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Flat-Plate
Solar Array Project

DOE/JPL-1012-75

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User Handbook for Block IV Silicon Solar Cell Modules

M.I. Smokler

September 1, 1982

Prepared for
U.S. Department of Energy
Through an Agreement with
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The JPL Flat-Plate Solar Array Project is sponsored by the U.S. Department of Energy and is part of the Photovoltaic Energy Systems Program to initiate a major effort toward the development of cost-competitive solar arrays.

This publication reports on work done under NASA Task RD-152, Amendment 66, DOE/NASA IAA No. DE-AI01-76ET20356.

ABSTRACT

The essential electrical and mechanical characteristics of Block IV photovoltaic solar-cell modules that have been tested by JPL are described. Such module characteristics as power output, nominal operating voltage, current-voltage characteristics, nominal operating cell temperature, and dimensions are tabulated. The limits of the environmental and other stress tests to which the modules are subjected are briefly described. Potential users of modules will find this listing helpful in selecting modules for use in arrays or alone.

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SECTION I

INTRODUCTION

The program of the Jet Propulsion Laboratory (JPL) Flat-Plate Solar Array Project (FSA) has included a series of competitive procurements, designated Block I through Block IV, of various quantities of solar cell modules. The objectives of this procurement effort were to stimulate reduction in manufacturing cost by encouraging technology advances and to provide modules for field testing of solar-cell arrays.

Block I included the purchase from five contractors of a quantity of modules having a total 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, consisting of the purchase of 123 kW of total power capacity from four contractors, introduced a degree of standardization by defining the module design specifications (JPL Document No. 5-342-1, Rev. B) and by providing for a design qualification test program. The Block II modules are described in Reference 1.

Block III consisted of procurement of a 205 kW of total power capacity from five contractors. The design specifications (JPL Document No. 5-342-1, Rev. C) and the qualification test program were essentially the same as those for Block II. The Block III modules are described in Reference 2.

Block IV varied from the prior procurements in that: the design specifications and the qualification tests were more stringent; the procurement allowed proposals from each contractor for either or both of two categories of module, intermediate-load and residential; and the procurement was effected in the form of sequential development and production contracts. Intermediate-load modules, defined in Reference 3, are intended for use in installations providing 20 kW to 500 kW. Typical applications would be power-generating stations for office buildings, apartment complexes, water pumping installations, shopping centers, and small industrial complexes. Residential modules, defined in Reference 4, are intended for rooftop installation on a single-family residence to provide 2 to 10 kW.

Each successful Block IV proposer was awarded a contract for development of about one kW of modules. For each design that completed qualification tests successfully, a subsequent production contract for 1 to 4 kW was issued. The total nominal purchased power from the seven contractors whose modules passed the tests is 32 kW, including development and production modules. The contractors are ARCO Solar, Inc.; Applied Solar Energy Corp. (ASEC); General Electric Co. (GE); Motorola Inc.; Photowatt International, Inc.; Solarex Corp., and Spire Corp. Eight designs are included, of which six are intermediate-load and two are residential. The descriptions of these designs is the content of this handbook.

During the period of the Block IV procurement, modules of four other designs were purchased by JPL, either as part of the Block IV procurement or seperately, in the latter case for the purpose of subjecting them to the complete set of Block IV qualification tests. These modules are described in Appendix A. At this time not all of them have completed the qualification tests. The four designs were submitted by ARCO Solar, GE, Solar Power Corp. and Solenergy Corp.

Figure 1, a view of part of the FSA field-test site at JPL, shows some of the Block IV modules assembled for obtaining field-test data in system configurations.

The purpose of this User Handbook is to supply engineering data for planning or investigating the application of Block IV modules. The user is advised of two cautionary statements: first, omission from this document of any solar-cell module does not imply that that module design does not meet the requirements of the Block IV specifications contained in References 3 and 4; second, in conformance with the Block IV specifications, module performance data at Nominal Operating Cell Temperature (NOCT) is based on NOCT values obtained at 100 mW/cm^2 insolation. However, as current practice is to obtain NOCT values at 80 mW/cm^2, both values of NOCT are listed for each module. Anyone requiring additional technical information should direct his request to the author, Melvin I. Smokler, or to L. Daniel Runkle, FSA Module Performance and Failure Analysis Area Manager, at the Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, California 91109.

