Low-Cost Solar
Array Project

5101-82

User Handbook for Block III Silicon Solar Cell Modules

M.I. Smokler

February 1, 1979

Prepared for
U.S. Department of Energy
by
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

CONTENTS

SECTION I

INTRODUCTION

The program of the Low-Cost Solar Array (LSA) Project has included a series of competitive procurements of production quantities of solar cell modules. The objectives of this procurement effort were to stimulate reduction in manufacturing cost and to provide modules for test of solar cell arrays in practical applications.

The first in this series of procurements, designated Block I, included the purchase from five contractors of a quantity of modules having a total nominal power output of approximately 58 kW. These modules were procured to the contractors' specifications as a means of ascertaining the state-of-the-art of terrestrial solar cell modules and of providing modules for early test and applications programs.

Block II, the second in the series of procurements, involved purchase of 123 kW of total power capacity from four contractors. Block II introduced a degree of standardization by defining the module design specifications and by providing for a design qualification test program. The Block II modules are described in JPL document 5101-36, "User Handbook for Block II Silicon Solar Cell Modules."

Block III, the third in the series, consisted of procurement of a nominal 205 kW of total power capacity from five contractors. The design specifications were essentially the same as for Block II. As no design or development was permitted under the contracts, only designs which previously had been qualified by JPL were eligible for Block III contracts.

Figure 1-1 illustrates an example of a subarray assembled from Block III modules, shown mounted on a handling dolly.

The purpose of this User Handbook is to supply engineering data necessary for planning or investigating application programs utilizing the Block III modules. Anyone requiring additional technical information should direct his request to the author, Melvin I. Smokler, or to Larry N. Dumas, LSA Project Operations Manager, at the Jet Propulsion Laboratory.

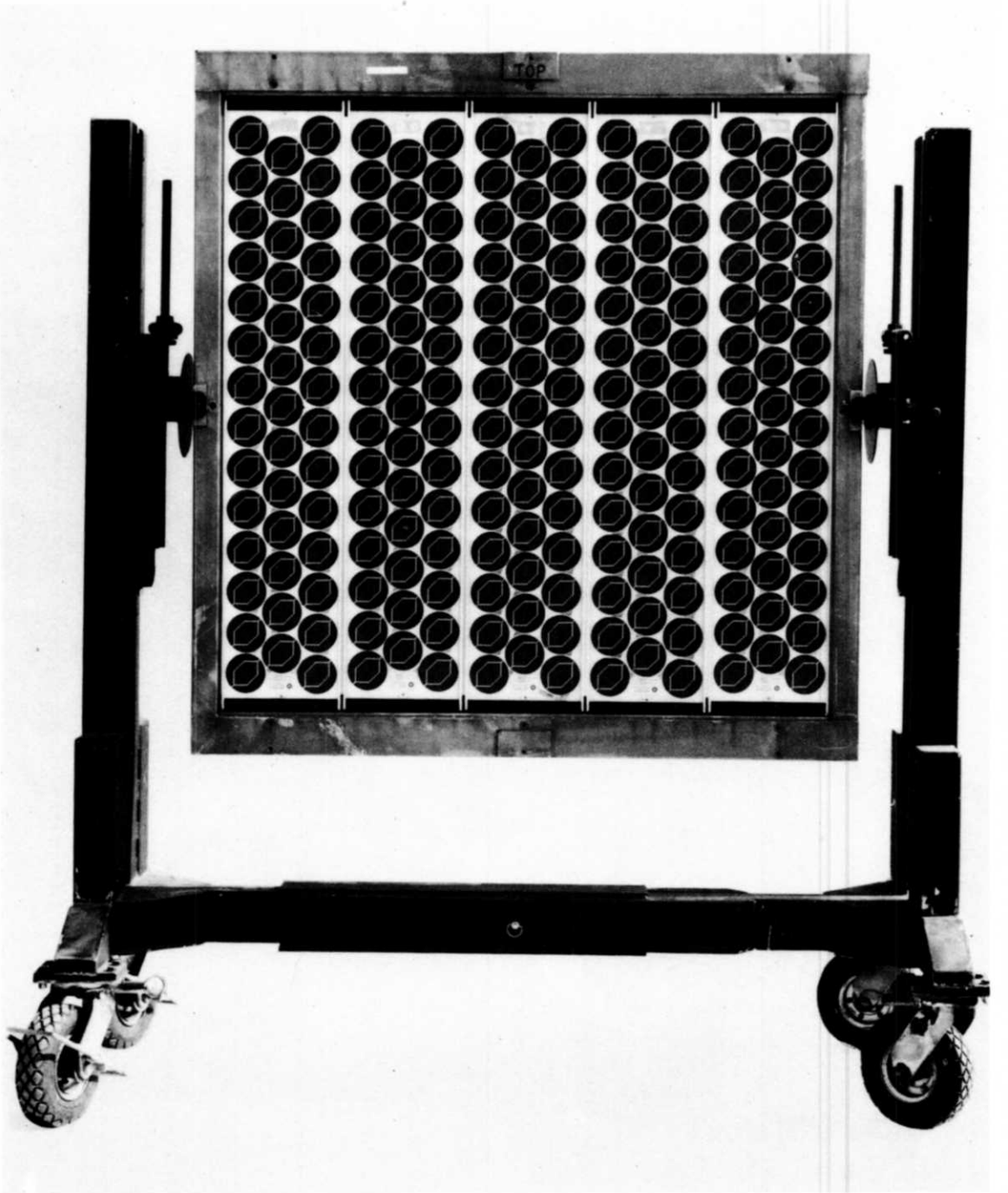


Figure 1-1. Example of Subarray Assembled from Block III Modules

SECTION II

MODULE DESCRIPTION

The Block III contractors were required to comply with a common set of requirements delineated in JPL Specification 5-342-1, Revision C, dated May 31, 1977, entitled Silicon Solar Cell Module Performance and Environmental Test Requirements. The principal requirements in this specification are:

(1) The configuration must permit assembly of modules into a 4 ft square subarray that produces not less than 60 W at rated output voltage when operated at a cell temperature of 60°C and exposed to insolation through an optical air mass of AM1.5 at a module irradiance of 100 mW/cm^2.

(2) Breakdown voltage from terminals to ground must exceed 1500 Vdc.

(3) Insulation resistance from terminals to ground, when measured at 1000 Vdc, must not be less than 100 MΩ.

(4) The modules must withstand the following test environment:

  (a) 50 thermal cycles between -40°C and +90°C.

  (b) 5 cycles of 95% relative humidity between 23°C and 41°C.

  (c) 100 cycles of simulated wind loading between +50 lb/ft^2 and -50 lb/ft^2.

As the specification permits some options in configuration and in materials, the resulting modules supplied by the five contractors differ in several respects. The complete descriptions of the five types of modules are given in Table 2-1, Module Characteristics.

Samples of each type of module were subjected to a qualification test program (see Appendix) to prove compliance with the requirements. In addition, all deliverable modules were subjected to an acceptance test, consisting of measurement of electrical performance and testing of insulation resistance and breakdown voltage.

Table 2-1. Module Characteristics

	MANUFACTURER	ARCO SOLAR	MOTOROLA	SENSOR TECHNOLOGY	SOLAR POWER	SOLAREX
IDENTIFYING	MFR'S MODEL NO.	10699-C	P-0170-770-J	20-10-1646	E-10008-F	A-0221-G
PHYSICAL	PHOTOGRAPHIC VIEWS	Figure 2-1	Figure 2-4	Figure 2-7	Figure 2-10	Figure 2-13
	OVERALL DIMENSIONS (inches)					
	LENGTH	46.0	23.0	22.9	46.0	22.9
	WIDTH	9.1	23.0	11.3	15.3	22.9
	HEIGHT	1.4	2.0	1.8	1.9	1.8
	WEIGHT (lbs)	8.1	14.5	8.2	16.3	9.8
	NO. OF MODULES PER 4 FOOT SQUARE SUBARRAY	5	4	8	3	4
	SUBARRAY PLANARITY RQMT (in/ft)	0.25	0.25	0.25	0.25	0.25
	MODULE DRAWING AND MATERIALS	Figure 2-2	Figure 2-5	Figure 2-8	Figure 2-11	Figure 2-14
	ELECTRICAL CONNECTIONS	Figure 2-2	Figure 2-5	Figure 2-8	Figure 2-11	Figure 2-14
	NO. OF CELLS	41	48	44	40	42
	CELL DIAMETER (inches)	3	3	2.2	4	3
	CELL CONFIGURATION	N-P	N-P	N-P	P-N	N-P
ELECTRICAL	QUALIFICATION PERFORMANCE (1)					
	POWER, RATED (Watts)	18.5	23.2	9.4	29.5	18.5
	VOLTAGE, RATED (Volts)	15.8	5.0	16.5	15.8	15.8
	CURRENT (Amps)	1.17	4.64	0.57	1.87	1.17
	SOC PERFORMANCE (SAMPLE) (2)					
	POWER, MAXIMUM (Watts)	19.3	23.1	10.1	31.4	19.1
	VOLTAGE AT MAX. POWER (Volts)	15.6	5.1	18.3	16.7	15.7
	CURRENT AT MAX. POWER (Amps)	1.24	4.52	0.55	1.88	1.21
	VOLTAGE, OPEN CIRCUIT (Volts)	20.9	6.4	22.5	21.6	21.3
	CURRENT, SHORT CIRCUIT (Amps)	1.40	4.91	0.62	1.98	1.42
	FILL FACTOR	0.66	0.74	0.72	0.73	0.63
	EFFICIENCY, MODULE (%)	7.2	6.8	6.1	6.9	5.6
	EFFICIENCY, ENCAPSULATED CELL (%)	10.4	10.6	9.8	9.7	9.8
	TEMPERATURE CHARACTERISTICS (I-V Curves)	Figure 2-3	Figure 2-6	Figure 2-9	Figure 2-12	Figure 2-15
	CIRCUIT DIAGRAM	Figure 2-2	Figure 2-5	Figure 2-8	Figure 2-11	Figure 2-14
	INSULATION RESISTANCE, MIN. (Meg Ω)	100	100	100	Not Applicable	100
	BREAKDOWN VOLTAGE, MIN. (Vdc) (3)	1500	1500	1500	Not Applicable	1500
THERMAL	NOMINAL OPERATING CELL TEMPERATURE (°C) (4)	57.2	61.0	49.0	52.5	53.1
ENVIRONMENTAL	TEMPERATURE RANGE (°C) (5)	-40 to +90	-40 to +90	-40 to +90	-40 to +90	-40 to +90
	HUMIDITY, MAXIMUM RELATIVE (%) (5)	95	95	95	95	95
	WIND LOAD, MAXIMUM (lb/ft^2) (5)	±50	±50	±50	±50	±50
LIFE	SERVICE LIFE DESIGN GOAL (Yrs)	10	10	10	10	10

NOTES

(1) Each module was required to produce not less than 86% of rated power when loaded to provide rated voltage under the following conditions:

A. Module irradiated with 100 mW/cm^2 insolation at air mass 1.5 (AM1.5).
B. Cell temperature equal to 60°C. See Appendix (Qualification Test Program) for details of electrical performance test.

