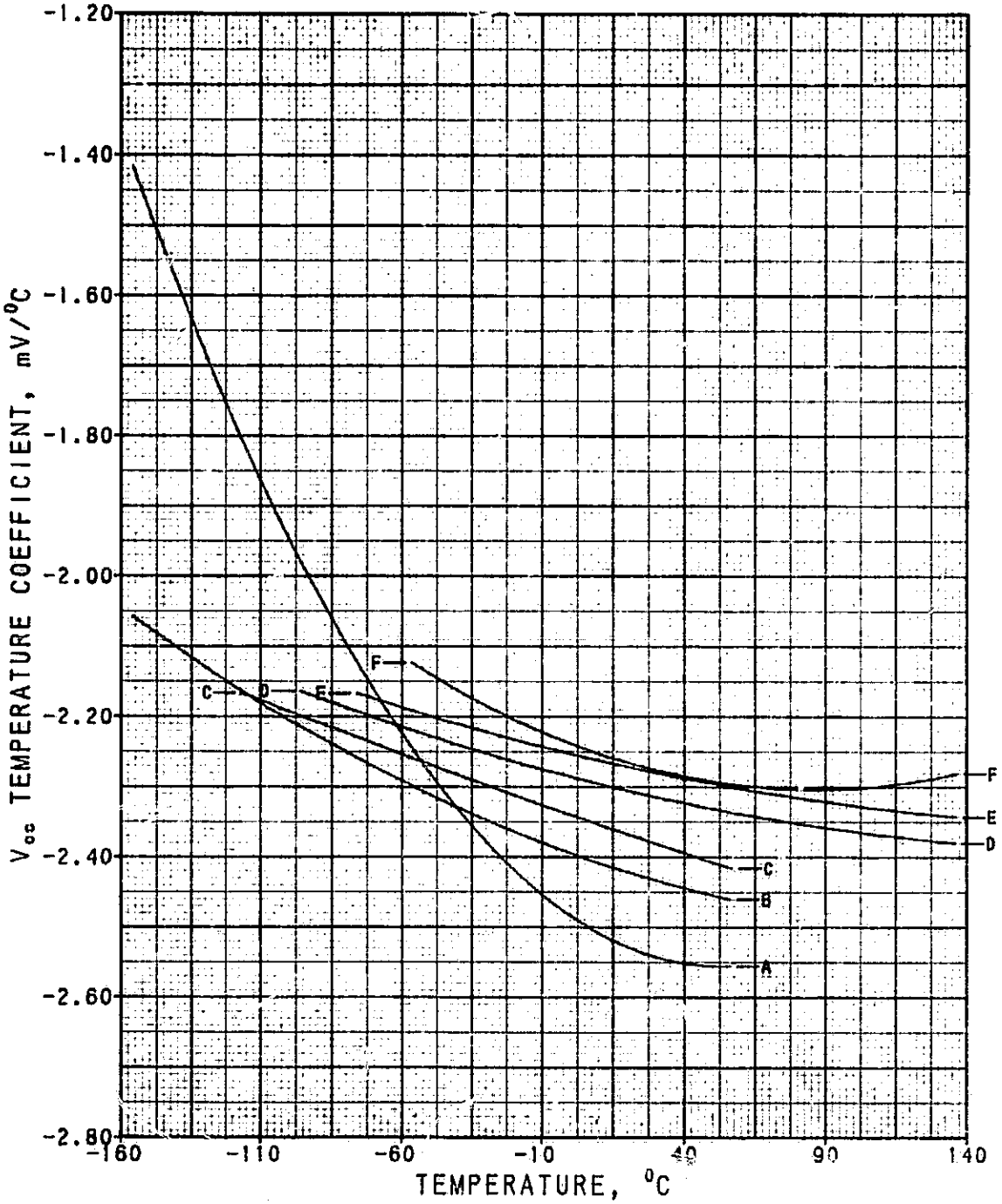
.038 CM THICK
SAMPLE SIZE 14

Figure 15. $I_{sc}$ Temperature Coefficient




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

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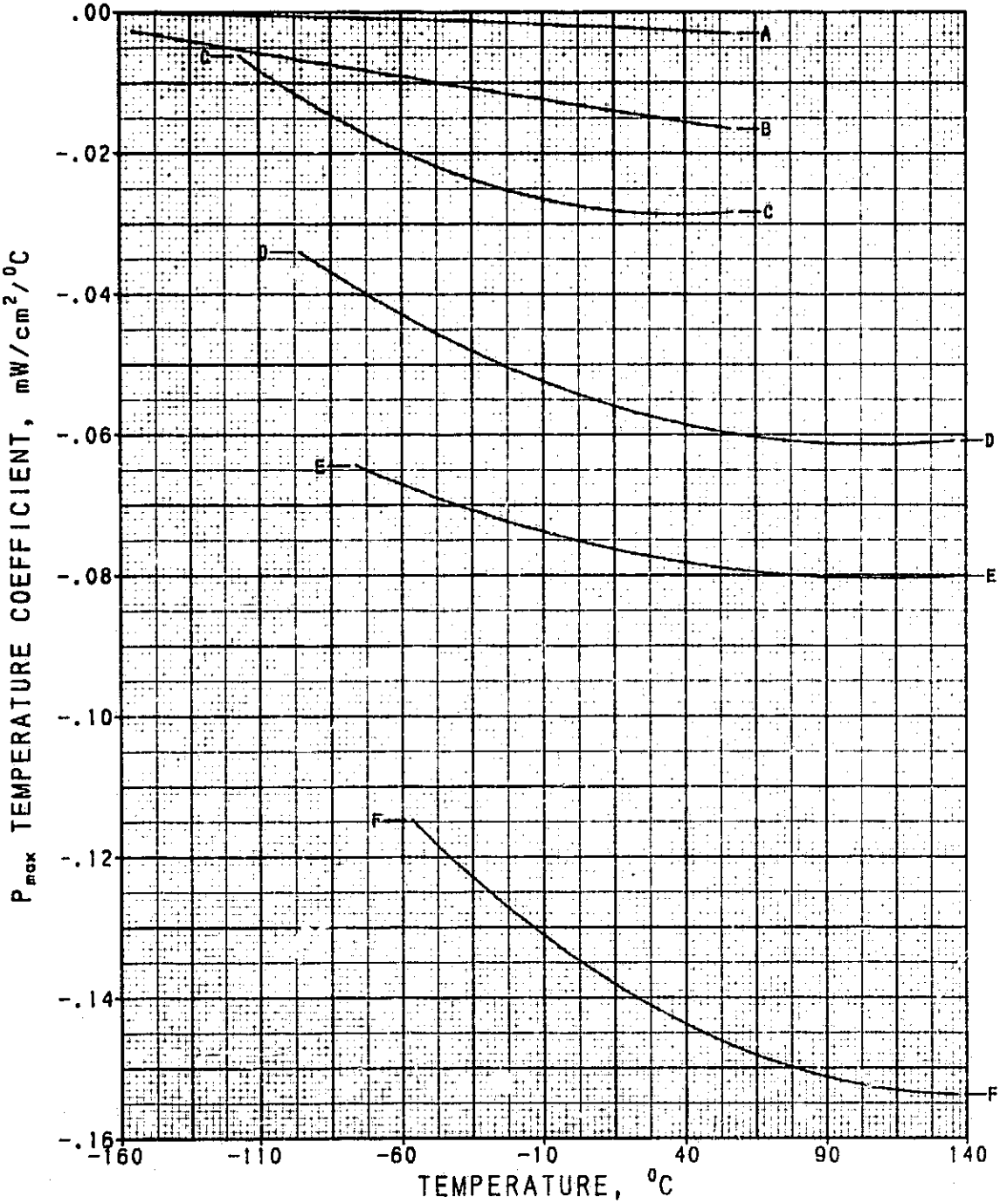
TA205 AR COATING
7940 COVER .35 MICRON CUT-ON
