NASA TECHNICAL MEMORANDUM

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CHARACTERIZATION OF THREE TYPES OF SILICON SOLAR CELLS FOR SEPS DEEP-SPACE MISSIONS

Volume II. Current-Voltage Characteristics of Solarex Textured P^+ 8 to 10 Mil, Planar P^+ 8 to 10 Mil and Planar P^+ 2 Mil Cells as a Function of Temperature and Intensity

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Volume II. Current-Voltage Characteristics of Solarex Textured P^+ 8 to 10 Mil, Planar P^+ 8 to 10 Mil and Planar P^+ 2 Mil Cells as a Function of Temperature and Intensity

I. INTRODUCTION

This is the second in a series of technical reports on the characterization of high performance solar cells under conditions of low temperatures and low intensities. Today's solar cells have been designed for maximum performance at 1 AU*, AM0, with little regard for the characteristics that would enhance their performance in deep space. In the late 1960's and early 1970's, data were generated on a few solar cells under Jupiter mission conditions; however, little has been produced since that time. The interest in solar cell performance under deep space conditions has been renewed as a result of the proposed SEPS Halley Comet Flyby and Tempel 2 Mission. These data generated in support of the SEPS program are aimed at identifying which of the currently available cells possess the best characteristics for deep space performance. This report contains data on three types of cells taken at 9 intensities and 11 temperatures identified along the SEPS Mission profile. Graphs and tables together with interpretive conclusions are presented for the three types of cells.

II. TEST PROGRAM

A. Solar Cell Descriptions

Three types of cells (Textured P^+ 8 to 10 mil, Planar P^+ 8 to 10 mil, and Planar P^+ 2 mil) from the Solarex Corporation, described in Table 1, were selected to compare under conditions of low temperature and low intensity, the performance of the textured cell to the planar cell and the performance of the thick cell (8 to 10 mil) to the thin cell (2 mil). All the cells tested were n on p with Al P^+ and had a 2 ohm-cm base resistivity.

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* For this and other acronyms see glossary.

B. Test Profile

The test profile for the evaluation of these cells is shown in Table 2. These temperature/intensity values were selected from the SEPS Halley Comet Flyby and Tempel 2 Mission environment. In addition to the I-V (current-voltage) data taken at various temperatures and intensities, dark I-V data were taken at 10 temperatures. The dark I-V data analysis will be the subject of a separate report.

C. Test Equipment

The cells were mounted to a copper plate using RTV 560. Each test set consisted of 16 cells; one set is shown mounted in Figure 1. The copper plate was then heat sunk to a plate configured for cooling with liquid nitrogen and for heating with hot air. The copper plate and two cells were thermocoupled and temperatures monitored continually. Cell temperatures were maintained independent of the incident solar intensity to within $\pm 0.5^{\circ}C$ from 65° to $-175^{\circ}C$. The cells were installed in a vacuum system having a 30-cm diameter, 6 mm thick UV grade fused quartz window and tested at a pressure of 1×10^{-4} pascal or less.

The illumination source was a Spectrolab filtered X-75 solar simulator. This system provides a combined beam from three 2.5 kW xenon lamps covering an area of 230 cm^2. Beam intensity was measured at each cell position and was determined to have a uniformity of ± 2 percent. The spectral output was modified through the use of a filter system to approximate the solar spectrum. Illumination levels were maintained through the use of a set of neutral density filters and by varying the position of the test chamber. Cell illumination level was monitored through the use of a water-cooled calibrated cell maintained at $28^{\circ}C \pm 0.5^{\circ}C$. One solar constant utilized in the calibration was 135.3 mW/cm^2.

A Spectrolab electronic load model D-1550 provided the variable load for the cells. The cell I-V curves were plotted on an X-Y recorder. Digital voltmeters were used to read the open circuit voltages and short circuit currents. All instruments were calibrated prior to the initiation of these tests. The test setup with associated instrumentation is shown in Figure 2.

III. PRESENTATION OF TEST RESULTS

Current-voltage characteristics for each of three sets of 16 silicon solar cells supplied by Solarex Corporation have been measured. The mean values of

each set observed at each operating condition (temperature and light intensity), together with observed standard deviations and mean efficiencies, are presented in both tables and graphs. The graphs are plotted from the data presented in the tables. The behavior of the individual best and worst cells of each set, selected on the basis of maximum power output at 0.086 solar constant/-100°C (where the SEPS will spend considerable time), is described by graphs of their efficiency versus light intensity and temperature. Current-voltage parameters of the best cell of each set selected on the basis of its maximum power output at 0.086 SC/-100°C are shown in Table 3. Fill factors which show data scatter within each group are given in Table 4 for three test conditions. Current-voltage curves for two cells are shown in Figure 3. The distribution of the maximum power output for the three types of cells is shown at 4 test conditions in Figures 4, 5 and 6.

A. General Features

The response of these sets of solar cells to simulated solar illumination and to various temperatures is found to have the following general features:

1. Short circuit current, I_{sc}, is directly proportional to input light intensity. The proportionality constant being nearly independent of temperature is a feature of good cell design.

2. Open circuit voltage, V_{oc}, increases linearly as cell temperature is lowered, with the slope being nearly independent of light flux. The absolute value of V_{oc} drops with increasing light intensity by approximately 50 percent from 0.040 to 1.0 SC.

3. Maximum power, MP, is directly proportional to the incident intensity at each temperature, with a monotonic decrease of the proportionality constant with increasing temperature.

a. Efficiency at maximum power output decreases steadily with increasing temperature, the mean value dropping approximately by a factor of 2 from -150°C to +50°C. This feature is independent of light intensity above 0.08 SC as expected from the close correlation in high performance cells between the maximum power conditions with the open circuit voltage and short circuit current features.

b. Maximum power current, I_{mp}, is directly proportional to light intensity and essentially independent of temperature. This feature is closely related to that of the short circuit current in these high performance cells.

c. Maximum power voltage, V_{mp}, decreases linearly with increasing cell temperature, independent of light intensity above 0.08 SC. This linear decrease feature is closely related to that of the open circuit voltage in these high performance cells.

4. Scatter of measured values within each of the set of 16 cells is indicated by the standard deviation values in the tables. Another measure of the scatter within each set is given by the fill factors at three test conditions and by discussion of a few individual cells, selected as having the best and the worst maximum power output at 0.086 SC and -100°C.

B. Textured P^+ 8 to 10 Mil Silicon Cell

I_{sc}, V_{oc}, I_{mp}, V_{mp}, and MP are plotted as functions of temperature and intensity in Figures 9 through 18. Average values with standard deviations are summarized in Tables 5 through 9. Cell efficiencies are plotted as functions of temperature and intensity in Figures 19 and 20 and summarized in Table 10. To illustrate the spread in individual cell performance, the efficiencies of the best and worst cells are plotted in Figures 21 and 22.

Large standard deviations (above 2 percent) begin to appear within this set of 16 cells in their V_{oc} below -125°C and below 0.063 SC. Similarly, large (above 2 percent) standard deviations appear in V_{mp} at and below -75°C and, at and below 0.128 SC. I_{mp} at 1 AU shows a reduction in mean value as the temperature is increased from +25°C to +65°C. This trend was evident in the I_{sc} at +65°C. Unexplained anomalies are evident in the efficiency data at -50°C and -75°C for both 0.086 and 0.063 Solar Constants.

C. Planar P^+ 8 to 10 Mil Silicon Cell

I_{sc}, V_{oc}, I_{mp}, V_{mp}, and MP are plotted as functions of temperature and intensity in Figures 23 through 32. Average values with standard deviations are shown in Tables 11 through 15. Cell efficiencies are listed in Table 16 and plotted as functions of temperature and intensity in Figures 33 and 34. Similarly, the efficiencies of the best and worst cells are shown in Figures 35 and 36.

V_{oc} shows standard deviations as large as 2 percent at and below -100°C and at and below 0.063 SC. V_{mp} displays similar large (above 2 percent) standard deviations at and below -50°C and 0.128 SC.

D. Planar P^+ 2 Mil Silicon Cell

I_{sc}, V_{oc}, I_{mp}, V_{mp}, and MP are plotted as functions of temperature and intensity in Figures 37 through 46. Average values with standard deviations are summarized in Tables 17 through 21. Cell efficiencies are plotted as functions of temperature and intensity in Figures 47 and 48 and listed in Table 22. In

addition, the best and worst cells efficiencies are plotted in Figures 49 and 50.

Large standard deviations (above 2 percent) begin to appear in V_{oc} at -125°C and 0.040 SC. Similarly, large standard deviations appear in V_{mp} at and below -50°C and at and below 0.128 SC.

IV. DISCUSSION OF RESULTS

A. General Features

A number of observations are made concerning the general characteristics of the data. The small standard deviations at and above 0.1 SC and -50°C in the data indicate that the measurements were apparently carried out with sufficient precision to enable discrimination of deviations of a few percent in the output from cell to cell at any given combination of temperature and light intensity. The small standard deviations in current which decrease with decreasing solar intensity are attributable to the beam nonuniformity of ±2 percent. There is some question as to whether a test lot of 16 cells is sufficient to provide reliable quality control statistics for these manufacturer lots at low temperatures and low intensities (LTLI).

Maximum power output was determined to be greatest both at 1 SC/+25°C and at LTLI for the textured P^+ 8 to 10 mil cells. The Planar P^+ 2 mil cells provided the lowest maximum power output at these conditions. Large variations in V_{mp} were observed for the three types of cells under LTLI conditions primarily as a sharp break in the I-V curve around the knee of the curve (broken knee). This behavior is indicative of edge channel problems arising from the cell fabrication process. An I-V curve indicating this problem is shown in Figure 3 along with the I-V curve for a high performing cell. This reduction in curvature of the I-V plot results in lowering of the MP of the cell and thereby reduces solar cell efficiency. The relative magnitude of this occurrence in the three sets of cells tested is seen in the fill factor distributions presented in Table 4. Efficiencies of the best and worst cells selected on the basis of maximum power output at 0.086 SC and -100°C show the extreme values in cell output within each test set. The current-voltage parameters listed for the best cell within each group in Table 3 demonstrate the capabilities of the individual cell type with the textured P^+ 8 to 10 mil cell having the highest efficiency at all test conditions. In constructing Table 3, incident intensities were normalized in order to provide an accurate comparison of best cell within each test group. In all three types of cells the best cell at LTLI was not the best cell under 1 AU conditions. Mean efficiencies at 1 SC/+25°C were determined to be 14.5 percent for the textured P^+

8 to 10 mil cells, 13.0 percent for the Planar P^+ 8 to 10 mil cells and 12.3 percent for the Planar P^+ 2 mil cells.

B. Comparison of Cell Front Surface Smoothness -- Textured to Planar

The textured surface provides a larger effective surface area to incident photons thereby resulting in greater current output of the cell. In addition, the textured cell would, in the absence of active thermal control, operate at a higher temperature than the planar cell under the same incident intensity conditions. However, since the temperature of these cells was actively controlled the latter feature was not examined.

I_{sc} values at 1 AU were about 6 to 8 percent greater in the textured cells than in the planar cells. Similarly, I_{mp} values at 1 AU were greater in the textured cells by about 7 to 11 percent. Average values of I_{mp} for the textured cells show at 1 SC similar values or slight decreases as the temperature was increased from +25°C to +65°C. This decrease in I_{mp} was more definite in the best cell data of Table 3. V_{oc} of the textured cells is about 3 percent greater at 1 AU but this difference decreased gradually as the temperature and intensity were reduced. V_{mp} values for these cells were approximately the same with the textured cell values never exceeding those of the planar cells by more than 1 percent. The larger deviations in V_{mp} of the planar cells are responsible for their reduced efficiencies at LTLI while the larger output current of the textured cells account for their higher efficiencies.

C. Comparison of Cell Thickness -- (8 to 10) Mil to 2 Mil

The 2 mil cell offers the advantage over the 8 to 10 mil cell of a higher power-to-weight ratio. The average weight of the 2 mil cell (including cover glass) was approximately 0.59 the average weight of the 8 to 10 mil cell. At 1 SC/+25°C the power-to-weight ratios for the 2 mil and the 8 to 10 mil cells were 266.4 watts/kilogram and 164.7 watts/kilogram, respectively; at 0.086 SC/ -100°C these values were 28.5 watts/kilogram and 19.0 watts/kilogram, respectively. The current and voltage output of the 2 mil cell was lower than the 8 to 10 mil cell under all test conditions. At 1 AU conditions, the I_{sc} and I_{mp} values of the 2 mil cell were about 3 to 4 percent less than the 8 to 10 mil cell with the V_{oc} and V_{mp} values lower by about 1-1/2 to 3 percent.

V. SUMMARY

The textured P^+ 8 to 10 mil cells provided the best performance at both 1 AU conditions and at LTLI conditions. Mean efficiencies at 1 SC/ +25°C were determined to be 14.5 percent for the textured P^+ 8 to 10 mil cells, 13.0 percent for the Planar P^+ 8 to 10 mil cells and 12.3 percent for the Planar P^+ 2 mil cells. All three types of cells showed evidence of variations in shunting impedance at LTLI by sharp breaks in their I-V curves around the maximum power point with resulting reductions in maximum power voltage. These undesirable shunting impedance variations are attributed to techniques utilized in processing of the cells. The performance observed for the three sets of cells is summarized by the graph of relative maximum power output, P/P_o (P_o is the power produced at 55°C at 1 AU) versus heliocentric distance in Figure 7. Figure 8 represents the array mission temperatures used in generating the P/P_o data. The three sets of cells produce approximately the same P/P_o outputs at large AU's with the exception at 5 AU where the 2 mil cells have a P/P_o value of 0.047 compared to 0.056 and 0.057 for the 8 to 10 mil textured and planar cells, respectively.

The reader is reminded that the ultimate response of the solar cell to the space environment would be influenced not only by temperature and incident intensity but also by particulate and electromagnetic radiation.

TABLE 1. TEST CELL DESCRIPTIONS

	Test Group 1	Test Group 2	Test Group 3
Number of Cells	16	16	16
Type	N/P Textured, Al P^+	N/P Planar, Al P^+	N/P Planar, Al P^+
Silicon	Boron-Doped, Czochralski P-Type	Boron-Doped, Czochralski P-Type	Boron-Doped, Czochralski P-Type
Size	2 x 2 x (.020 to .025 cm) (8 to 10 Mil)	2 x 2 x (.020 to .025 cm) (8 to 10 Mil)	2 x 2 x .005 cm (2 Mil)
Base Resistivity	2 ohm-cm	2 ohm-cm	2 ohm-cm
Junction Depth	Shallow	Shallow	Shallow
Contacts	Ti-Pd-Ag	Ti-Pd-Ag	Ti-Pd-Ag
Grids	Fine Line (3/19)	Fine Line (3/19)	Fine Line (3/19)
Cover Glass	Ceria-Doped Microsheet	Ceria-Doped Microsheet	Ceria-Doped Microsheet
Cover Glass Adhesive	Sylgard	Sylgard	Sylgard
Antireflective Coating	Tantalum Oxide	Tantalum Oxide	Tantalum Oxide
Comments	Production Run	Production Run	Production Run

TABLE 2. TEST PROFILE

Illumination Level (SC)	Temperature (°C)
1.00	0, 25, 55, 65
0.64	-25, 0, 25, 55
0.39	-50, -25, 0, 25, 55
0.25	-75, -50, -25, 0, 25
0.174	-100, -75, -50, -25, 0
0.128	-125, -100, -75, -50, -25
0.086	-150, -125, -100, -75, -50
0.063	-150, -125, -100, -75, -50
0.040	-175, -150, -125, -100, -75
Dark I-V	50, 25, 0, -25, -50, -75, -100, -125, -150, -175

NOTE: 55°C at 0.39 SC was not achievable in two of the three test groups.

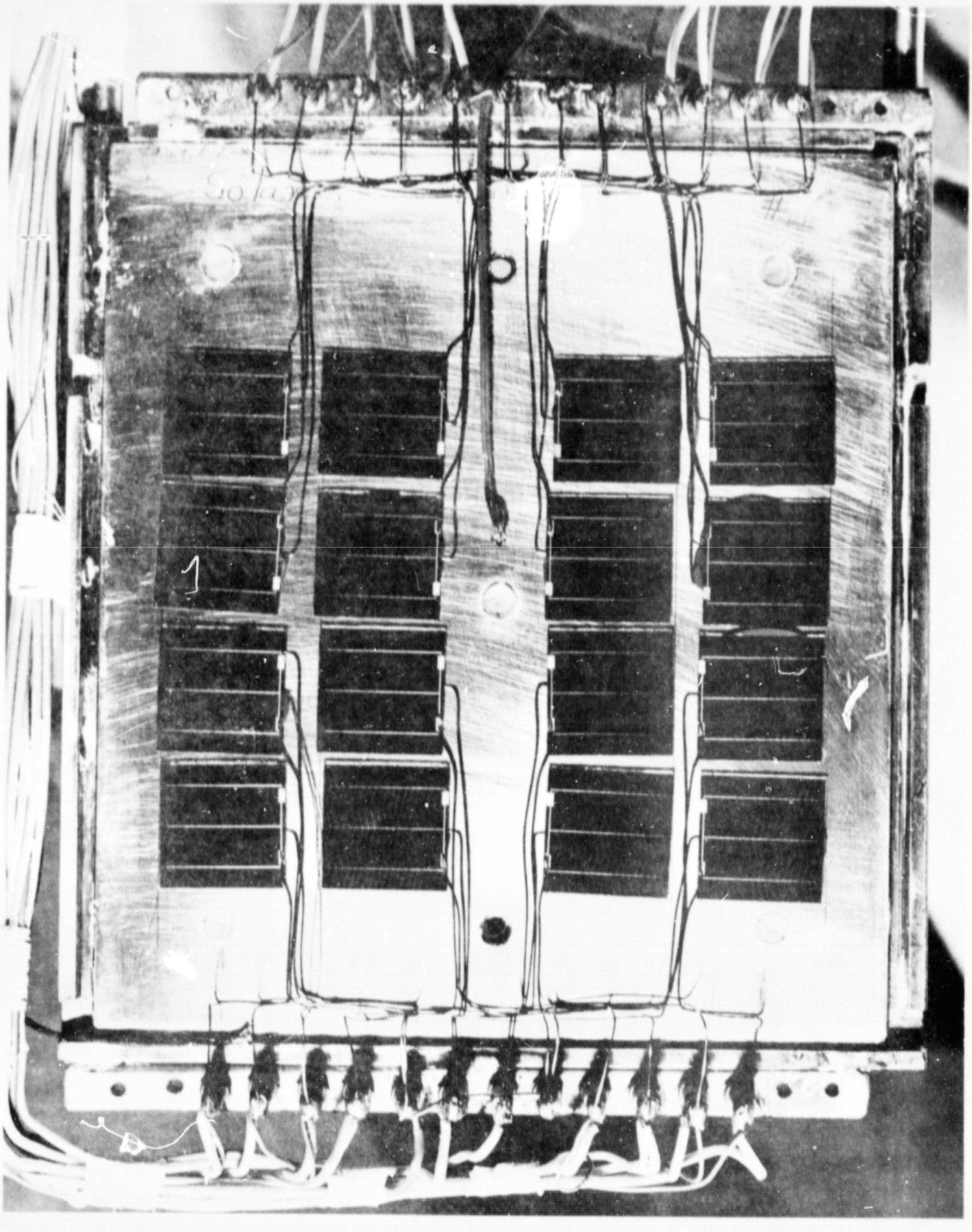

Figure 1. Solar Cell Test Plate

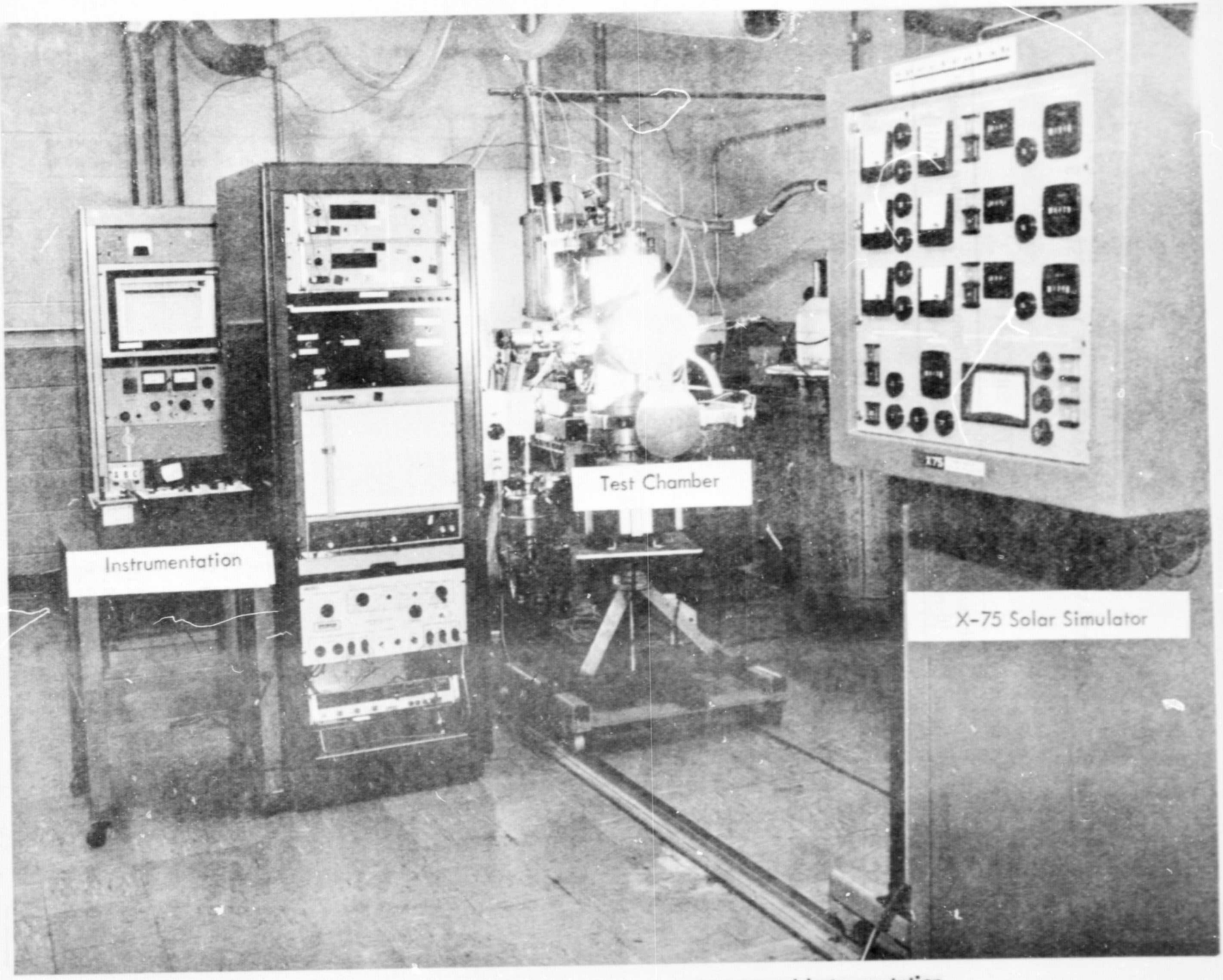

Figure 2. Solar Cell Characterization Equipment and Instrumentation

TABLE 3. CURRENT-VOLTAGE PARAMETERS OF THE BEST CELLS

Parameter	TYPE SILICON CELL		
	Solarex Textured P^+ (8 to 10 Mil)	Solarex Planar P^+ (8 to 10 Mil)	Solarex Planar P^+ (2 Mil)
I_{sc}			
1 SC/55°C	175.7	164	152
1 SC/25°C	173.7	163	148
0.086 SC/-100°C	13.3	13.2	11.6
0.040 SC/-150°C	6.2	5.7	5.3
V_{oc}			
1 SC/55°C	533	514	510
1 SC/25°C	595	577	576
0.086 SC/-100°C	813	805	804
0.040 SC/-150°C	904	902	904
I_{mp}			
1 SC/55°C	159	147.7	140
1 SC/25°C	162.6	150	139
0.086 SC/-100°C	12.8	12.2	10.5
0.040 SC/-150°C	5.2	5.2	4.3
V_{mp}			
1 SC/55°C	420	418	415
1 SC/25°C	480	482	480
0.086 SC/-100°C	741	743	732
0.040 SC/-150°C	824	815	732
MP			
1 SC/55°C	66.8	61.7	58.1
1 SC/25°C	78.1	72.3	66.7
0.086 SC/-100°C	9.58	9.06	7.68
0.040 SC/-150°C	4.27	4.23	3.15
Eff			
1 SC/55°C	12.3	11.4	10.7
1 SC/25°C	14.4	13.4	12.2
0.086 SC/-100°C	20.6	19.5	16.5
0.040 SC/-150°C	19.7	19.5	14.6

NOTE: Best Cells selected for highest maximum power output at 0.086 SC/-100°C. Incident intensity normalized for uniform intensity.

TABLE 4. FILL FACTORS FOR SOLAREX CELLS AT 3 TEST CONDITIONS

Solar Constant/ Temperature (°C)	Fill Factors (No. of Cells) Textured, P^+ 2 ohm-cm .020 to .025 cm	Planar, P^+ 2 ohm-cm .020 to .025 cm	Planar, P^+ 2 ohm-cm .005 cm
1 SC/25°C	.75 (3) .76 (7) .77 (6)	.74 (2) .75 (8) .76 (2) .77 (3) .78 (1)	.74 (3) .75 (2) .76 (3) .77 (3) .78 (4) .79 (1)
0.086 SC/-100°C	.65 to .67 (3) .69 to .70 (2) .77 to .79 (2) .81 to .84 (6) .86 to .87 (3)	.68 to .69 (2) .71 to .73 (3) .76 to .77 (2) .80 to .82 (4) .83 to .85 (5)	.66 to .69 (2) .71 to .74 (4) .75 to .79 (6) .80 to .83 (4)
0.040 SC/-150°C	.55 (1) .60 (1) .63 to .66 (3) .68 (3) .70 to .73 (3) .74 to .76 (5)	.51 (1) .58 (1) .60 to .63 (3) .67 to .72 (7) .76 (1) .78 to .79 (2) .82 (1)	.50 (1) .54 (1) .57 to .59 (5) .61 to .65 (6) .66 (1) .70 to .71 (2)

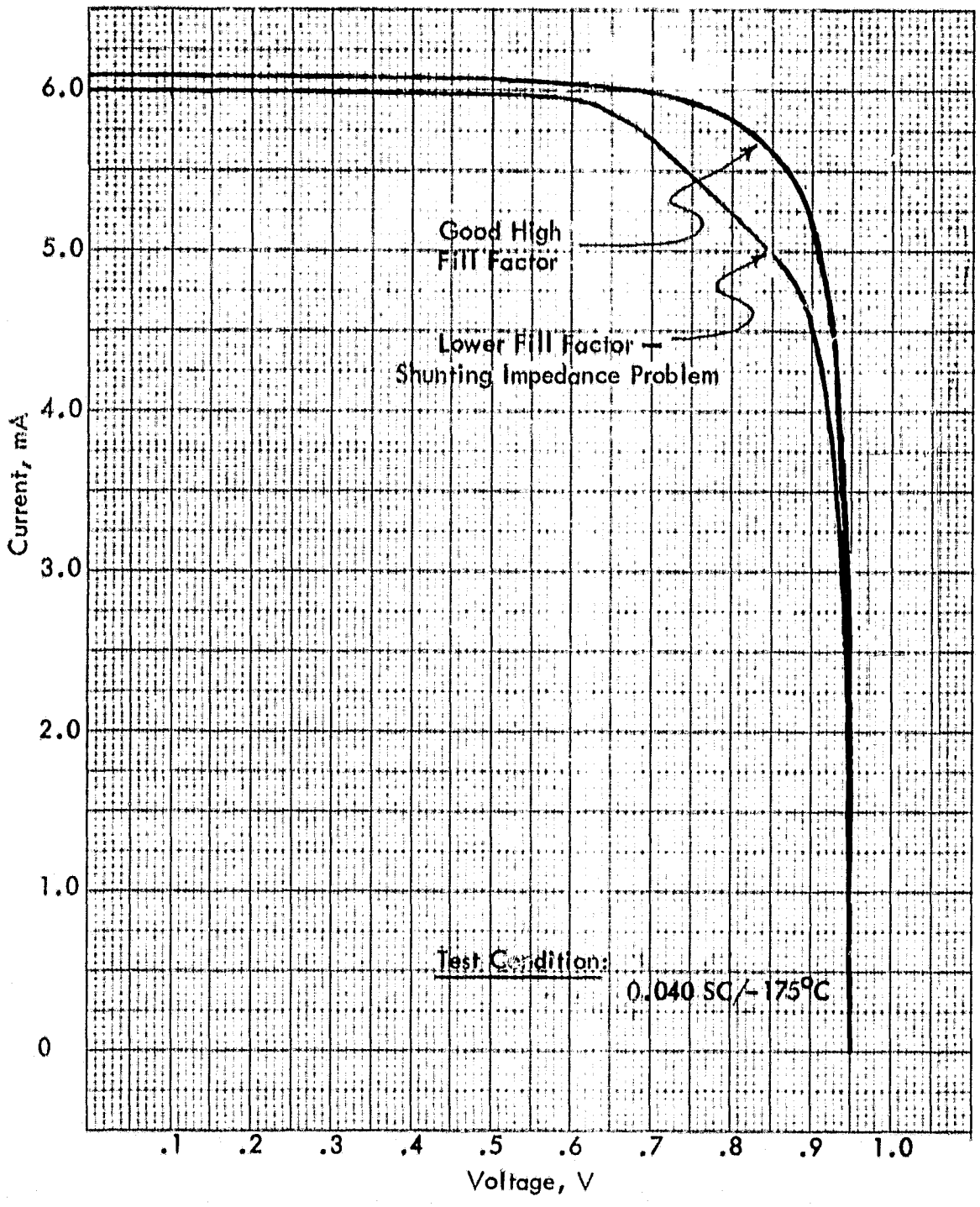

Figure 3. Current-Voltage Curves for Two Textured P^+ 8 to 10 Mil Cells at 0.040 SC/-175°C