(2) Standard Operating Conditions (SOC) are:

A. Module irradiated with 100 mW/cm^2 insolation at air mass 1.5 (AM1.5)
B. Cell temperature equal to NOCT. (See Note (4))

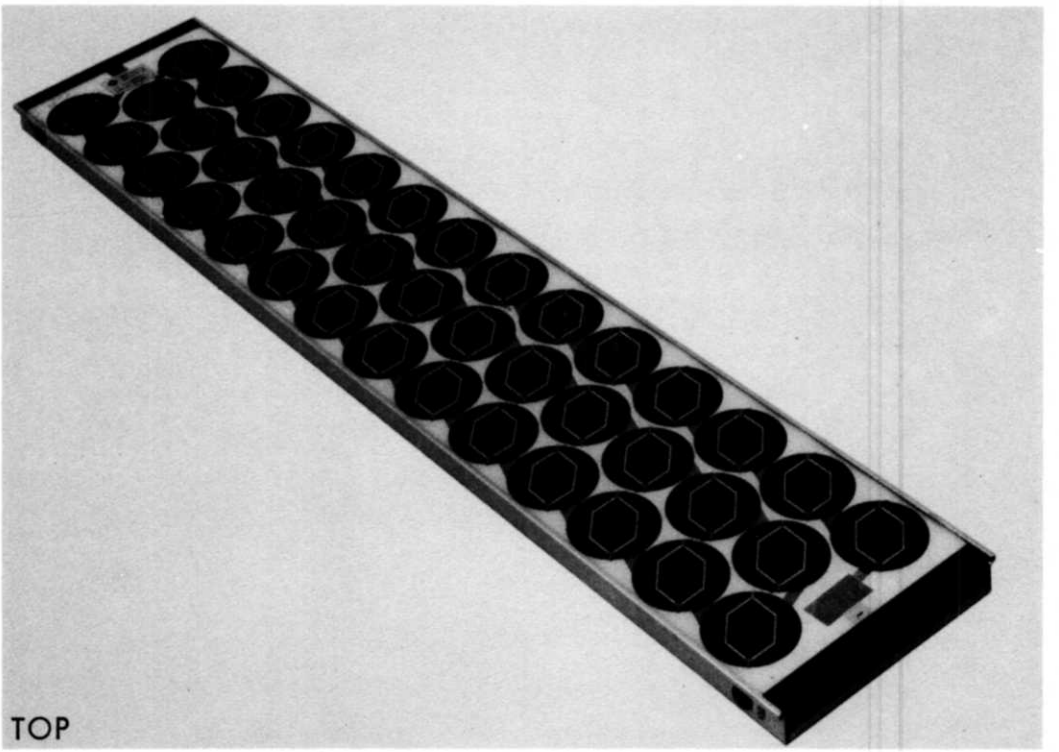
The data presented here for each module design shows the characteristics obtained by measurement and extrapolation of the performance of one sample module of that design. I-V curves for the sample modules are given in Figures 2-3, 2-6, 2-9, 2-12, and 2-15.

(3) Modules should not be series connected to produce system operating voltage in excess of 250 Vdc at standard operating conditions (SOC).

(4) Nominal Operating Cell Temperature is the cell temperature with the module in the Standard Thermal Environment (STE) defined as follows:

Insolation	= 100 mW/cm^2
Air Temperature	= 20°C
Average Wind Velocity	= 1 m/s
Electrical Load	= Open circuit
Mounting	= Normal to solar noon on structure typical of application

(5) The data given are the test limits, not measured limits. For details see Appendix (Qualification Test Program).



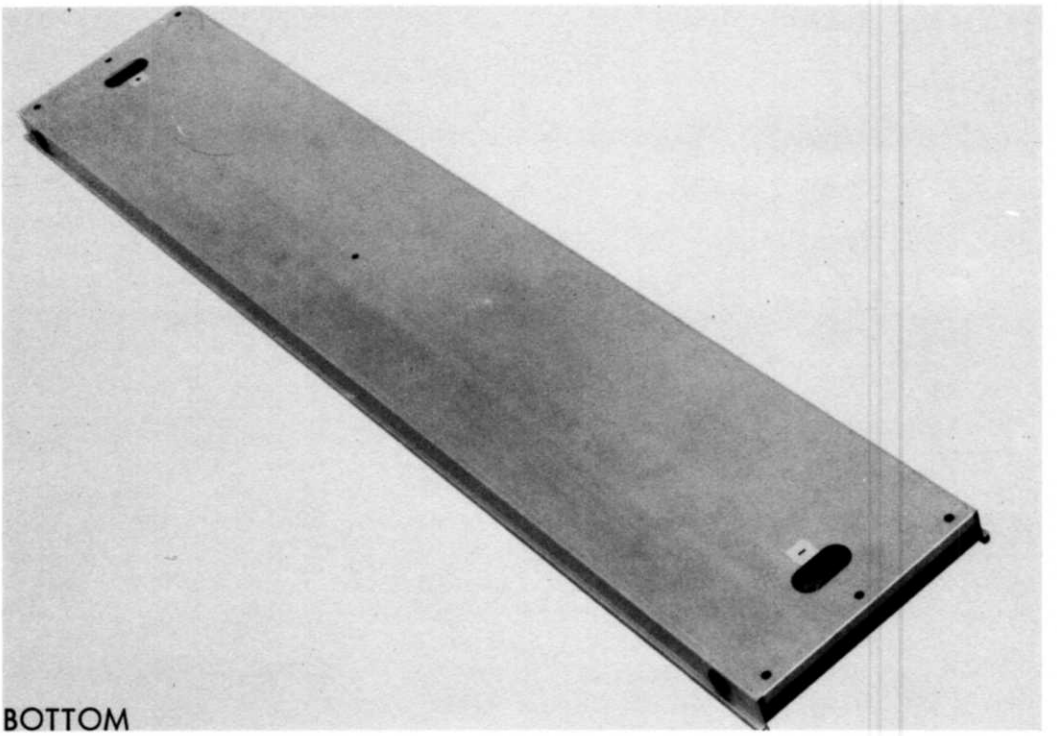
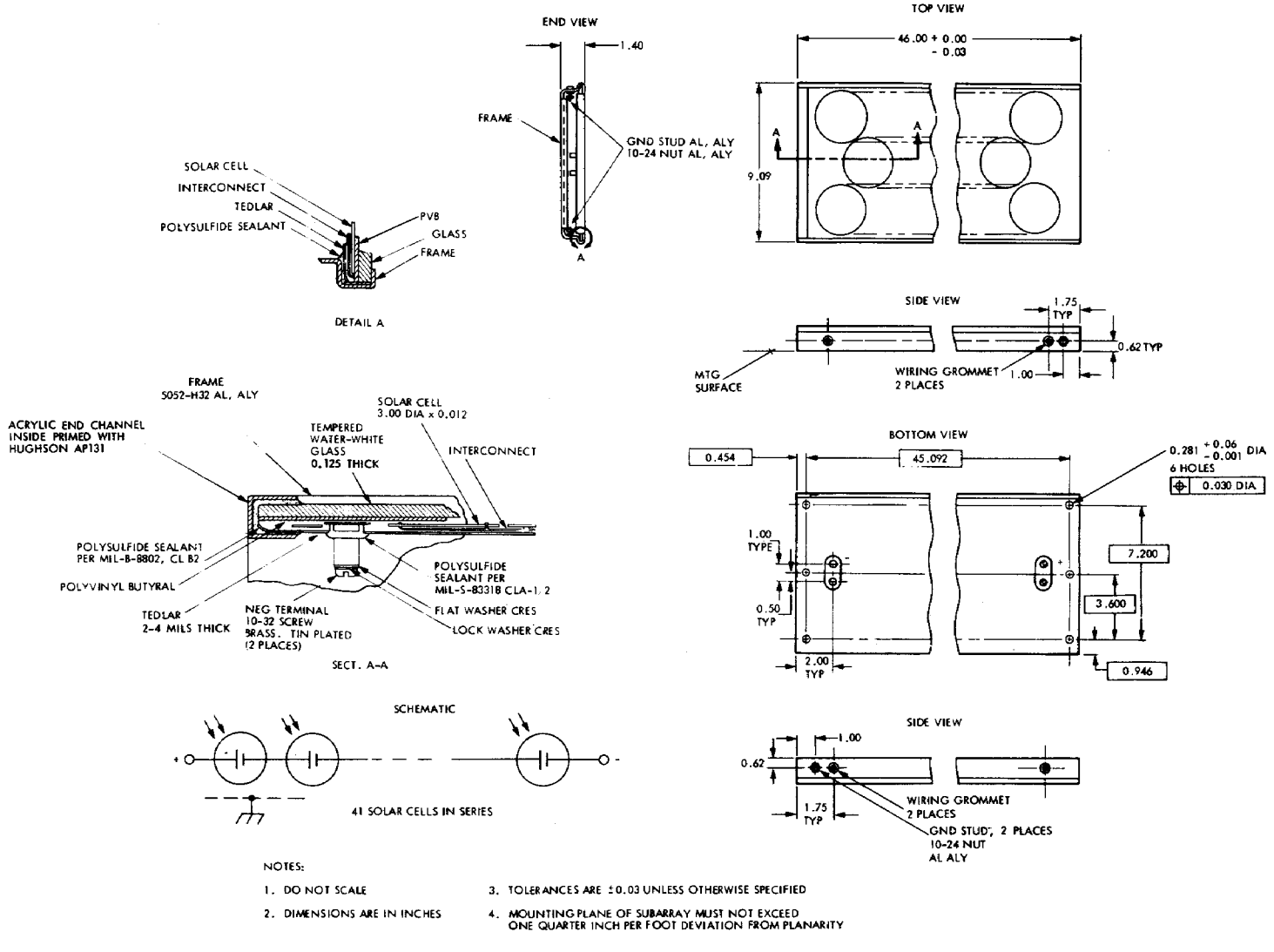


Figure 2-1. ARCO Solar Module: Photographic Views



NOTES:

1. DO NOT SCALE
2. DIMENSIONS ARE IN INCHES
3. TOLERANCES ARE ±0.03 UNLESS OTHERWISE SPECIFIED
4. MOUNTING PLANE OF SUBARRAY MUST NOT EXCEED ONE QUARTER INCH PER FOOT DEVIATION FROM PLANARITY