.038 CM THICK
SAMPLE SIZE 14

Figure 16. $V_{oc}$ Temperature Coefficient




| ID | mW/cm$^2$ |
|---|---|
| A | 5.0 |
| B | 25.0 |
| C | 50.0 |
| D | 100.0 |
| E | 135.3 |
| F | 250.0 |

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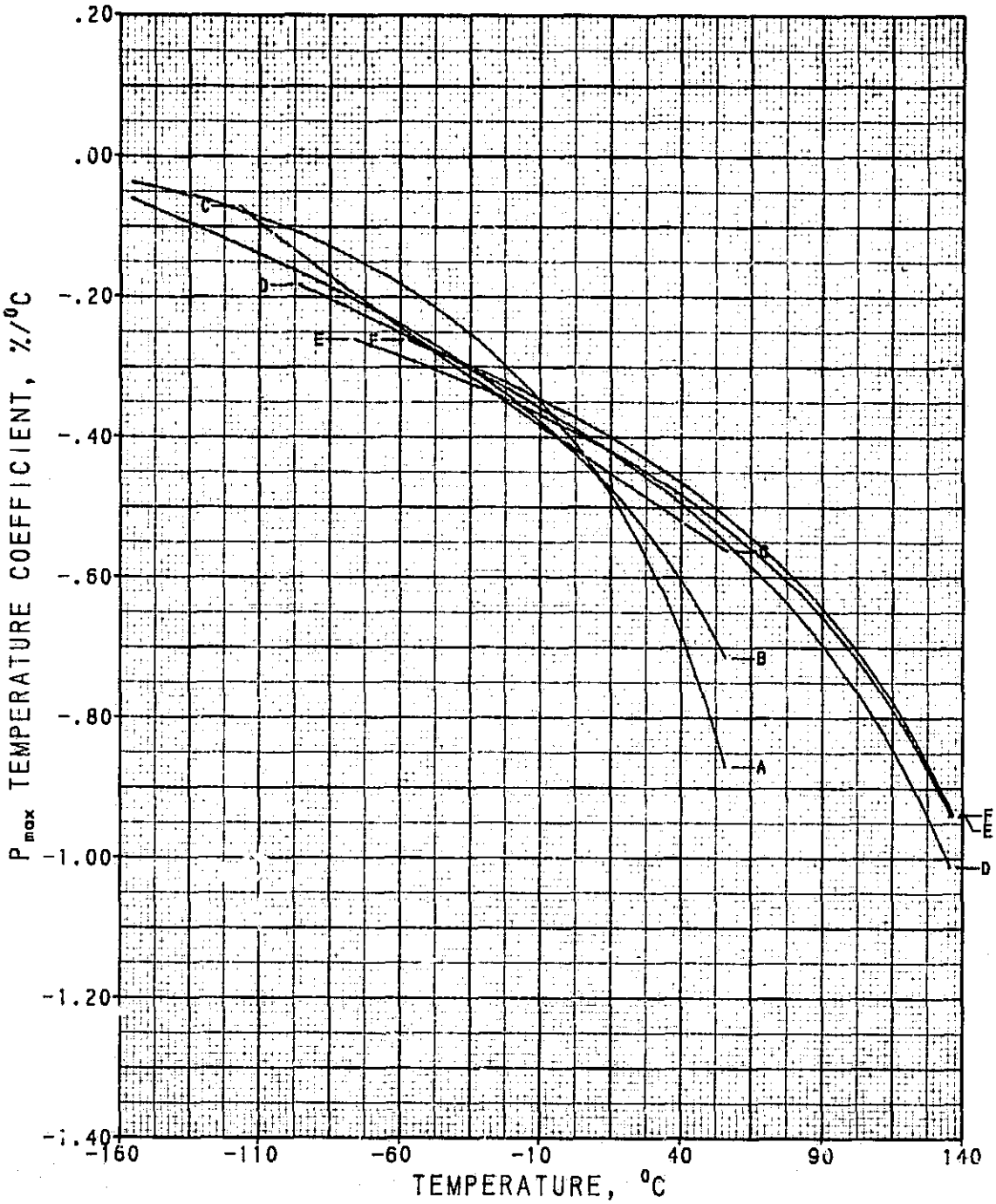
.038 CM THICK
SAMPLE SIZE 14