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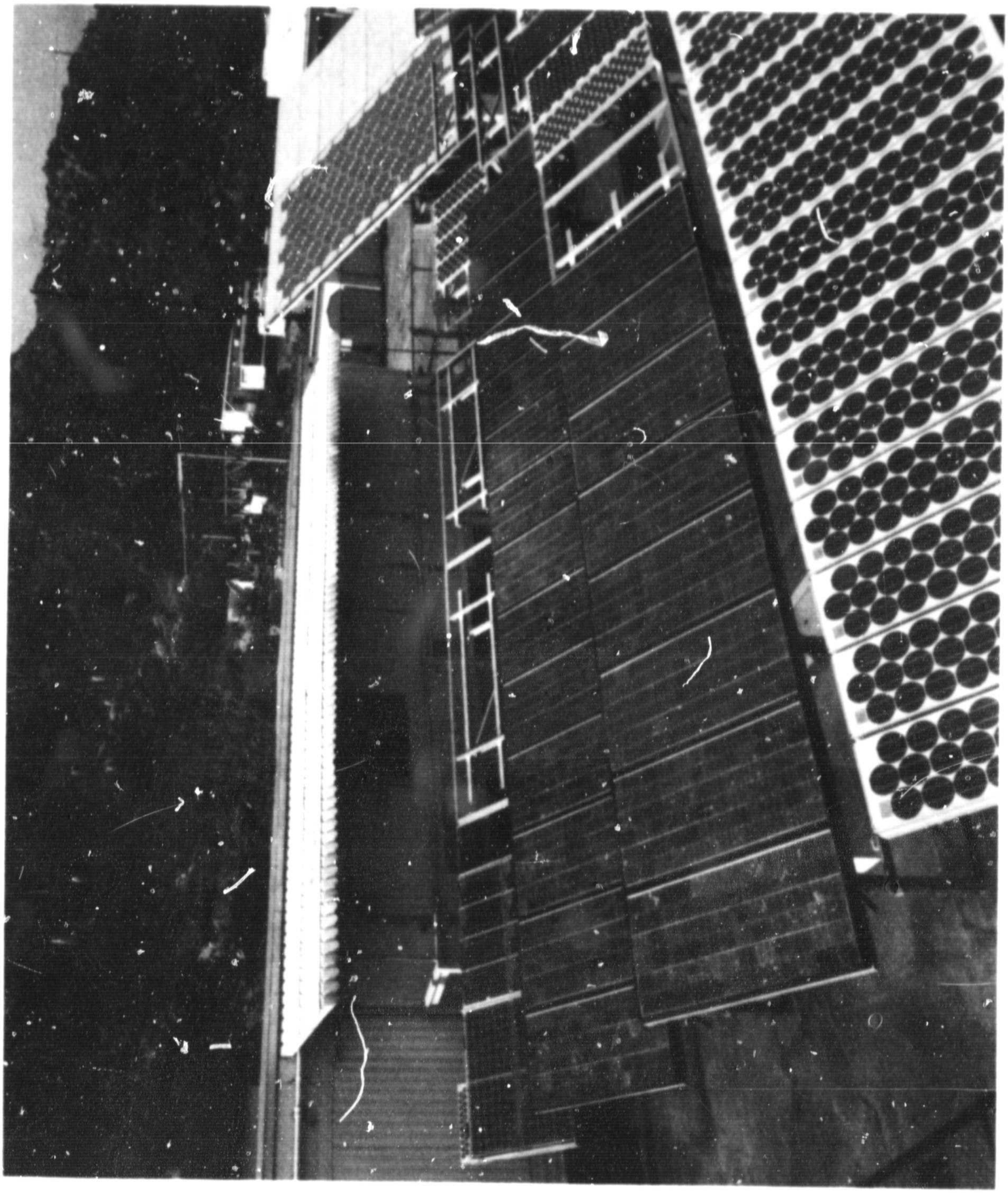

Figure 1. Block IV Modules at JPL Field-Test Site

SECTION II

MODULE DESCRIPTIONS

The Block IV intermediate-load modules were obliged to meet the requirements of Reference 3. The principal requirements are:

(1) Module power must be defined as the power at Nominal Operating Voltage (V_{NO}) under Standard Operating Conditions (SOC). SOC is defined as an irradiance level of 100 mW/cm^2, an optical air mass of AM1.5, and a cell temperature equal to Nominal Operating Cell Temperature (NOCT). NOCT is defined as the cell temperature under the following conditions:

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.

(2) Breakdown voltage from terminals to ground must exceed 2000 Vdc.

(3) Circuit design must protect against module degradation due to cell heating in a short-circuited module with an open-circuit cell failure.

(4) Maximum module dimensions must not exceed 1.2 x 1.2 m (47.244 x 47.244 in.).

(5) The modules must withstand the following test environment (see Appendix B for details and criteria):

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

(b) 5 cycles of 90% relative humidity betweeen 23°C and 40°C.

(c) 10,000 cycles of mechanical cyclic pressure, simulating wind and other loads of $\pm$2.4 kPa ($\pm$50 lb/ft^2).

(d) Twisted mounting surface of 20 mm/m (1/4 in./ft).

(e) Impact of simulated hailstones of 20 mm (3/4 in.) diameter, travelling at 20.1 m/s (45 mi/h).

The residential modules were obliged to meet the requirements of Reference 4. These requirements are identical with those for the intermediate-load modules except that the breakdown voltage limit is 1500 Vdc and that shingle-type modules must be subjected to a wind-resistance test uplift loading of 1.7 kPa (35 lb/ft^2) in lieu of the mechanical cyclic-loading test.

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Samples of each module design were subjected to a qualification test program (see Appendix B) 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 breakdwon voltage.

A detailed description of each of the eight modules is given in Table 1. Some of these details are given in the table in the form of references to photographs, drawings, and I-V curves, all of which are included in this handbook to provide a comprehensive description of the Block IV modules.