Figure 2-2. ARCO Solar Module: Drawing

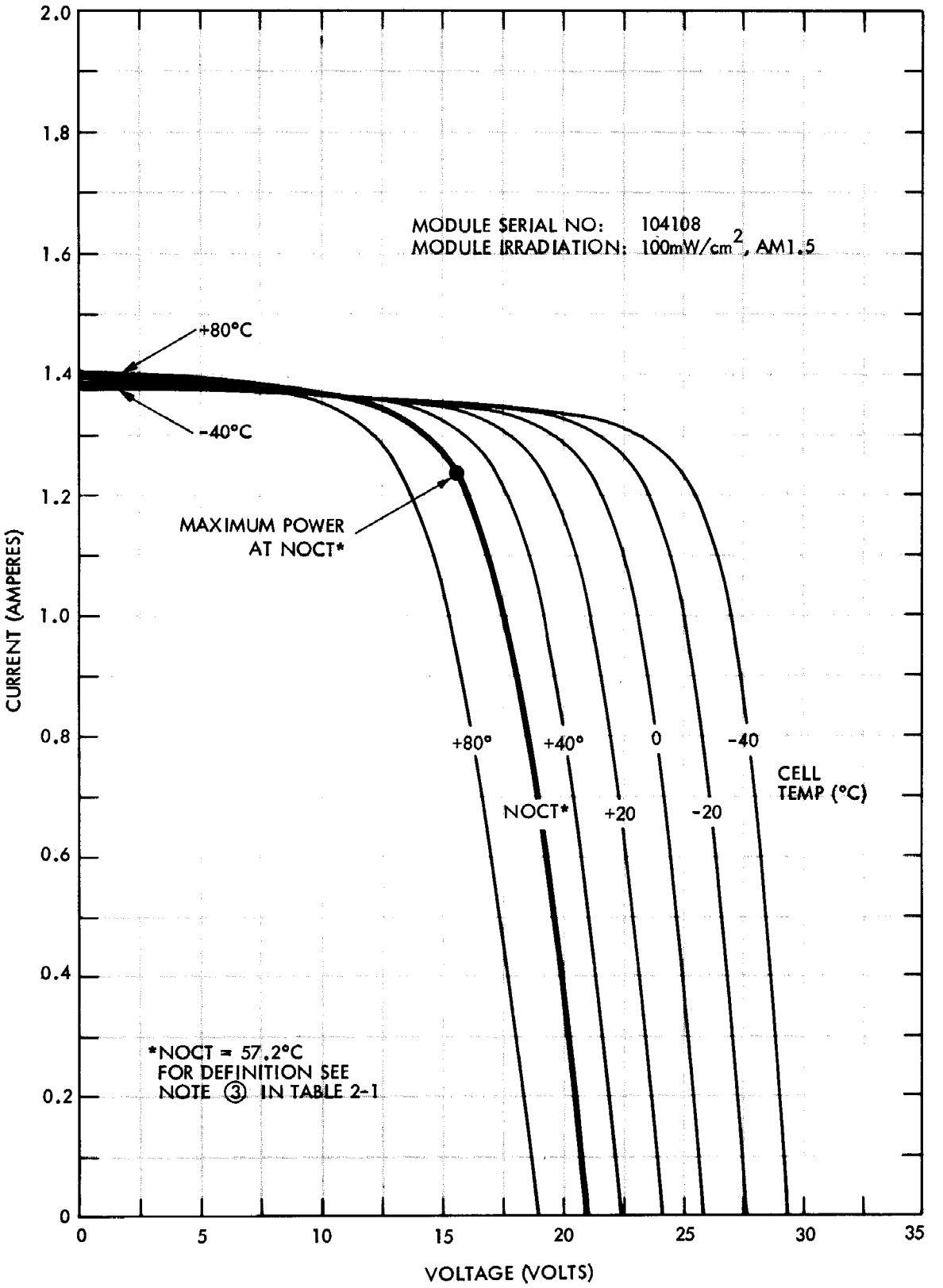
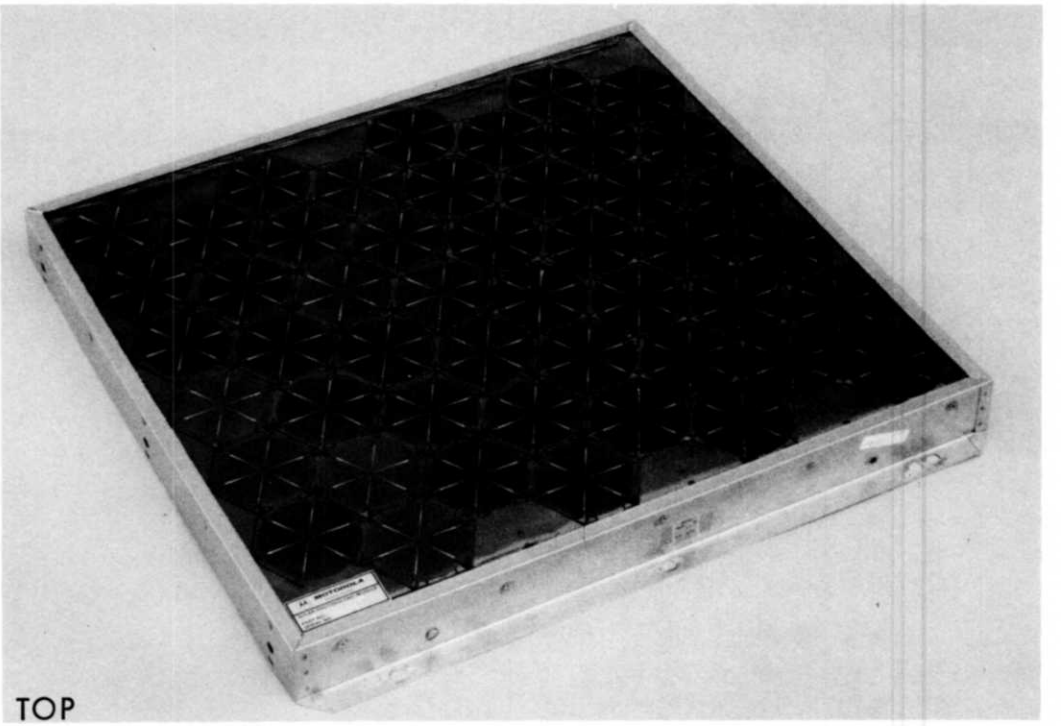