Figure 17. Absolute $P_{max}$ Temperature Coefficient




| ID | mW/cm² |
|---|---|
| A | 5.0 |
| B | 25.0 |
| C | 50.0 |
| D | 100.0 |
| E | 135.3 |
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Figure 18. Percent $P_{max}$ Temperature Coefficient

Table 1. Average Short Circuit Current

OCLI VIOLET
N/P 2 OHM-CM CG SILICON
2 X 2 X .025 CM
CR-AU-AG 3 X 19 GRID LINES
TA2O5 AR COATING
7940 COVER .35 MICRON CUT-ON
.038 CM THICK
SAMPLE SIZE 14

| CELL TEMP. (DEG. C) | SOLAR INTENSITY (MW/CM**2) 5.00 | 25.00 | 50.00 | 100.00 | 135.30 | 250.00 |
|---|---|---|---|---|---|---|
| -160.00 | 1.21 | 6.17 | - | - | - | - |
| | (.04) | (.19) | | | | |
| -140.00 | 1.24 | 6.21 | - | - | - | - |
| | (.04) | (.19) | | | | |
| -120.00 | 1.25 | 6.25 | 12.29 | - | - | - |
| | (.04) | (.19) | (.39) | | | |
| -100.00 | 1.27 | 6.36 | 12.50 | 25.31 | - | - |
| | (.04) | (.17) | (.36) | (.91) | | |
| -80.00 | 1.28 | 6.50 | 12.85 | 25.76 | 35.37 | - |
| | (.03) | (.13) | (.28) | (.76) | (1.01) | |
| -60.00 | 1.30 | 6.64 | 13.08 | 26.20 | 35.95 | 65.52 |
| | (.02) | (.10) | (.21) | (.60) | (.72) | (1.43) |
| -40.00 | 1.32 | 6.61 | 13.31 | 26.76 | 36.44 | 66.59 |
| | (.02) | (.08) | (.16) | (.50) | (.58) | (1.09) |
| -20.00 | 1.34 | 6.71 | 13.47 | 27.16 | 37.03 | 67.63 |
| | (.02) | (.06) | (.12) | (.45) | (.48) | (.95) |
| .00 | 1.35 | 6.79 | 13.61 | 27.65 | 37.55 | 68.64 |
| | (.02) | (.05) | (.14) | (.68) | (.53) | (.86) |
| 20.00 | 1.36 | 6.88 | 13.75 | 28.10 | 37.93 | 69.62 |
| | (.02) | (.05) | (.14) | (.44) | (.40) | (.80) |
| 40.00 | 1.39 | 6.97 | 13.95 | 28.35 | 38.49 | 70.56 |
| | (.02) | (.05) | (.15) | (.43) | (.42) | (.78) |
| 60.00 | 1.40 | 7.04 | 14.13 | 28.72 | 38.84 | 71.49 |
| | (.01) | (.05) | (.12) | (.44) | (.43) | (.76) |
| 80.00 | - | - | - | 29.01 | 39.37 | 72.41 |
| | | | | (.41) | (.36) | (.79) |
| 100.00 | - | - | - | 29.33 | 39.83 | 73.24 |
| | | | | (.48) | (.42) | (.76) |
| 120.00 | - | - | - | 29.49 | 40.26 | 74.11 |
| | | | | (.53) | (.39) | (.77) |
| 140.00 | - | - | - | 29.94 | 40.76 | 74.99 |
| | | | | (.48) | (.47) | (.75) |

NOTE: STANDARD DEVIATIONS ARE GIVEN IN PARENTHESES.

Table 2. Average Open Circuit Voltage

OCLI VIOLET
N/P 2 OHM-CM CG SILICON
2 X 2 X .025 CM
CR-AU-AG 3 X 19 GRID LINES
TA2O5 AR COATING
7940 COVER .35 MICRON CUT-ON
.038 CM THICK
SAMPLE SIZE 14