Table 1. Block IV Module Characteristics

	Manufacturer	ARCO Solar	ASEC	GE	Motorola	Photowatt	Solarex	Solarex	Spire
IDENT	MFR's Part No.	012110-E	60-3062-F	47J[illegible]7731-C	MSP43D40-G	ML-1961-D	580-BT-I-C	580-BT-R-C	058-0007-A
	Module Type[a]	INT	INT	RES	INT	INT	INT	RES	INT
PHYSICAL	Photographic Views	Figure 2	Figure 5	Figure 8	Figure 12	Figure 15	Figure 18	Figure 21	Figure 25
	Overall Dimensions [mm (in.)]								
	Length	1219 (48.0)	1198 (47.2)	818 (32.2)	1198 (47.2)	1199 (47.2)	1200 (47.3)	1193 (47.0)	1200 (47.2)
	Width	305 (12.0)	696 (27.4)	669 (26.4)	356 (14.0)	444 (17.5)	635 (25.0)	628 (24.7)	417 (16.4)
	Height	54 (2.1)	39 (1.5)	7.6 (0.3)	38 (1.5)	51 (2.0)	51 (2.0)	16 (0.63)	62 (2.4)
	Weight kg(lbs)	5.2 (11.4)	13.5 (29.7)	4.0 (8.8)	5.8 (12.8)	7.4 (16.3)	13.9 (30.6)	11.2 (24.6)	7.8 (17.2)
	Support Structure Planarity Rqmt [mm/m (in./ft)][b]	20 (0.25)	20 (0.25)	20 (0.25)	20 (0.25)	20 (0.25)	20 (0.25)	20 (0.25)	20 (0.25)
	Module Drawing and Materials	Figure 3	Figure 6	Figure 9	Figure 13	Figure 16	Figure 19	Figure 22	Figure 26
	Module Installation	Figure 3	Figure 6	Figure 10	Figure 13	Figure 16	Figure 19	Figure 23	Figure 26
	Electrical Connections	Figure 3	Figure 6	Figure 9	Figure 13	Figure 16	Figure 19	Figure 22	Figure 26
	Cells								
	Quantity	35	136	19	33	72	72	72	108
	Size [mm (in.)]	Dia: 102.9 (4.05)	Dia: 76.2 (3.0)	Dia: 100 (3.94)	100.3 x 100.3 (3.95 x 3.95)	Dia: 76.2 (3.0)	95 x 95 (3.74 x 3.74)	95 x 95 (3.74 x 3.74)	63.5 x 63.5 (2.5 x 2.5)
	Packing Factor	0.76	0.74	0.76	0.76	0.62	0.85	0.87	0.84
	Base Material	Cz	Cz	Cz	Cz	Cz	SEMI-XTL	SEMI-XTL	Cz
	Junction	n/p	n/p	n/p	n/p p+	n/p p+	n/p p+	n/p p+	n/p p+
	Front Metallization	Printed Ag	Ti-Pd-Ag	Printed Ag	Pd-Ni-Solder	Ni-Solder	Ti-Pd-Ag	Ti-Pd-Ag	Ti-Pd-Ag
	Back Metallization	Printed Al, Ag	Ti-Pd-Ag	Printed Al,Ag	Pd-Ni-Solder	Ni-Solder	Al-SnAg	Al-SnAg	Ti-Pd-Ag
ELECTRICAL	Nominal Performance[c]								
	Power, rated (watts)	32.0	71.0	14.4	32.9	33.0	53.0	50.0	49.1
	Voltage, rated (volts)	15.0	14.0	6.6	15.0	5.0	13.5	4.2	14.0
	Current (amps)	2.13	5.07	2.18	2.19	6.6	3.9	11.9	3.5
	SOC Performance[c,d,e]								
	Power, maximum (watts)	31.5	74.7	14.2	33.1	33.4	54.8	50.9	48.2
	Voltage at max power (volts)	14.6	14.4	6.6	14.5	4.85	13.6	4.31	13.5
	Current at max power (amps)	2.16	5.18	2.15	2.28	6.88	4.02	11.8	3.56
	Voltage, open circuit (volts)	19.2	18.3	9.3	17.8	6.24	17.5	5.74	18.0
	Current short circuit (amps)	2.43	5.46	2.53	2.53	7.63	4.61	13.7	3.68
	Fill factor	0.70	0.75	0.60	0.74	0.70	0.70	0.65	0.72
	Efficiency, Module (%)	8.5	9.0	7.3	7.8	6.3	7.2	6.8	9.6
	Eff., encapsulated cell (%)	11.2	12.2	9.6	10.3	10.2	8.5	7.8	11.4
	28°C Performance[e]								
	Power, maximum (watts)	35.7	84.6	18.8	37.3	38.6	62.6	61.2	57.0
	Voltage at max power (volts)	16.6	16.5	8.5	16.2	5.68	16.1	5.27	16.2
	Current at max power (amps)	2.15	5.11	2.21	2.30	6.79	3.90	11.6	3.52
	Voltage, open circuit (volts)	21.0	20.2	11.0	19.5	6.98	19.6	6.70	20.3
	Current, short circuit (amps)	2.42	5.40	2.53	2.50	7.58	4.50	13.2	3.64
	Fill factor	0.70	0.78	0.68	0.76	0.73	0.71	0.69	0.77
	Efficiency, module (%)	9.6	10.1	9.6	8.8	7.2	8.2	8.2	11.4
	Eff., encapsulated cell (%)	12.6	13.6	12.6	11.6	11.6	9.6	9.4	13.6
	I-V curves[e]	Figure 4	Figure 7	Figure 11	Figure 14	Figure 17	Figure 20	Figure 24	Figure 27
	Circuit Diagram	Figure 3	Figure 6	Figure 9	Figure 13	Figure 16	Figure 19	Figure 22	Figure 26
	Breakdown Voltage, Min. $(V_{dc})^{b,f}$	2000	2000	note g	2000	2000	2000	note g	2000

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Table 1. Block IV Module Characteristics (Cont'd)