Figure 2-3. ARCO Solar Module: I-V Curves



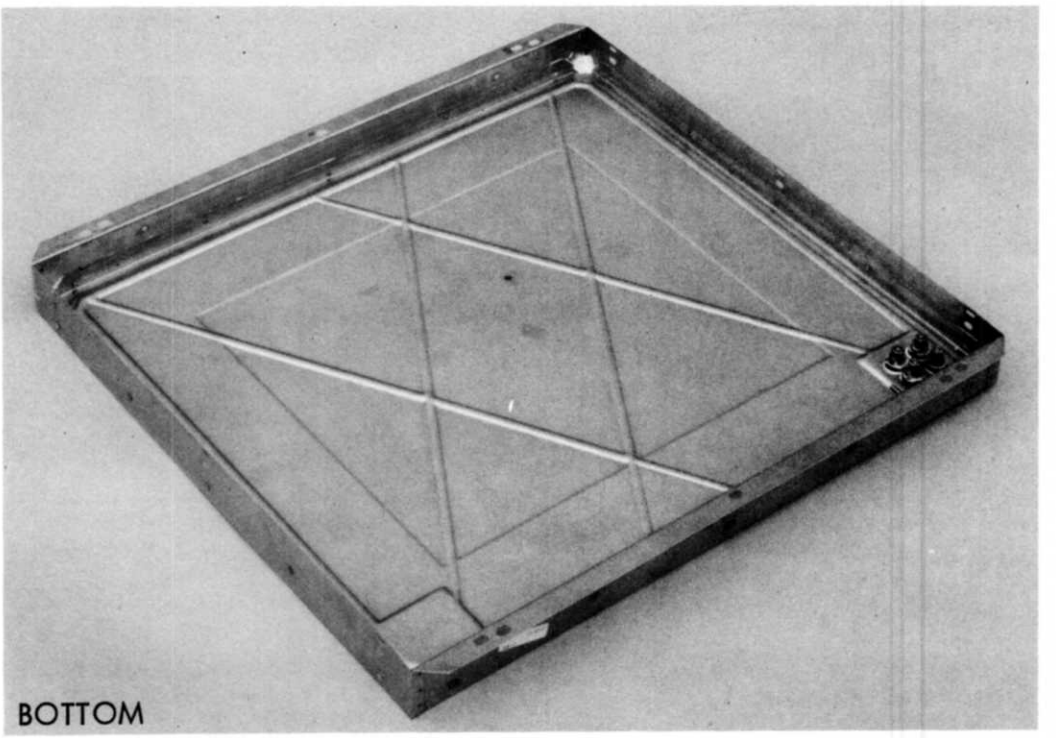


Figure 2-4. Motorola Module: Photographic Views

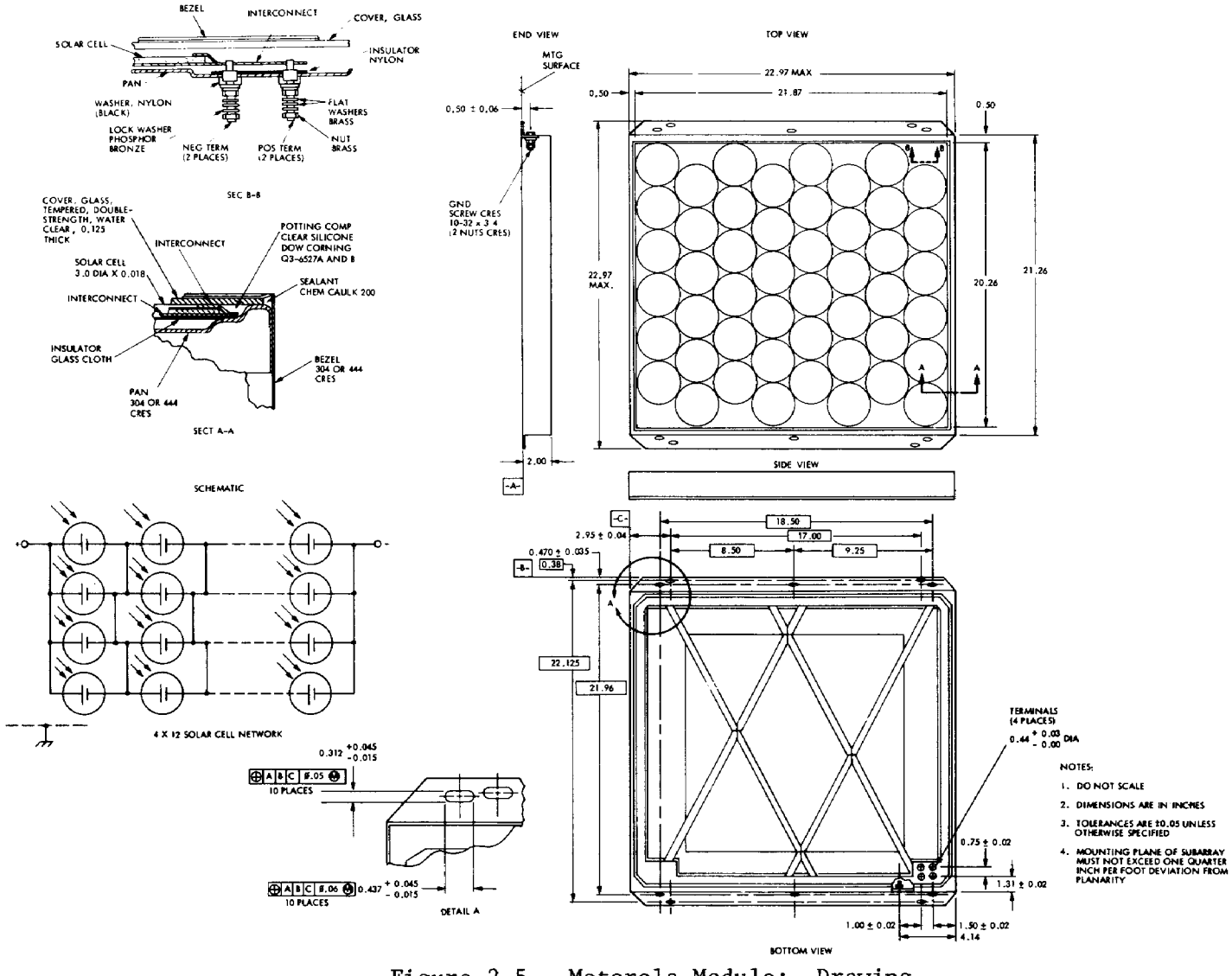


Figure 2-5. Motorola Module: Drawing

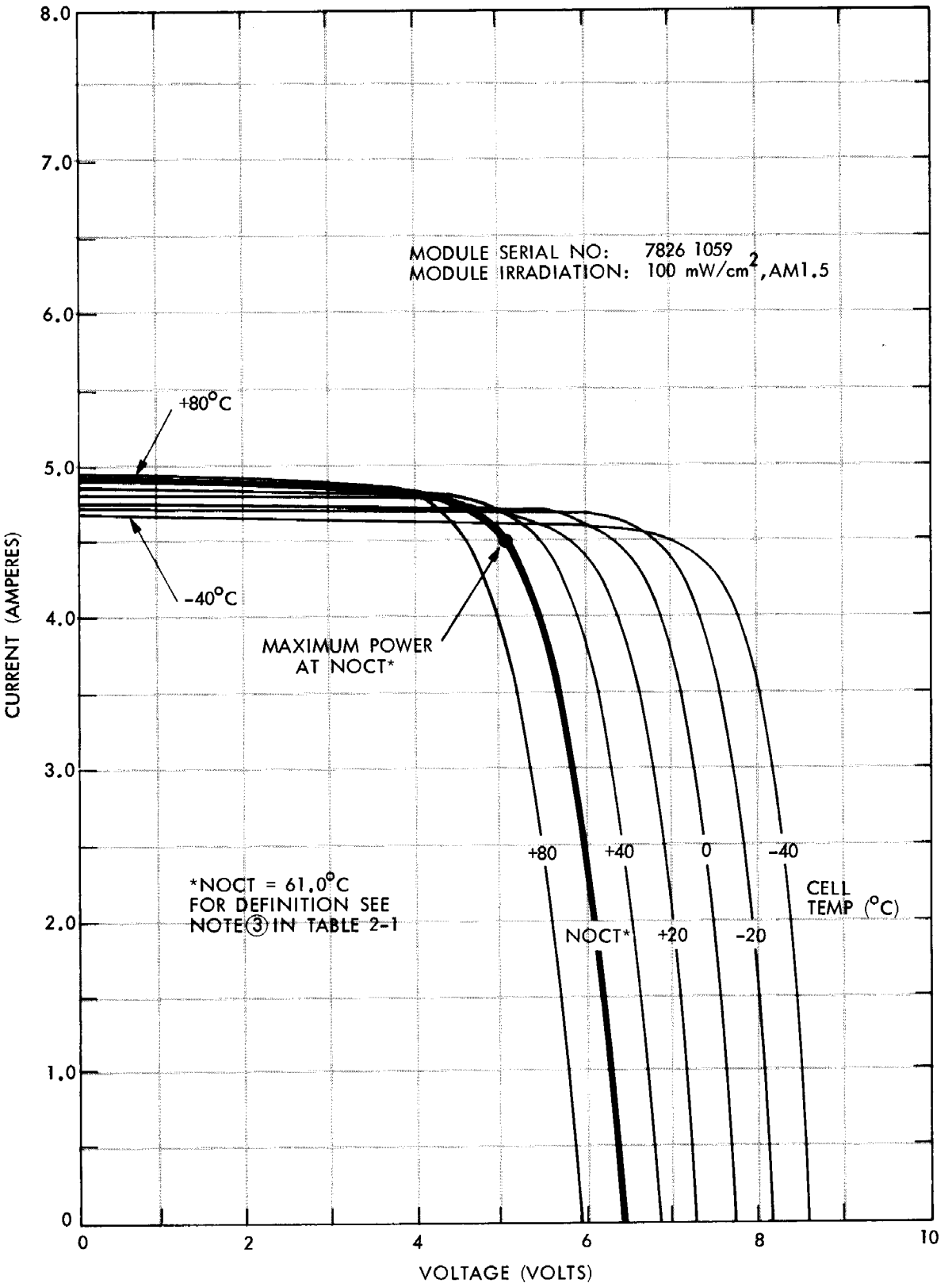
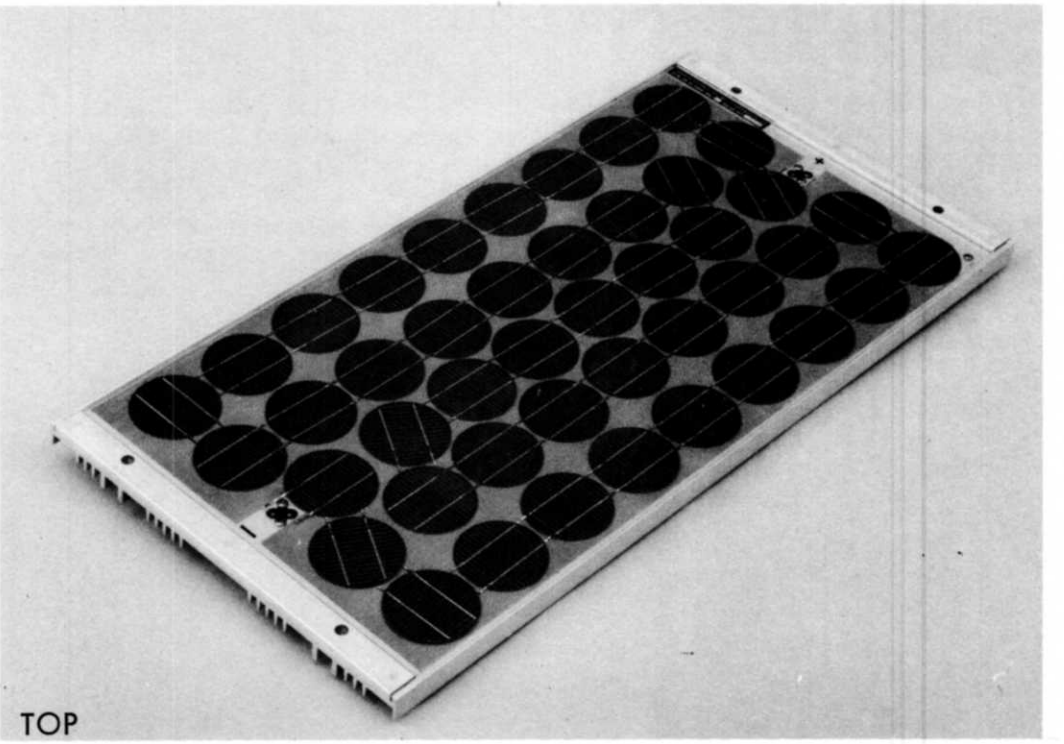