| CELL TEMP. (DEG. C) | SOLAR INTENSITY (MW/CM**2) 5.00 | 25.00 | 50.00 | 100.00 | 135.30 | 250.00 |
|---|---|---|---|---|---|---|
| -160.00 | 881.82 (40.61) | 966.74 (3.21) | - | - | - | - |
| -140.00 | 847.59 (35.61) | 925.52 (4.26) | - | - | - | - |
| -120.00 | 811.72 (37.59) | 883.23 (4.08) | 901.59 (3.17) | - | - | - |
| -100.00 | 781.06 (22.66) | 838.65 (4.59) | 857.92 (3.30) | 874.27 (3.12) | - | - |
| -80.00 | 740.56 (17.19) | 794.88 (3.96) | 812.69 (3.15) | 830.99 (2.78) | 836.01 (5.98) | - |
| -60.00 | 696.31 (13.57) | 749.16 (3.15) | 768.34 (2.17) | 787.24 (1.94) | 792.46 (4.47) | 810.09 (1.97) |
| -40.00 | 649.65 (11.10) | 703.26 (2.44) | 724.15 (1.51) | 743.07 (1.28) | 749.17 (1.15) | 767.15 (1.59) |
| -20.00 | 601.04 (10.32) | 655.34 (2.07) | 678.19 (1.24) | 696.44 (1.00) | 704.16 (1.64) | 723.41 (2.30) |
| .00 | 551.84 (7.97) | 608.37 (1.77) | 630.06 (1.22) | 651.41 (.95) | 659.90 (2.11) | 679.72 (1.67) |
| 20.00 | 502.01 (7.62) | 560.65 (2.09) | 583.40 (1.43) | 606.46 (1.31) | 613.86 (1.66) | 633.94 (2.05) |
| 40.00 | 452.21 (8.81) | 511.85 (1.86) | 537.23 (1.53) | 559.82 (1.66) | 567.66 (1.51) | 588.73 (1.64) |
| 60.00 | 401.23 (6.41) | 462.21 (1.83) | 487.96 (2.10) | 512.74 (1.88) | 522.06 (1.79) | 543.01 (1.85) |
| 80.00 | - | - | - | 465.54 (1.89) | 477.04 (2.03) | 494.76 (5.80) |
| 100.00 | - | - | - | 419.34 (2.15) | 430.04 (2.49) | 451.11 (2.32) |
| 120.00 | - | - | - | 371.80 (2.71) | 383.91 (2.56) | 406.07 (2.40) |
| 140.00 | - | - | - | 323.66 (3.54) | 335.97 (2.84) | 358.05 (2.83) |

NOTE: STANDARD DEVIATIONS ARE GIVEN IN PARENTHESES.

Table 3. Average Maximum Power Current

OCLI VIOLET
N/P 2 OHM-CM CG SILICON
2 X 2 X .025 CM
CP-AU-AG 3 X 19 GRID LINES
TA2O5 AR COATING
7940 COVER .35 MICRON CUT-ON
.038 CM THICK
SAMPLE SIZE 14

| CELL TEMP. (DEG. C) | SOLAR INTENSITY (MW/CM**2) 5.00 | 25.00 | 50.00 | 100.00 | 135.30 | 250.00 |
|---|---|---|---|---|---|---|
| -160.00 | .97 | 5.36 | - | - | - | - |
| | (.08) | (.27) | | | | |
| -140.00 | .99 | 5.42 | - | - | - | - |
| | (.08) | (.26) | | | | |
| -120.00 | 1.00 | 5.51 | 11.14 | - | - | - |
| | (.08) | (.25) | (.43) | | | |
| -100.00 | 1.01 | 5.65 | 11.45 | 23.79 | - | - |
| | (.08) | (.25) | (.42) | (.90) | | |
| -80.00 | 1.03 | 5.82 | 11.84 | 24.18 | 33.55 | - |
| | (.08) | (.23) | (.37) | (.73) | (1.03) | |
| -60.00 | 1.05 | 5.97 | 12.06 | 24.62 | 34.07 | 61.71 |
| | (.08) | (.19) | (.27) | (.59) | (.85) | (1.38) |
| -40.00 | 1.07 | 5.99 | 12.29 | 24.99 | 33.82 | 62.75 |
| | (.08) | (.16) | (.21) | (.53) | (.78) | (1.17) |
| -20.00 | 1.11 | 6.09 | 12.51 | 25.37 | 34.05 | 63.37 |
| | (.07) | (.14) | (.21) | (.43) | (.57) | (.90) |
| .00 | 1.13 | 6.16 | 12.55 | 25.55 | 34.55 | 63.89 |
| | (.07) | (.12) | (.22) | (.50) | (.61) | (.81) |
| 20.00 | 1.14 | 6.21 | 12.53 | 26.01 | 35.09 | 64.23 |
| | (.06) | (.09) | (.16) | (.46) | (.45) | (.85) |
| 40.00 | 1.14 | 6.29 | 12.74 | 26.14 | 35.07 | 64.45 |
| | (.05) | (.10) | (.17) | (.49) | (.45) | (.74) |
| 60.00 | 1.14 | 6.24 | 12.65 | 26.28 | 34.93 | 64.73 |
| | (.05) | (.09) | (.17) | (.39) | (.45) | (1.00) |
| 80.00 | - | - | - | 26.05 | 35.27 | 64.68 |
| | | | | (.42) | (.49) | (.80) |
| 100.00 | - | - | - | 25.75 | 35.02 | 64.32 |
| | | | | (.59) | (.64) | (.75) |
| 120.00 | - | - | - | 25.32 | 34.25 | 63.73 |
| | | | | (.48) | (.47) | (.94) |
| 140.00 | - | - | - | 24.88 | 33.46 | 62.55 |
| | | | | (.53) | (.45) | (.97) |

NOTE: STANDARD DEVIATIONS ARE GIVEN IN PARENTHESES.

Table 4. Average Maximum Power Voltage

OCLI VIOLET
N/P 2 OHM-CM CG SILICON
2 X 2 X .025 CM
CR-AU-AG 3 X 19 GRID LINES
TA2O5 AR COATING
7940 COVER .35 MICRON CUT-ON
.038 CM THICK
SAMPLE SIZE 14