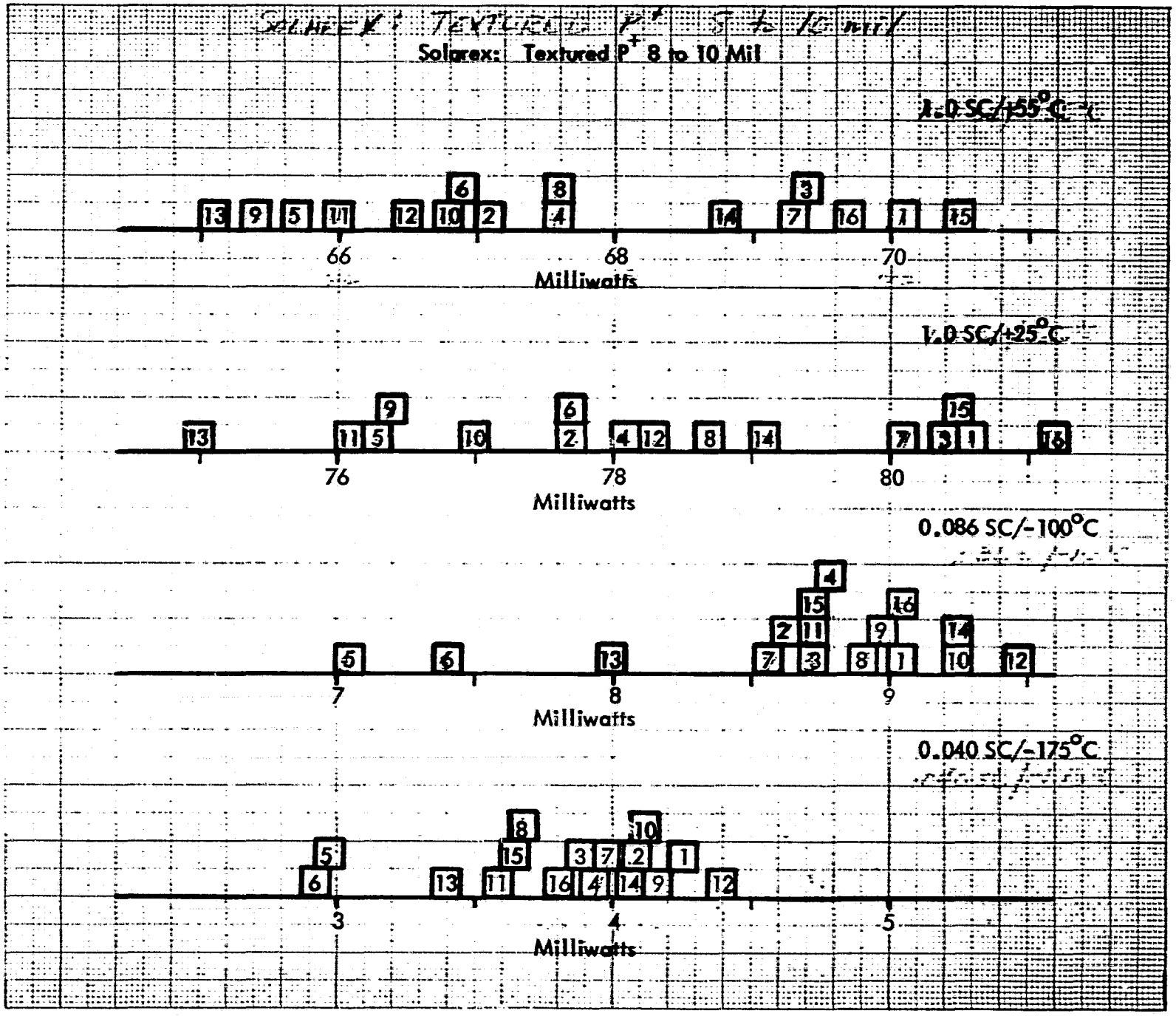

Figure 4. Distribution of Textured P^+ 8 to 10 Mil Cells at 4 Test Conditions as a Function of Maximum Power Output

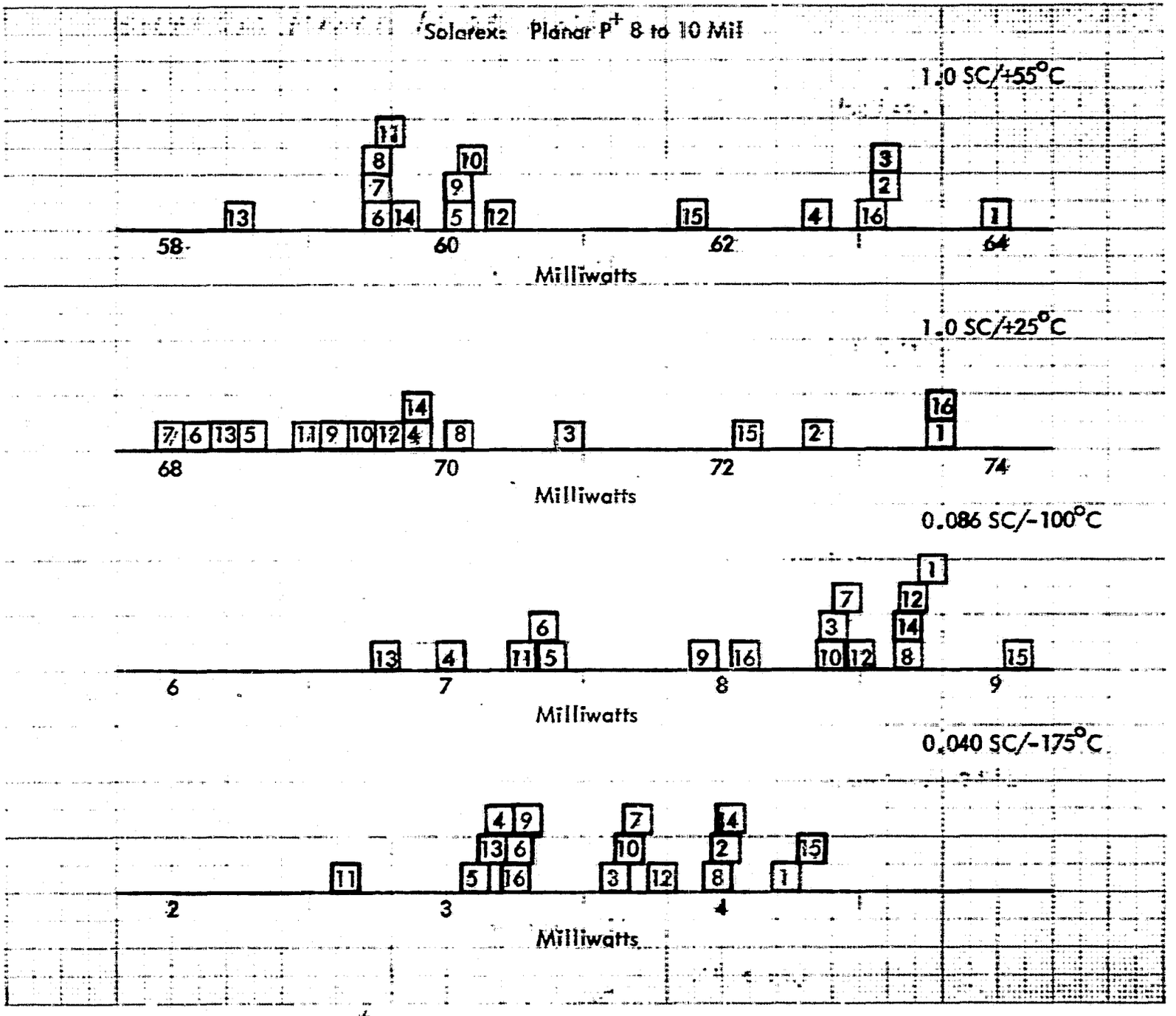

Figure 5. Distribution of Planar P+ 8 to 10 Mil Cells at 4 Test Conditions as a Function of Maximum Power Output

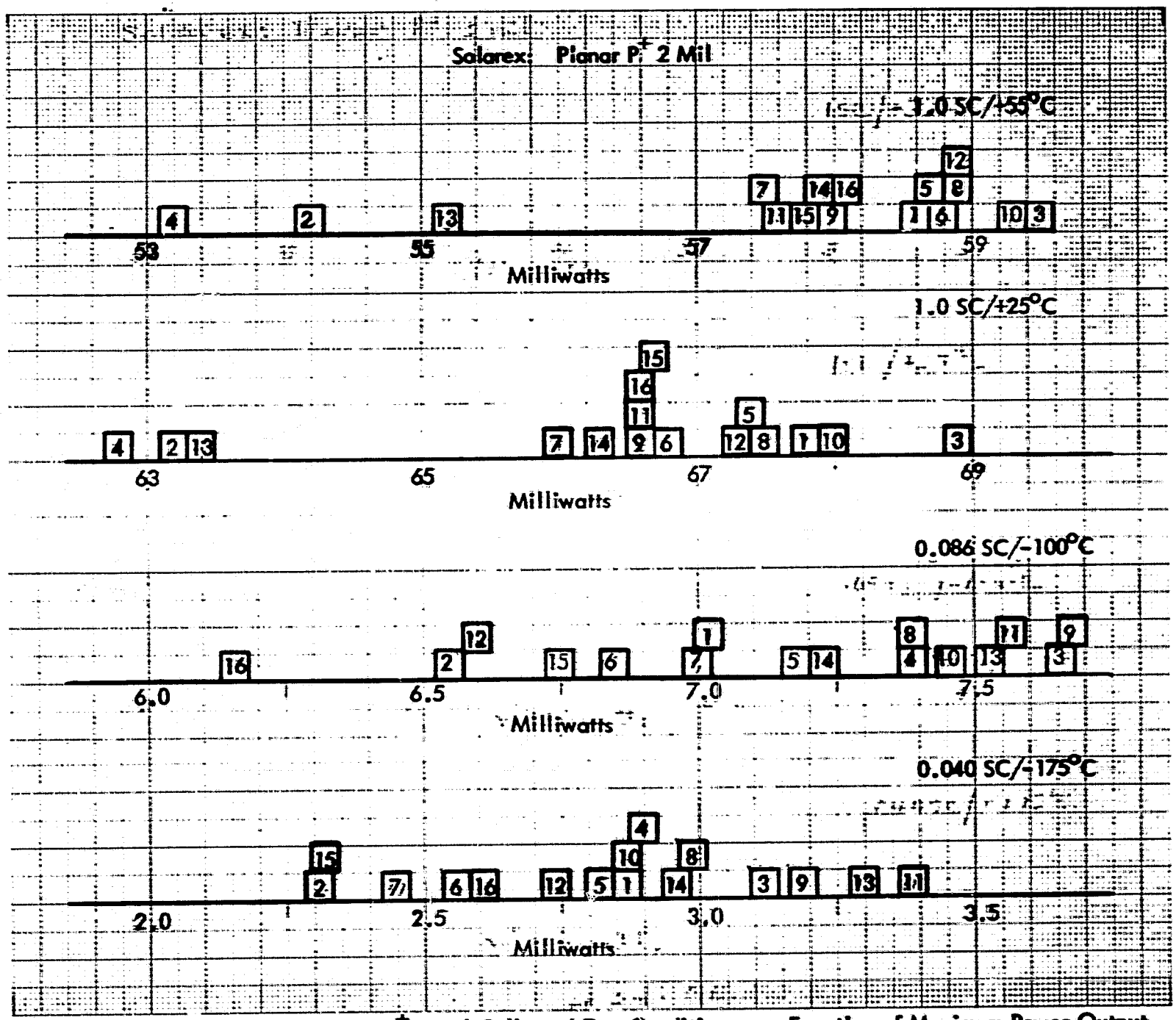

Figure 6. Distribution of Planar P^+ 2 Mil Cells at 4 Test Conditions as a Function of Maximum Power Output