		ARCO Solar	ASEC	GE	Motorola	Photowatt	Solarex	Solarex	Spire
THERMAL	Nominal Operating Cell Temperature, NOCT (°C)[d]								
	At 100 mW/cm² insolation	52	54	68	56	54	55	65	55
	At 80 mW/cm² insolation	46	47	58	49	47	49	56	49
	Temperature Coefficients[h]								
	ΔV/ΔT (Volts/°C)	−0.086	−0.083	−0.049	−0.078	−0.030	−0.086	−0.029	−0.097
	ΔI/ΔT (Amps/°C)	+0.0011	+0.0027	+0.0097	+0.0011	+0.0027	+0.0046	+0.0136	+0.0015
ENVIRONMENT	Temperature range (°C)[b]	−40 to +90	−40 to +90	−40 to +90	−40 to +90	−40 to +90	−40 to +90	−40 to +90	−40 to +90
	Humidity, max relative (%)[b]	90	90	95	90	90	90	90	90
	Wind load, max [kPa (lbs/ft²)][b]	±2.4 (±50)	±2.4 (±50)	1.7 (35)	±2.4 (±50)	±2.4 (±50)	±2.4 (±50)	±1.7 (±35)	±2.4 (±50)
	Hail impact, max hailstone[b] [mm (in.)]	20.0 (0.75)	20.0 (0.75)	20.0 (0.75)	20.0 (0.75)	20.0 (0.75)	20.0 (0.75)	20.0 (0.75)	20.0 (0.75)

NOTES

[a]INT = Module intended for use in intermediate-load centers, defined here as installations providing 20 kW to 500 kW.
RES = Module intended for use on single-family residence in installations providing 2 kW to 10 kW.

[b]The data given are tested limits, not module limits. For details see Appendix B (Qualification Test Program).

[c]Each module is expected to produce not less than 95% of rated power when loaded to provide rated voltage under Standard Operating Conditions (SOC), i.e.:

1. Module irradiated with 100 mW/cm² insolation at air mass 1.5 (AM1.5) spectrum.
2. Cell temperature equal to NOCT (per Block IV Specifications; see note d).

[d]The Block IV Specifications define NOCT (Nominal Operating Cell Temperature) as the cell temperature with the module in the Standard Thermal Environment defined as follows:

Insolation	=	100 mW/cm²
Air temperature	=	20°C
Average wind velocity	=	1 m/s
Electrical load	=	open circuit
Mounting	=	normal to solar noon on structure typical of application

Practice at the time of publication is to measure NOCT with the module in the Nominal Thermal Environment, which is the same as the Standard Thermal Environment except that the insolation level is 80 mW/cm².

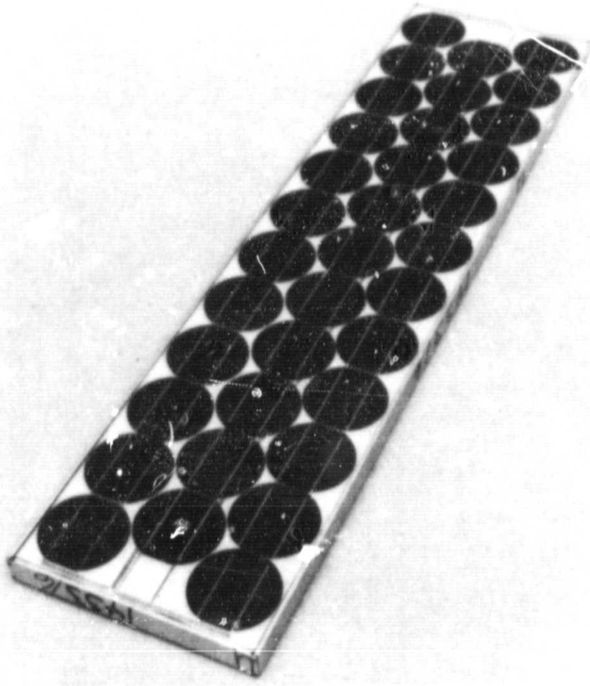
[e]The data presented here for each module design were obtained by measurement and extrapolation of the performance of one sample module of that design. The radiation source was a Large-Area Pulsed Solar Simulator calibrated by use of a calibrated reference cell of the same spectral response as the module to irradiate the module with the equivalent of 100 mW/cm² at AM1.5. Module temperature was approximately 25°C. Extrapolation was performed by computer, based upon a set of measured temperature coefficients (voltage, current, and series resistance) for each module design. The resultant families of I-V curves for the sample modules are given in Figures 4, 7, 11, 14, 17, 20, 24, and 27.

[f]Modules should not be series-connected to obtain system voltages under worst-case conditions (100 mW/cm² insolation, 0°C cell temperature, open circuit) exceeding:

500 volts for intermediate load modules
250 volts for residential modules

[g]Not applicable. This module has no exposed conductive surface and is intended for installation in a non-conductive assembly.

[h]These coefficients are for use in the neighborhood of the maximum power points on the module I-V curves. They are useful for determining power output at a selected voltage and temperature when the available I-V curve was made at a different temperature. For details see Reference 3, Appendix B.