Figure 2-6. Motorola Module: I-V Curves



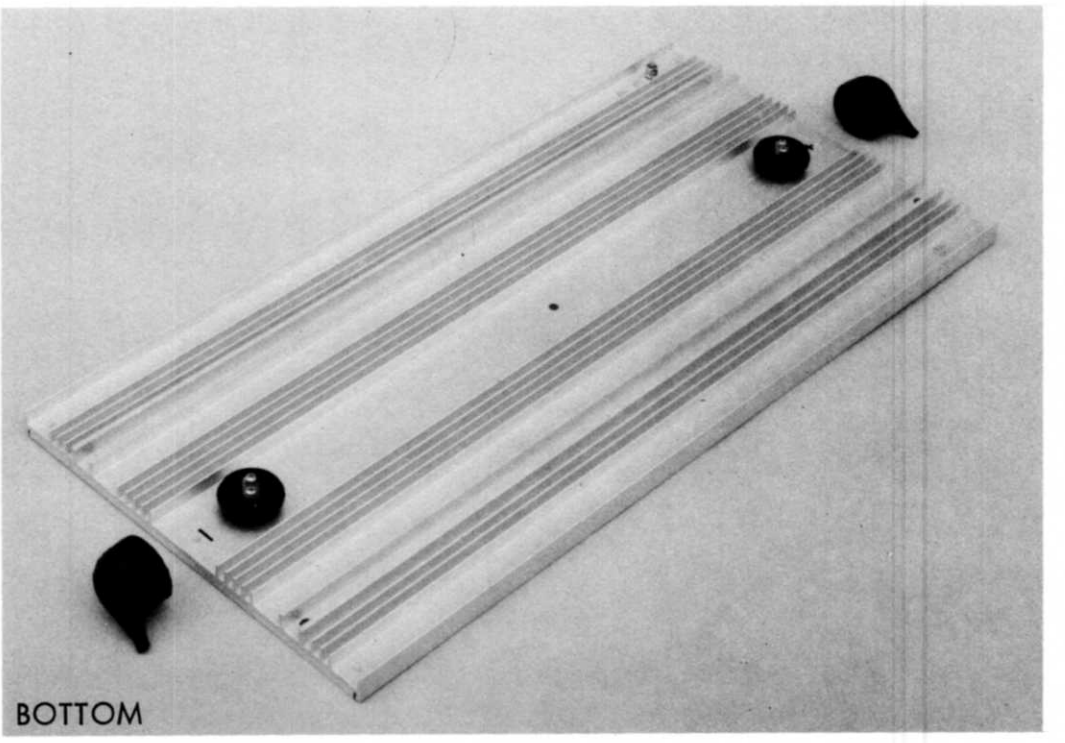


Figure 2-7. Sensor Technology Module: Photographic Views

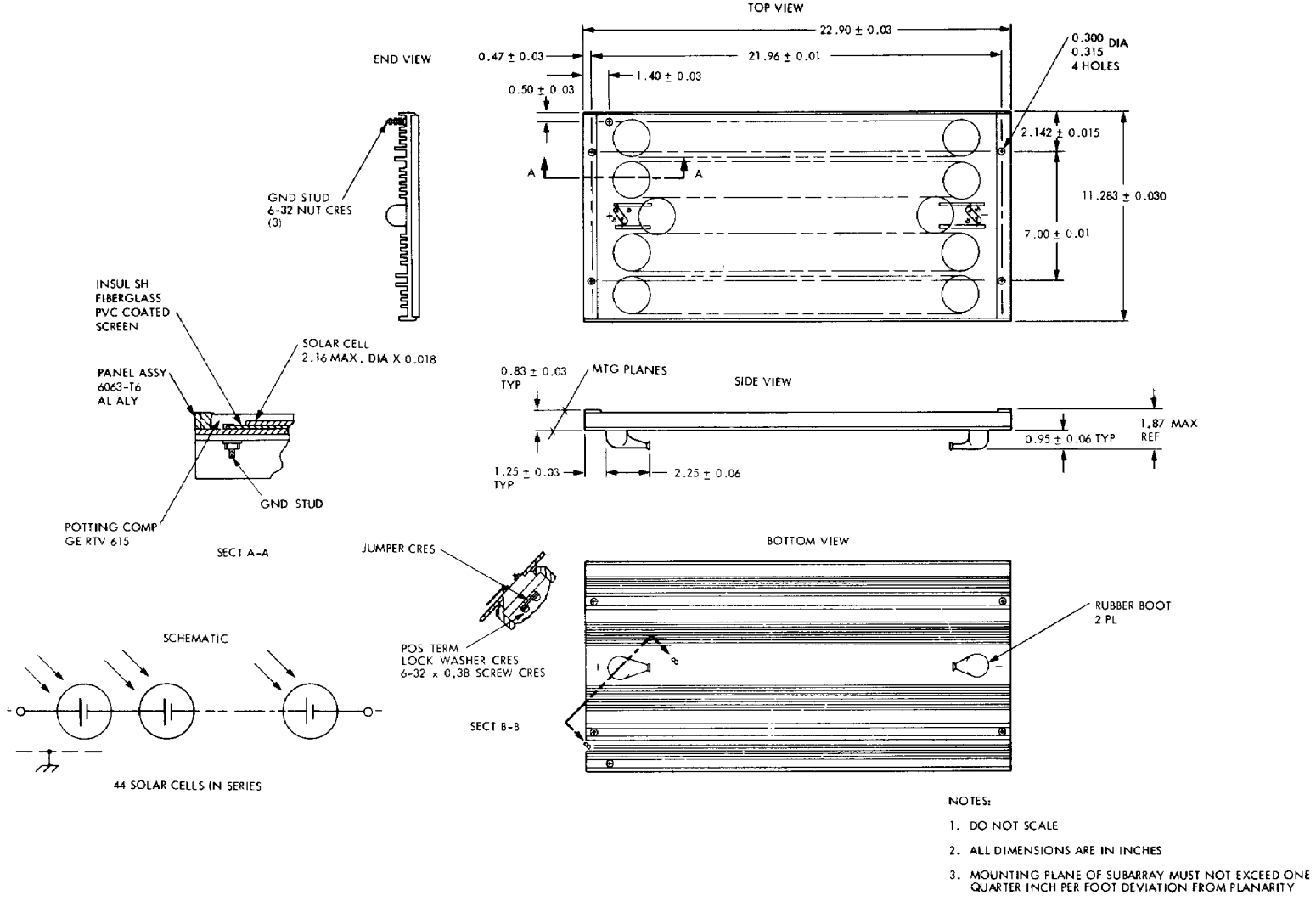


Figure 2-8. Sensor Technology Module: Drawing

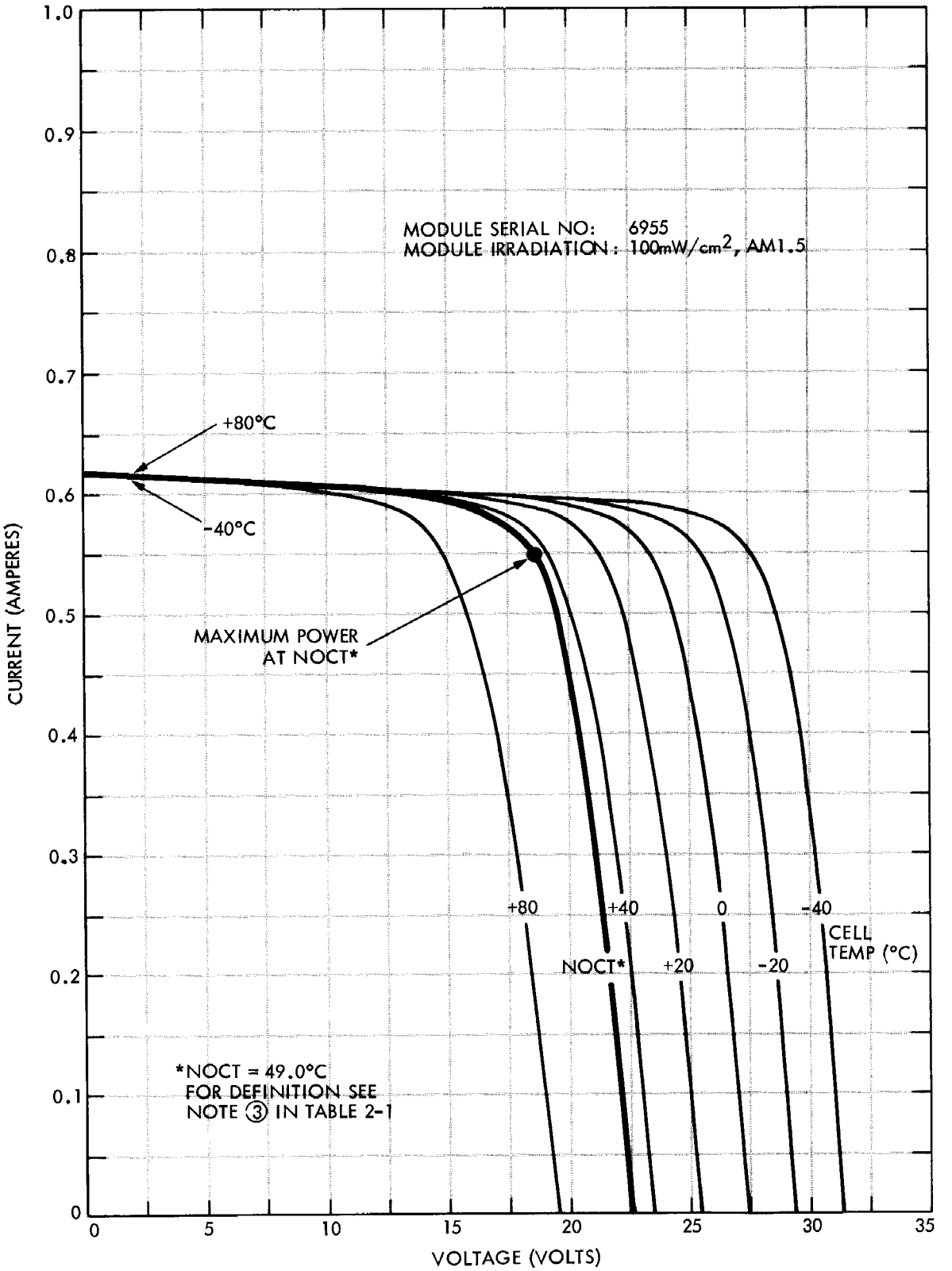
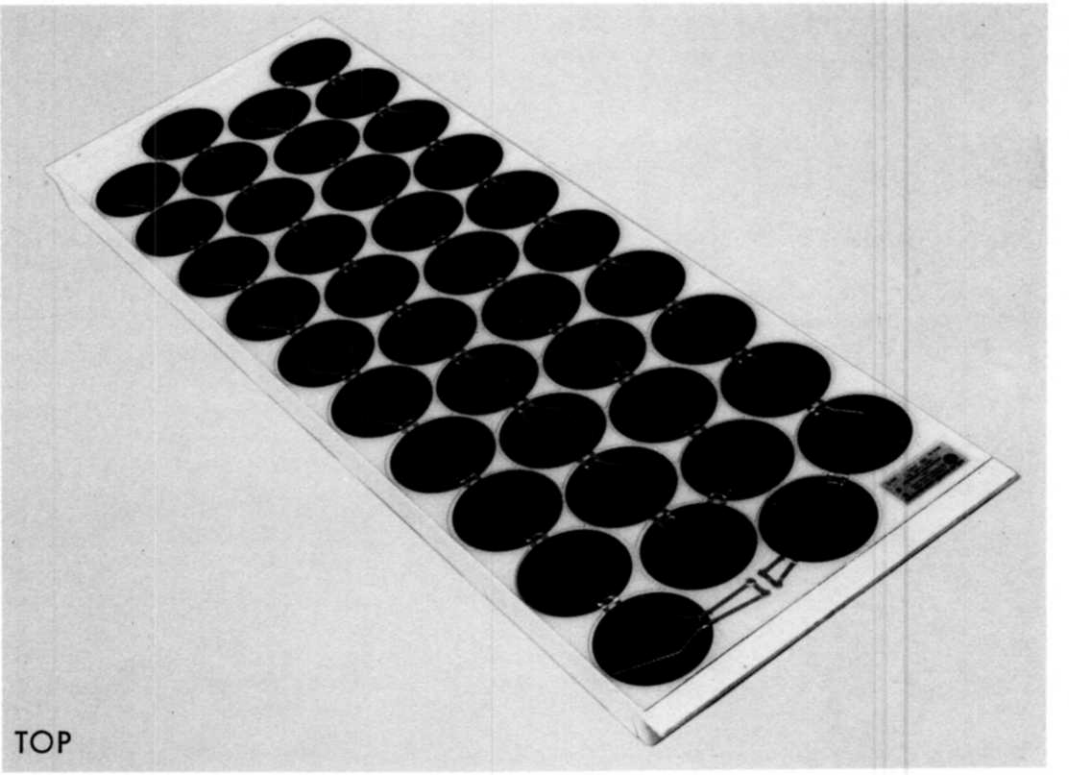