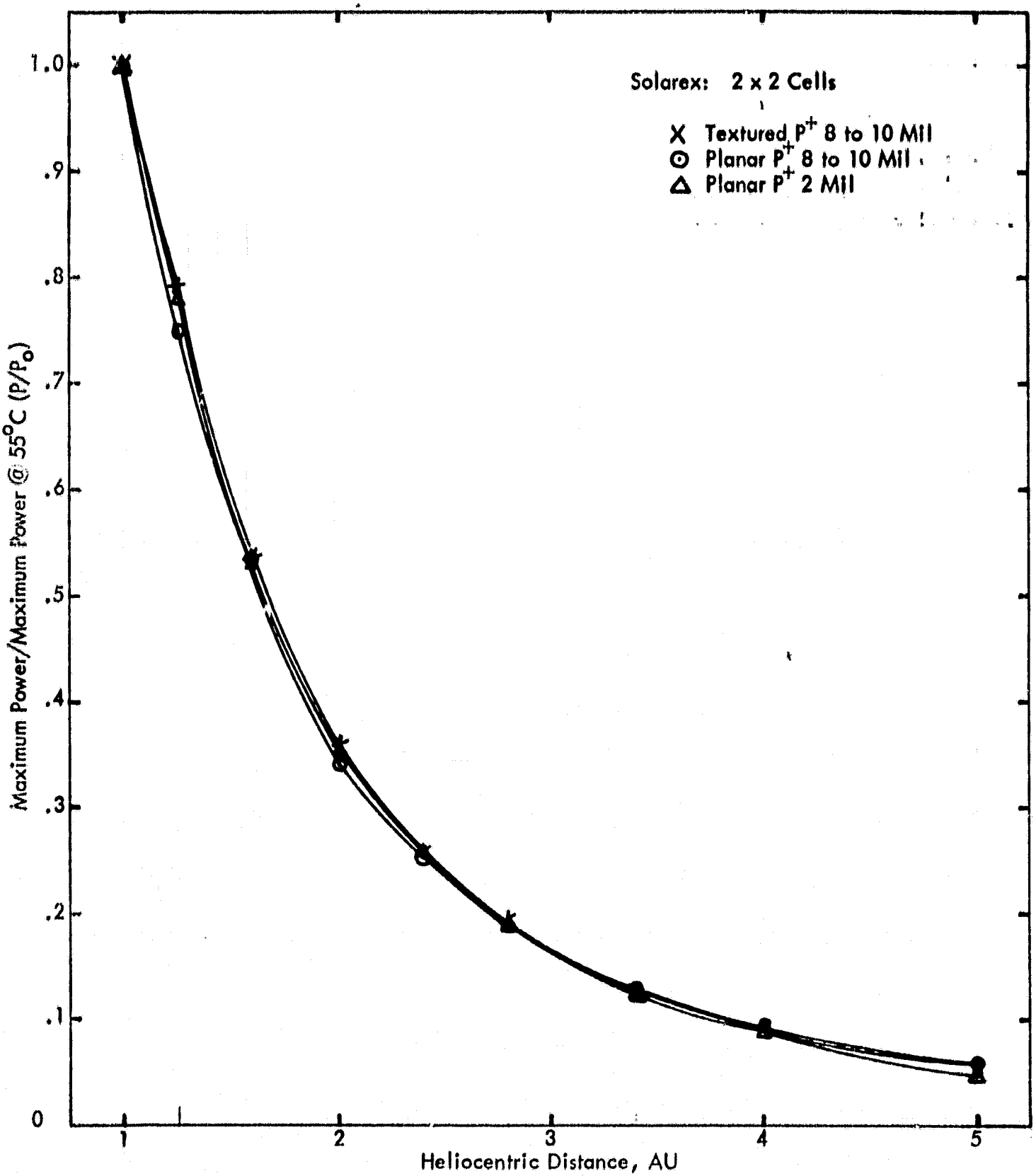

Figure 7. P/P_o as a Function of Heliocentric Distance

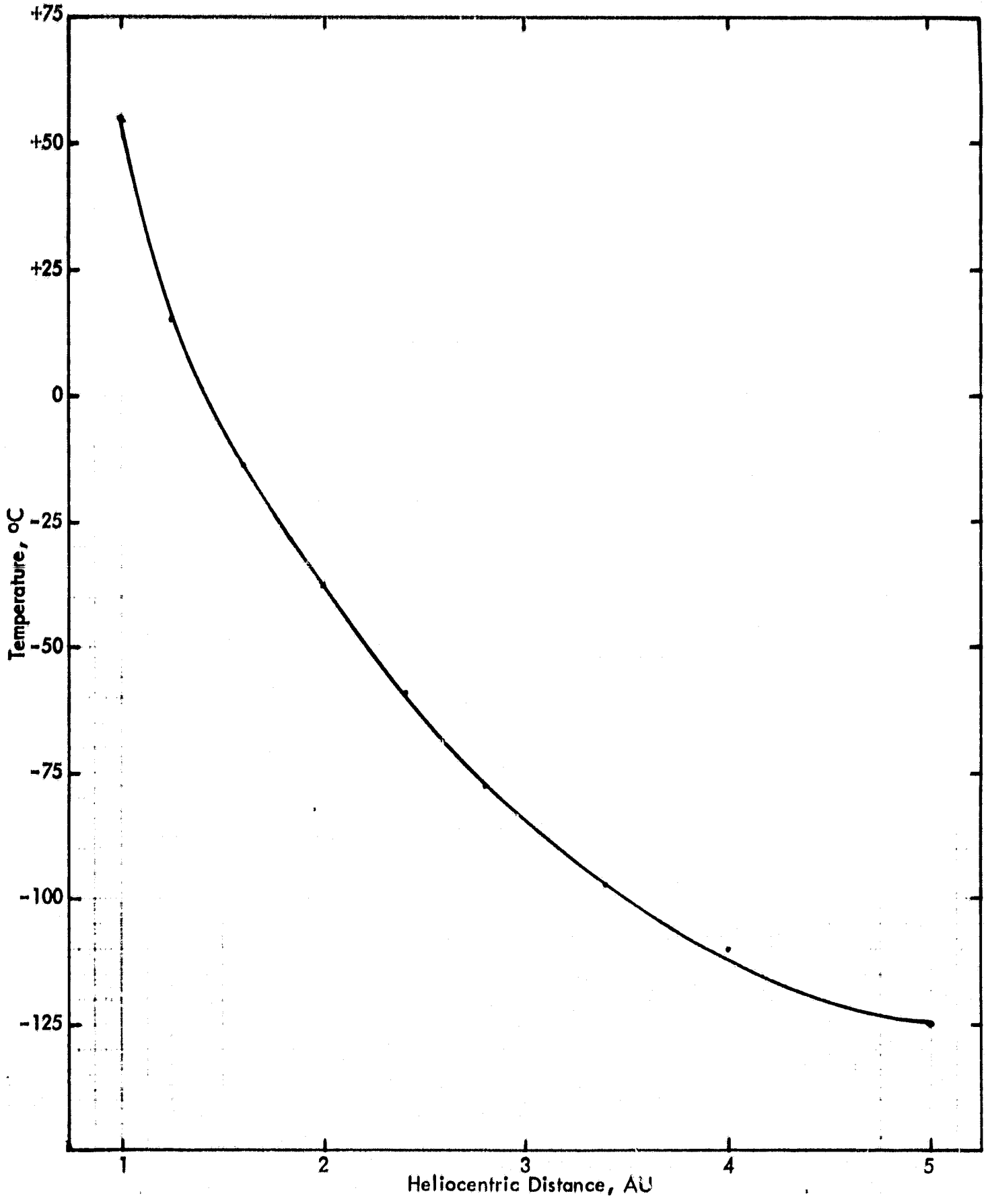

Figure 8. Solar Array Temperature Versus AU

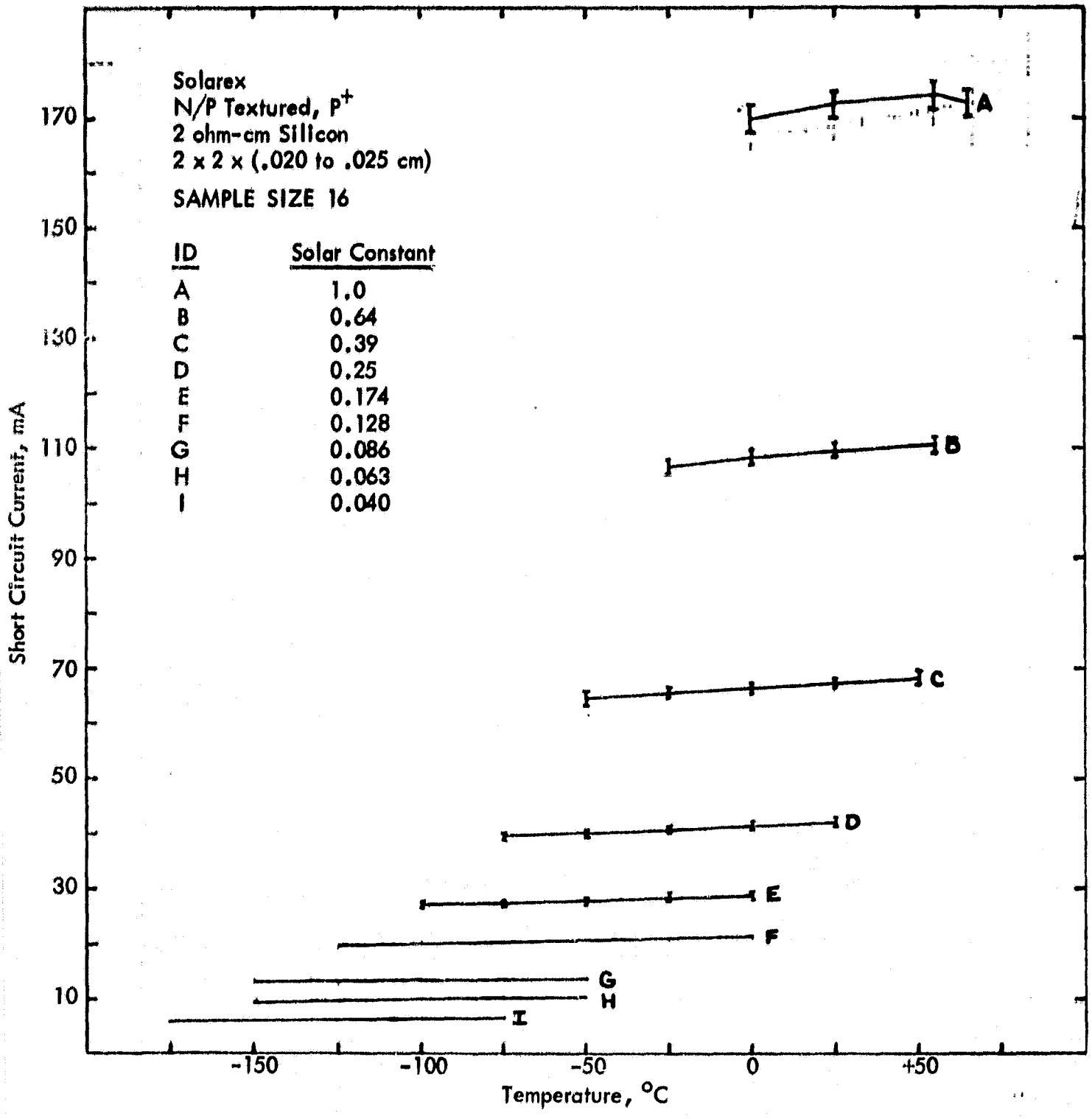

Figure 9. Average I_{sc} as a Function of Temperature

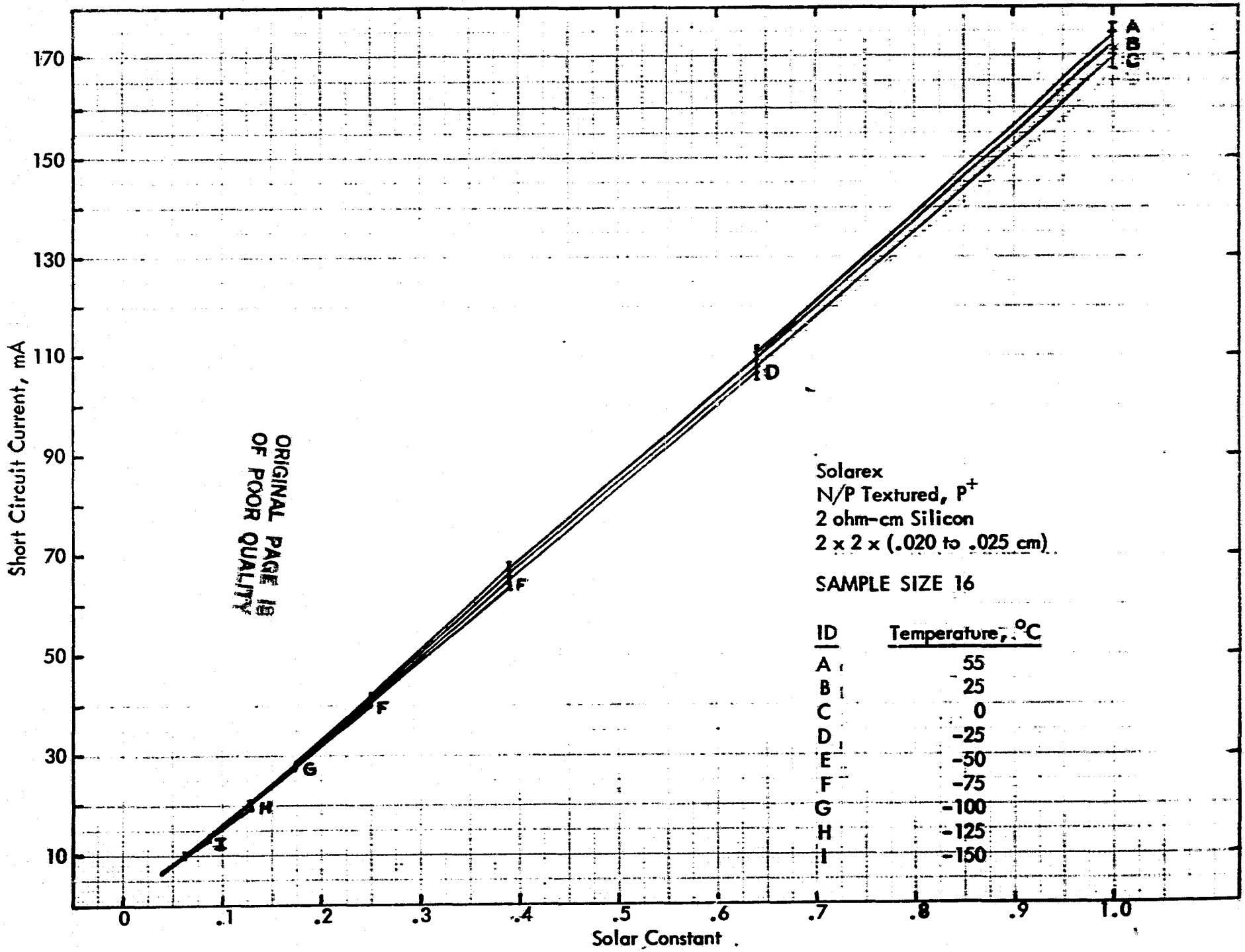

Figure 10. Average I_{sc} as a Function of Intensity

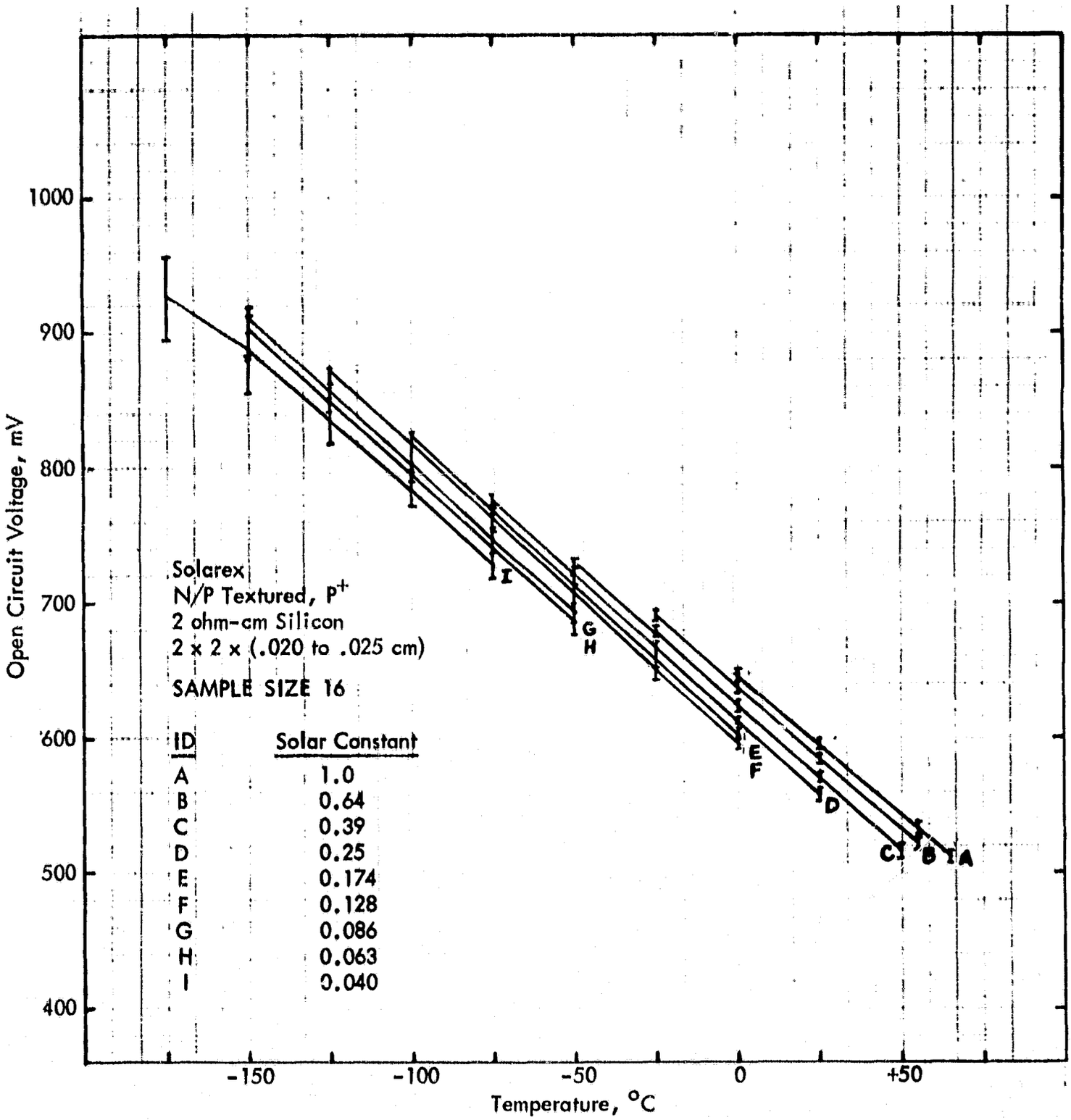

Figure 11. Average V_{oc} as a Function of Temperature

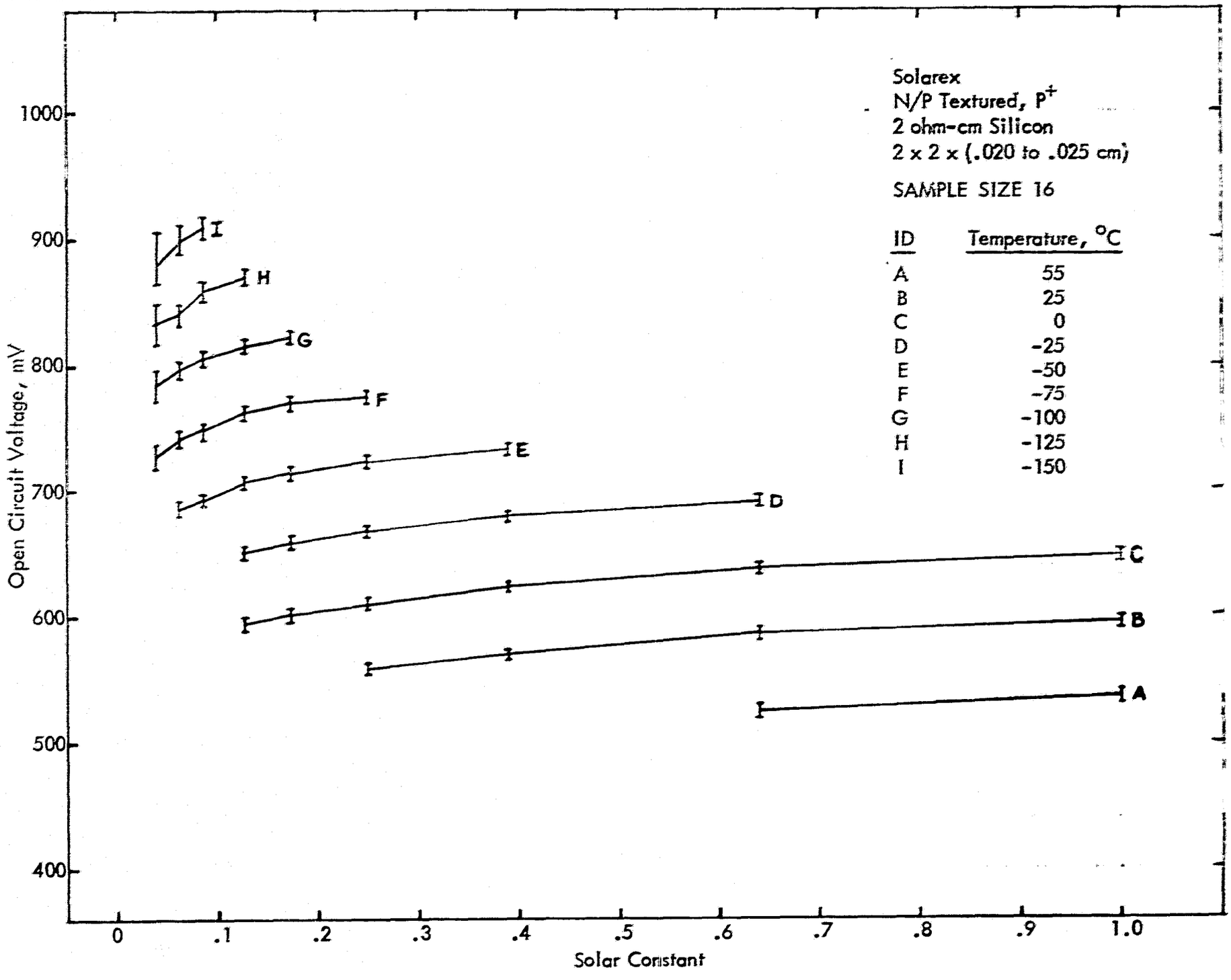

Figure 12. Average V_{oc} as a Function of Intensity

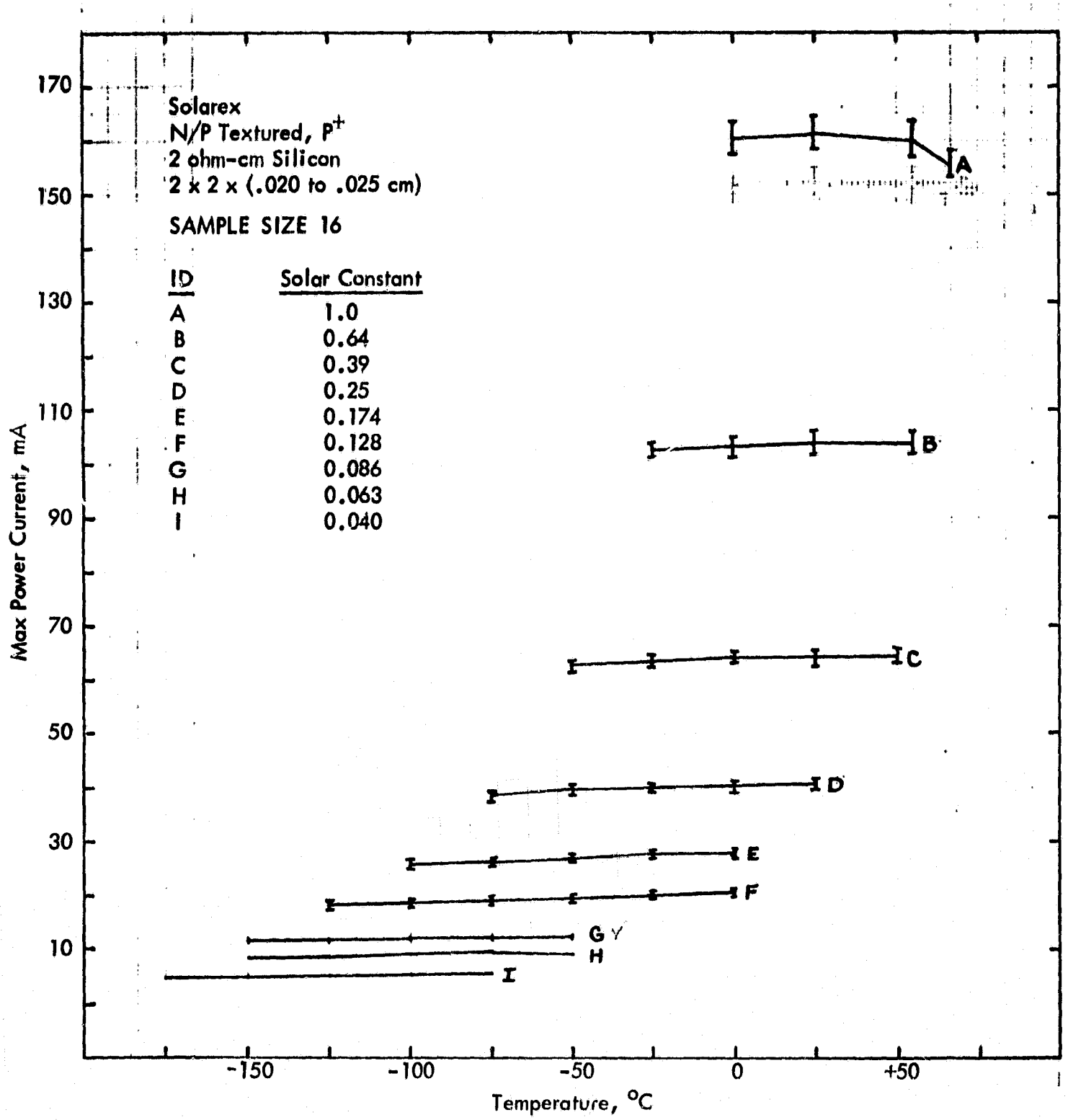

Figure 13. Average I_{mp} as a Function of Temperature

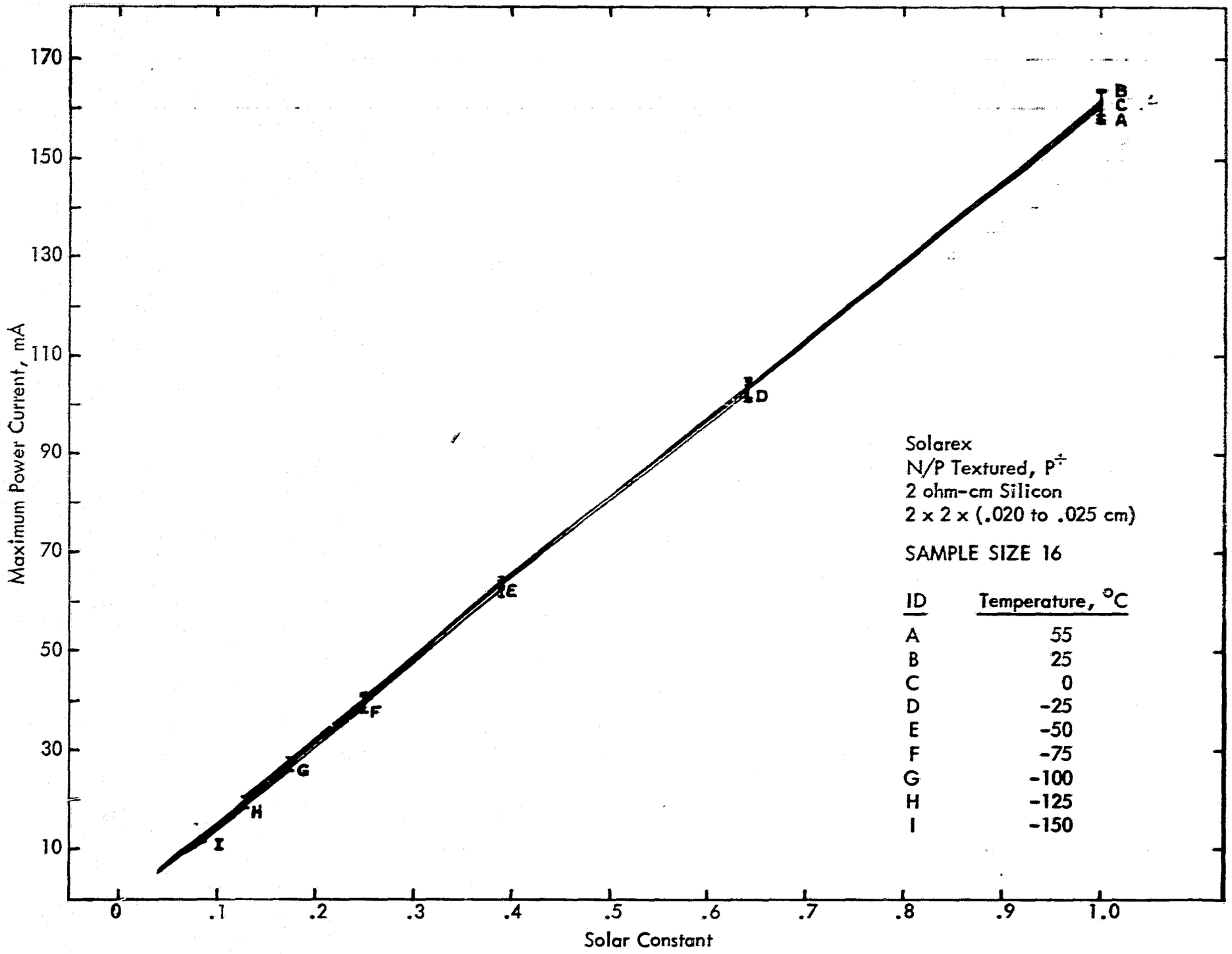

Figure 14. Average I_{mp} as a Function of Intensity

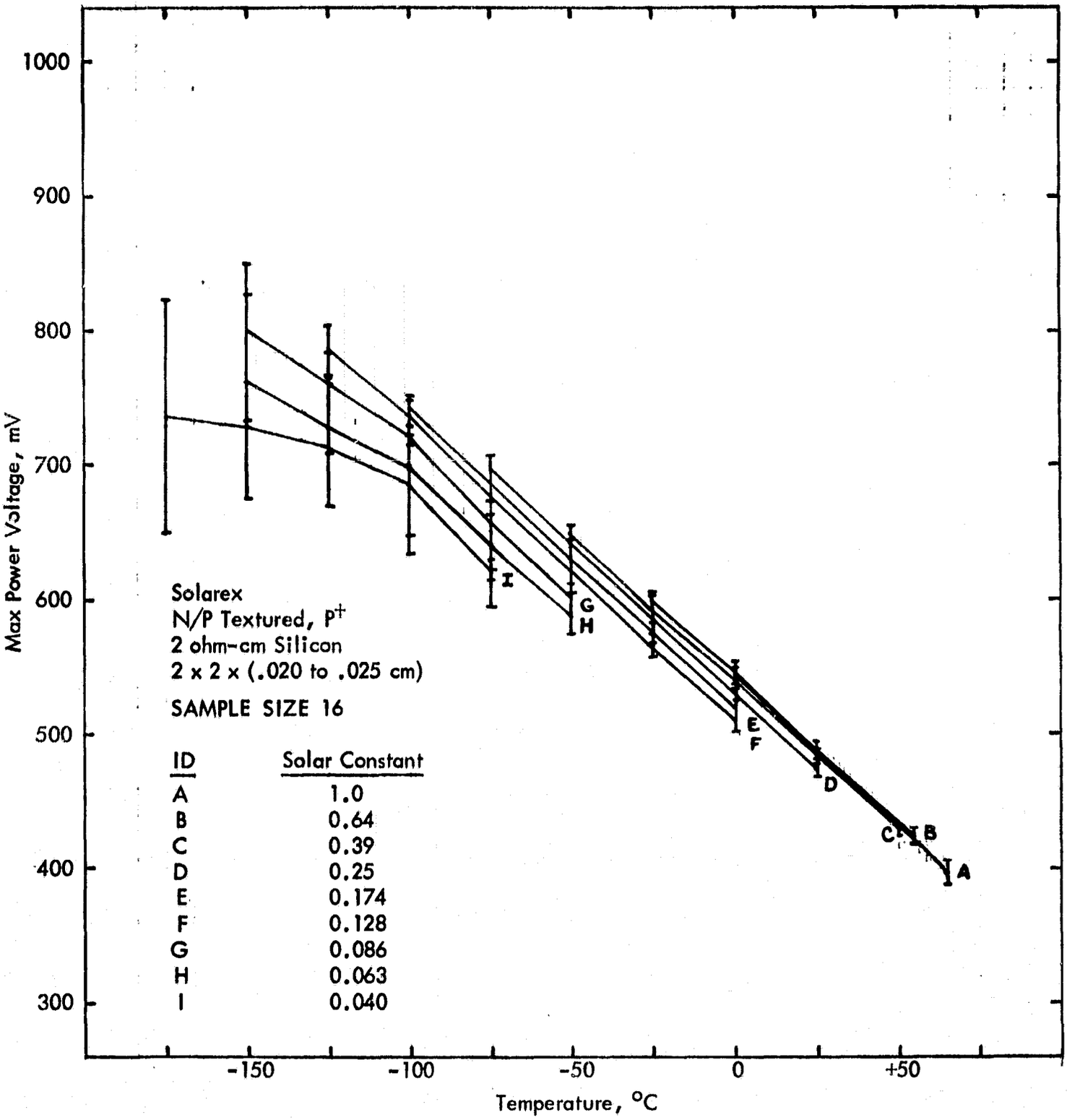

Figure 15. Average V_{mp} as a Function of Temperature

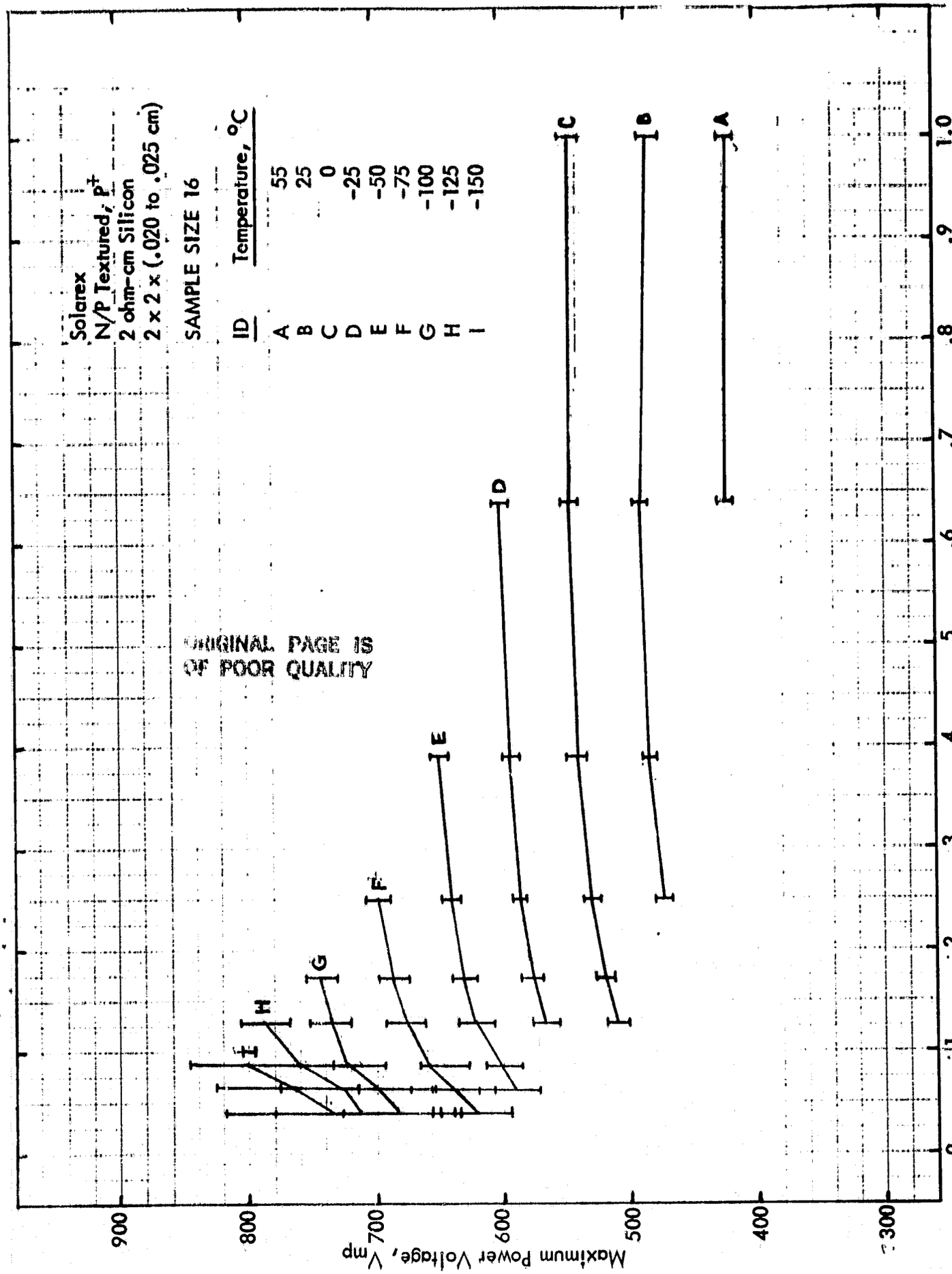

Figure 16. Average V_{mp} as a Function of Intensity

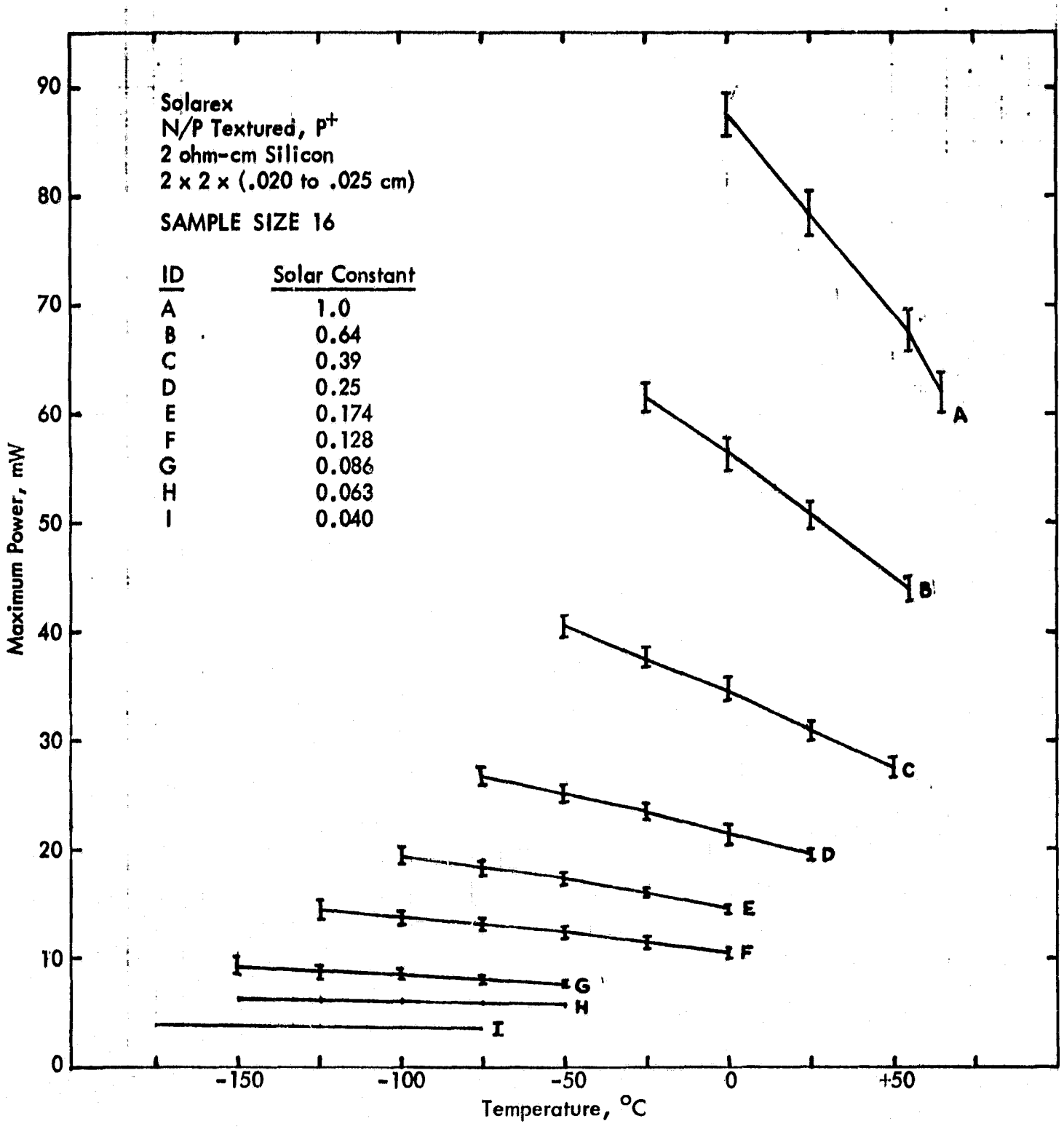

Figure 17. Average MP as a Function of Temperature

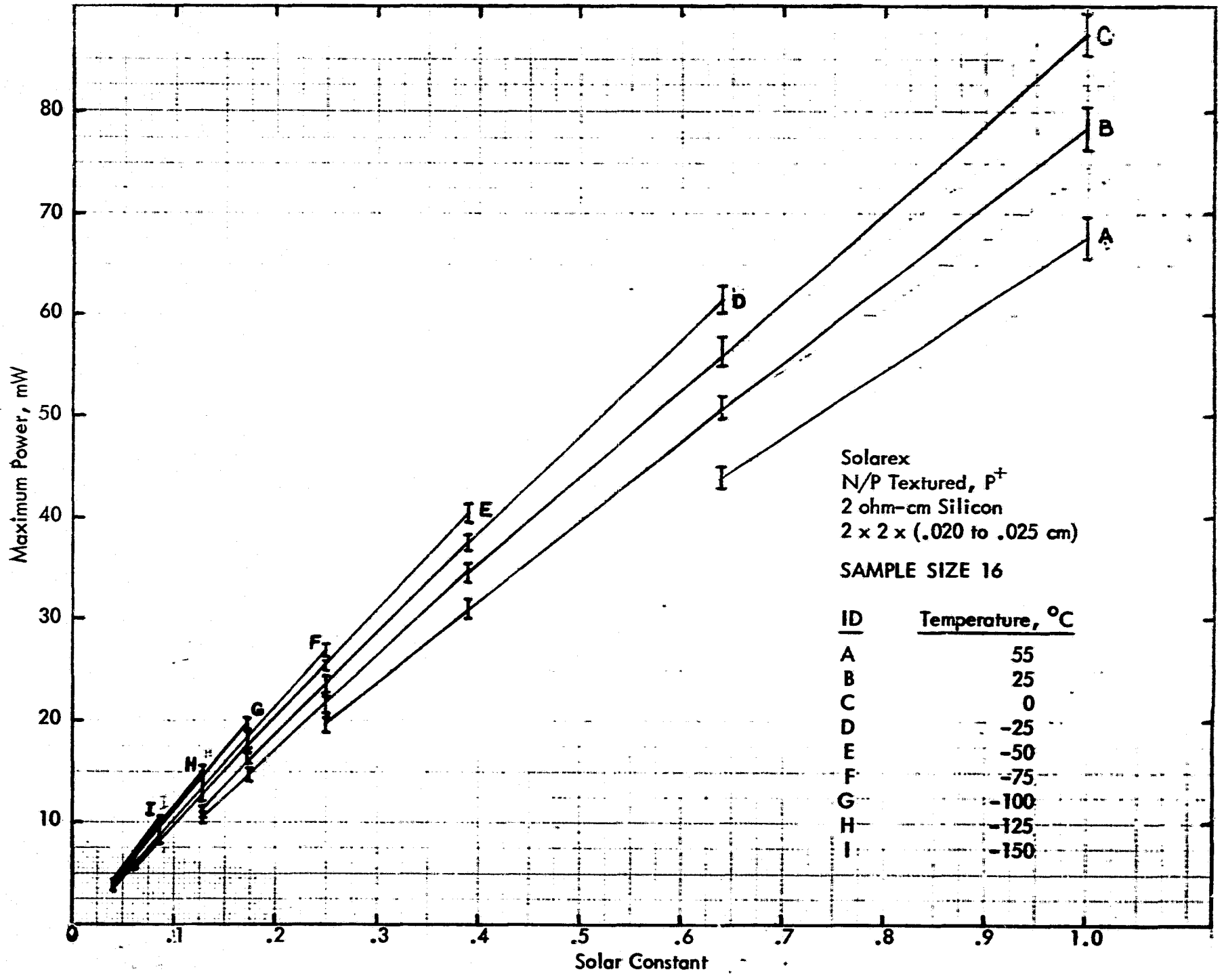

Figure 18. Average MP as a Function of Intensity

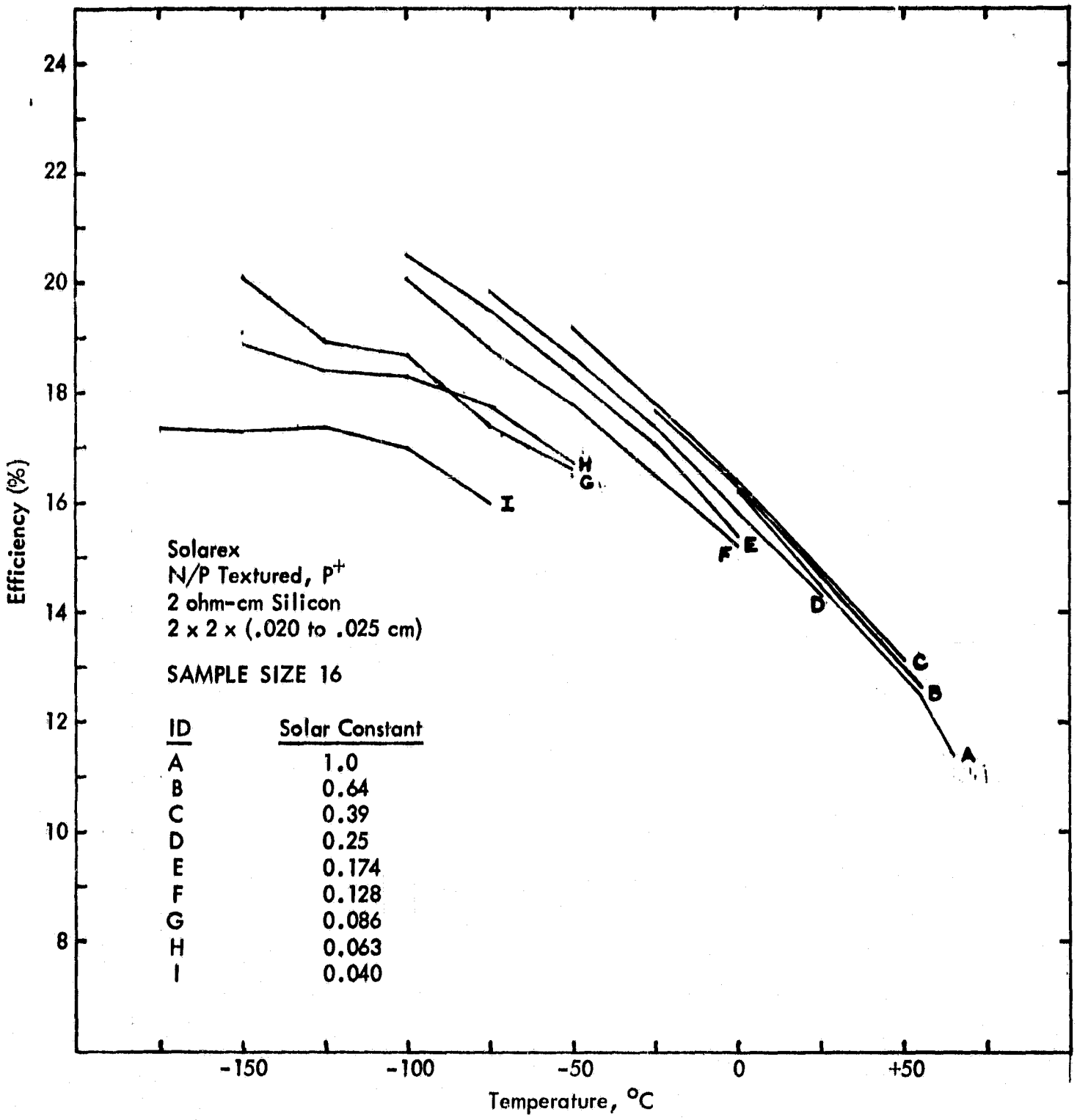

Figure 19. Average Efficiency as a Function of Temperature

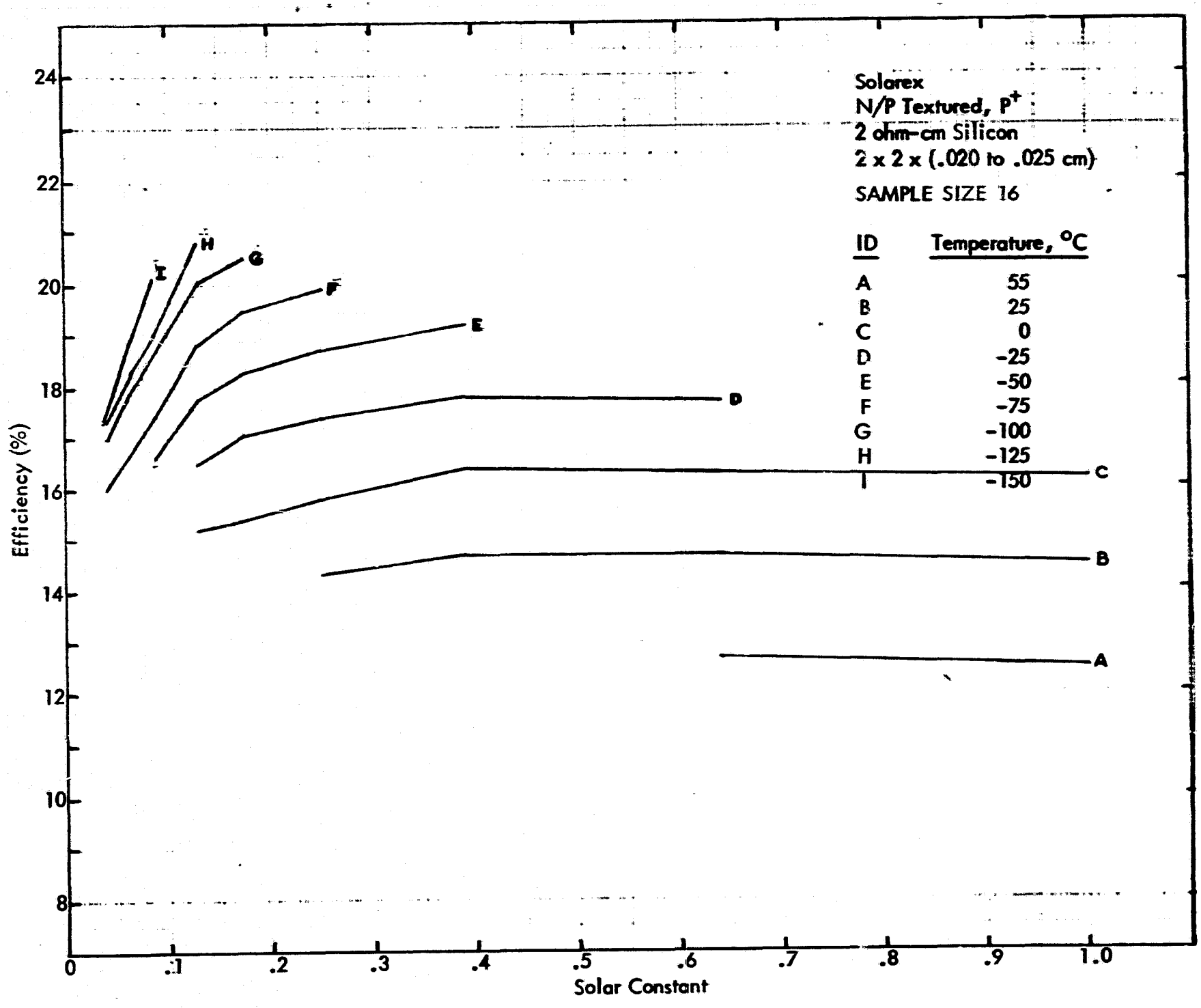

Figure 20. Average Efficiency as a Function of Intensity

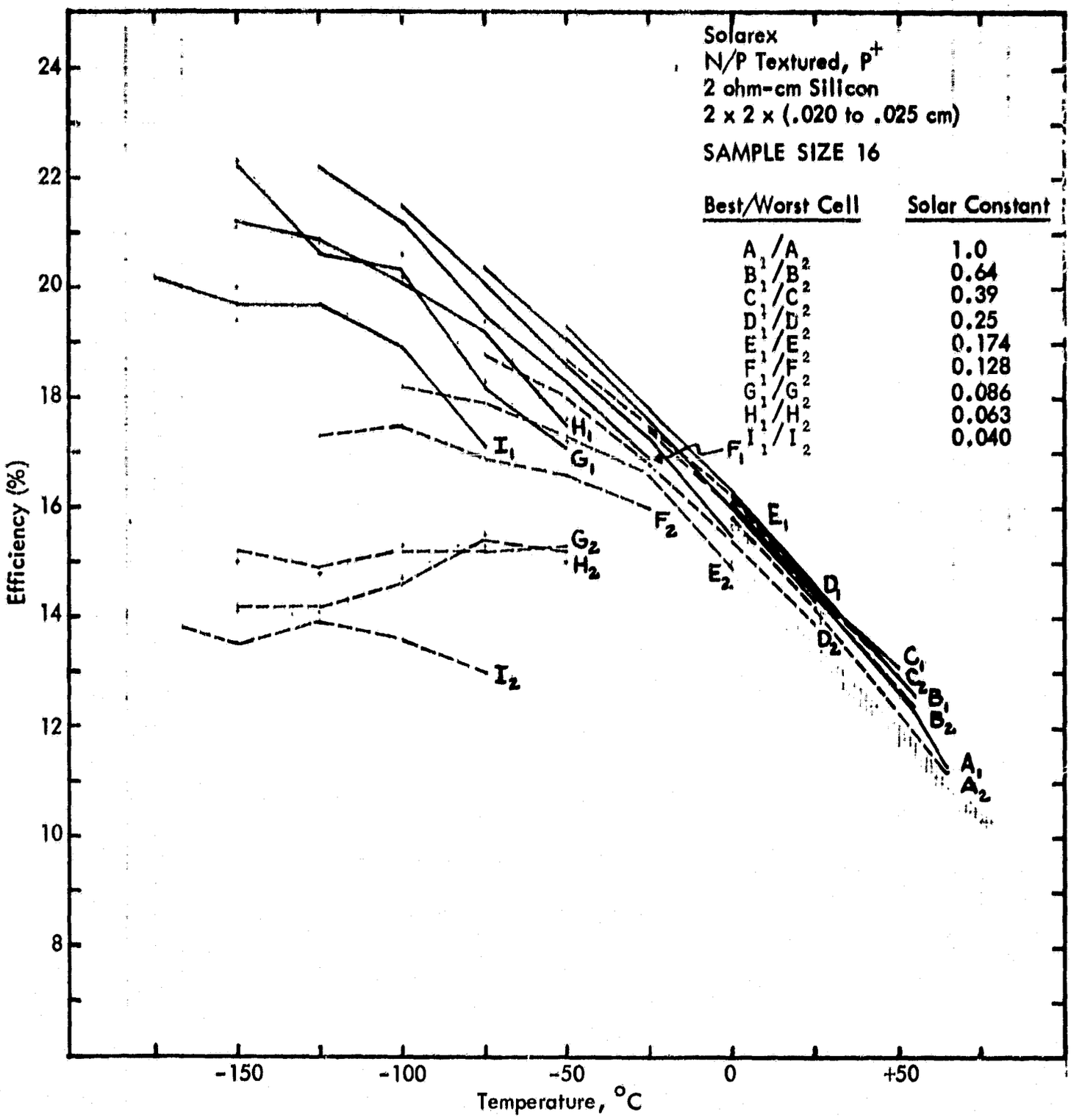

Figure 21. Efficiency of the Best/Worst Cells as a Function of Temperature

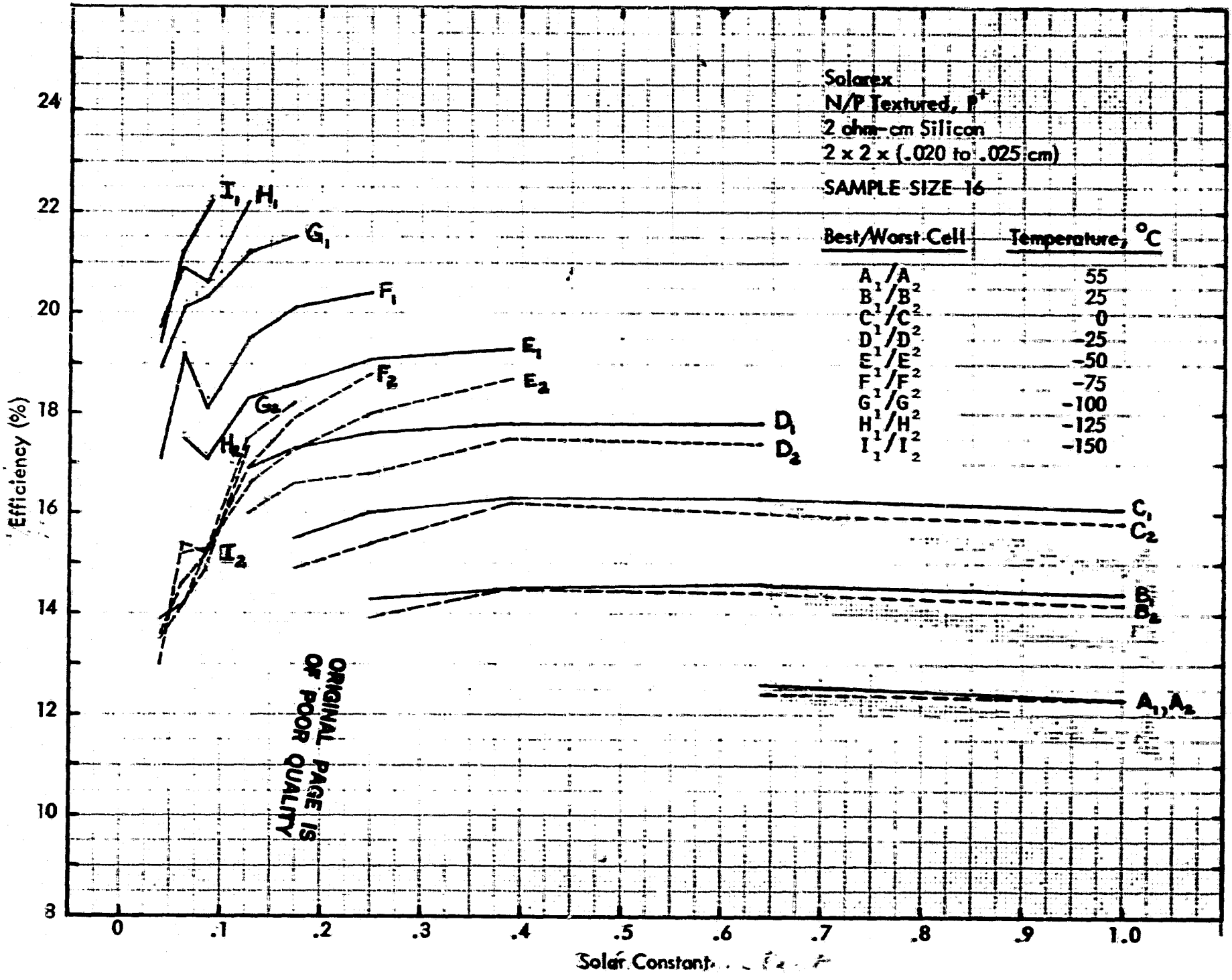

Figure 22. Efficiency of the Best/Worst Cells as a Function of Intensity

TABLE 5. AVERAGE I_{sc} (mA)

Solarex
N/P P^+ Textured 2 ohm-cm Silicon
2 x 2 x (.020 to .025 cm)
Ti-Pd-Ag Contacts 3/19 Lines
Tantalum Oxide AR Coating
Ceria-Doped Microsheet Filter

SAMPLE SIZE 16

Temperature	Solar Constants								
	1.0	0.64	0.39	0.25	0.174	0.128	0.086	0.063	0.040
65°C	172.9 (2.8)								
55°C	174.2 (2.4)	110.6 (1.5)	68.3* (1.0)						
25°C	172.4 (2.4)	109.9 (1.4)	67.4 (1.0)	42.0 (.6)					
0°C	169.8 (2.5)	108.3 (1.7)	66.8 (1.0)	41.5 (.5)	28.8 (.5)	21.0 (.0)			
-25°C		106.7 (1.5)	65.6 (1.0)	40.8 (.6)	28.5 (.6)	20.9 (.3)			
-50°C			64.4 (1.2)	40.3 (.6)	27.9 (.3)	20.7 (.3)	13.7 (.2)	10.1 (.1)	
-75°C				39.9 (.7)	27.6 (.5)	20.3 (.3)	13.4 (.2)	10.1 (.1)	6.4 (.1)
-100°C					27.3 (.5)	20.0 (.3)	13.2 (.2)	10.0 (.1)	6.4 (.1)
-125°C						19.6 (.3)	12.9 (.2)	9.7 (.1)	6.3 (.1)
-150°C							13.1 (.2)	9.5 (.1)	6.2 (.1)
-175°C									6.0 (.1)

NOTE: *Data taken at 50°C
Standard Deviations are given in parentheses.

TABLE 6. AVERAGE V_{oc} (mV)

Solarex
N/P P^+ Textured 2 ohm-cm Silicon
2 x 2 x (.020 to .025 cm)
Ti-Pd-Ag Contacts 3/19 Lines
Tantalum Oxide AR Coating
Ceria-Doped Microsheet Filter

SAMPLE SIZE 16

Temperature	Solar Constants								
	1.0	0.64	0.39	0.25	0.174	0.128	0.086	0.063	0.040
65°C	512.5 (5.5)								
55°C	534.9 (5.0)	523.0 (4.7)	517.3* (4.2)						
25°C	595.8 (5.3)	585.9 (4.5)	570.3 (4.3)	558.1 (5.0)					
0°C	648.4 (5.1)	638.4 (4.7)	624.9 (4.0)	610.8 (4.7)	603.1 (4.9)	594.1 (5.8)			
-25°C		691.4 (4.4)	680.3 (4.0)	667.9 (4.5)	659.9 (5.4)	650.1 (5.3)			
-50°C			732.6 (4.2)	722.7 (4.5)	714.1 (4.8)	706.3 (5.3)	693.3 (6.5)	685.1 (6.8)	
-75°C				777.1 (4.4)	769.2 (4.9)	762.4 (5.5)	747.2 (7.3)	742.9 (6.6)	727.4 (8.6)
-100°C					823.3 (4.9)	817.4 (5.4)	806.9 (6.7)	797.9 (7.4)	784.2 (11.0)
-125°C						869.9 (5.8)	859.9 (7.7)	850.4 (8.9)	834.9 (16.6)
-150°C							910.2 (8.5)	901.4 (12.3)	880.7 (27.9)
-175°C									926.7 (32.1)

NOTE: *Data taken at 50°C
Standard Deviations are given in parentheses.