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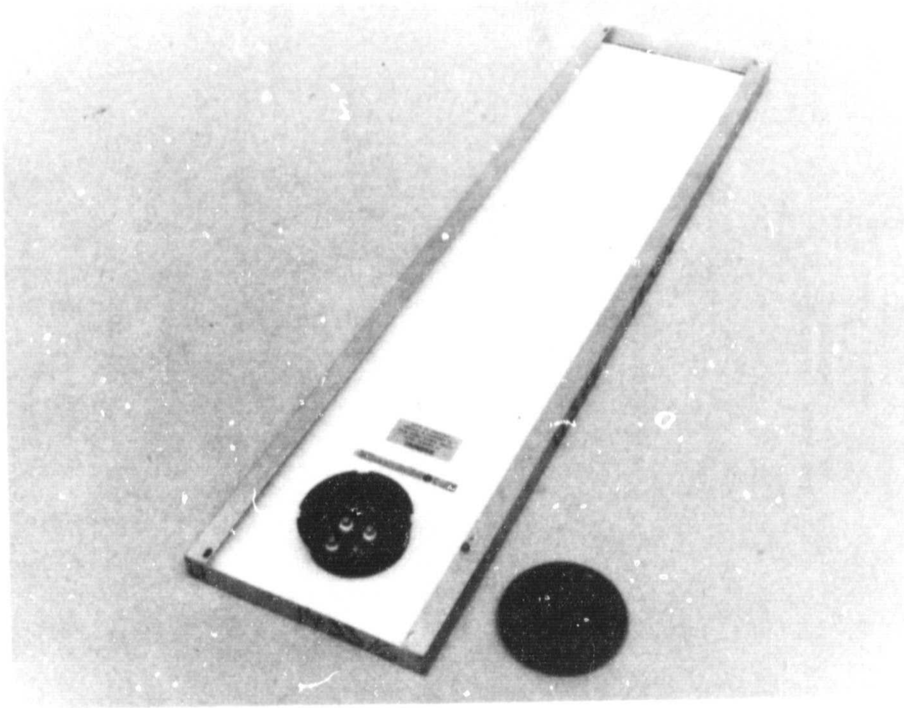

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Figure 2. ARCO Solar Module: Photographic Views

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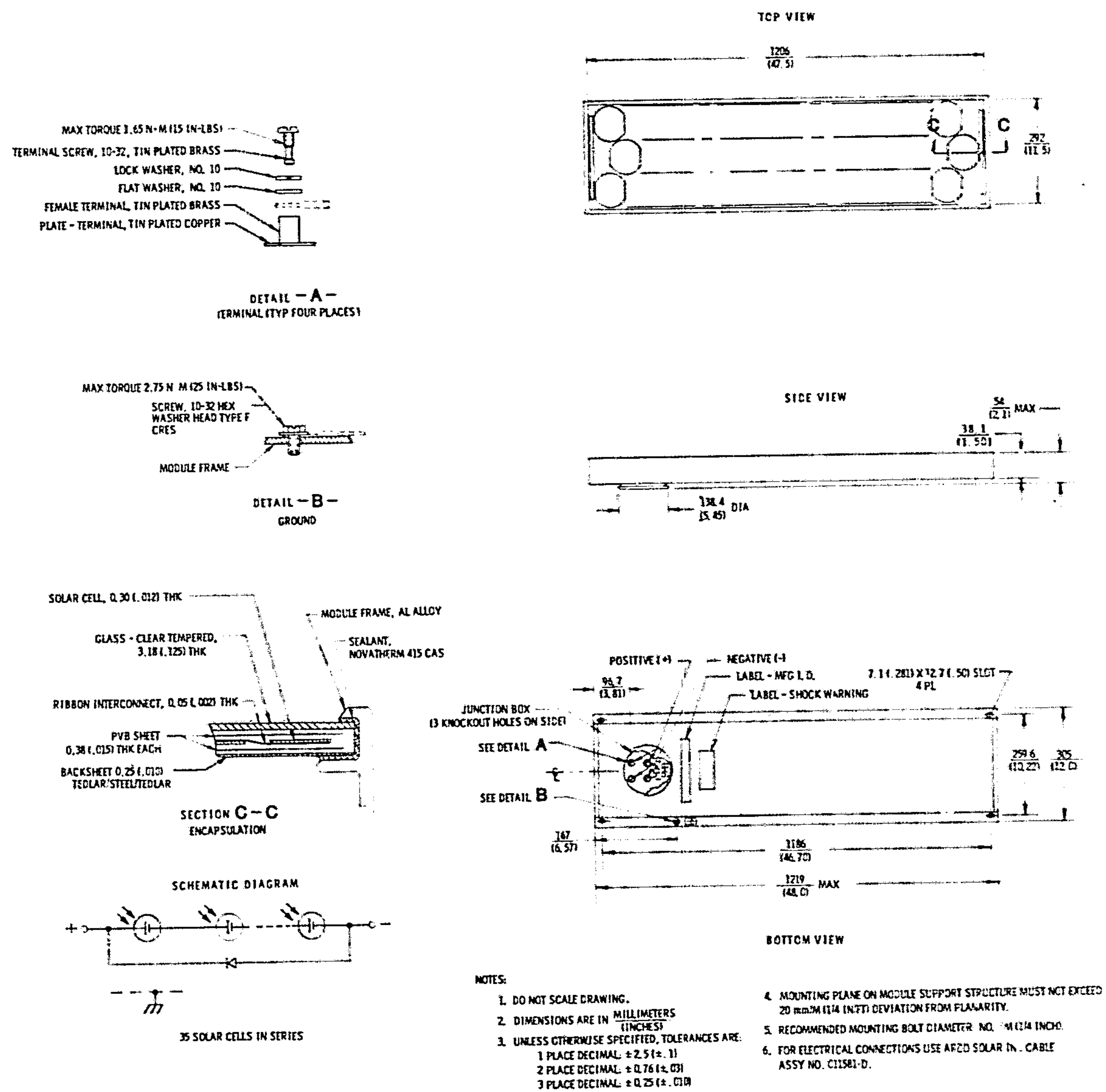