Figure 2-9. Sensor Technology Module: I-V Curves



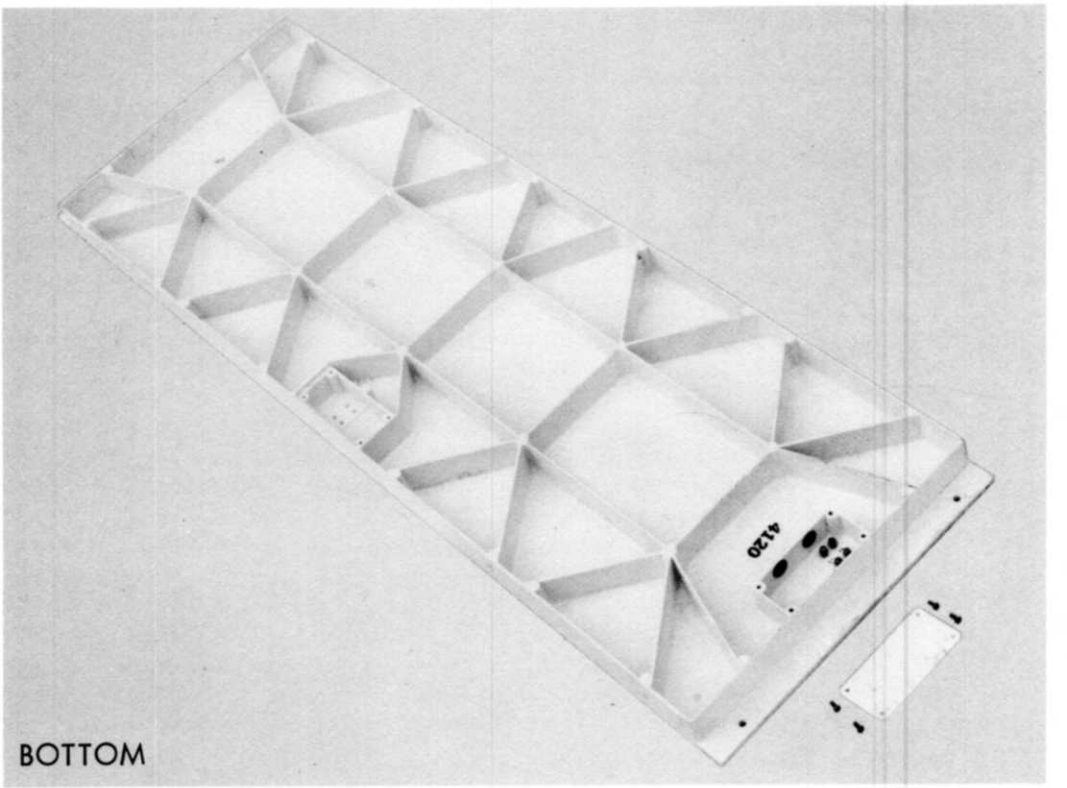


Figure 2-10. Solar Power Module: Photographic Views

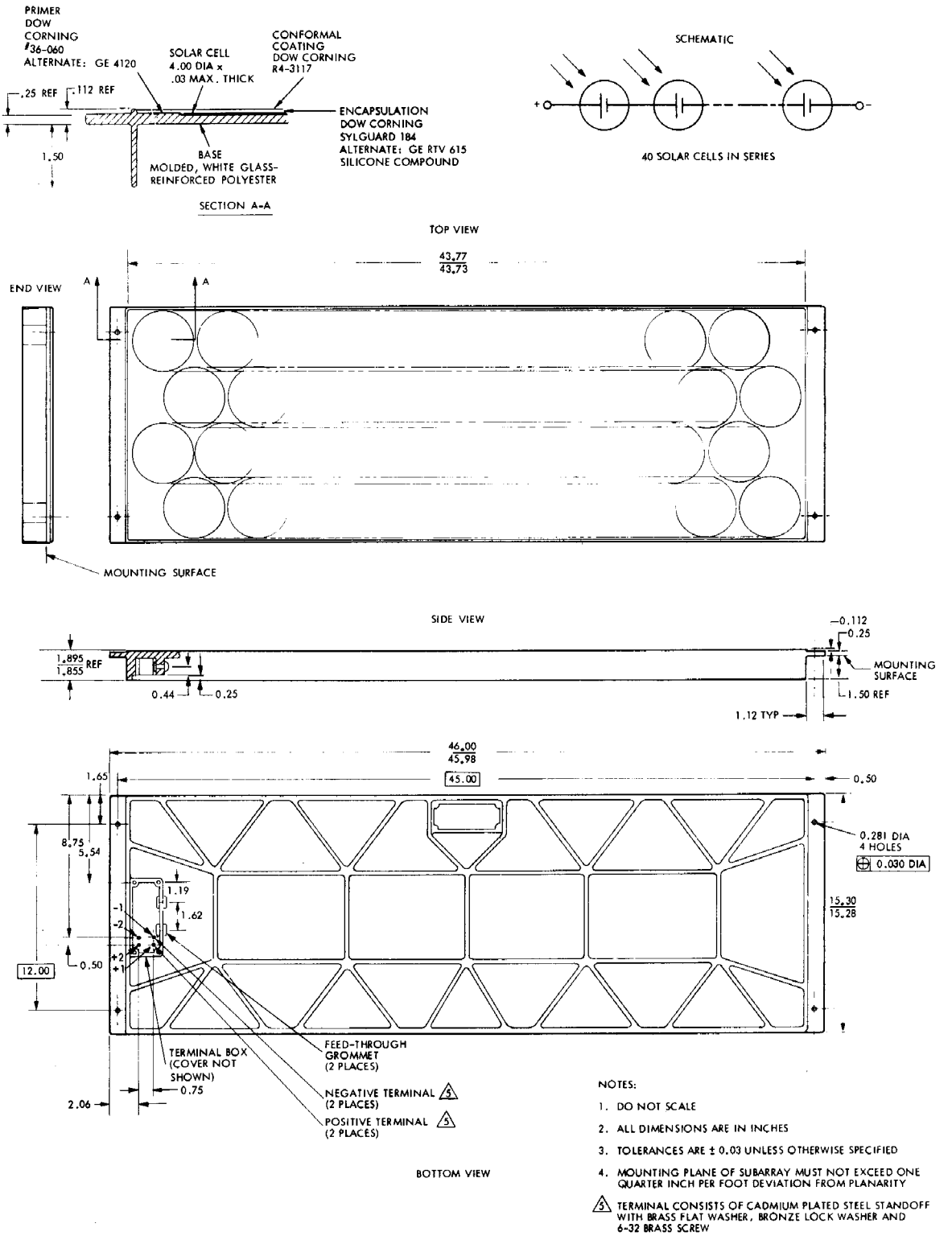


Figure 2-11. Solar Power Module: Drawing

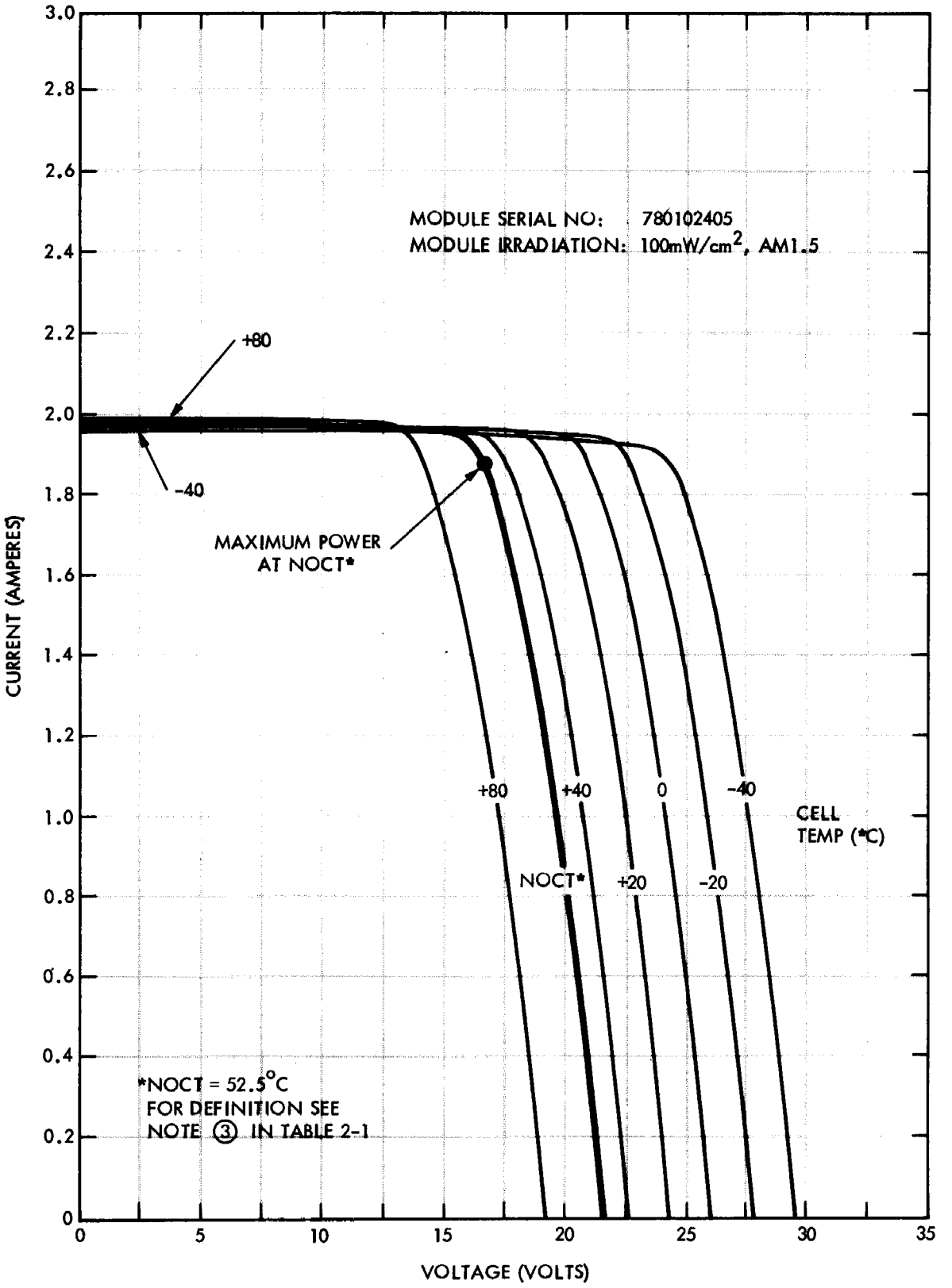
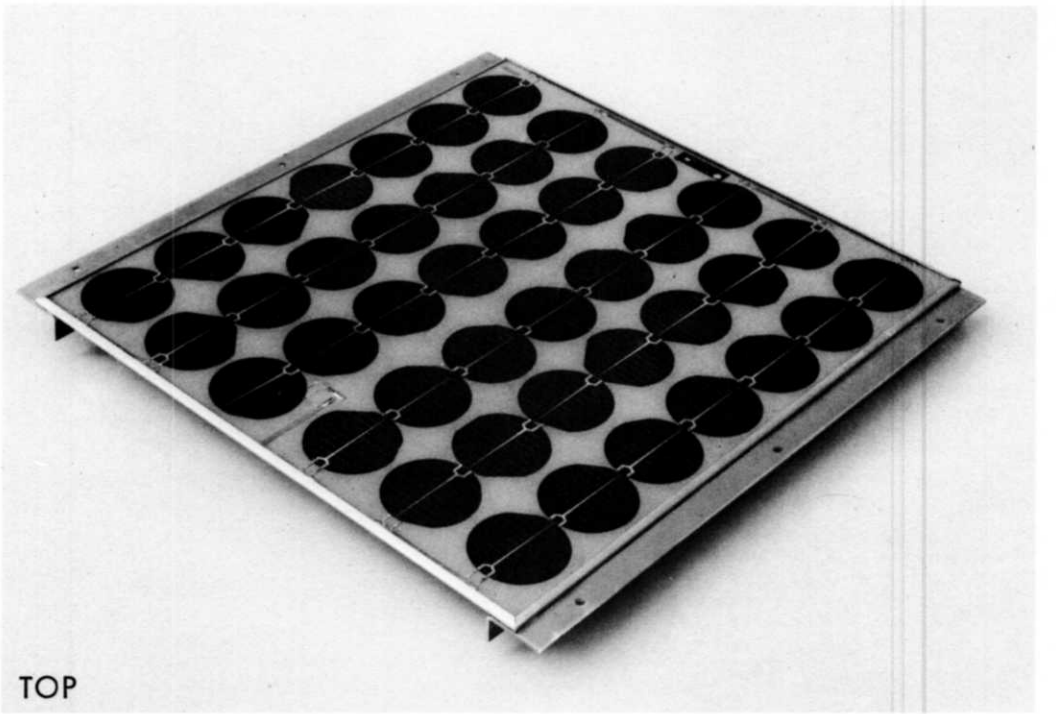