TABLE 7. AVERAGE I_{mp} (mA)

Solarex
N/P P^+ Textured 2 ohm-cm Silicon
2 x 2 x (.020 to .025 cm)
Ti-Pd-Ag Contacts 3/19 Lines
Tantalum Oxide AR Coating
Ceria-Doped Microsheet Filter

SAMPLE SIZE 16

Temperature	Solar Constants								
	1.0	0.64	0.39	0.25	0.174	0.128	0.086	0.063	0.040
65°C	155.8 (2.4)								
55°C	160.3 (3.2)	103.9 (1.6)	64.2* (1.0)						
25°C	161.6 (2.9)	103.9 (1.6)	63.9 (1.3)	40.6 (.6)					
0°C	160.5 (2.9)	103.0 (1.9)	64.1 (1.1)	40.2 (1.4)	27.8 (.5)	20.6 (.4)			
-25°C		102.4 (1.6)	63.3 (1.0)	40.0 (.7)	27.8 (.5)	20.2 (.4)			
-50°C			62.4 (1.3)	39.5 (.7)	27.3 (.5)	19.7 (.5)	12.8 (.4)	9.7 (.3)	
-75°C				38.6 (.8)	26.7 (.7)	19.2 (.6)	12.3 (.4)	9.5 (.4)	5.5 (.3)
-100°C					26.0 (.9)	18.9 (.7)	12.0 (.6)	9.0 (.4)	5.4 (.2)
-125°C						18.3 (.9)	11.5 (.6)	8.6 (.4)	5.3 (.2)
-150°C							11.7 (.6)	8.4 (.3)	5.2 (.3)
-175°C									5.2 (.2)

NOTE: *Data taken at 50°C.
Standard Deviations are given in parentheses.

TABLE 8. AVERAGE V_{mp} (mV)

Solarex
N/P P^+ Textured 2 ohm-cm Silicon
2 x 2 x (.020 to .025 cm)
Ti-Pd-Ag Contacts 3/19 Lines
Tantalum Oxide AR Coating
Ceria-Doped Microsheet Filter

SAMPLE SIZE 16

Temperature	Solar Constants								
	1.0	0.64	0.39	0.25	0.174	0.128	0.086	0.063	0.040
65°C	397.3 (9.3)								
55°C	422.6 (6.5)	424.6 (5.3)	430.4* (5.4)						
25°C	484.7 (7.6)	489.8 (6.1)	484.3 (6.1)	474.9 (7.2)					
0°C	545.1 (8.0)	547.7 (6.0)	541.4 (6.6)	531.4 (7.0)	521.4 (8.2)	511.1 (8.7)			
-25°C		600.7 (6.5)	594.5 (7.0)	587.0 (7.0)	578.4 (8.6)	566.3 (9.4)			
-50°C			650.2 (6.9)	641.5 (8.0)	632.5 (9.6)	623.3 (11.0)	603.6 (12.5)	589.8 (14.5)	
-75°C				697.5 (8.1)	688.6 (10.5)	677.7 (11.7)	658.1 (16.6)	640.3 (16.5)	622.8 (27.8)
-100°C					742.0 (11.3)	737.8 (14.6)	723.2 (27.1)	700.0 (34.0)	684.5 (48.9)
-125°C						786.0 (20.7)	760.3 (37.4)	728.0 (46.8)	713.3 (70.3)
-150°C							801.7 (56.0)	763.4 (72.7)	729.2 (91.2)
-175°C									736.6 (86.0)

NOTE: *Data taken at 50°C.
Standard Deviations are given in parentheses.

TABLE 9. AVERAGE MP (mW)

Solarex
N/P P^+ Textured 2 ohm-cm Silicon
2 x 2 x (.020 to .025 cm)
Ti-Pd-Ag Contacts 3/19 Lines
Tantalum Oxide AR Coating
Ceria-Doped Microsheet Filter

SAMPLE SIZE 16

Temperature	Solar Constants								
	1.0	0.64	0.39	0.25	0.174	0.128	0.086	0.063	0.040
65°C	61.9 (1.8)								
55°C	67.7 (1.9)	44.1 (1.1)	27.6* (.7)						
25°C	78.4 (2.0)	50.9 (1.2)	30.9 (.9)	19.3 (.5)					
0°C	87.5 (2.0)	56.4 (1.4)	34.7 (.9)	21.4 (.9)	14.5 (.4)	10.5 (.3)			
-25°C		61.5 (1.3)	37.6 (.9)	23.5 (.6)	16.1) (.4)	11.5 (.4)			
-50°C			40.6 (1.1)	25.3 (.7)	17.3 (.5)	12.3 (.5)	7.7 (.3)	5.7 (.3)	
-75°C				26.9 (.8)	18.4 (.6)	13.0 (.6)	8.1 (.4)	6.1 (.4)	3.5 (.3)
-100°C					19.3 (.9)	13.9 (.8)	8.7 (.7)	6.2 (.5)	3.7 (.4)
-125°C						14.4 (1.0)	8.8 (.8)	6.3 (.7)	3.8 (.4)
-150°C							9.4 (1.0)	6.4 (.8)	3.8 (.4)
-175°C									3.8 (.4)

NOTE: *Data taken at 50°C.
Standard Deviations are given in parentheses.

TABLE 10. AVERAGE EFFICIENCY (%)

Solarex
N/P P^+ Textured 2 ohm-cm Silicon
2 x 2 x (.020 to .025 cm)
Ti-Pd-Ag Contacts 3/19 Lines
Tantalum Oxide AR Coating
Ceria-Doped Microsheet Filter

SAMPLE SIZE 16

Temperature	Solar Constants								
	1.0	0.64	0.39	0.25	0.174	0.128	0.086	0.063	0.040
65°C	11.4								
55°C	12.5	12.7	13.1*						
25°C	14.5	14.7	14.7	14.3					
0°C	16.2	16.3	16.4	15.8	15.4	15.2			
-25°C		17.7	17.8	17.4	17.1	16.5			
-50°C			19.2	18.7	18.3	17.8	16.6	16.7	
-75°C				19.9	19.5	18.8	17.4	17.8	16.0
-100°C					20.5	20.1	18.7	18.3	17.0
-125°C						20.8	18.9	18.4	17.4
-150°C							20.1	18.9	17.3
-175°C									17.6

NOTE: *Data taken at 50°C.