| CELL TEMP. (DEG. C) | SOLAR INTENSITY (MW/CM**2) 5.00 | 25.00 | 50.00 | 100.00 | 135.30 | 250.00 |
|---|---|---|---|---|---|---|
| -160.00 | 660.36 (73.40) | 842.93 (31.41) | - | - | - | - |
| -140.00 | 639.21 (66.81) | 808.07 (27.11) | - | - | - | - |
| -120.00 | 622.79 (65.14) | 775.57 (24.86) | 807.79 (14.51) | - | - | - |
| -100.00 | 605.43 (58.40) | 739.57 (17.16) | 765.71 (11.89) | 790.36 (8.33) | - | - |
| -80.00 | 583.50 (47.04) | 703.71 (15.78) | 729.50 (9.41) | 748.43 (7.32) | 749.79 (6.54) | - |
| -60.00 | 557.64 (39.35) | 663.57 (11.77) | 679.86 (7.17) | 699.71 (4.86) | 702.43 (5.41) | 720.43 (4.86) |
| -40.00 | 525.00 (30.07) | 615.86 (9.52) | 633.50 (6.77) | 658.21 (3.81) | 662.86 (4.24) | 672.71 (5.58) |
| -20.00 | 483.07 (24.67) | 565.86 (8.14) | 581.07 (3.79) | 605.79 (4.68) | 617.07 (3.77) | 625.29 (4.53) |
| .00 | 439.14 (19.23) | 519.29 (6.09) | 535.64 (3.93) | 558.79 (1.97) | 567.00 (3.04) | 578.43 (4.73) |
| 20.00 | 392.64 (24.58) | 471.21 (6.55) | 492.43 (5.14) | 511.43 (1.70) | 516.50 (3.06) | 534.64 (4.29) |
| 40.00 | 354.21 (14.05) | 419.79 (6.38) | 442.07 (2.84) | 462.86 (3.46) | 471.50 (4.52) | 488.93 (2.30) |
| 60.00 | 306.36 (12.78) | 374.64 (3.65) | 398.00 (2.66) | 414.79 (4.42) | 426.71 (2.70) | 440.64 (3.10) |
| 80.00 | - | - | - | 370.00 (2.96) | 379.00 (2.57) | 394.21 (4.53) |
| 100.00 | - | - | - | 329.21 (2.46) | 333.86 (3.28) | 350.50 (3.74) |
| 120.00 | - | - | - | 285.64 (2.87) | 295.50 (3.48) | 306.86 (3.21) |
| 140.00 | - | - | - | 241.43 (2.28) | 255.21 (3.02) | 261.71 (3.89) |

NOTE: STANDARD DEVIATIONS ARE GIVEN IN PARENTHESES.

Table 5. Average Maximum Power

OCLI VIOLET
N/P 2 OHM-CM CG SILICON
2 X 2 X .025 CM
CR-AU-AG 3 X 19 GRID LINES
TA2O5 AR COATING
7940 COVER .35 MICRON CUT-ON
.038 CM THICK
SAMPLE SIZE 14

| CELL TEMP. (DEG. C) | SOLAR INTENSITY (MW/CM**2) 5.00 | 25.00 | 50.00 | 100.00 | 135.30 | 250.00 |
|---|---|---|---|---|---|---|
| -160.00 | .65 | 4.52 | - | - | - | - |
| | (.11) | (.33) | | | | |
| -140.00 | .63 | 4.38 | - | - | - | - |
| | (.11) | (.31) | | | | |
| -120.00 | .63 | 4.28 | 9.00 | - | - | - |
| | (.11) | (.28) | (.46) | | | |
| -100.00 | .62 | 4.18 | 8.77 | 18.80 | - | - |
| | (.10) | (.25) | (.42) | (.81) | | |
| -80.00 | .61 | 4.10 | 8.56 | 18.10 | 25.16 | - |
| | (.09) | (.21) | (.33) | (.65) | (.91) | |
| -60.00 | .59 | 3.97 | 8.20 | 17.23 | 23.93 | 44.46 |
| | (.08) | (.17) | (.24) | (.47) | (.63) | (1.08) |
| -40.00 | .56 | 3.69 | 7.78 | 16.45 | 22.42 | 42.21 |
| | (.07) | (.13) | (.19) | (.40) | (.54) | (.77) |
| -20.00 | .54 | 3.44 | 7.27 | 15.37 | 21.01 | 39.63 |
| | (.06) | (.11) | (.14) | (.33) | (.43) | (.59) |
| .00 | .50 | 3.20 | 6.72 | 14.28 | 19.59 | 36.96 |
| | (.04) | (.09) | (.15) | (.26) | (.37) | (.39) |
| 20.00 | .45 | 2.93 | 6.17 | 13.30 | 18.12 | 34.34 |
| | (.04) | (.07) | (.10) | (.25) | (.30) | (.41) |
| 40.00 | .41 | 2.64 | 5.63 | 12.10 | 16.54 | 31.51 |
| | (.03) | (.07) | (.09) | (.24) | (.24) | (.36) |
| 60.00 | .35 | 2.34 | 5.03 | 10.90 | 14.90 | 28.52 |
| | (.03) | (.05) | (.07) | (.21) | (.22) | (.44) |
| 80.00 | - | - | - | 9.64 | 13.37 | 25.50 |
| | | | | (.17) | (.18) | (.38) |
| 100.00 | - | - | - | 8.48 | 11.69 | 22.54 |
| | | | | (.16) | (.18) | (.29) |
| 120.00 | - | - | - | 7.23 | 10.12 | 19.56 |
| | | | | (.17) | (.16) | (.30) |
| 140.00 | - | - | - | 6.01 | 8.54 | 16.37 |
| | | | | (.14) | (.15) | (.29) |

NOTE: STANDARD DEVIATIONS ARE GIVEN IN PARENTHESES.