Figure 2-12. Solar Power Module: I-V Curves



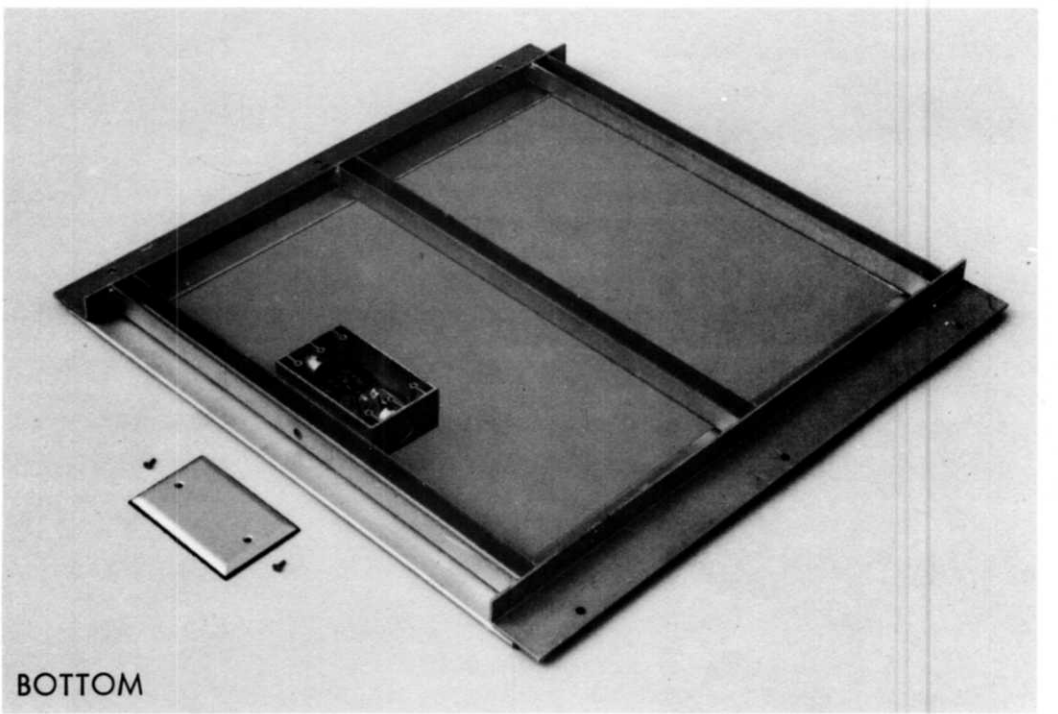


Figure 2-13. Solarex Module: Photographic Views

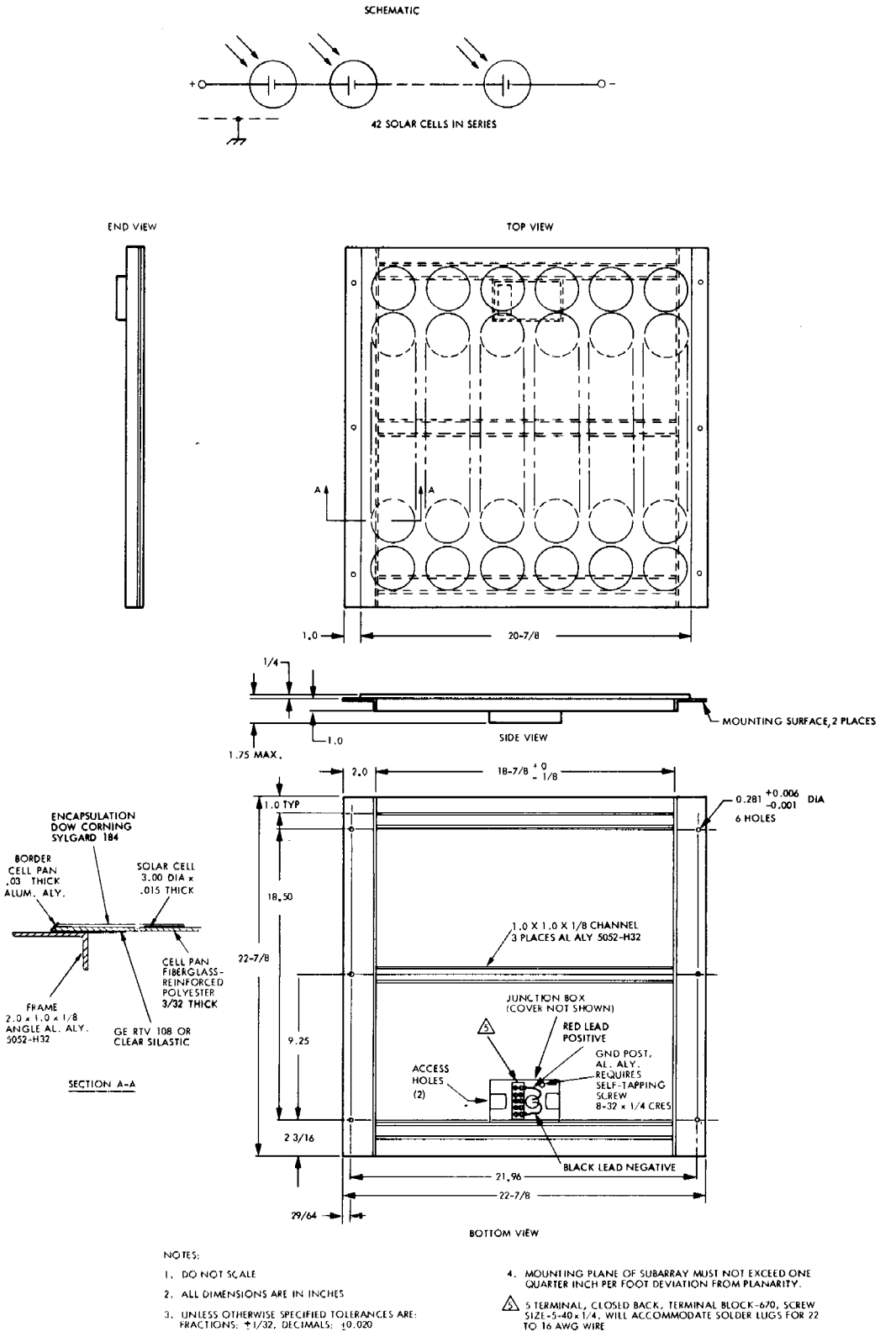


Figure 2-14. Solarex Module: Drawing

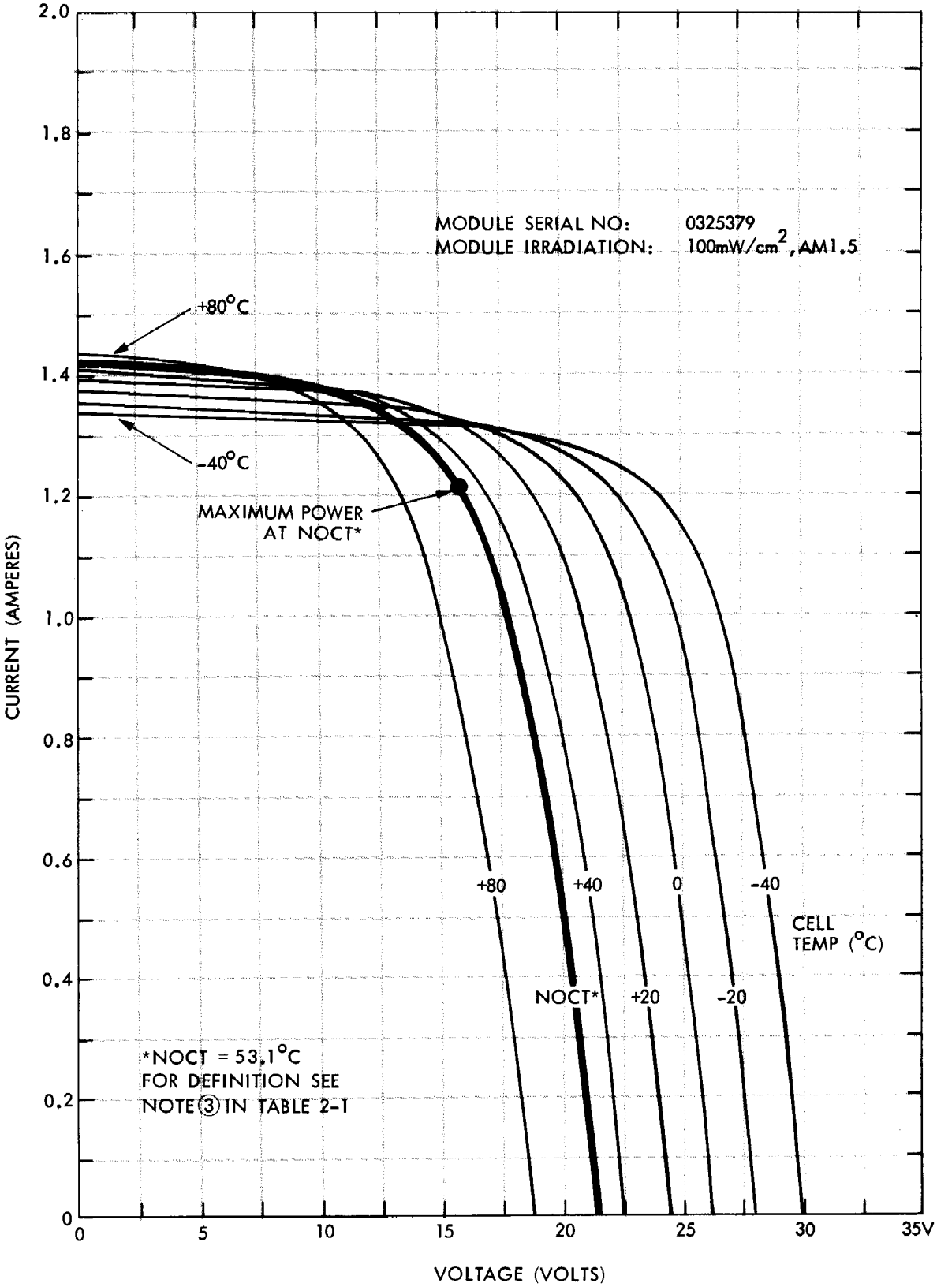


Figure 2-15. Solarex Module: I-V Curves

APPENDIX

QUALIFICATION TEST PROGRAM

During initial production of each Block III module design, a sample lot was subjected to a qualification test program to prove compliance with required ranges of environmental exposure. The integrity of the production process was verified throughout subsequent production by applying the same tests to periodically selected samples.