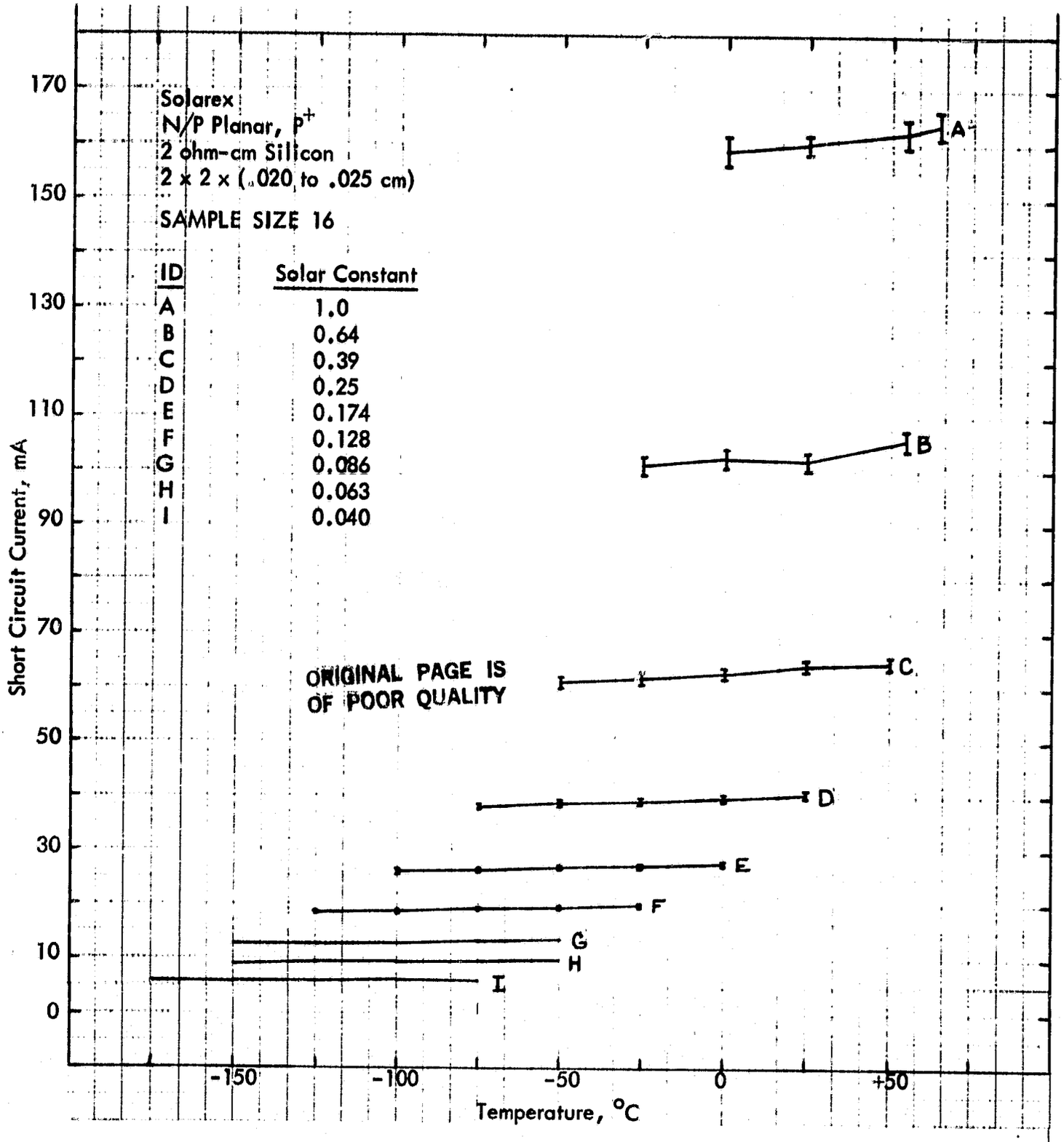

Figure 23. Average I_{sc} as a Function of Temperature

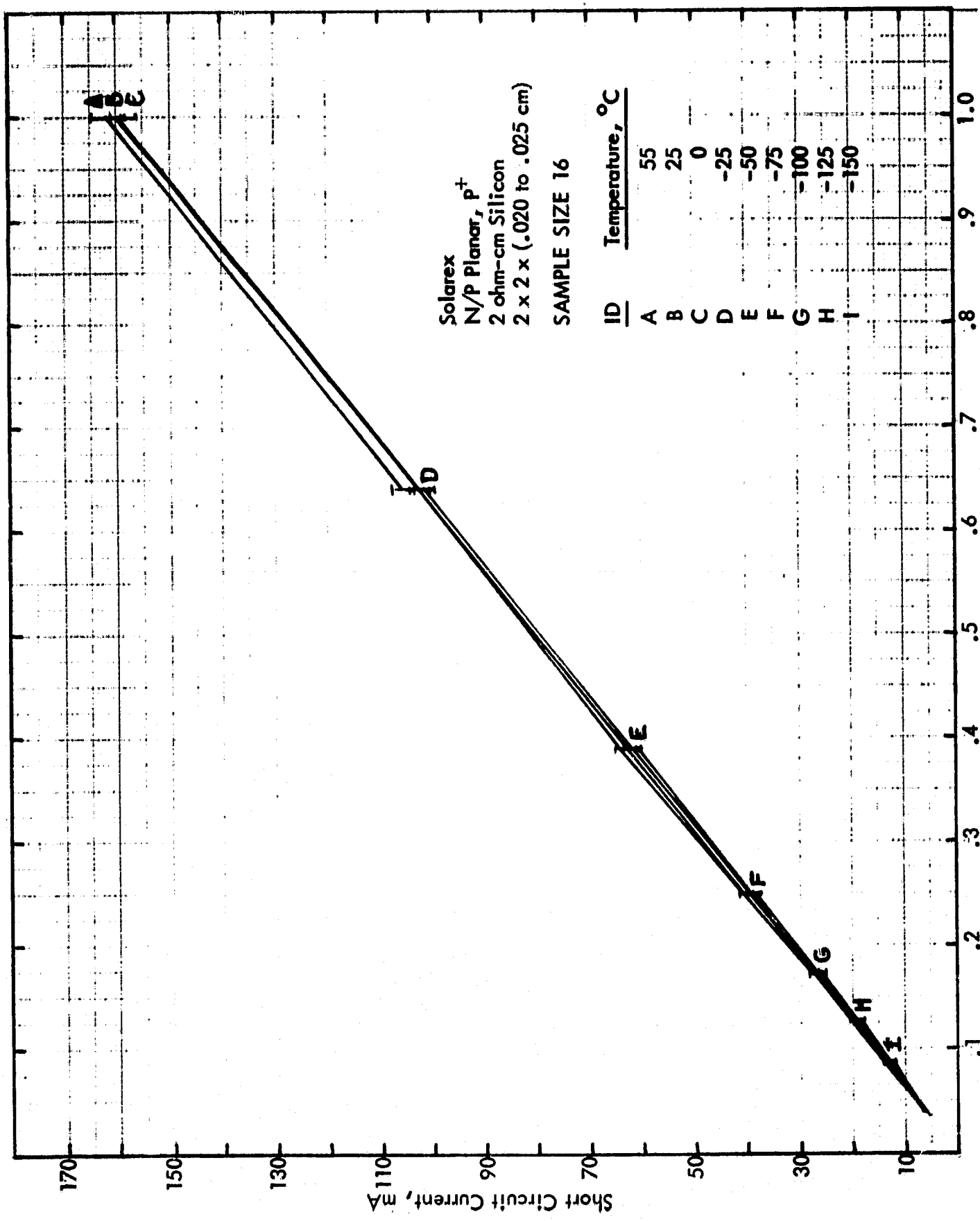

Figure 24. Average I_{sc} as a Function of Intensity

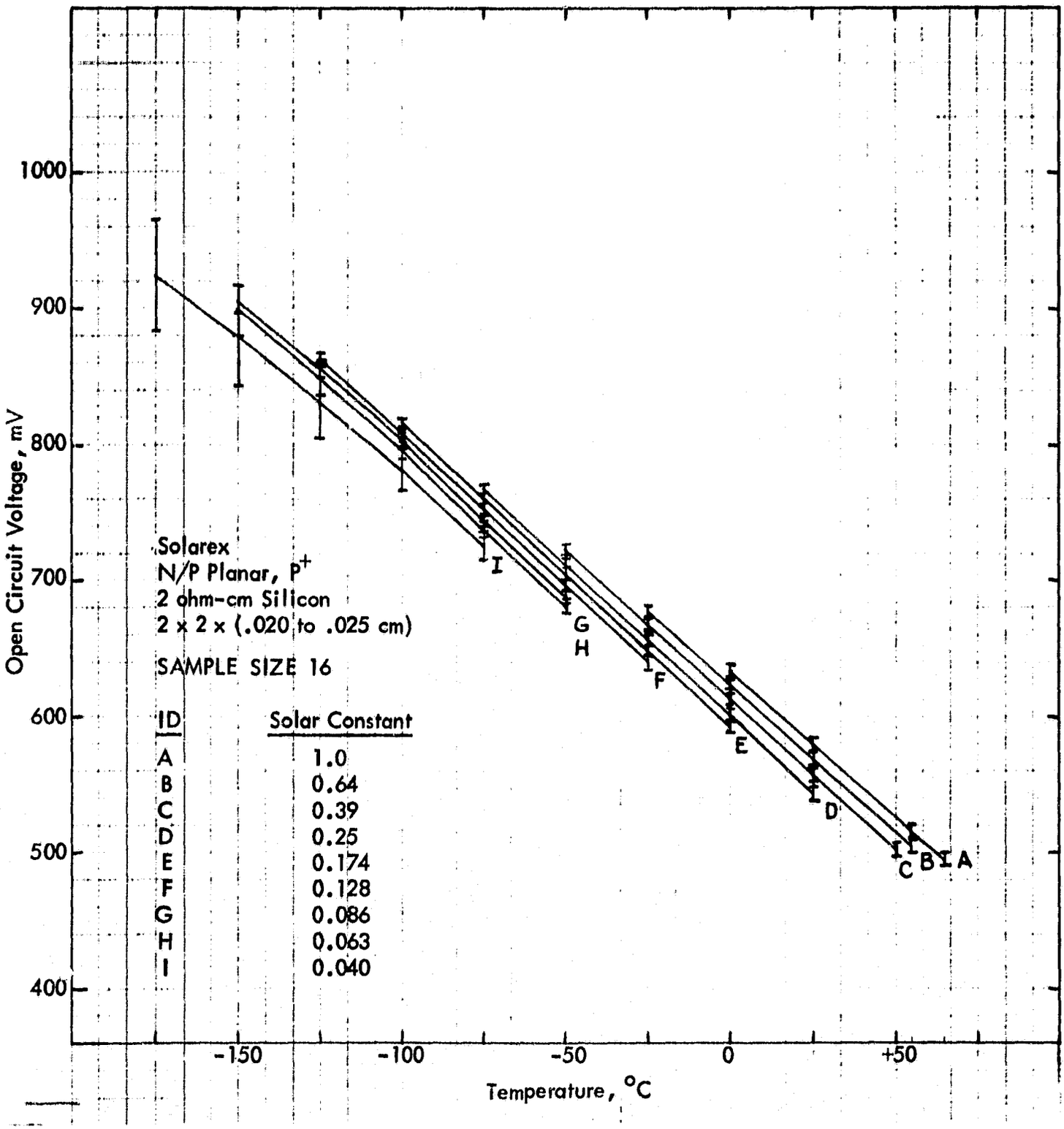

Figure 25. Average V_{oc} as a Function of Temperature

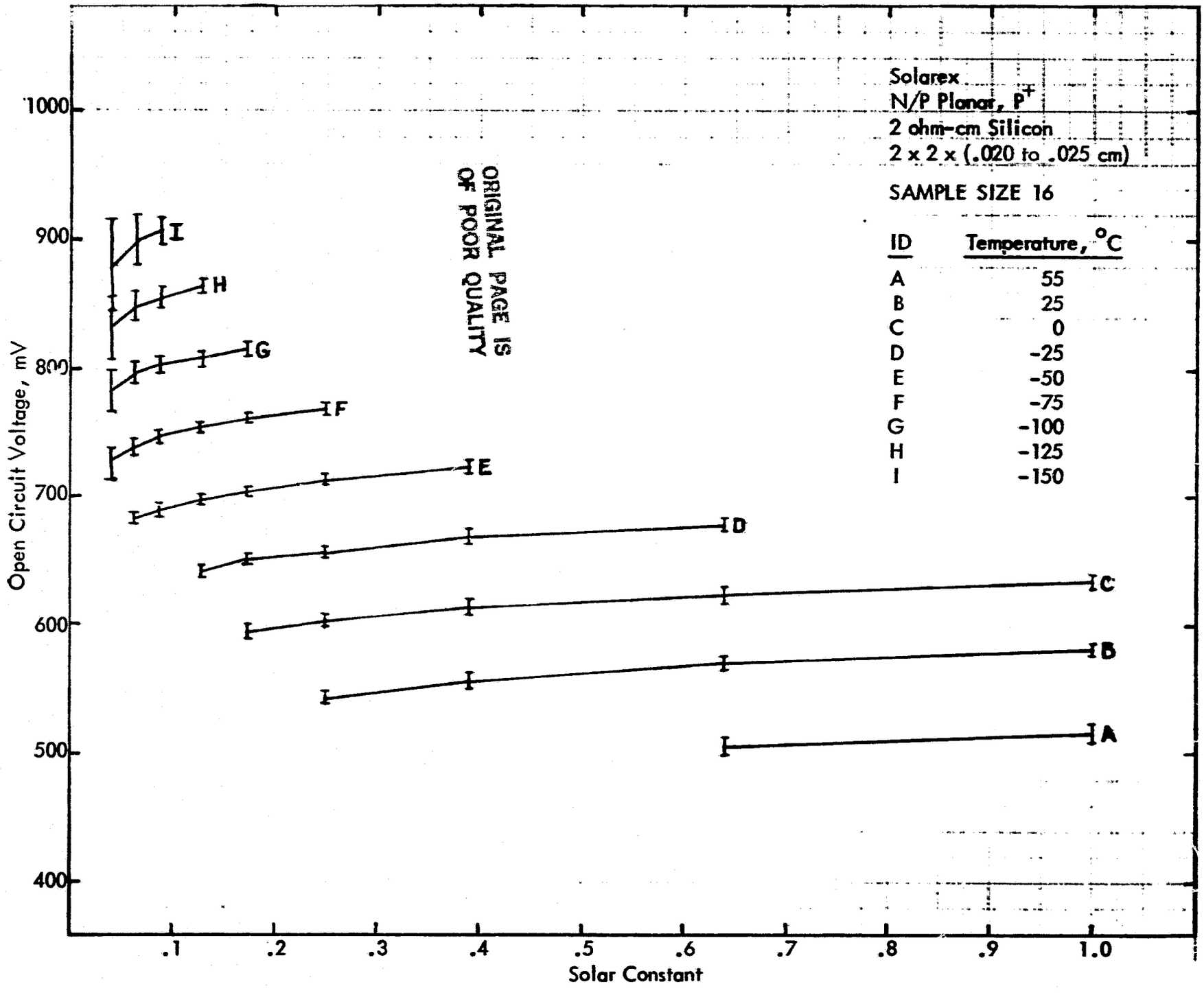

Figure 26. Average V_{oc} as a Function of Intensity

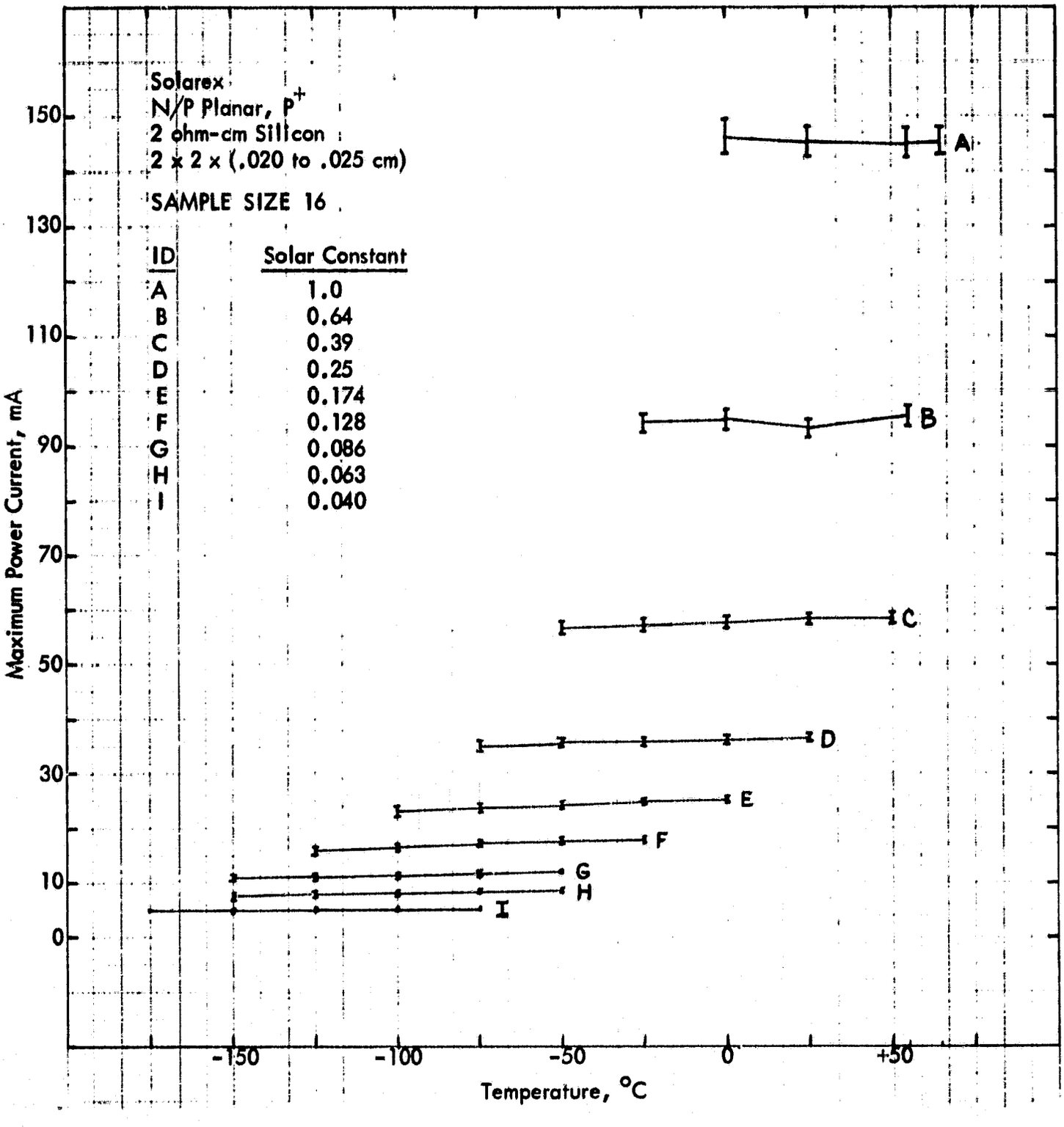

Figure 27. Average I_{mp} as a Function of Temperature

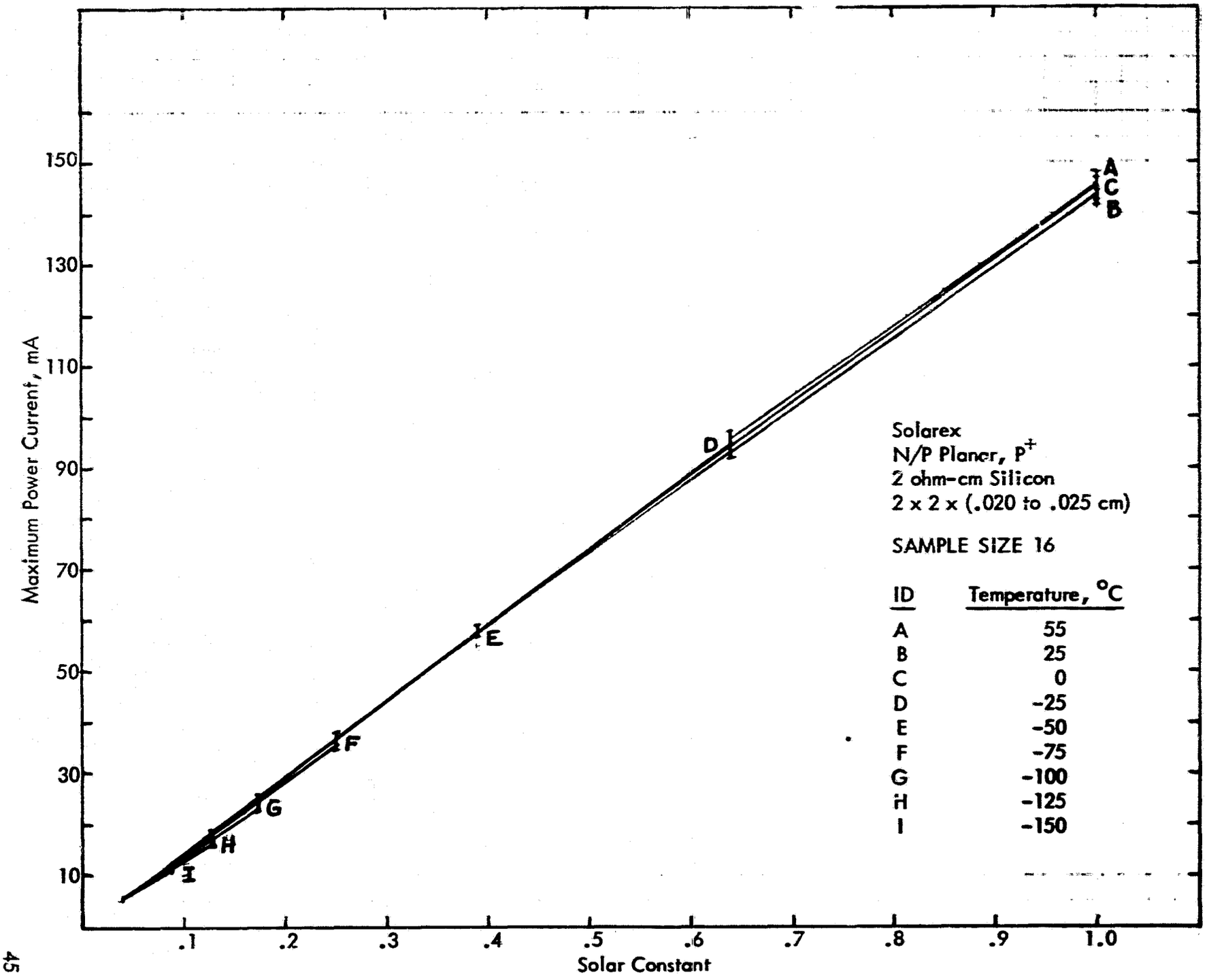

Figure 28. Average I_{mp} as a Function of Intensity

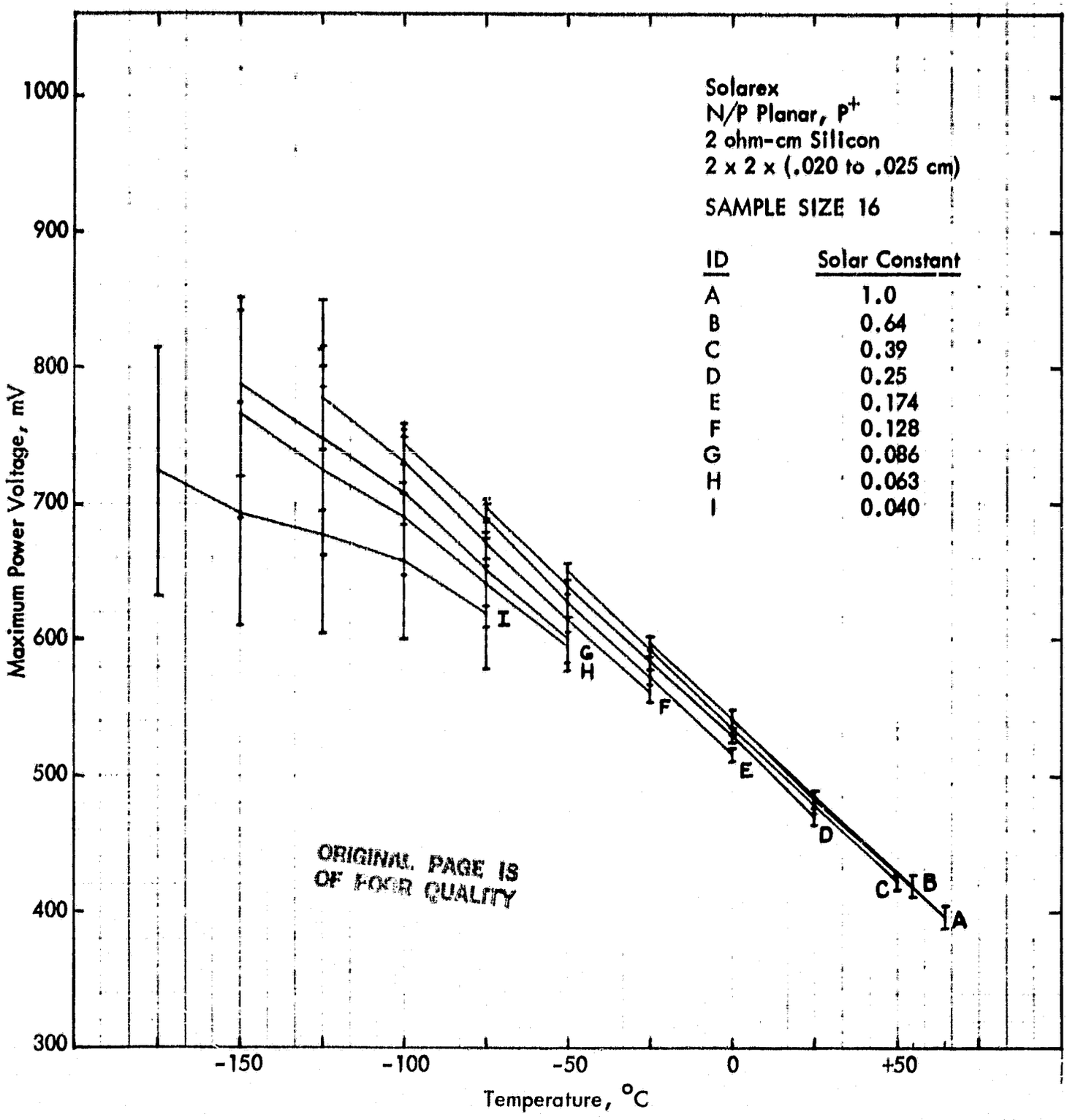

Figure 29. Average V_{mp} as a Function of Temperature

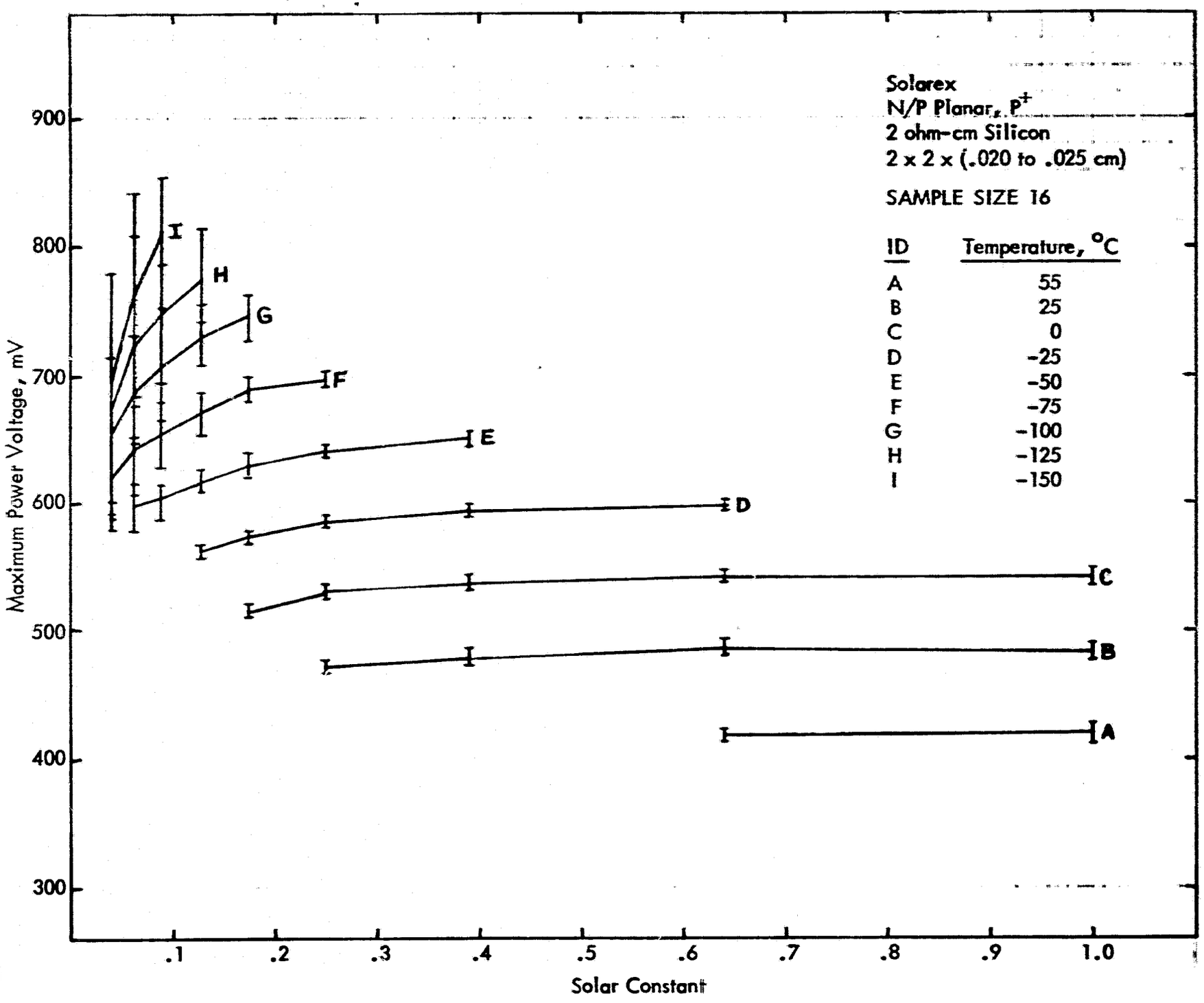

Figure 30. Average V_{mp} as a Function of Intensity

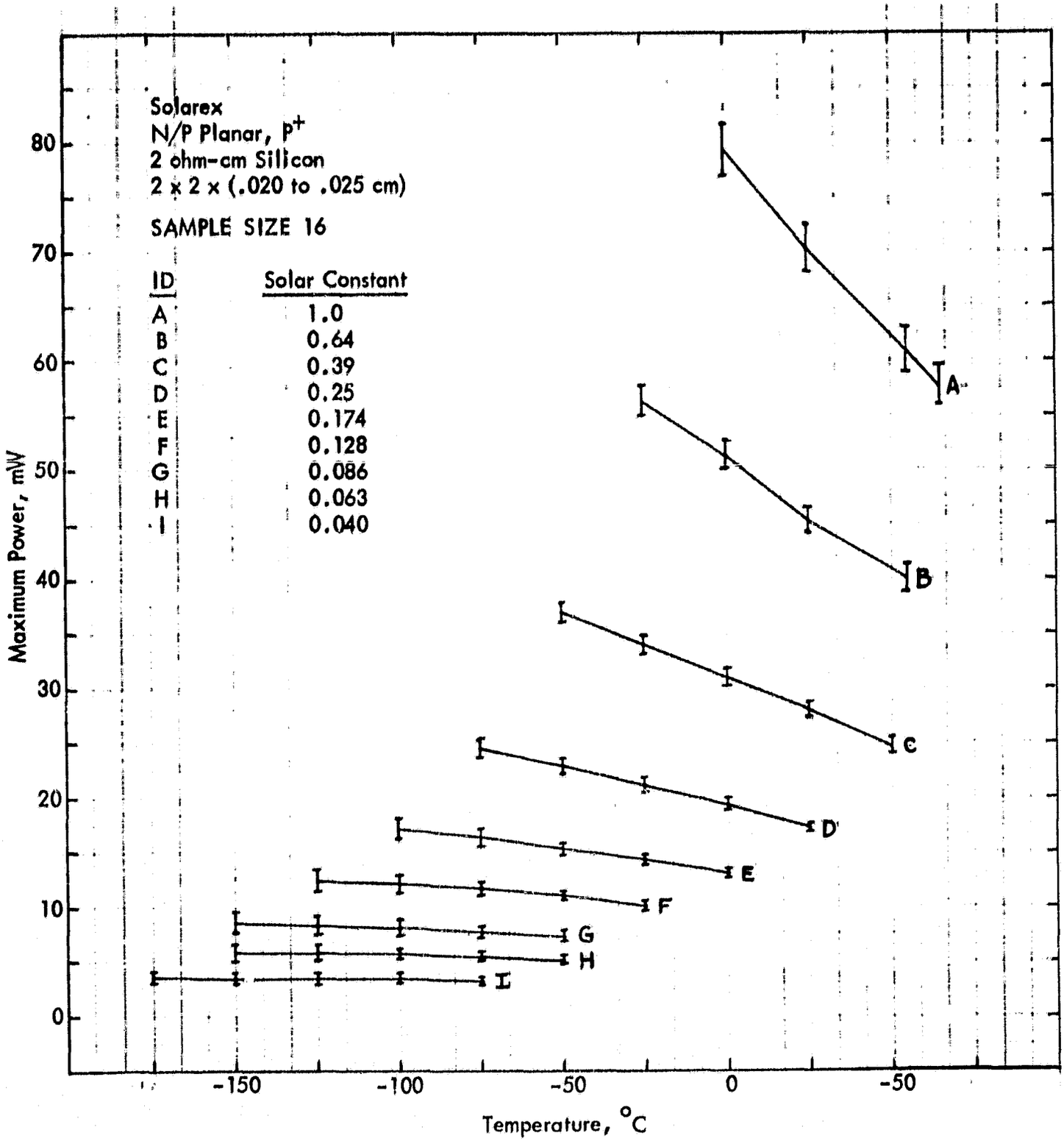

Figure 31. Average MP as a Function of Temperature

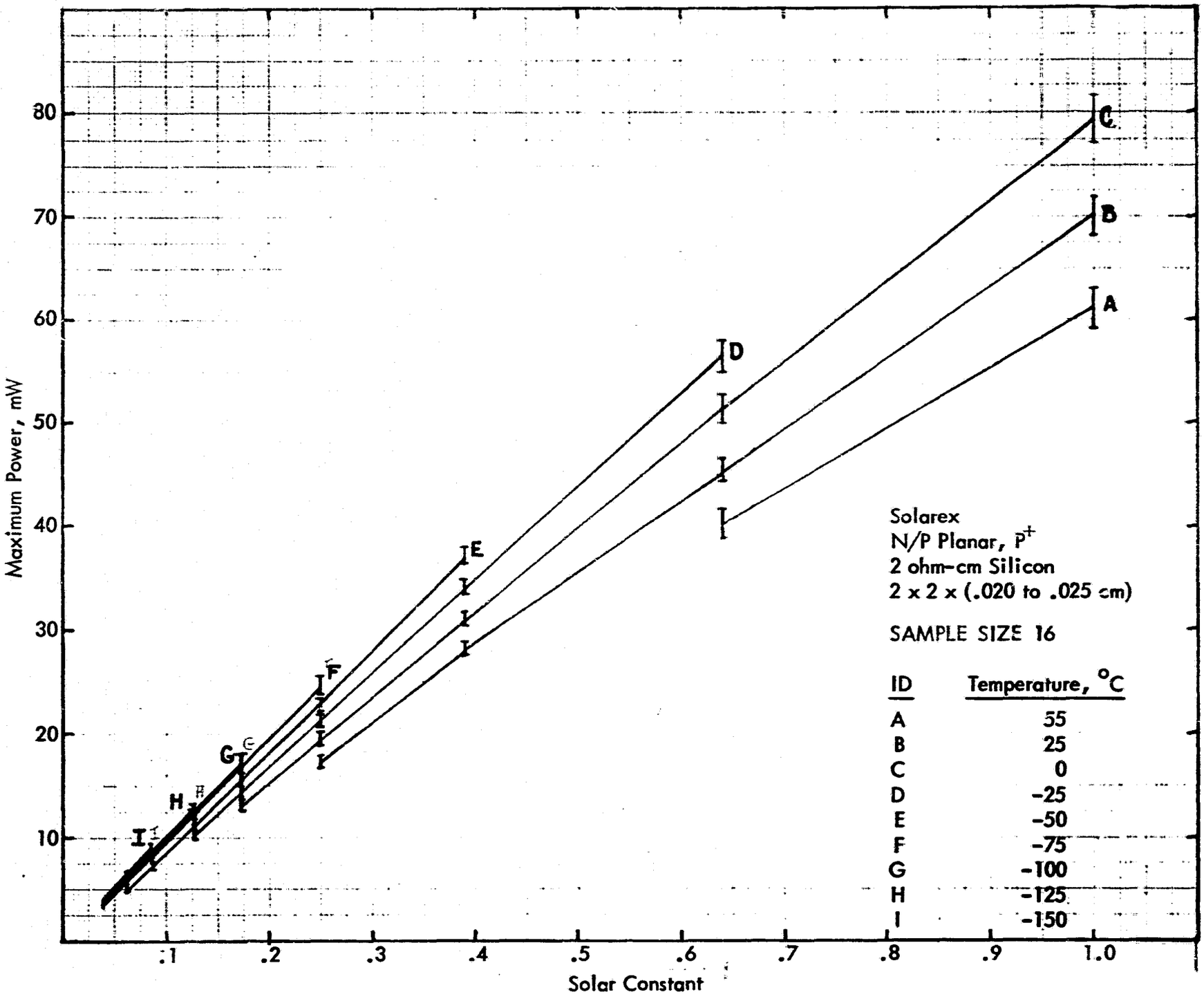

Figure 32. Average MP as a Function of Intensity

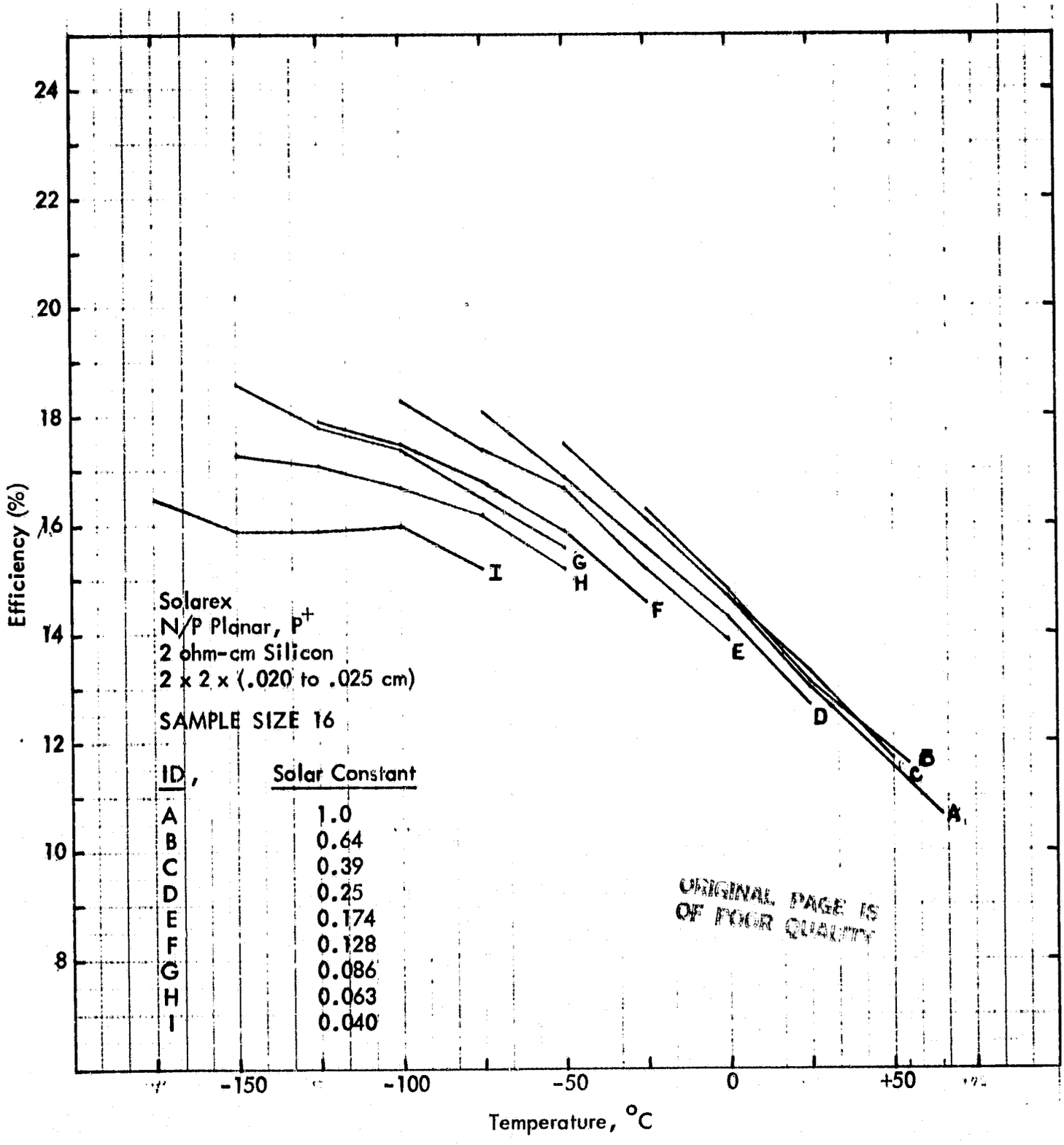

Figure 33. Average Efficiency as a Function of Temperature

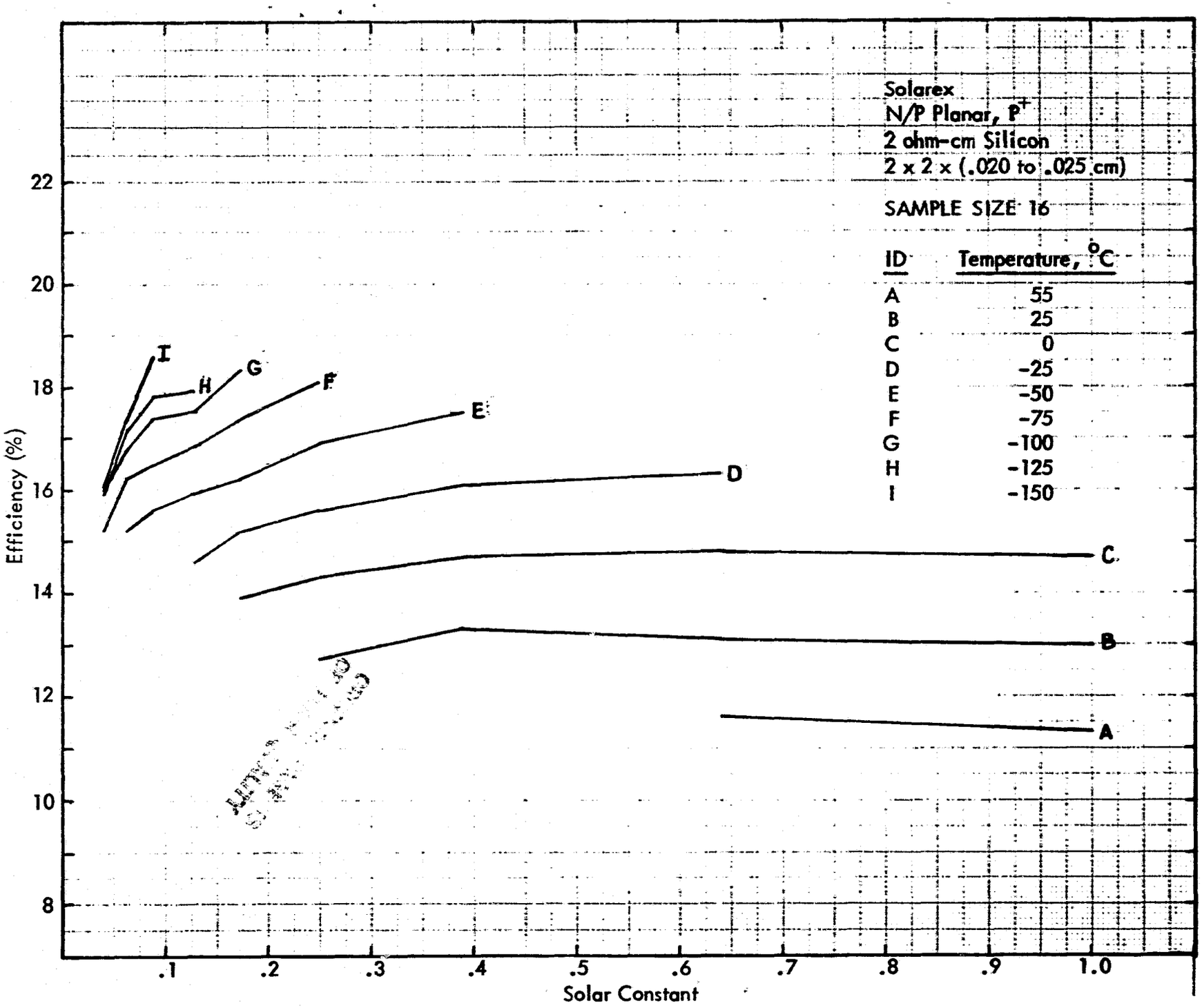

Figure 34. Average Efficiency as a Function of Intensity

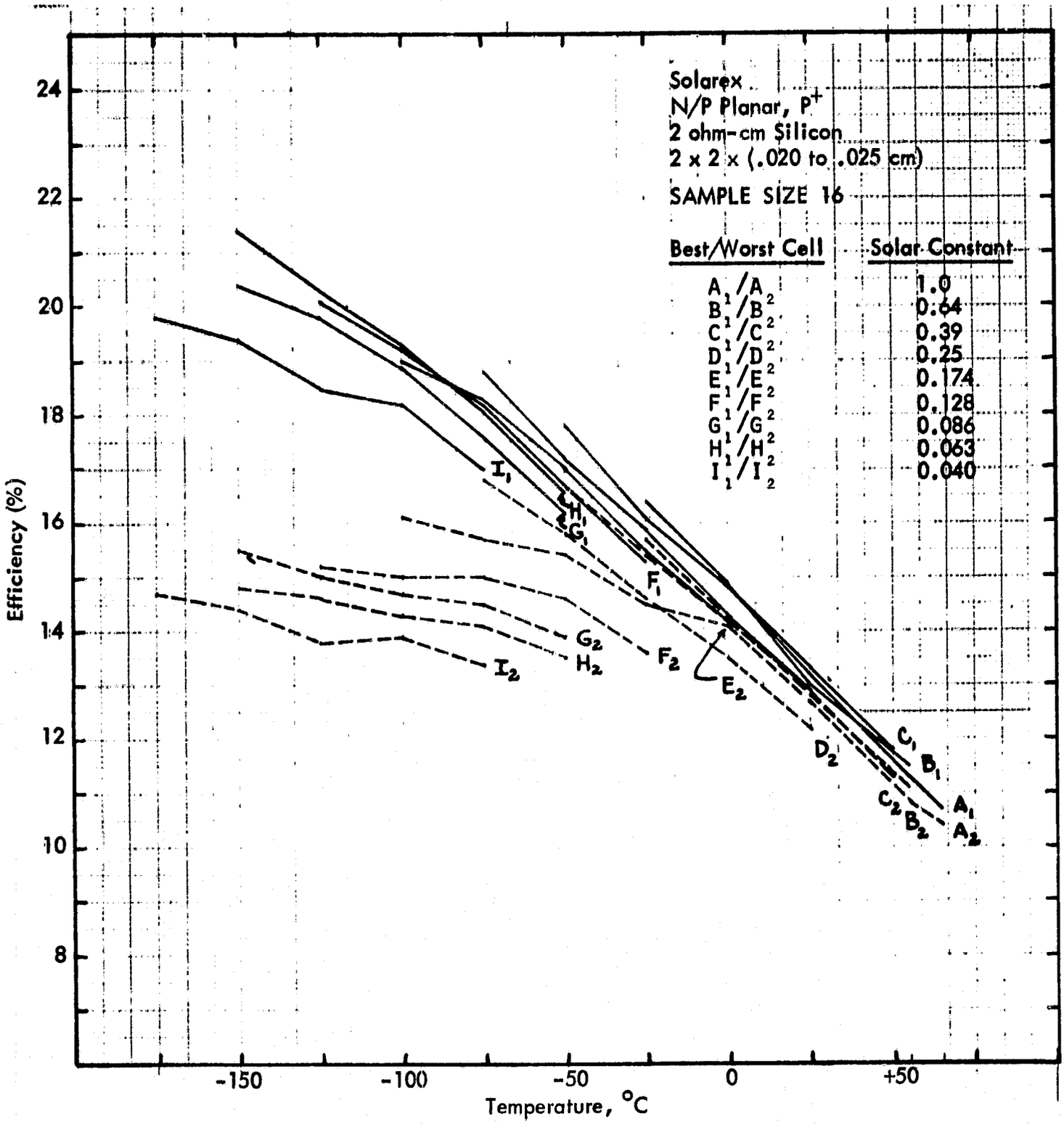

Figure 35. Efficiency of the Best/Worst Cells as a Function of Temperature

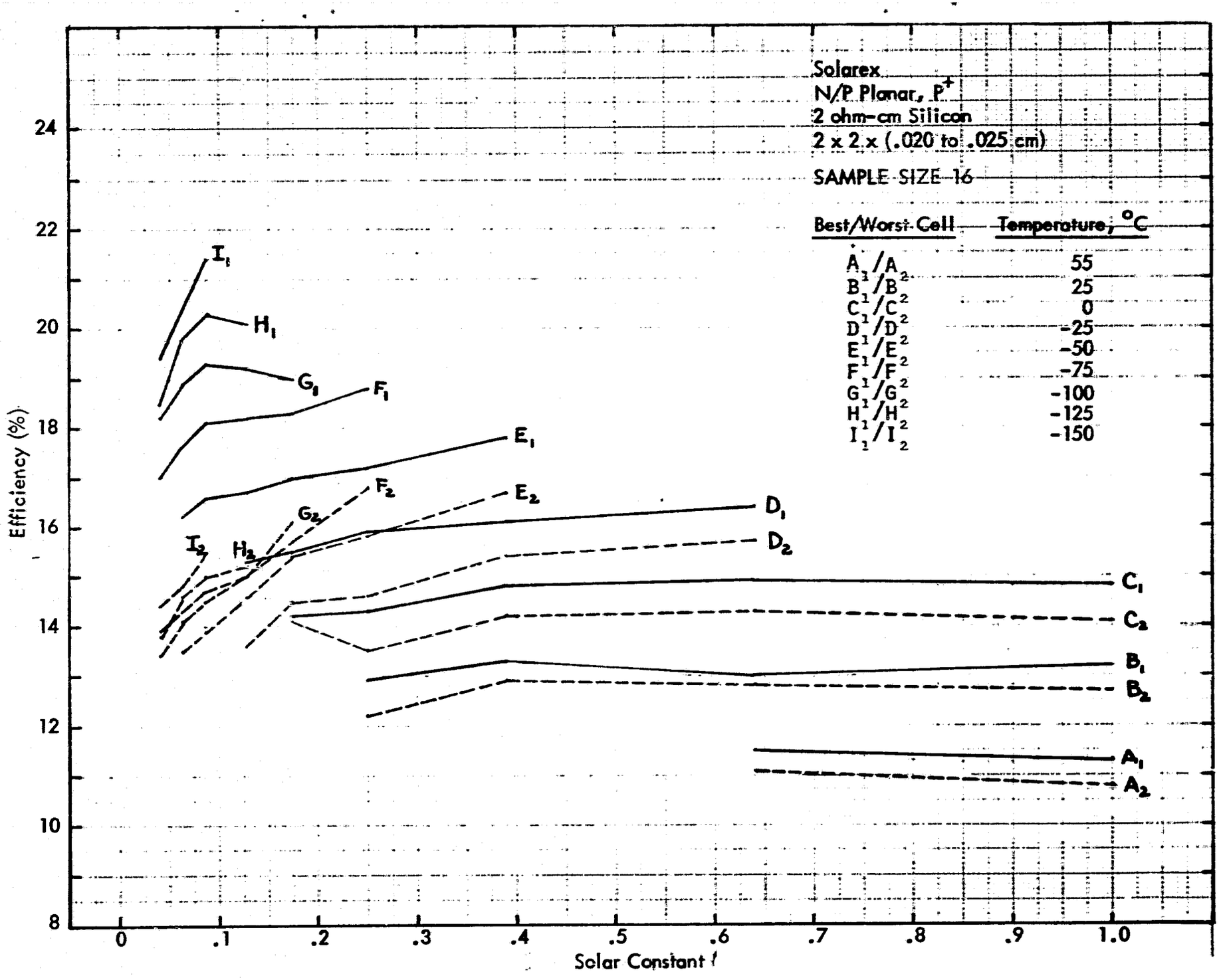

Figure 36. Efficiency of the Best/Worst Cells as a Function of Intensity

TABLE 11. AVERAGE I_{sc} (mA)

Solarex
N/P P^+ Planar 2 ohm-cm Silicon
2 x 2 x (.020 to .025 cm)
Ti-Pd-Ag Contacts 3/19 Lines
Tantalum Oxide AR Coating
Ceria-Doped Microsheet Filter
SAMPLE SIZE 16

emperature	Solar Constants								
	1.0	0.64	0.39	0.25	0.174	0.128	0.086	0.063	0.040
65°C	163.6 (2.5)								
55°C	162.0 (2.6)	105.8 (1.8)	64.8* (1.1)						
25°C	160.1 (1.8)	102.0 (1.7)	64.1 (1.0)	40.5 (0.6)					
0°C	158.9 (2.6)	102.5 (1.7)	62.9 (1.1)	39.9 (0.6)	27.8 (0.4)				
-25°C		101.2 (1.7)	61.9 (1.2)	39.2 (0.5)	27.2 (0.4)	20.0 (0.2)			
-50°C			61.2 (1.0)	38.8 (0.7)	27.0 (0.3)	19.7 (0.3)	13.4 (0.2)	9.8 (0.1)	
-75°C				38.3 (0.4)	26.5 (0.4)	19.3 (0.3)	13.2 (0.2)	9.7 (0.1)	5.9 (0.1)
-100°C					26.1 (0.5)	18.8 (0.3)	12.9 (0.2)	9.4 (0.1)	6.0 (0.1)
-125°C						18.4 (0.3)	12.6 (0.2)	9.3 (0.2)	5.8 (0.1)
-150°C							12.7 (0.2)	9.0 (0.1)	5.7 (0.1)
-175°C									5.6 (0.1)

NOTE: *Data taken at 50°C.
Standard Deviations are given in parentheses.

TABLE 12. AVERAGE V_{oc} (mV)

Solarex
N/P P^+ Planar 2 ohm-cm Silicon
2 x 2 x (.020 to .025 cm)
Ti-Pd-Ag Contacts 3/19 Lines
Tantalum Oxide AR Coating
Ceria-Doped Microsheet Filter
SAMPLE SIZE 16

Temperature	Solar Constants								
	1.0	0.64	0.39	0.25	0.174	0.128	0.086	0.063	0.040
65°C	495.2 (5.5)								
55°C	516.8 (5.8)	505.4 (5.9)	502.6* (5.6)						
25°C	580.2 (5.1)	569.9 (5.1)	557.2 (5.3)	543.8 (5.1)					
0°C	634.9 (4.9)	624.9 (4.6)	613.6 (4.9)	602.3 (4.8)	593.3 (4.6)				
-25°C		678.9 (4.3)	668.4 (4.7)	657.9 (4.8)	649.6 (4.7)	641.4 (4.8)			
-50°C			723.1 (4.4)	713.6 (4.3)	705.3 (4.4)	697.4 (4.2)	688.5 (4.9)	682.3 (5.8)	
-75°C				768.4 (3.6)	761.1 (3.9)	753.4 (4.6)	745.8 (5.0)	738.9 (6.3)	726.5 (10.3)
-100°C					815.0 (3.8)	809.1 (4.7)	803.1 (5.8)	796.0 (7.6)	782.4 (15.2)
-125°C						863.1 (4.2)	856.1 (7.2)	848.1 (12.2)	831.3 (26.1)
-150°C							906.4 (9.0)	899.1 (18.9)	880.4 (37.2)
-175°C									924.8 (41.3)

NOTE: *Data taken at 50°C.
Standard Deviations are given in parentheses.

TABLE 13. AVERAGE I_{mp} (mA)

Solarex
N/P P^+ Planar 2 ohm-cm Silicon