Figure 3. ARCO Solar Module: Drawing

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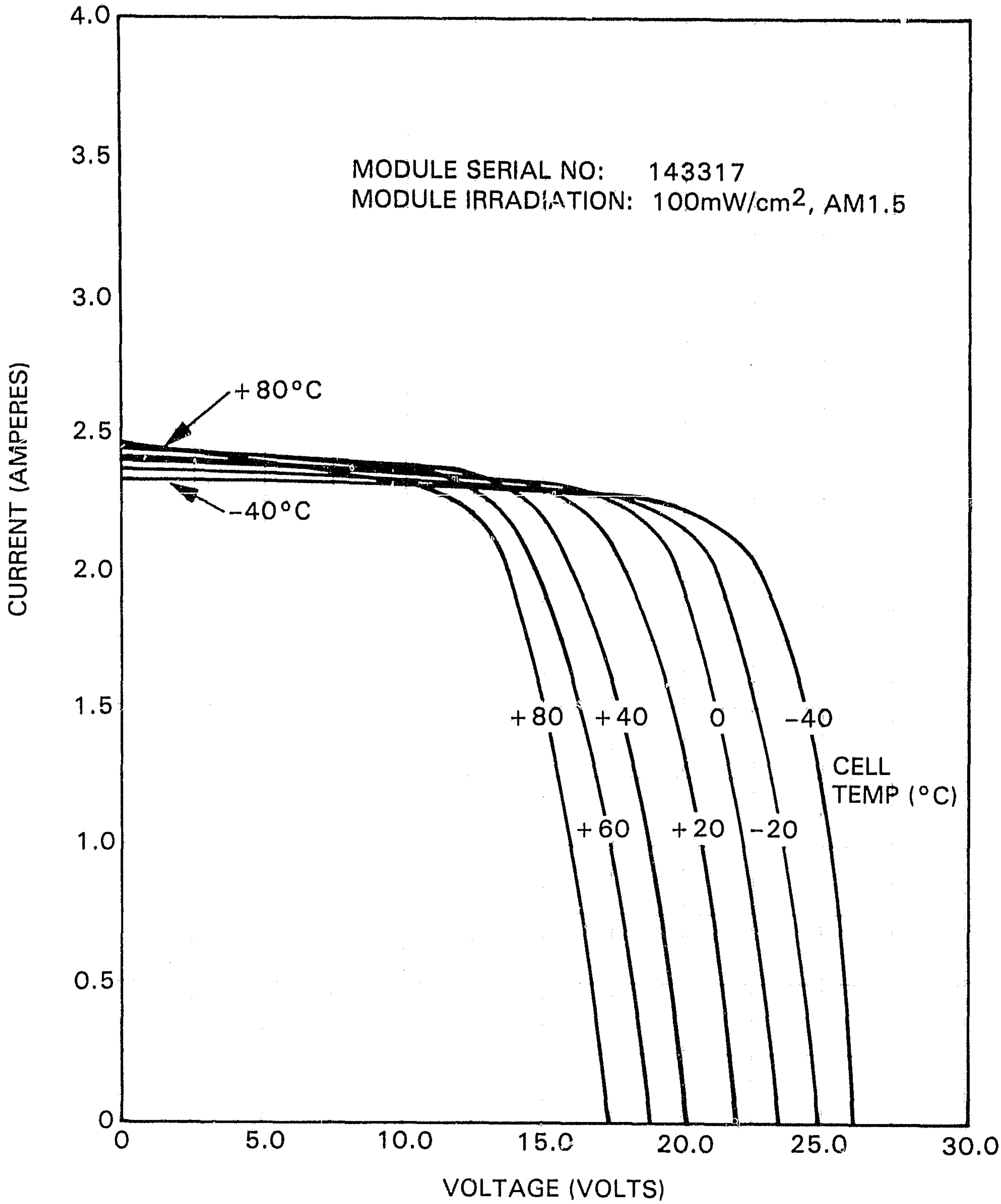

Figure 4. ARCO Solar Module: I-V Curves

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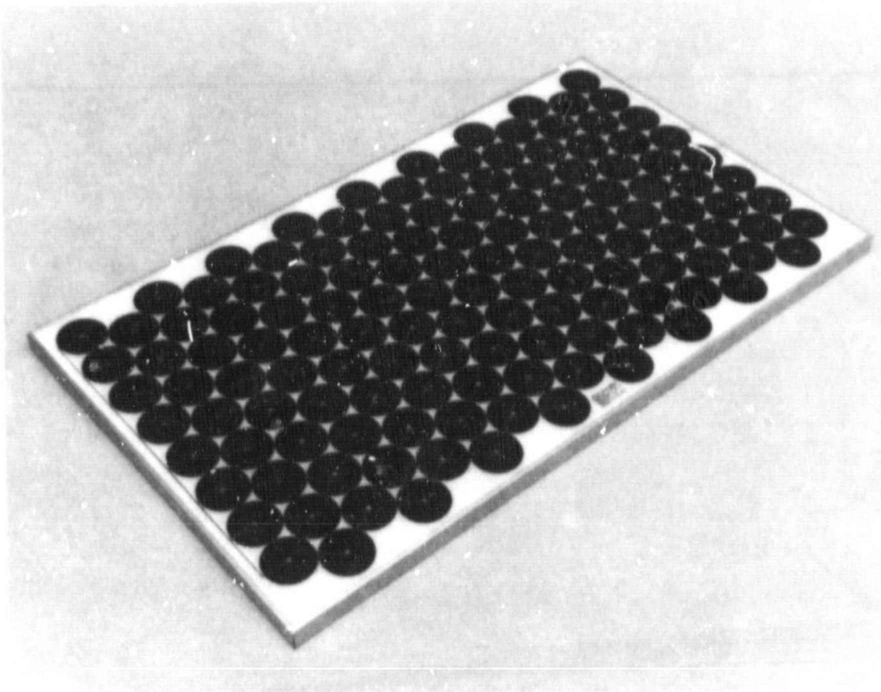