The block diagram in Figure A-1 shows the qualification test sequence with the names of individual tests given in blocks, which are alphabetically coded. Note that some tests occur more than once in the sequence. The description of each test is as follows:

A. Visual Inspection

This consists of detailed visual examination of the module for mechanical degradation to a degree judged to threaten continued successful performance of the module. Such degradation may appear as breaks, cracks, delamination, spalling, etc.

B. Electrical Performance

The purpose of this test is to obtain current-voltage (I-V) characteristic curves, first to establish a performance baseline, and subsequently to examine for performance degradation. Furthermore, the test verifies that the module design produces the required power output, i.e., not less than 86% of the rated power, where the latter is the expected power output when the module is loaded to produce rated voltage under the following conditions:

(1) Module irradiated with 100 mW/cm^2 simulated insolation at air mass 1.5 (AM1.5).

(2) Cell temperature stabilized at $60^{\circ}C$ by control of ambient air temperature.

When the test is performed to examine for performance degradation, the purpose is to verify that the stresses of the qualification tests do not cause more than 5% degradation in power output, measured under the above conditions.

Typically, the electrical performance test is run at a cell temperature other than $60^{\circ}C$, a common value being $28^{\circ}C$. In such a case, the point on the I-V curve that is comparable to the rated voltage

point on the 60°C I-V curve will have previously been determined by a combined experimental and analytical procedure involving calculation and application of temperature coefficients for current and voltage.

C. Insulation Resistance

This test verifies that the insulation resistance between the (shorted-together) output terminals of the module and module ground is not less than 100 MΩ, measured with 1000 V applied, of either polarity. The test is applicable only to module designs that have exposed metal surfaces requiring a ground terminal.

D. Dielectric Breakdown

This test verifies that the insulation between the (shorted-together) output terminals of the module and module ground will not suffer dielectric breakdown when subjected to 1500 Vdc. The voltage is applied over a 45-second period in uniformly spaced 500 V steps and held at the 1500 V level for one minute. The test is applicable only to module designs that include a ground terminal.

E. Thermal Cycling

This test requires that the module be subjected to 50 cycles of cell temperature variation between -40°C and +90°C. The variation is approximately linear, at a rate not exceeding 100°C per hour, with a period not exceeding six hours per cycle.

F. Humidity Cycling

This test requires that the module be subjected to the humidity regime depicted in Figure A-2. The subsequent electrical performance test must follow within one hour of removal of the module from the humidity chamber.

G. Mechanical Load Cycling

This test verifies, by simulation, that wind which produces mechanical loading of 50 lbs/ft^2 will not result in mechanical or electrical degradation. The test is performed by applying 100 cycles of mechanical load, normal to the module surface, ranging between +50 and -50 lbs/ft^2.

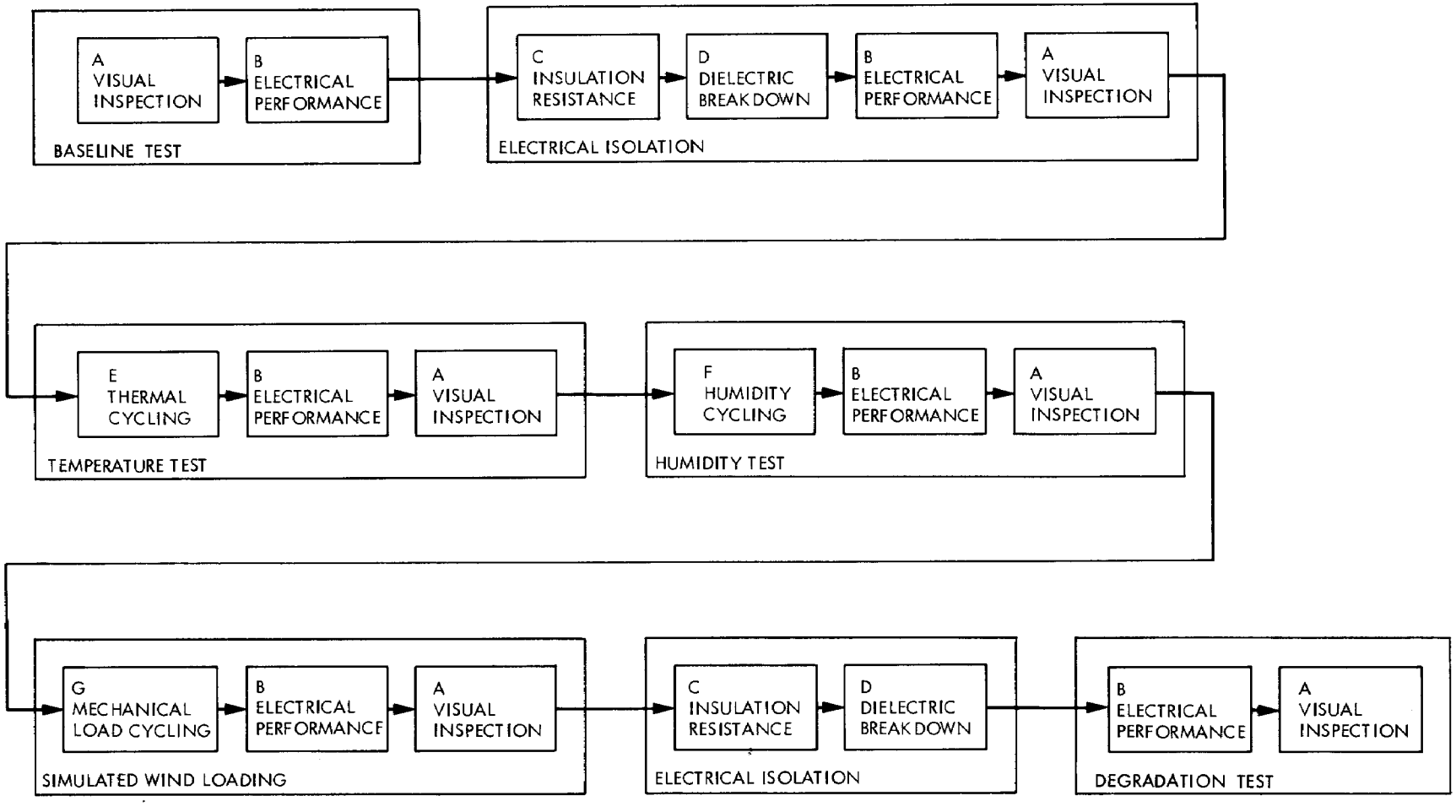


Figure A-1. Qualification Test Sequence

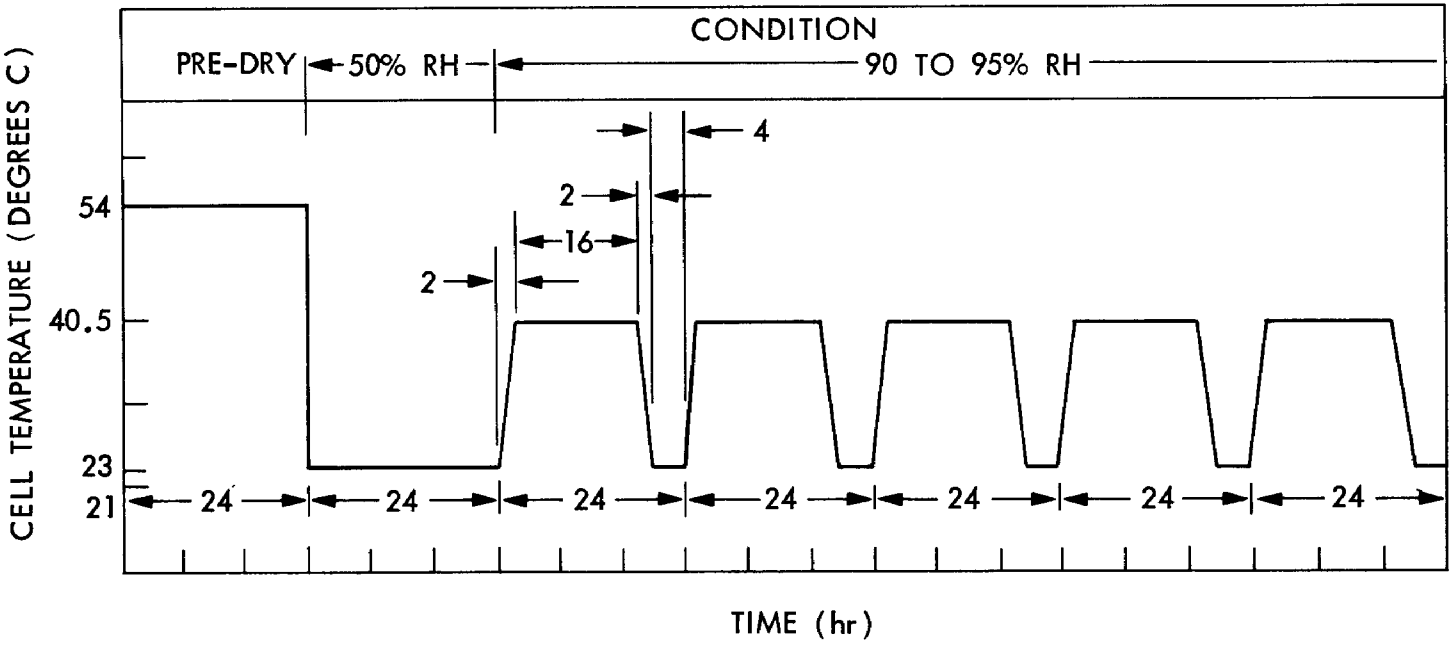


Figure A-2. Humidity Cycle