2 x 2 x (.020 to .025 cm)
Ti-Pd-Ag Contacts 3/19 Lines
Tantalum Oxide AR Coating
Ceria-Doped Microsheet Filter
SAMPLE SIZE 16

Temperature	Solar Constants								
	1.0	0.64	0.39	0.25	0.174	0.128	0.086	0.063	0.040
65°C	145.6 (2.4)								
55°C	145.2 (2.6)	95.6 (1.8)	58.4* (1.0)						
25°C	145.4 (2.7)	93.3 (1.6)	58.4 (0.9)	36.6 (0.6)					
0°C	146.3 (3.3)	94.9 (1.8)	57.8 (1.0)	36.3 (0.6)	25.3 (.5)				
-25°C		94.3 (1.6)	57.3 (1.1)	35.9 (0.7)	24.9 (.5)	18.0 (.4)			
-50°C			56.8 (1.0)	35.8 (0.8)	24.2 (.6)	17.8 (.5)	12.1 (.4)	8.7 (.4)	
-75°C				35.2 (0.9)	23.8 (.9)	17.4 (.6)	11.8 (.4)	8.6 (.4)	5.3 (0.3)
-100°C					23.1 (.9)	16.6 (.7)	11.4 (.5)	8.2 (.5)	5.3 (0.3)
-125°C						16.0 (.8)	11.1 (.6)	8.0 (.5)	5.1 (.3)
-150°C							11.0 (.5)	7.7 (.5)	5.0 (.3)
-175°C									5.0 (.3)

NOTE: *Data taken at 50°C.
Standard Deviations are given in parentheses.

TABLE 14. AVERAGE V_{mp} (mV)

Solarex
N/P P^+ Planar 2 ohm-cm Silicon
2 x 2 x (.020 to 0.25 cm)
Ti-Pd-Ag Contacts 3/19 Lines
Tantalum Oxide AR Coating
Ceria-Doped Microsheet Filter
SAMPLE SIZE 16

Temperature	Solar Constants								
	1.0	0.64	0.39	0.25	0.174	0.128	0.086	0.063	0.040
65°C	396.1 (7.1)								
55°C	419.8 (7.8)	419.3 (7.1)	422.2* (6.2)						
25°C	482.9 (7.0)	485.7 (6.1)	478.4 (5.9)	469.1 (5.6)					
0°C	542.3 (6.8)	541.7 (5.4)	535.6 (5.3)	530.4 (5.9)	516.4 (5.5)				
-25°C		598.1 (5.2)	593.1 (5.6)	585.8 (6.1)	573.9 (6.4)	561.8 (7.2)			
-50°C			651.1 (6.2)	640.1 (6.1)	628.7 (11.7)	616.3 (10.3)	601.8 (16.3)	596.1 (18.8)	
-75°C				697.1 (7.8)	690.9 (10.0)	671.5 (16.7)	652.6 (26.4)	642.7 (32.5)	619.1 (41.3)
-100°C					745.3 (14.5)	731.5 (24.6)	708.3 (42.3)	690.1 (42.9)	658.1 (57.3)
-125°C						778.3 (38.1)	748.9 (53.5)	724.6 (61.5)	677.5 (72.2)
-150°C							787.3 (65.4)	766.8 (76.0)	693.0 (82.0)
-175°C									724.0 (91.7)

NOTE: *Data taken at 50°C.
Standard Deviations are given in parentheses.

TABLE 15. AVERAGE MP (mW)

Solarex
N/P P^{+} Planar 2 ohm-cm Silicon
2 x 2 x (.020 to .025 cm)
Ti-Pd-Ag Contacts 3/19 Lines
Tantalum Oxide AR Coating
Ceria-Doped Microsheet Filter
SAMPLE SIZE 16

Temperature	Solar Constants								
	1.0	0.64	0.39	0.25	0.174	0.128	0.086	0.063	0.040
65°C	57.7 (1.8)								
55°C	61.0 (2.1)	40.1 (1.3)	24.7* (0.7)						
25°C	70.2 (2.1)	45.3 (1.2)	28.0 (0.7)	17.2 (0.4)					
0°C	79.3 (2.3)	51.4 (1.3)	31.0 (0.8)	19.4 (0.6)	13.1 (0.3)				
-25°C		56.4 (1.3)	34.0 (0.9)	21.1 (0.6)	14.3 (0.4)	10.1 (0.3)			
-50°C			37.0 (0.9)	22.9 (0.7)	15.3 (0.5)	11.0 (0.4)	7.3 (.4)	5.2 (.3)	
-75°C				24.5 (0.9)	16.4 (0.8)	11.7 (0.6)	7.7 (.5)	5.5 (.4)	3.3 (.3)
-100°C					17.2 (0.9)	12.1 (0.8)	8.1 (.7)	5.7 (.5)	3.5 (.4)
-125°C						12.4 (1.0)	8.3 (.8)	5.8 (.7)	3.4 (.5)
-150°C							8.6 (.9)	5.9 (.7)	3.4 (.5)
-175°C									3.6 (.5)

NOTE: *Data taken at 50°C.
Standard Deviations are given in parentheses.

TABLE 16. AVERAGE EFFICIENCY (%)

Solarex
N/P P^+ Planar 2 ohm-cm Silicon
2 x 2 x (.020 to .025 cm)
Ti-Pd-Ag Contacts 3/19 Lines
Tantalum Oxide AR Coating
Ceria-Doped Microsheet Filter

SAMPLE SIZE 16

Temperature	Solar Constants								
	1.0	0.64	0.39	0.25	0.174	0.128	0.086	0.063	0.040
65°C	10.7								
55°C	11.3	11.6	11.7*						
25°C	13.0	13.1	13.3	12.7					
0°C	14.7	14.8	14.7	14.3	13.9				
-25°C		16.3	16.1	15.6	15.2	14.6			
-50°C			17.5	16.9	16.2	15.9	15.6	15.2	
-75°C				18.1	17.4	16.8	16.5	16.2	15.2
-100°C					18.3	17.5	17.4	16.7	16.0
-125°C						17.9	17.8	17.1	15.9
-150°C							18.6	17.3	15.9
-175°C									16.5

NOTE: *Data taken at 50°C.