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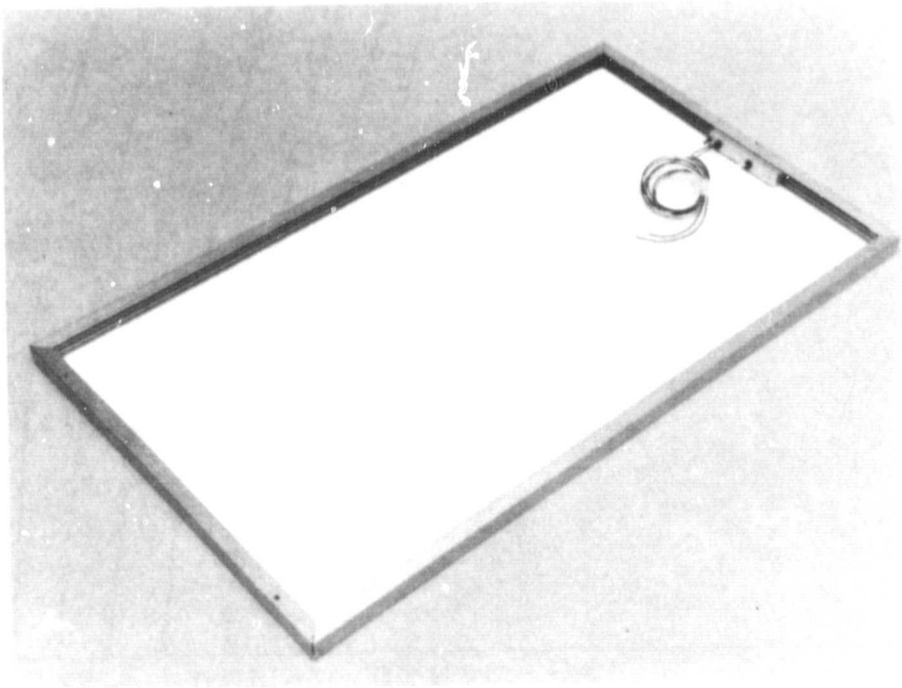

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Figure 5. ASEC Module: Photographic Views

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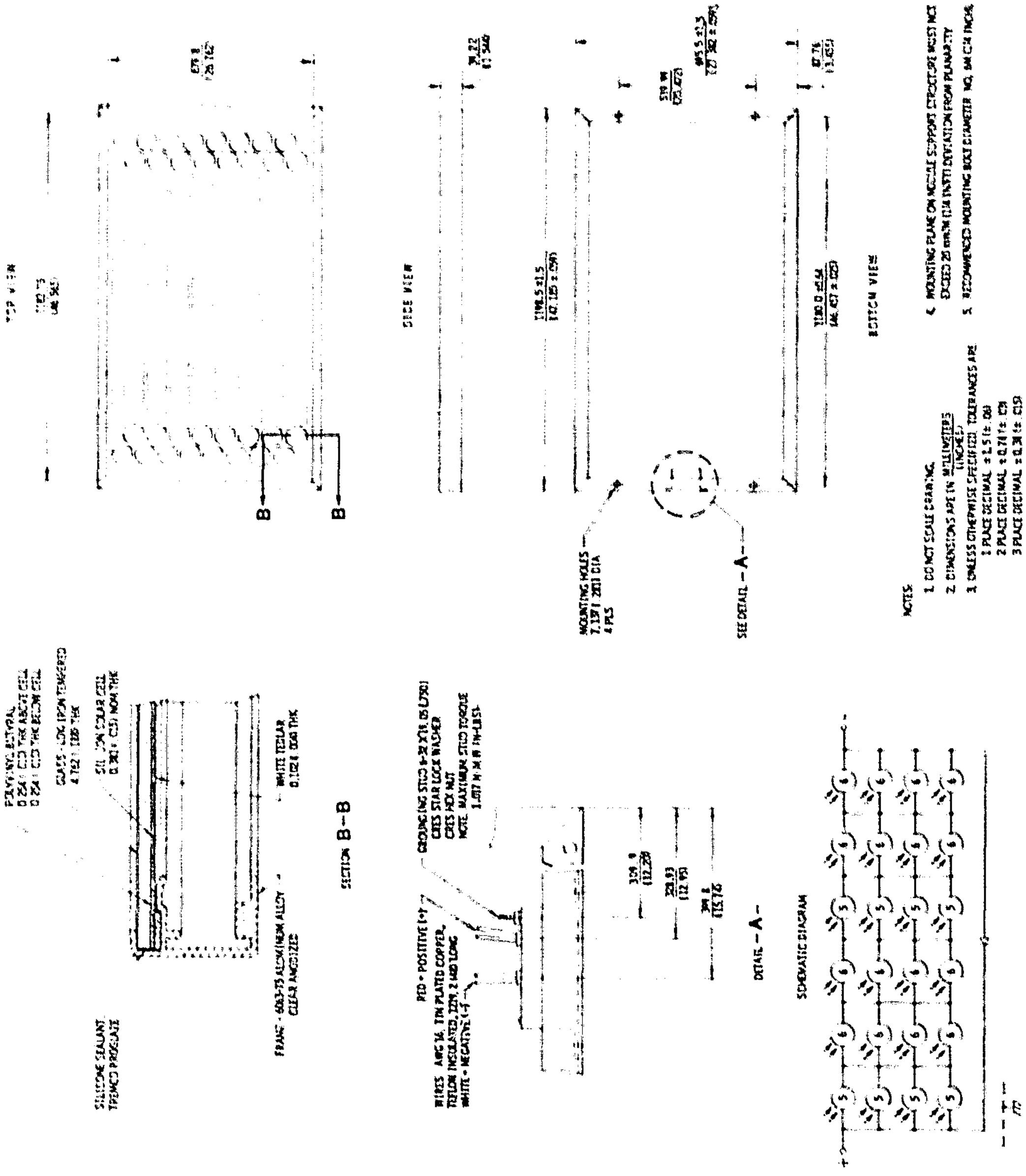