Table 6. Average Curve Factor

OCLI VIOLET
N/P 2 OHM-CM CG SILICON
2 X 2 X .025 CM
CR-AU-AG 3 X 19 GRID LINES
TA2O5 AR COATING
7940 COVER .35 MICRON CUT-ON
.038 CM THICK
SAMPLE SIZE 14

| CELL TEMP. (DEG. C) | SOLAR INTENSITY (MW/CM**2) 5.00 | 25.00 | 50.00 | 100.00 | 135.30 | 250.00 |
|---|---|---|---|---|---|---|
| -160.00 | .6037 (.0798) | .7581 (.0493) | - | - | - | - |
| -140.00 | .6032 (.0825) | .7630 (.0511) | - | - | - | - |
| -120.00 | .6144 (.0879) | .7740 (.0474) | .8127 (.0317) | - | - | - |
| -100.00 | .6211 (.0863) | .7830 (.0429) | .8180 (.0279) | .8496 (.0167) | - | - |
| -80.00 | .6363 (.0834) | .7928 (.0356) | .8194 (.0238) | .8456 (.0158) | .8508 (.0144) | - |
| -60.00 | .6503 (.0802) | .7969 (.0326) | .8148 (.0165) | .8353 (.0102) | .8400 (.0078) | .8377 (.0088) |
| -40.00 | .6591 (.0703) | .7946 (.0279) | .8074 (.0186) | .8271 (.0112) | .8210 (.0104) | .8263 (.0086) |
| -20.00 | .6651 (.0612) | .7829 (.0257) | .7961 (.0140) | .8124 (.0102) | .8058 (.0096) | .8099 (.0073) |
| .00 | .6639 (.0537) | .7739 (.0227) | .7841 (.0150) | .7928 (.0128) | .7906 (.0086) | .7921 (.0044) |
| 20.00 | .6546 (.0527) | .7590 (.0204) | .7692 (.0110) | .7805 (.0065) | .7784 (.0090) | .7781 (.0070) |
| 40.00 | .6468 (.0402) | .7404 (.0194) | .7515 (.0124) | .7622 (.0075) | .7569 (.0095) | .7585 (.0050) |
| 60.00 | .6230 (.0398) | .7190 (.0174) | .7304 (.0120) | .7402 (.0072) | .7351 (.0079) | .7348 (.0074) |
| 80.00 | - | - | - | .7138 (.0074) | .7117 (.0063) | .7118 (.0074) |
| 100.00 | - | - | - | .6892 (.0070) | .6826 (.0083) | .6823 (.0047) |
| 120.00 | - | - | - | .6595 (.0064) | .6548 (.0102) | .6498 (.0060) |
| 140.00 | - | - | - | .6198 (.0052) | .6236 (.0068) | .6097 (.0067) |

NOTE: STANDARD DEVIATIONS ARE GIVEN IN PARENTHESES.

Table 7. Average AMO Efficiency

OCLI VIOLET
N/P 2 OHM-CM CG SILICON
2 X 2 X .025 CM
CR-AU-AG 3 X 19 GRID LINES
TA2O5 AR COATING
7940 COVER .35 MICRON CUT-ON
.038 CM THICK
SAMPLE SIZE 14

| CELL TEMP. (DEG. C) | SOLAR INTENSITY (MW/CM**2) 5.00 | 25.00 | 50.00 | 100.00 | 135.30 | 250.00 |
|---|---|---|---|---|---|---|
| -160.00 | 12.93 | 18.07 | - | - | - | - |
| | (2.17) | (1.31) | | | | |
| -140.00 | 12.68 | 17.52 | - | - | - | - |
| | (2.20) | (1.24) | | | | |
| -120.00 | 12.54 | 17.10 | 18.00 | - | - | - |
| | (2.16) | (1.13) | (.93) | | | |
| -100.00 | 12.34 | 16.71 | 17.55 | 18.80 | - | - |
| | (2.03) | (1.01) | (.84) | (.81) | | |
| -80.00 | 12.13 | 16.40 | 17.11 | 18.10 | 18.60 | - |
| | (1.81) | (.86) | (.66) | (.65) | (.68) | |
| -60.00 | 11.75 | 15.86 | 16.40 | 17.23 | 17.69 | 17.78 |
| | (1.60) | (.68) | (.47) | (.47) | (.46) | (.43) |
| -40.00 | 11.28 | 14.77 | 15.57 | 16.45 | 16.57 | 16.88 |
| | (1.35) | (.53) | (.39) | (.40) | (.40) | (.31) |
| -20.00 | 10.72 | 13.78 | 14.54 | 15.37 | 15.53 | 15.85 |
| | (1.11) | (.46) | (.28) | (.33) | (.32) | (.24) |
| .00 | 9.92 | 12.79 | 13.45 | 14.28 | 14.48 | 14.78 |
| | (.89) | (.37) | (.30) | (.26) | (.27) | (.16) |
| 20.00 | 8.94 | 11.71 | 12.34 | 13.30 | 13.40 | 13.74 |
| | (.81) | (.30) | (.21) | (.25) | (.22) | (.17) |
| 40.00 | 8.12 | 10.57 | 11.26 | 12.10 | 12.22 | 12.60 |
| | (.60) | (.26) | (.18) | (.24) | (.18) | (.14) |
| 60.00 | 6.99 | 9.35 | 10.07 | 10.90 | 11.02 | 11.41 |
| | (.50) | (.21) | (.15) | (.21) | (.16) | (.18) |
| 80.00 | - | - | - | 9.64 | 9.88 | 10.20 |
| | | | | (.17) | (.13) | (.15) |
| 100.00 | - | - | - | 8.48 | 8.64 | 9.02 |
| | | | | (.16) | (.13) | (.11) |
| 120.00 | - | - | - | 7.23 | 7.48 | 7.82 |
| | | | | (.17) | (.12) | (.12) |
| 140.00 | - | - | - | 6.01 | 6.31 | 6.55 |
| | | | | (.14) | (.11) | (.12) |

NOTE: STANDARD DEVIATIONS ARE GIVEN IN PARENTHESES.