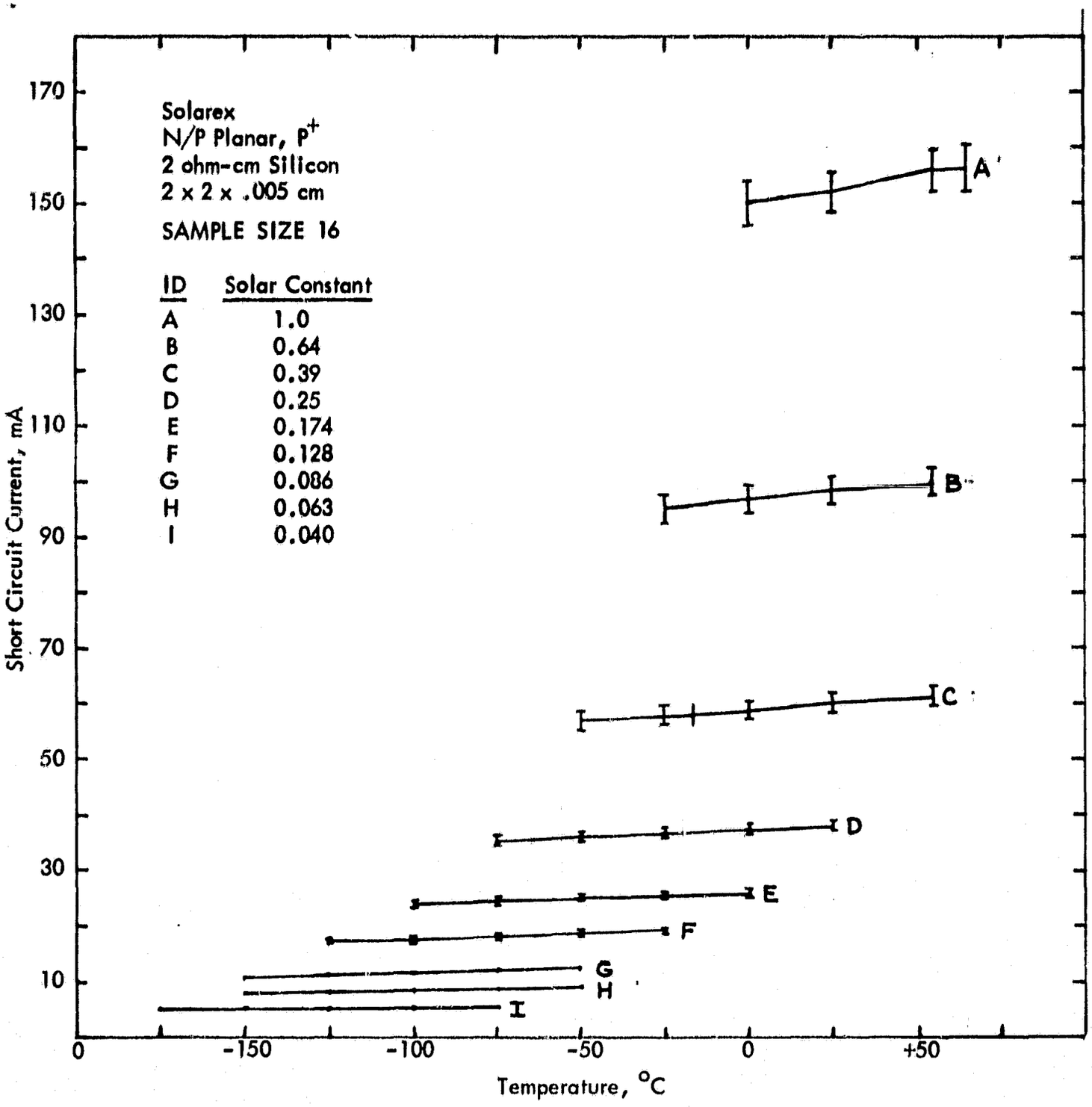

Figure 37. Average I_{sc} as a Function of Temperature

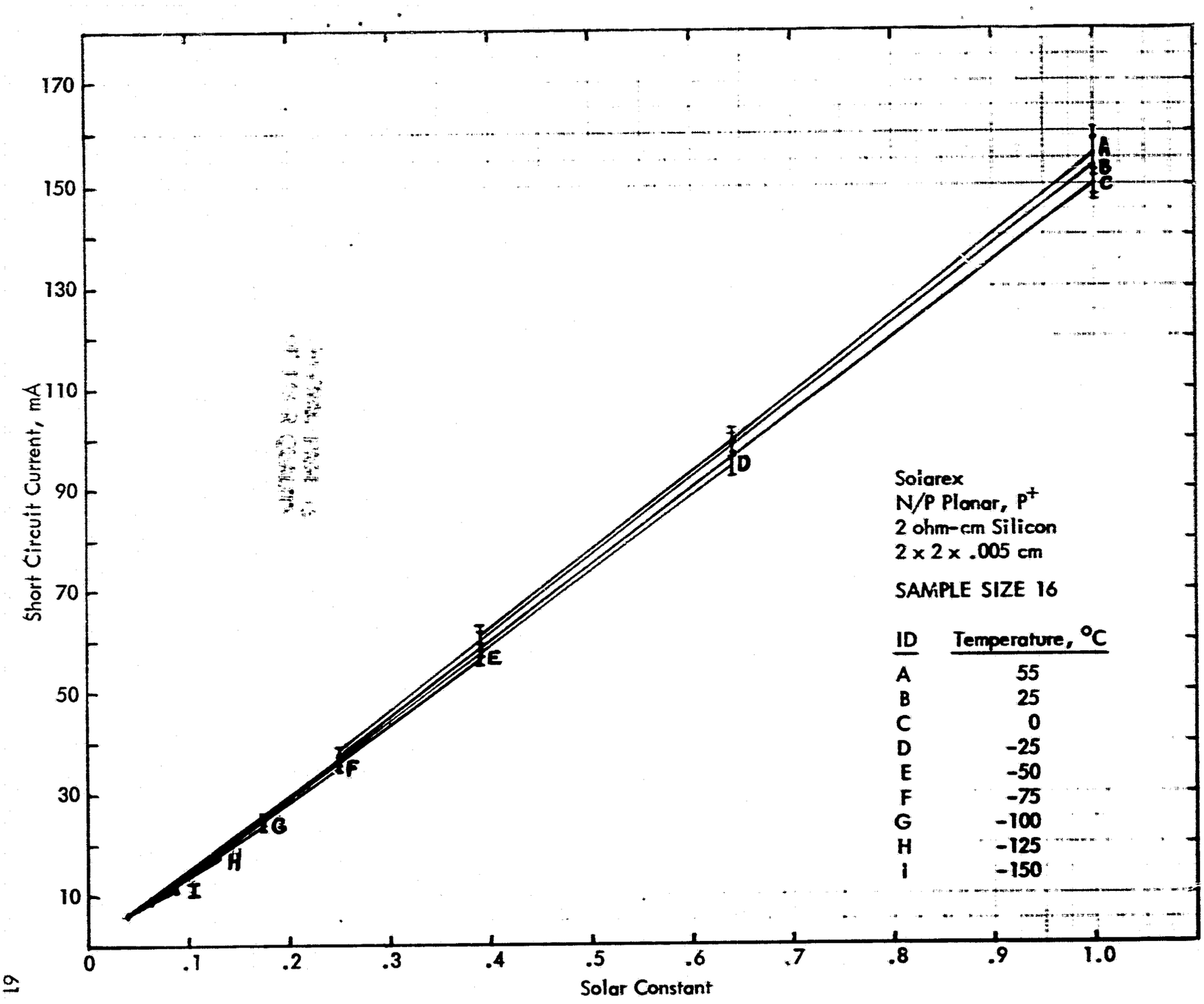

Figure 38. Average I_{sc} as a Function of Intensity

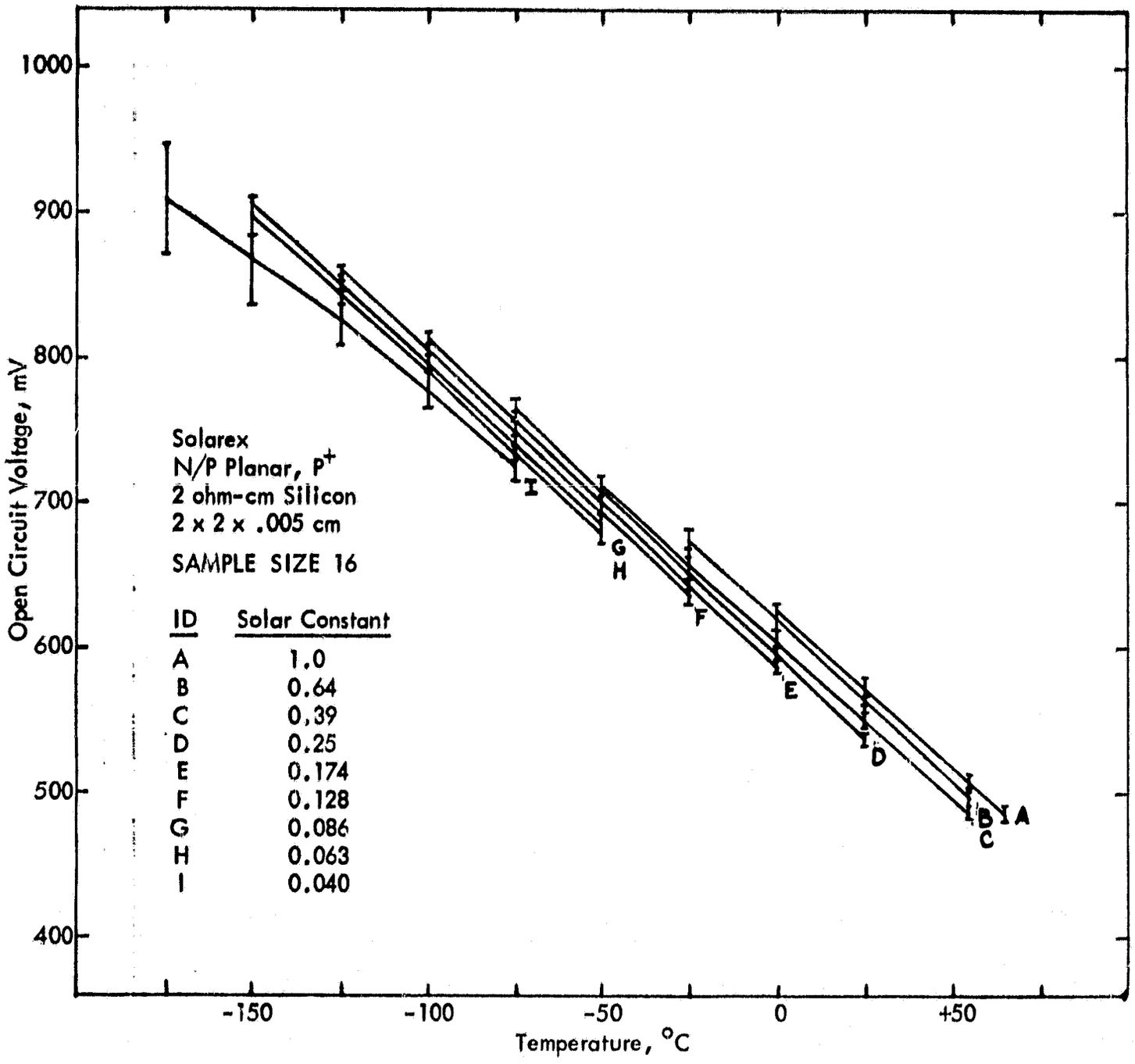

Figure 39. Average V_{oc} as a Function of Temperature

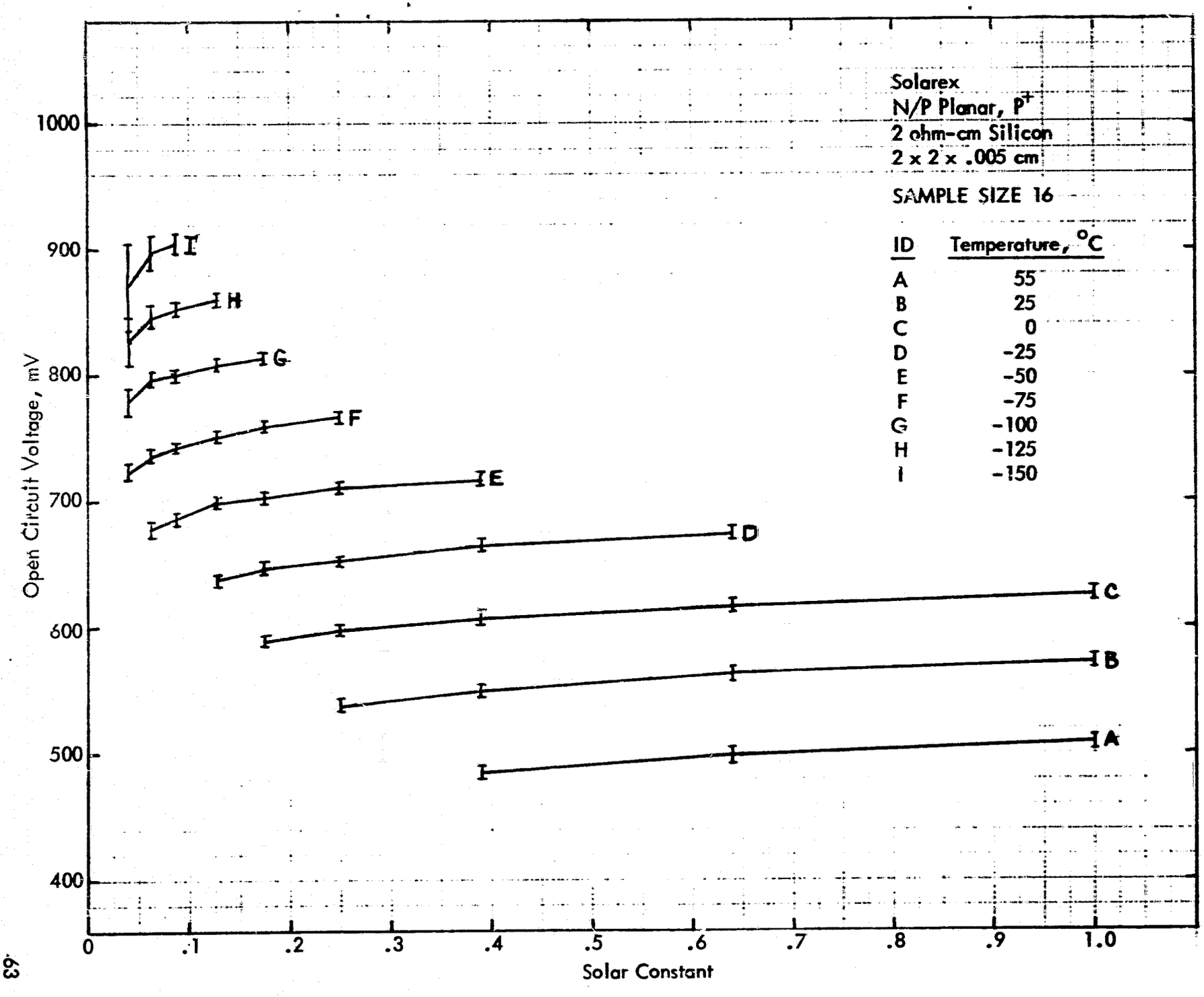

Figure 40. Average V_{oc} as a Function of Intensity

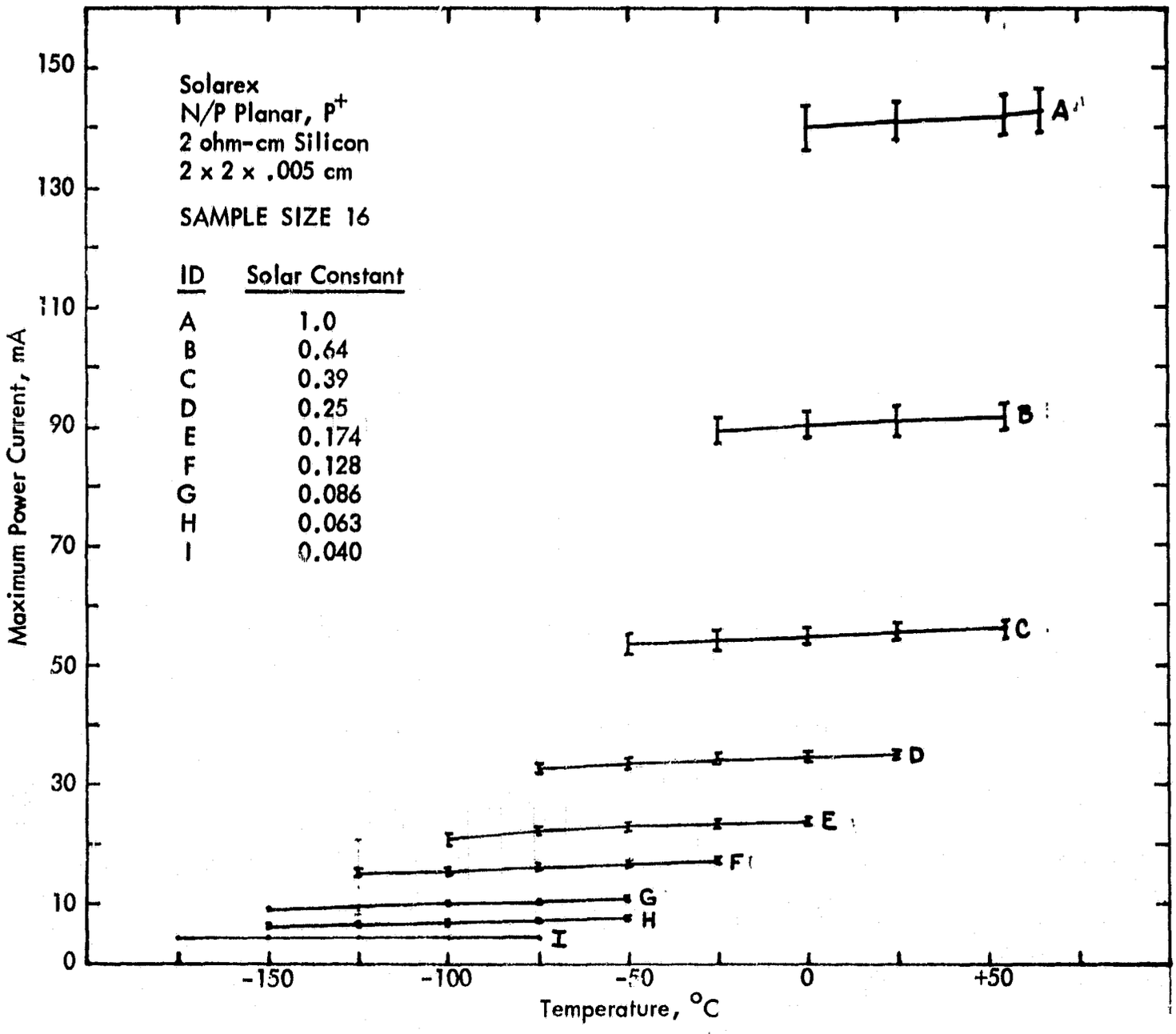

Figure 41. Average I_{mp} as a Function of Temperature

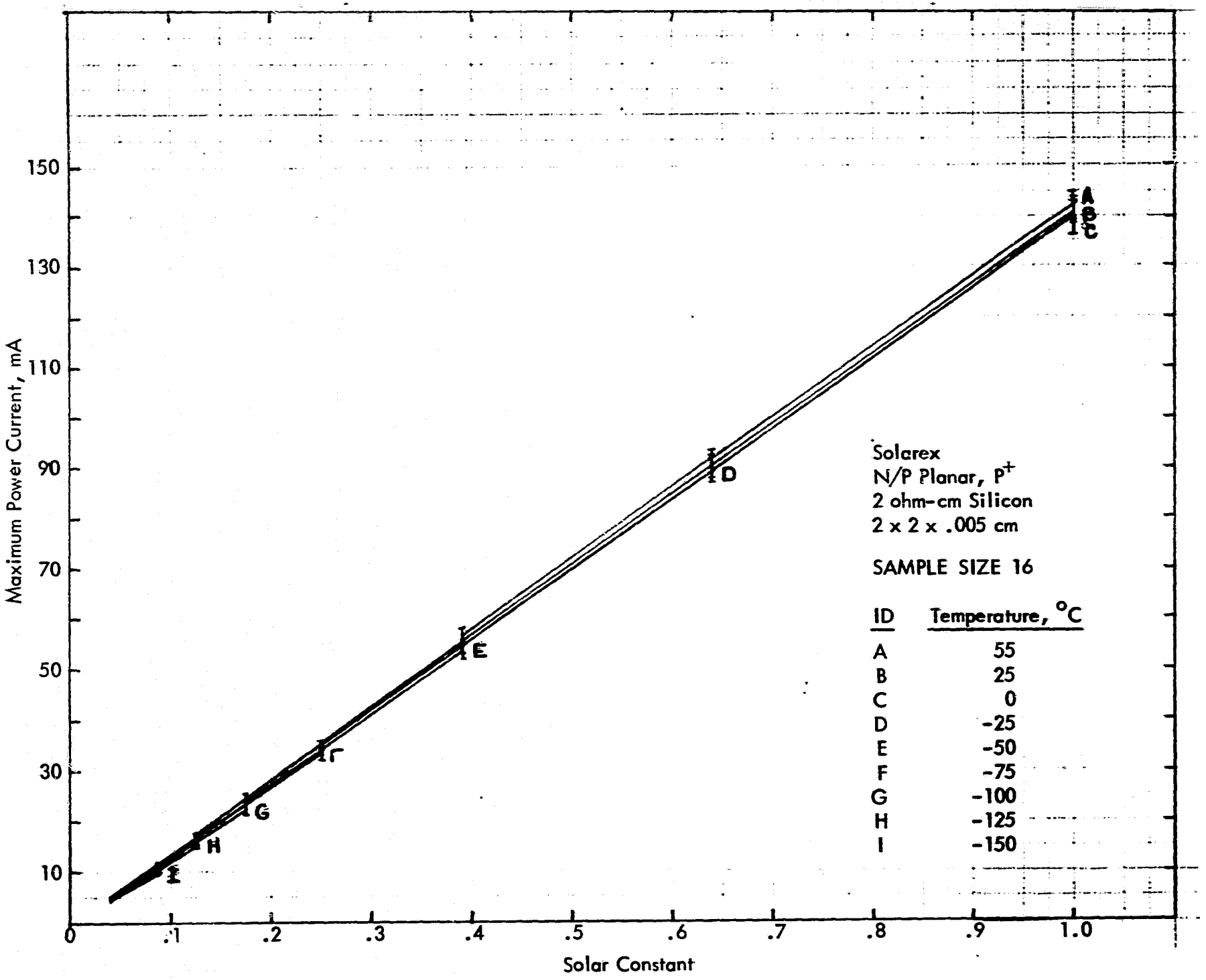

Figure 42. Average I_{mp} as a Function of Intensity

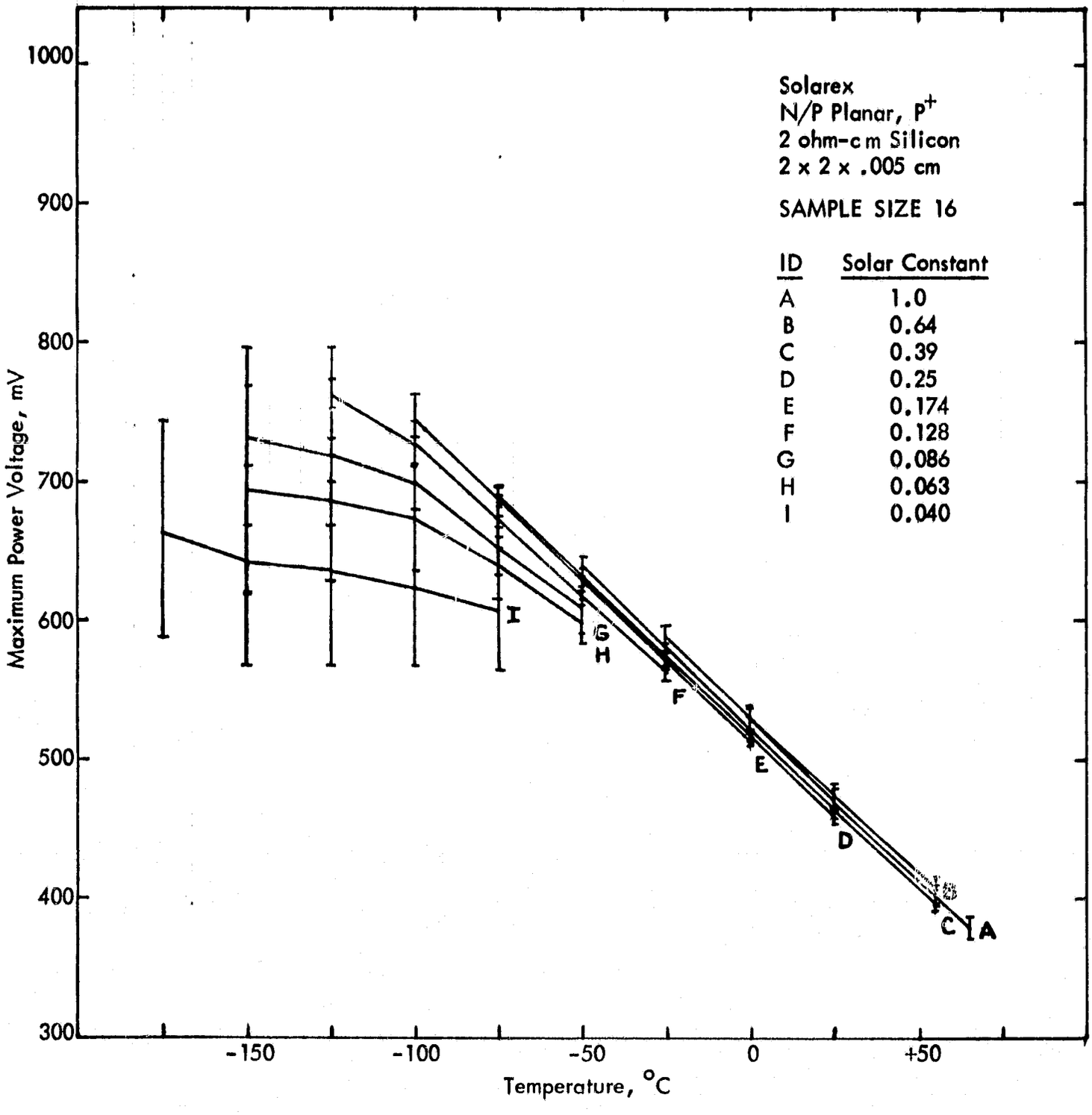

Figure 43. Average V_{mp} as a Function of Temperature

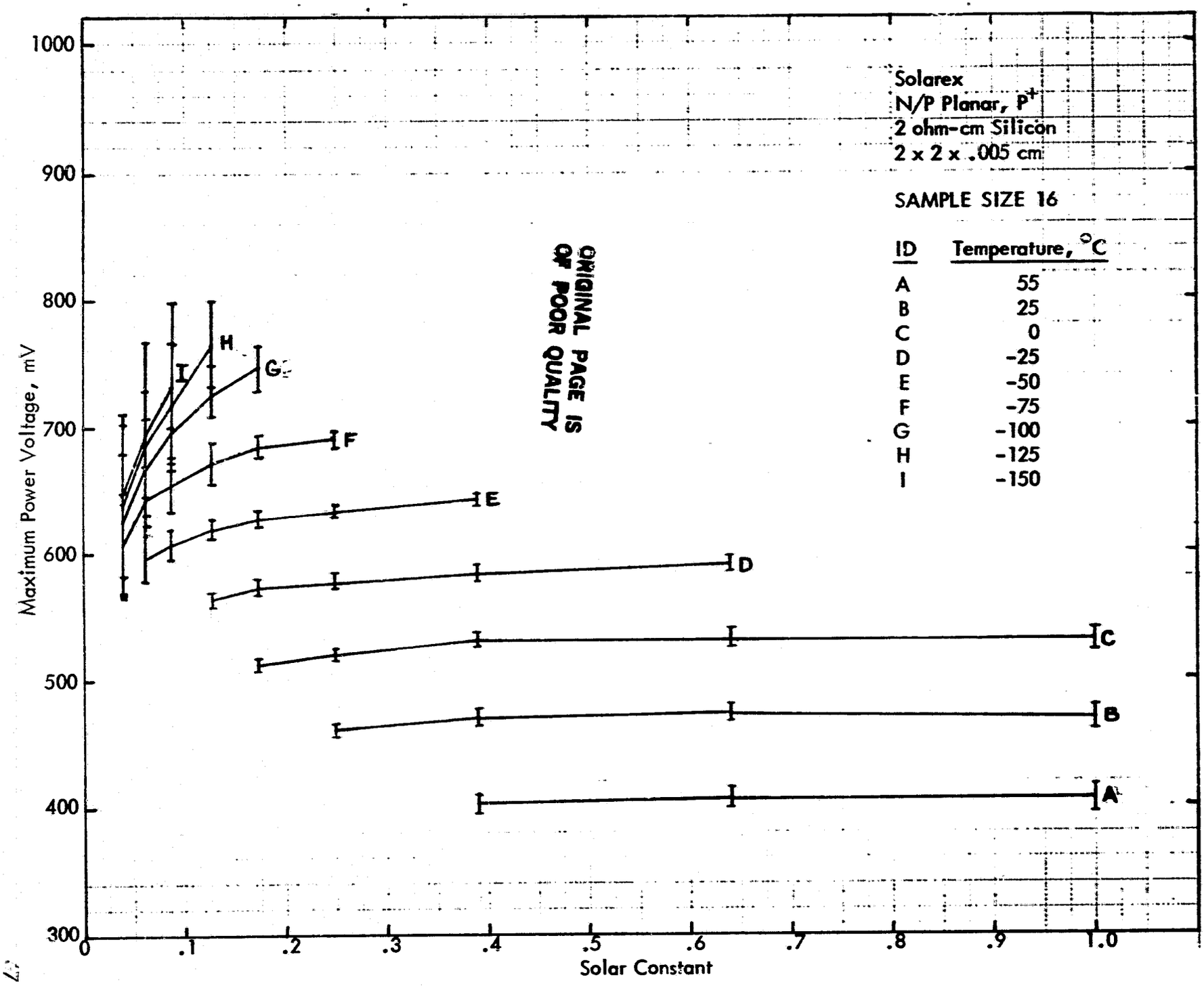

Figure 44. Average V_{mp} as a Function of Intensity

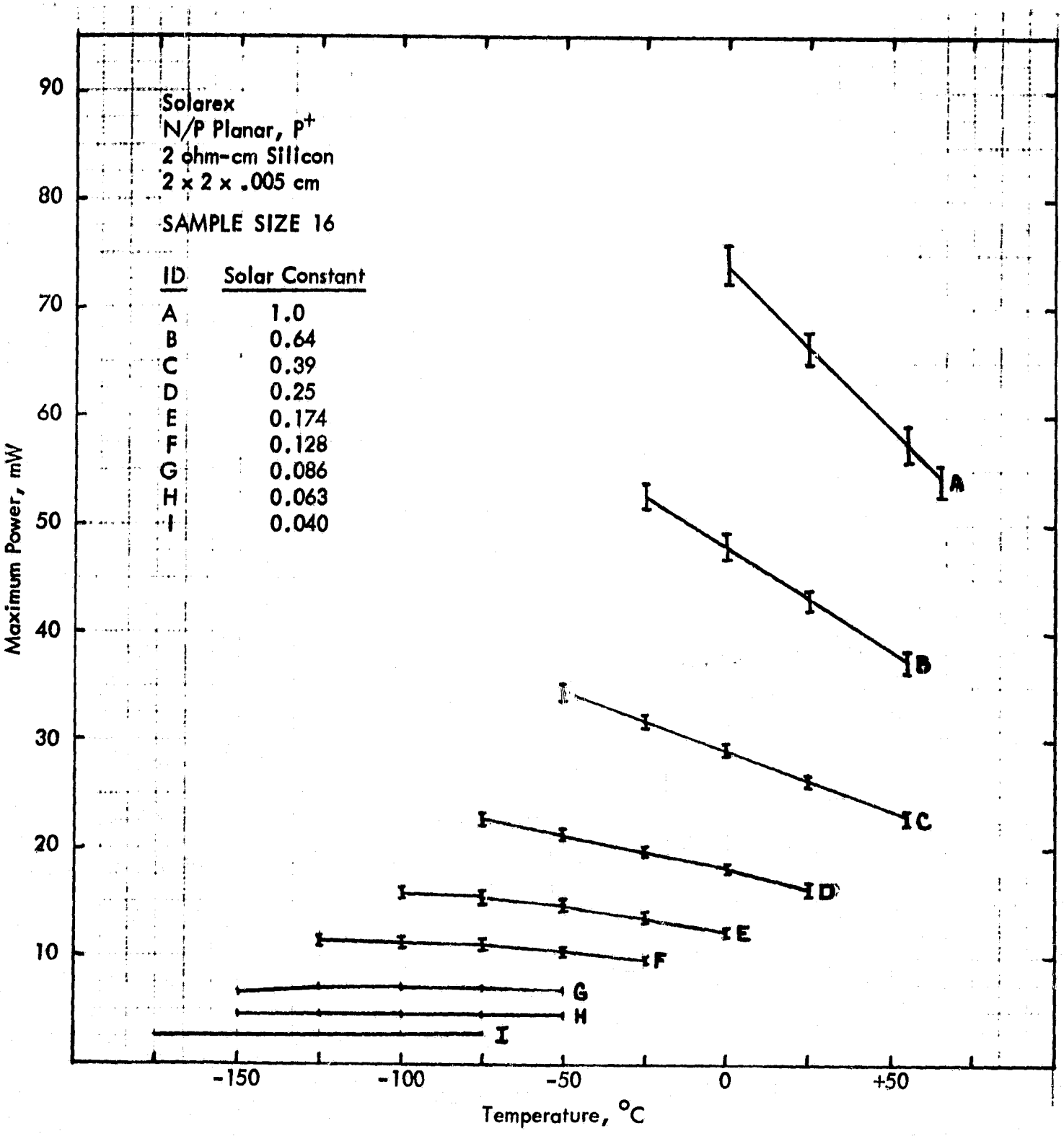

Figure 45. Average MP as a Function of Temperature

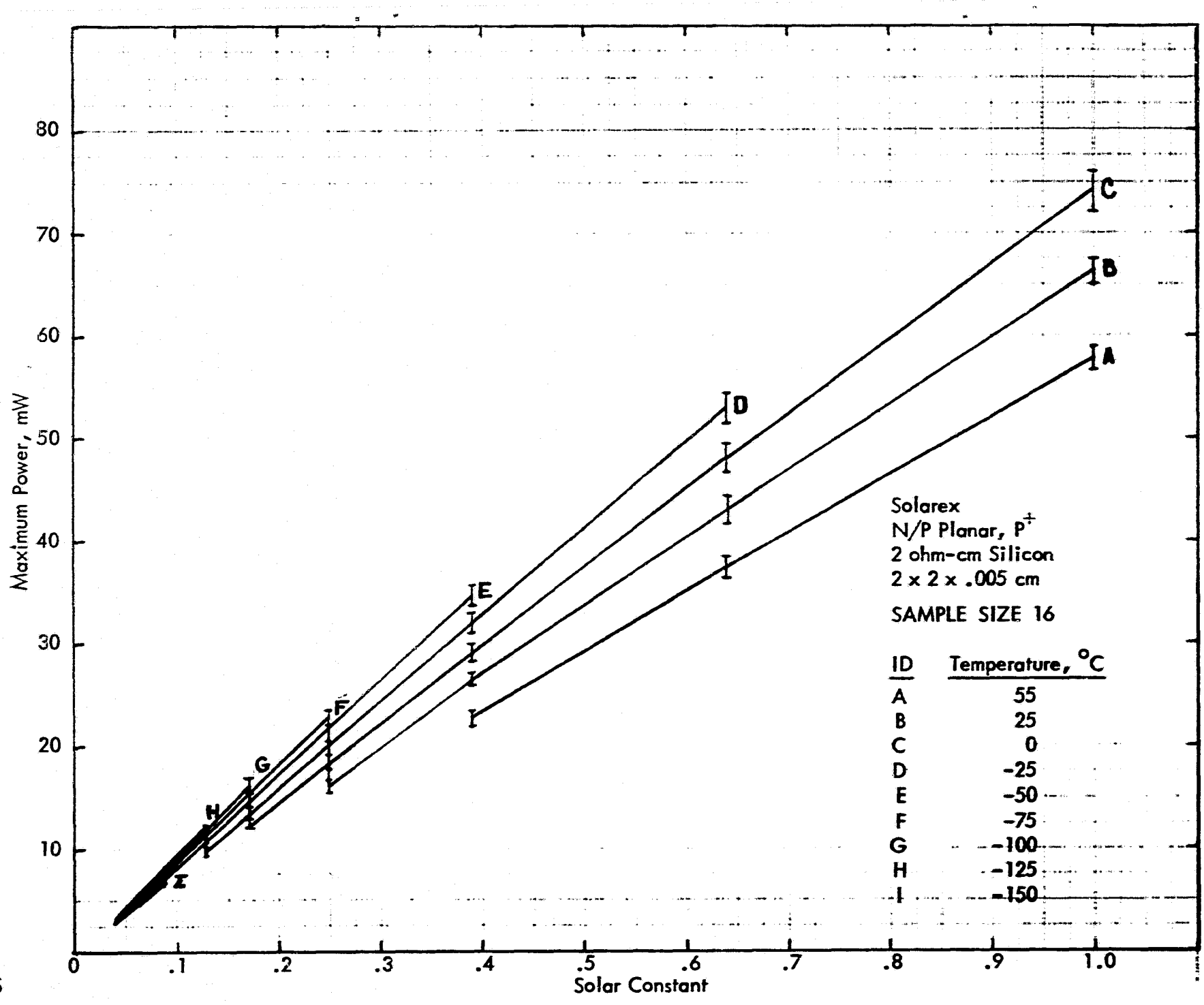

Figure 46. Average MP as a Function of Intensity

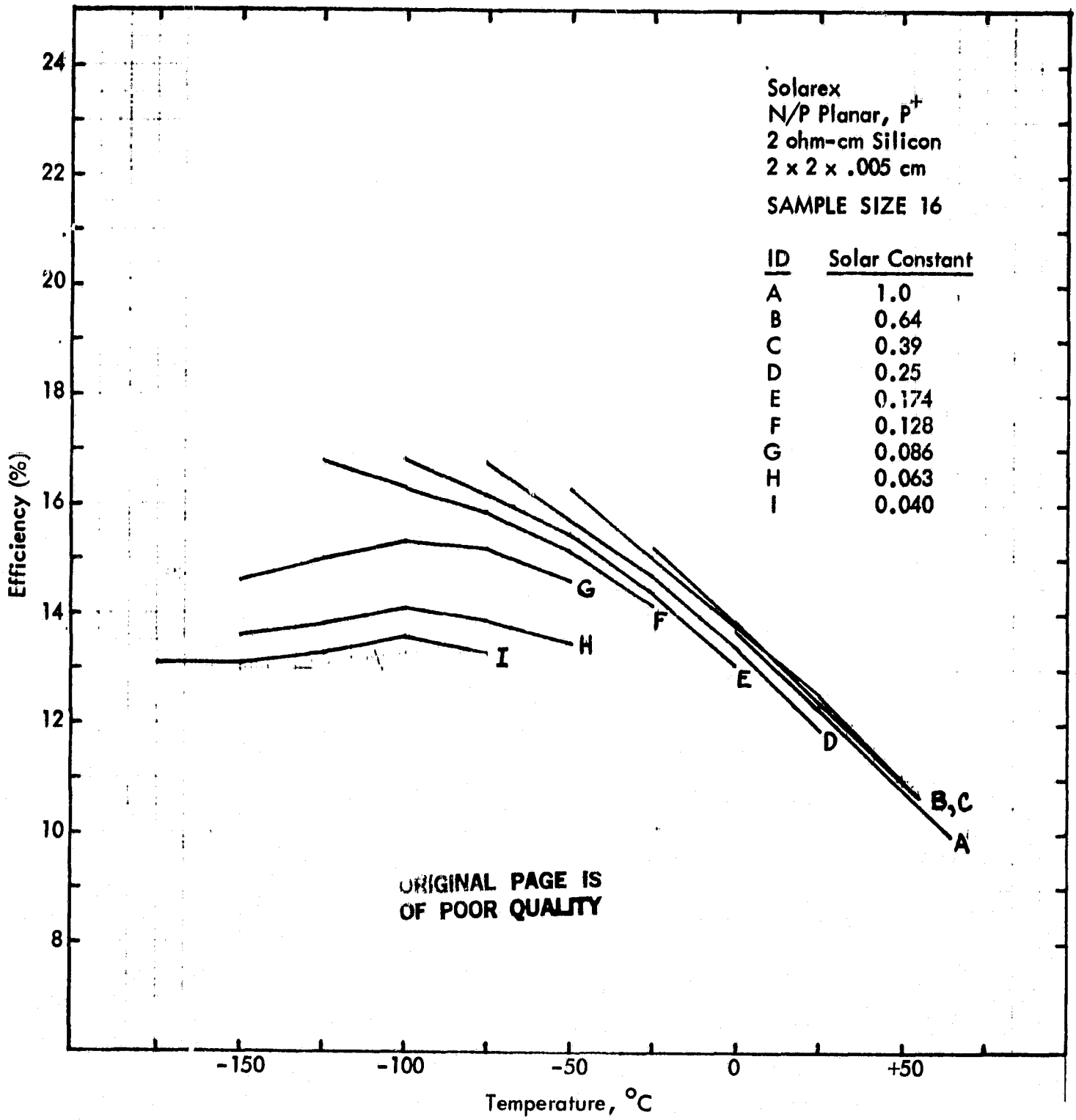

Figure 47. Average Efficiency as a Function of Temperature

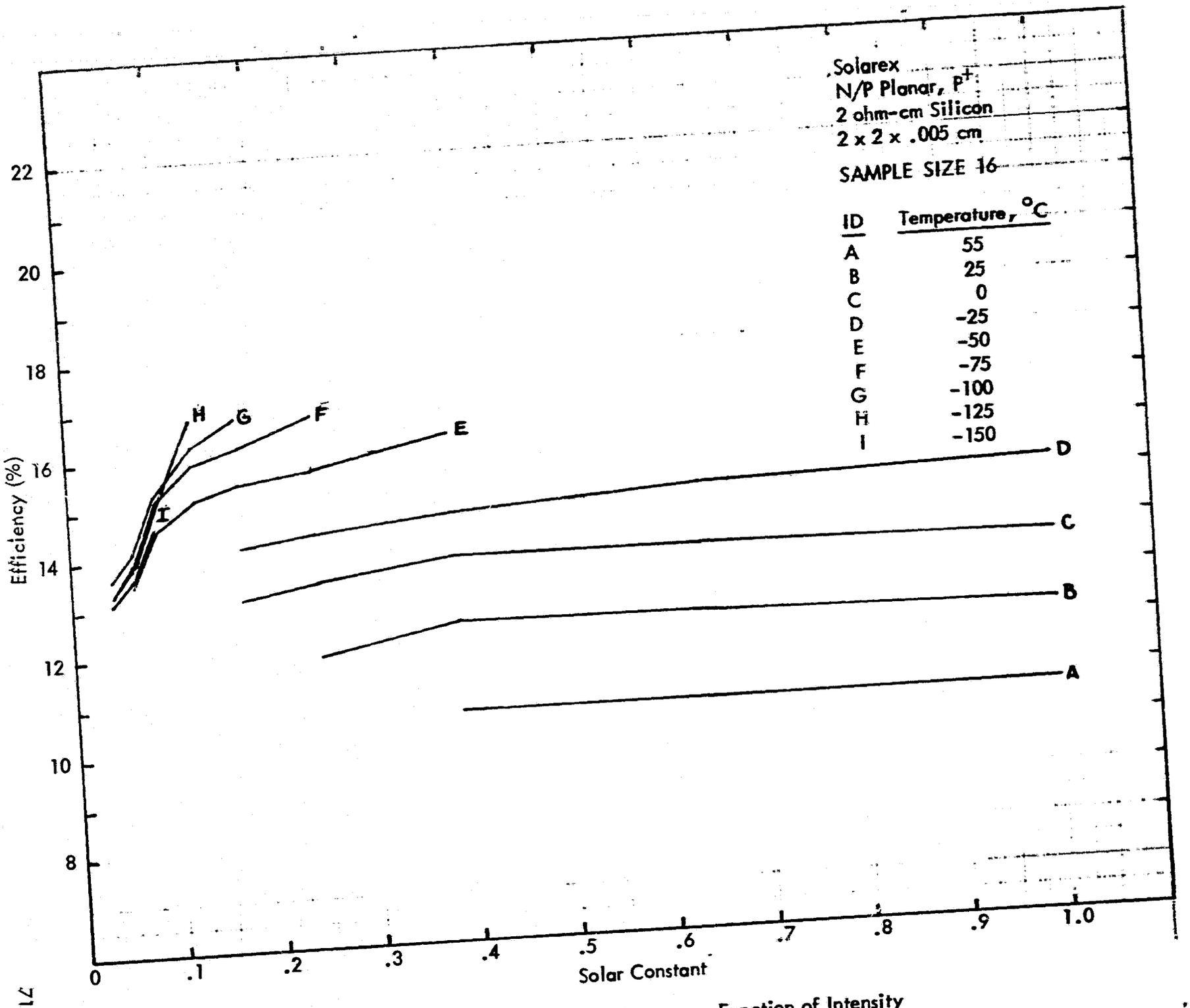

Figure 48. Average Efficiency as a Function of Intensity

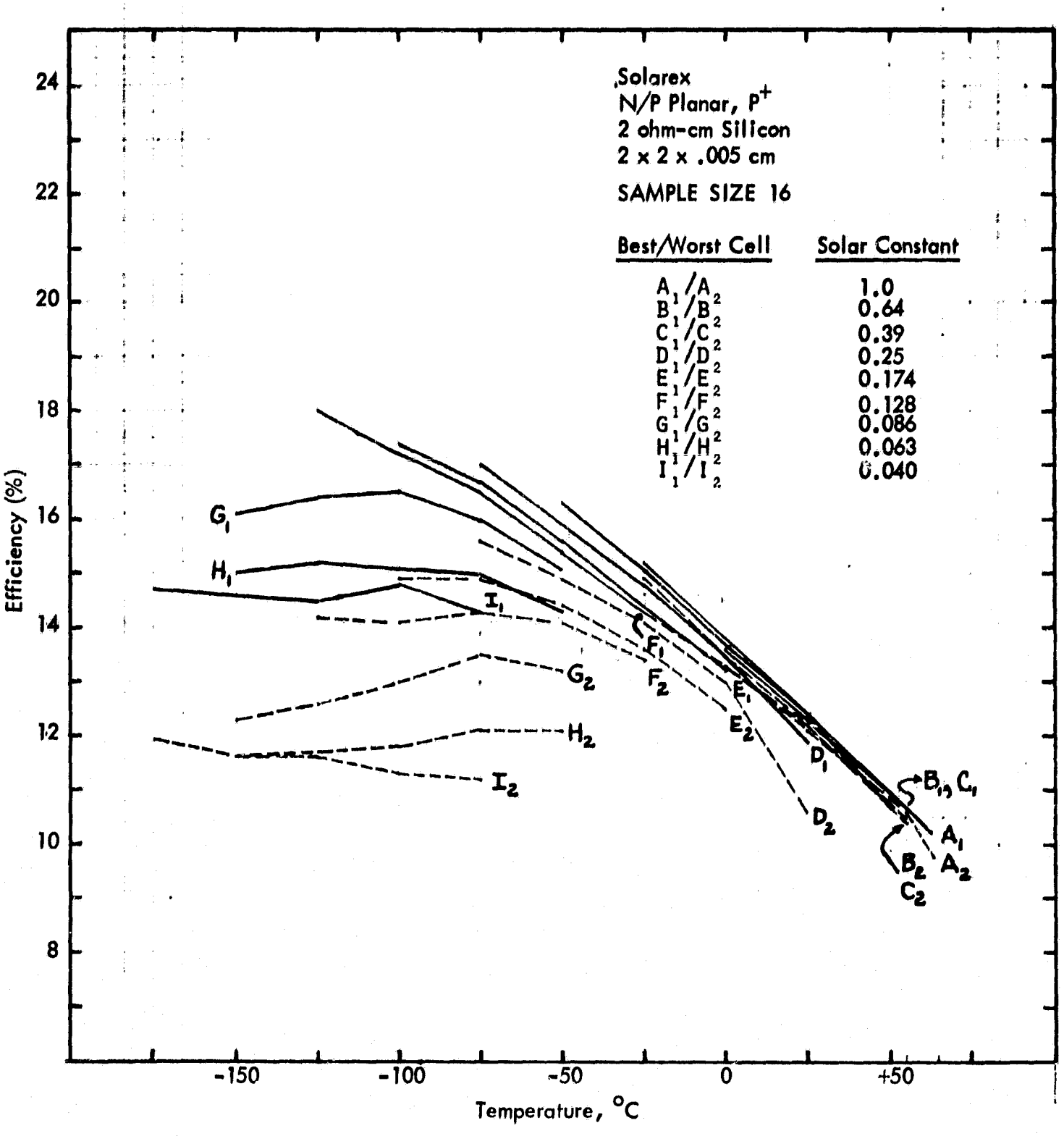

Figure 49. Efficiency of the Best/Worst Cells as a Function of Temperature

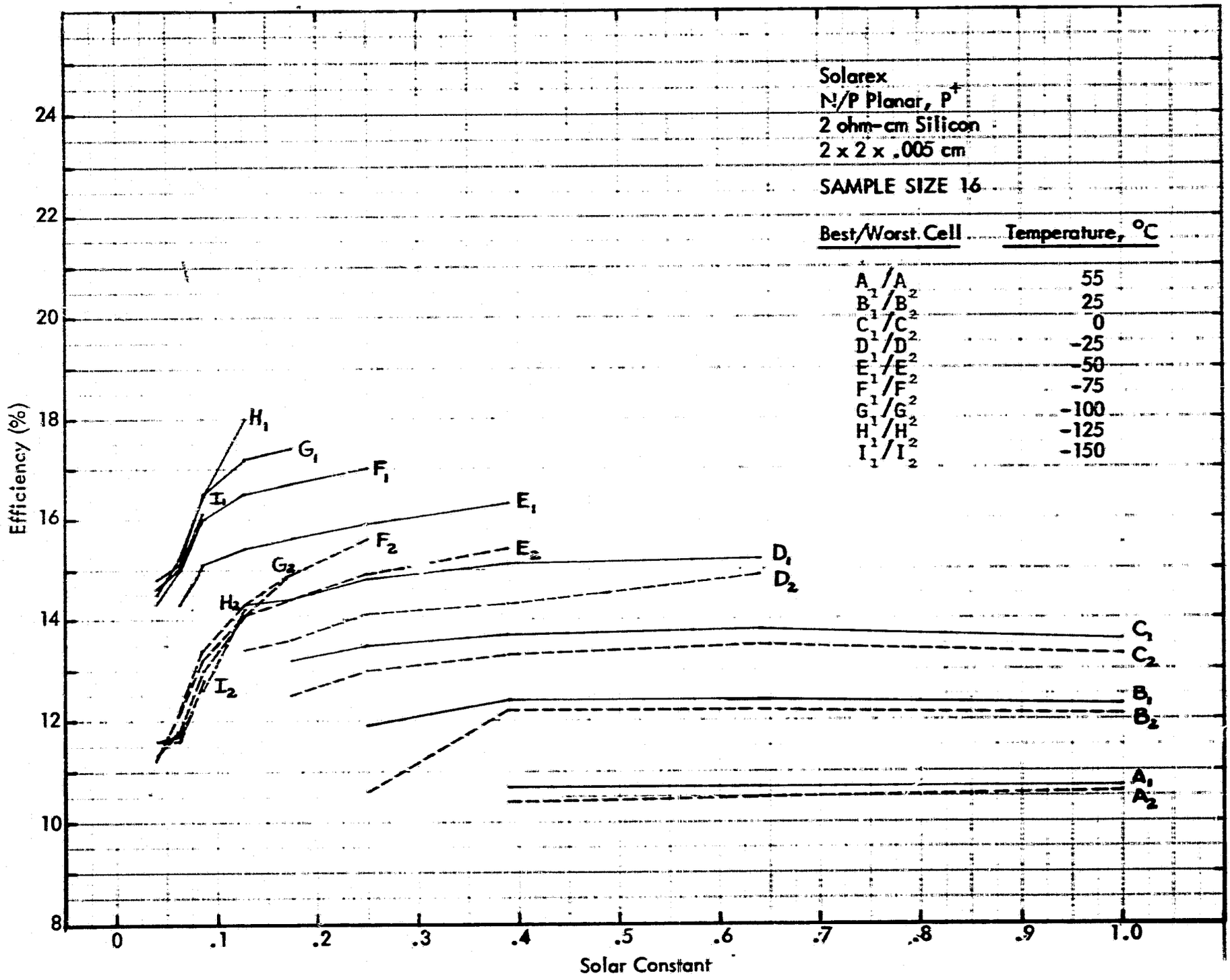

Figure 50. Efficiency of the Best/Worst Cells as a Function of Intensity

TABLE 17. AVERAGE I_{sc} (mA)

Solarex
N/P P^+ Planar 2 ohm-cm Silicon
2 x 2 x .005 cm
Ti-Pd-Ag Contacts 3/19 Lines
Tantalum Oxide AR Coating
Ceria-Doped Microsheet Filter

SAMPLE SIZE 16

Temperature	Solar Constants								
	1.0	0.64	0.39	0.25	0.174	0.128	0.086	0.063	0.040
65°C	156.4 (4.2)								
55°C	156.0 (3.8)	99.9 (2.6)	61.5 (1.6)						
25°C	152.1 (3.7)	98.4 (2.5)	60.3 (1.7)	38.4 (0.8)					
0°C	150.1 (3.8)	96.9 (2.3)	58.9 (1.6)	37.8 (0.9)	26.0 (0.6)				
-25°C		95.0 (2.4)	58.2 (1.8)	37.0 (0.9)	25.6 (0.6)	19.1 (0.4)			
-50°C			57.1 (1.6)	36.1 (0.9)	25.2 (0.6)	18.7 (0.5)	12.5 (0.2)	9.1 (0.2)	
-75°C				35.5 (0.8)	24.6 (0.6)	18.2 (0.4)	12.2 (0.2)	8.9 (0.2)	5.8 (0.1)
-100°C					23.9 (0.6)	17.6 (0.4)	11.8 (0.2)	8.6 (0.2)	5.6 (0.1)
-125°C						17.5 (0.3)	11.4 (0.2)	8.3 (0.2)	5.5 (0.1)
-150°C							10.9 (0.2)	8.0 (0.2)	5.3 (0.1)
-175°C									5.1 (0.1)

NOTE: Standard Deviations are given in parentheses.

TABLE 18. AVERAGE V_{oc} (mV)

Solarex
N/P P^+ Planar 2 ohm-cm Silicon
2 x 2 x .005 cm
Ti-Pd-Ag Contacts 3/19 Lines
Tantalum Oxide AR Coating
Ceria-Doped Microsheet Filter

SAMPLE SIZE 16

Temperature	Solar Constants								
	1.0	0.64	0.39	0.25	0.174	0.128	0.086	0.063	0.040
65°C	487.1 (5.3)								
55°C	508.7 (5.1)	498.1 (4.6)	486.1 (4.3)						
25°C	572.8 (5.3)	562.9 (4.7)	551.7 (4.5)	539.0 (4.3)					
0°C	626.5 (5.1)	618.6 (4.3)	607.9 (4.4)	597.9 (4.3)	589.0 (4.1)				
-25°C		673.6 (4.6)	663.9 (5.5)	654.5 (4.1)	646.8 (4.1)	638.5 (4.1)			
-50°C			717.6 (4.3)	710.0 (4.2)	703.4 (4.0)	695.5 (4.0)	686.3 (4.3)	678.2 (4.6)	
-75°C				766.0 (4.1)	759.2 (4.1)	752.5 (4.4)	743.8 (4.2)	736.1 (5.1)	724.1 (6.9)
-100°C					814.6 (4.1)	808.6 (5.1)	799.5 (4.8)	797.4 (6.3)	779.5 (10.2)
-125°C						860.2 (5.0)	852.8 (6.0)	845.9 (8.5)	828.5 (18.9)
-150°C							905.9 (7.3)	897.4 (12.7)	870.4 (31.6)
-175°C									911.3 (38.9)

NOTE: Standard Deviations are given in parentheses.

TABLE 19. AVERAGE I_{mp} (mA)

Solarex
N/P P^+ Planar 2 ohm-cm Silicon
2 x 2 x .005 cm
Ti-Pd-Ag Contacts 3/19 Lines
Tantalum Oxide AR Coating
Ceria-Doped Microsheet Filter

SAMPLE SIZE 16

Temperature	Solar Constants								
	1.0	0.64	0.39	0.25	0.174	0.128	0.086	0.063	0.040
65°C	142.9 (3.6)								
55°C	142.1 (3.4)	91.7 (2.2)	56.2 (1.5)						
25°C	141.1 (3.3)	91.1 (2.6)	55.8 (1.4)	35.1 (0.8)					
0°C	140.0 (3.8)	90.3 (2.3)	54.9 (1.5)	34.9 (0.8)	24.0 (0.6)				
-25°C		89.3 (2.2)	54.3 (1.7)	34.4 (0.8)	23.6 (0.6)	17.4 (0.5)			
-50°C			53.6 (1.6)	33.6 (0.9)	23.2 (0.7)	17.0 (0.5)	11.2 (0.3)	7.7 (0.4)	
-75°C				32.9 (0.8)	22.4 (0.7)	16.4 (0.6)	10.8 (0.3)	7.4 (0.4)	4.8 (0.2)
-100°C					21.2 (0.8)	15.5 (0.6)	10.2 (0.4)	7.1 (0.3)	4.7 (0.2)
-125°C						15.2 (6.7)	9.7 (0.3)	6.9 (0.3)	4.5 (.3)
-150°C							9.3 (0.3)	6.7 (0.2)	4.4 (.2)
-175°C									4.3 (.2)

NOTE: Standard Deviations are given in parentheses.

TABLE 20. AVERAGE V_{mp} (mV)

Solarex
N/P P^+ Planar 2 ohm-cm Silicon
2 x 2 x .005 cm
Ti-Pd-Ag Contacts 3/19 Lines
Tantalum Oxide AR Coating
Ceria-Doped Microsheet Filter

SAMPLE SIZE 16

Temperature	Solar Constants								
	1.0	0.64	0.39	0.25	0.174	0.128	0.086	0.063	0.040
65°C	379.2 (9.8)								
55°C	405.8 (11.6)	406.0 (8.3)	402.3 (6.9)						
25°C	470.7 (9.7)	472.9 (7.4)	471.1 (6.2)	461.9 (5.1)					
0°C	529.9 (10.5)	531.1 (7.7)	529.9 (5.7)	521.4 (5.3)	513.7 (6.3)				
-25°C		591.1 (7.7)	584.8 (6.7)	577.5 (4.9)	572.6 (5.9)	563.7 (5.6)			
-50°C			642.1 (5.0)	633.6 (5.9)	628.2 (7.3)	619.1 (7.8)	[illegible].8 (11.9)	597.1 (14.6)	
-75°C				691.1 (6.7)	683.8 (8.0)	672.6 (11.5)	654.4 (19.7)	642.4 (26.1)	605.9 (41.4)
-100°C					746.4 (14.5)	728.5 (20.0)	699.1 (32.7)	673.6 (40.0)	624.0 (56.8)
-125°C						764.8 (32.4)	718.4 (54.5)	686.3 (59.8)	636.6 (67.8)
-150°C							732.3 (65.4)	695.2 (73.6)	640.2 (73.9)
-175°C									665.3 (76.2)

NOTE: Standard Deviations are given in parentheses.

TABLE 21. AVERAGE MP (mW)

Solarex
N/P P^+ Planar 2 ohm-cm Silicon
2 x 2 x .005 cm
Ti-Pd-Ag Contacts 3/19 Lines
Tantalum Oxide AR Coating
Ceria-Doped Microsheet Filter

SAMPLE SIZE 16

Temperature	Solar Constants								
	1.0	0.64	0.39	0.25	0.174	0.128	0.086	0.063	0.040
65°C	54.2 (1.7)								
55°C	57.7 (1.7)	37.2 (1.0)	22.6 (0.6)						
25°C	66.4 (1.7)	43.1 (1.1)	26.3 (0.7)	16.1 (0.6)					
0°C	74.0 (2.1)	48.0 (1.2)	29.1 (0.8)	18.2 (0.4)	12.3 (0.3)				
-25°C		52.8 (1.3)	31.9 (1.1)	19.8 (0.5)	13.5 (0.4)	9.8 (0.3)			
-50°C			34.4 (1.1)	21.3 (0.6)	14.6 (0.5)	10.5 (0.4)	6.8 (0.3)	4.6 (.3)	
-75°C				22.7 (0.6)	15.3 (0.6)	11.0 (0.5)	7.1 (.4)	4.7 (.3)	2.9 (.2)
-100°C					15.9 (0.8)	11.3 (0.7)	7.1 (.5)	4.8 (.4)	2.9 (.3)
-125°C						11.6 (0.9)	7.0 (.6)	4.7 (.5)	2.9 (.3)
-150°C							6.8 (.7)	4.6 (.5)	2.8 (.3)
-175°C									2.8 (.3)

NOTE: Standard Deviations are given in parentheses.

TABLE 22. AVERAGE EFFICIENCY (%)

Solarex
N/P P^{+} Planar 2 ohm-cm Silicon
2 x 2 x .005 cm
Ti-Pd-Ag Contacts 3/19 Lines
Tantalum Oxide AR Coating
Ceria-Doped Microsheet Filter

SAMPLE SIZE 16

Temperature	Solar Constants								
	1.0	0.64	0.39	0.25	0.174	0.128	0.086	0.063	0.040
65°C	10.0								
55°C	10.7	10.7	10.7						
25°C	12.3	12.4	12.5	11.9					
0°C	13.7	13.8	13.8	13.4	13.1				
-25°C		15.2	15.0	14.7	14.4	14.2			
-50°C			16.3	15.7	15.5	15.2	14.6	13.5	
-75°C				16.8	16.2	15.9	15.2	13.9	13.3
-100°C					16.8	16.3	15.3	14.1	13.6
-125°C						16.8	15.0	13.8	13.3
-150°C							14.6	13.6	13.1
-175°C									13.1

NOTE: Standard Deviations are given in parentheses.

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GLOSSARY

AU	Astronomical Unit
AM0	Air Mass Zero
I-V	Current-Voltage
I_{mp}	Maximum Power Current
I_{sc}	Short Circuit Current
LTLI	Low Temperature and Low Intensity
MP	Maximum Power
P^+	Back Surface Field
P/P_o	Ratio of Maximum Power to Maximum Power at 55°C
Planar	Refers to a Smooth Silicon Front Surface
SEPS	Solar Electric Propulsion System
SC	Solar Constant
Textured	Refers to a Rough Silicon Front Surface which Provides a Lower Reflectance for the Cell
UV	Ultraviolet
V_{mp}	Maximum Power Voltage
V_{oc}	Open Circuit Voltage

APPROVAL

CHARACTERIZATION OF THREE TYPES OF SILICON SOLAR CELLS FOR SEPS DEEP SPACE MISSIONS

Volume II. Current-Voltage Characteristics of Solarex Textured P^+ 8 to 10 Mil, Planar P^+ 8 to 10 Mil and Planar P^+ 2 Mil Cells as a Function of Temperature and Intensity

By A. F. Whitaker, S. A. Little, and V. A. Wooden

The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

RAYMOND L. GAUSE
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