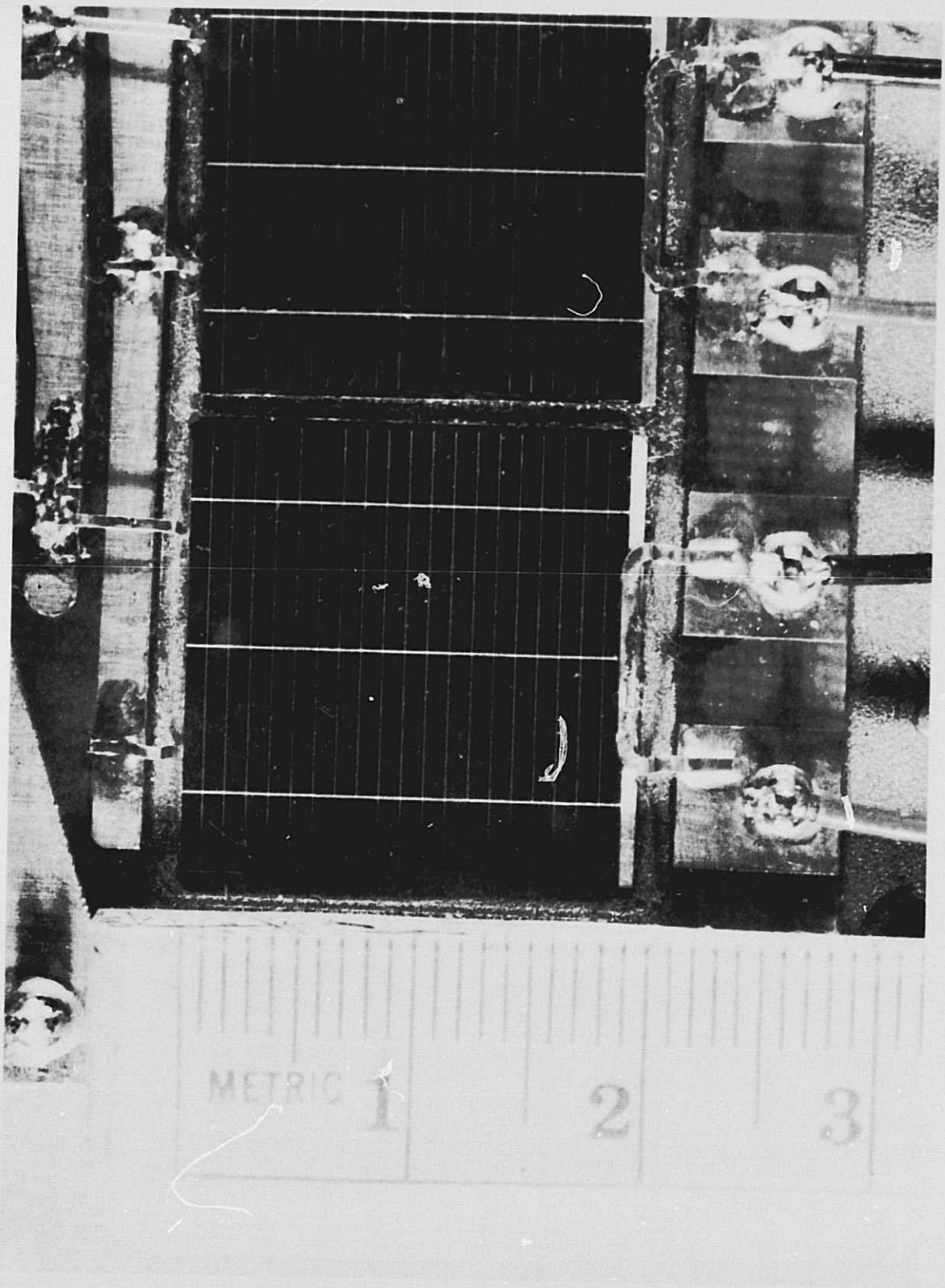


Figure A-1. Solar Cell

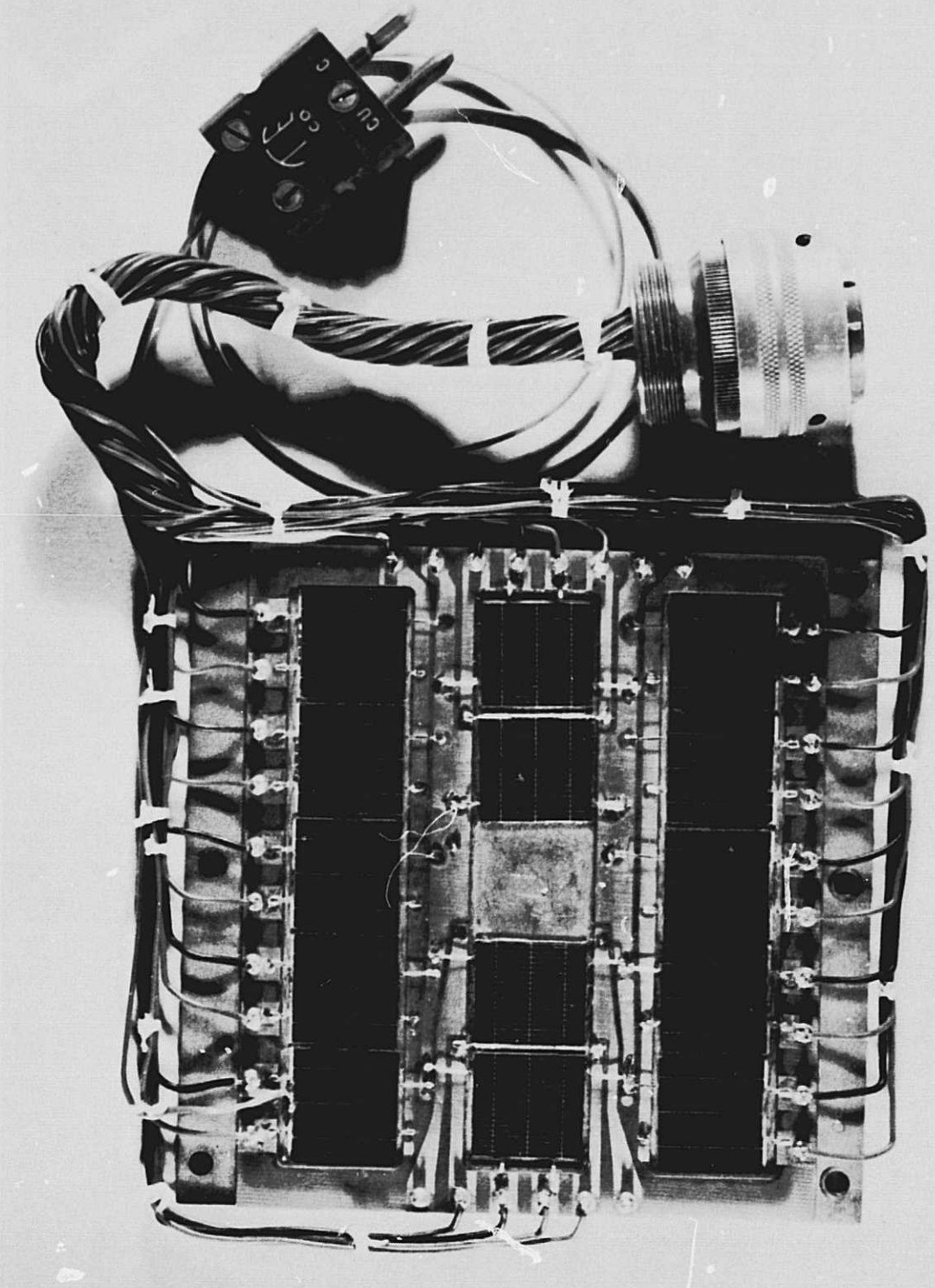

Figure A-2. Test Plate

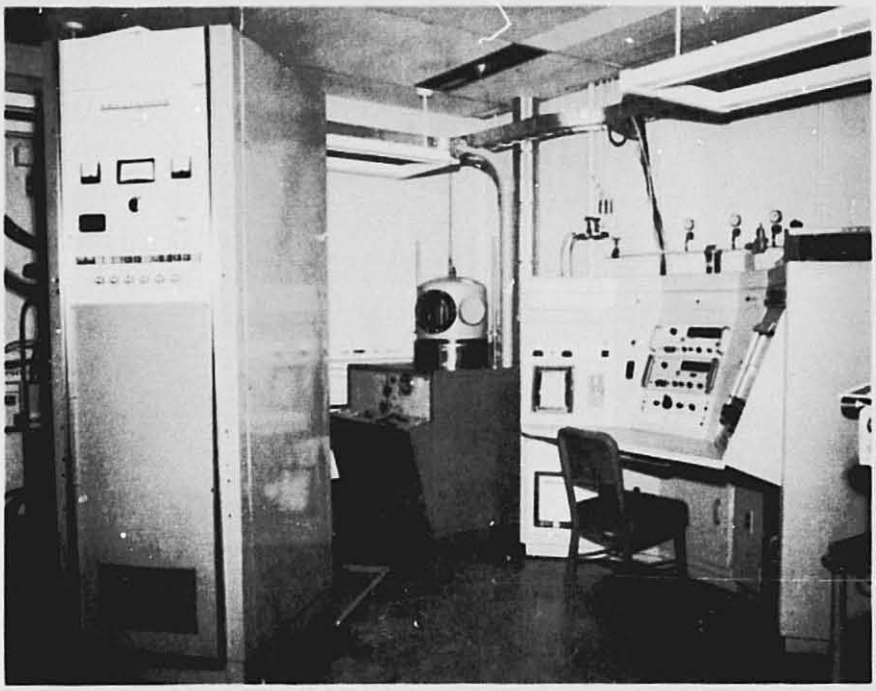

Figure A-3. Solar Cell Characterization Facility

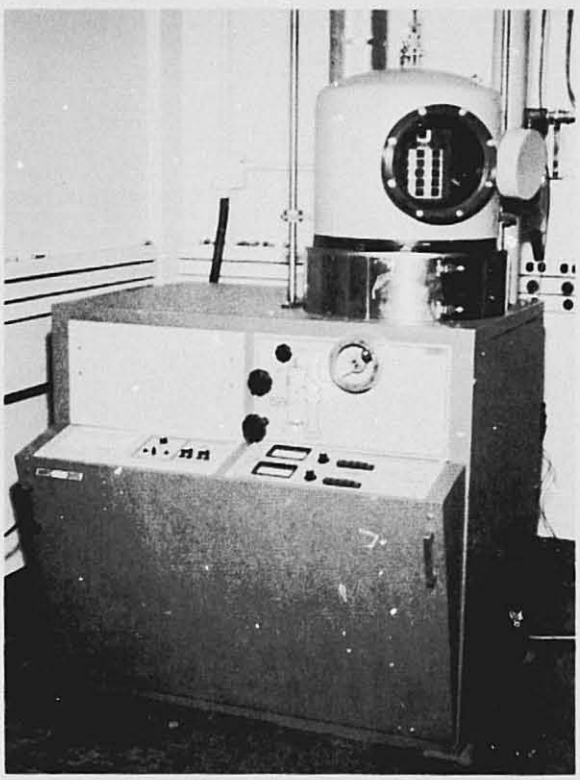



Figure A-4. Solar Cell Environmental Test Chamber



NASA — JPL — Coml., L.A., Calif.