Figure 6. ASEC Module: Drawing

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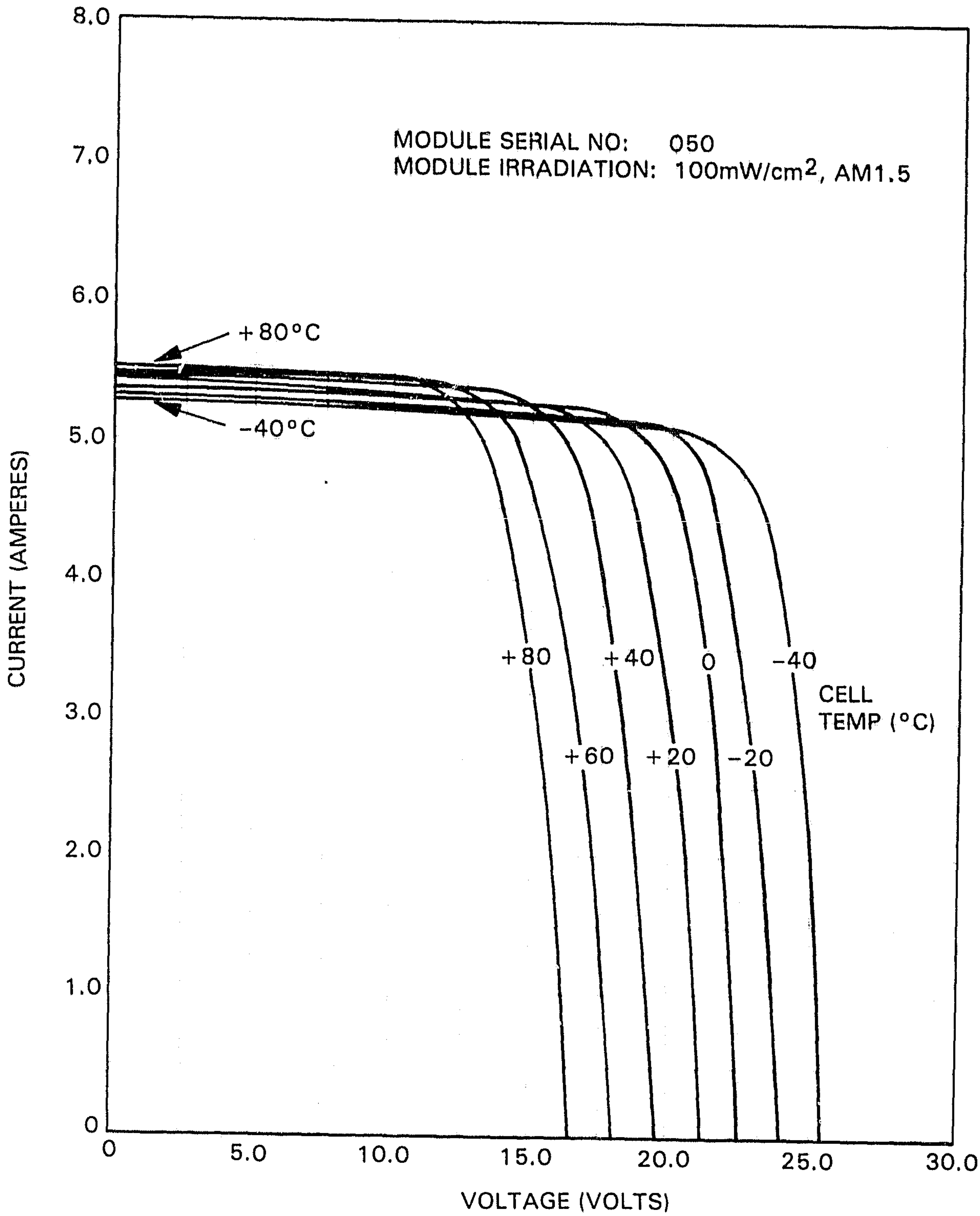
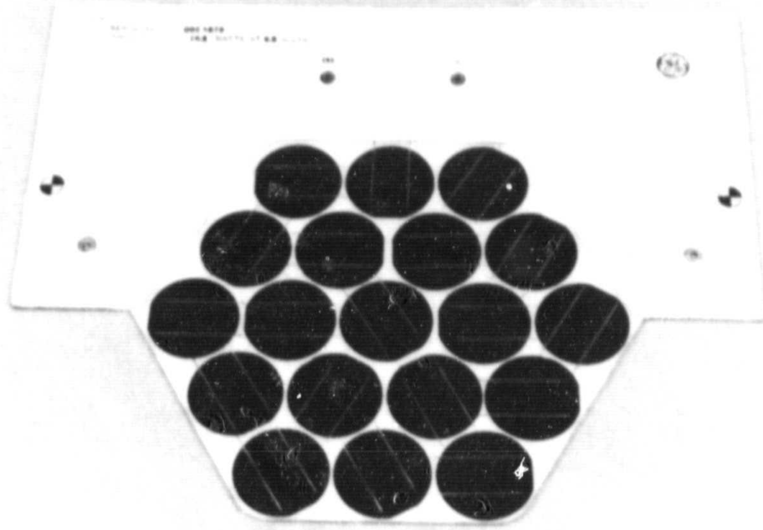


Figure 7. ASEC Module: I-V Curves



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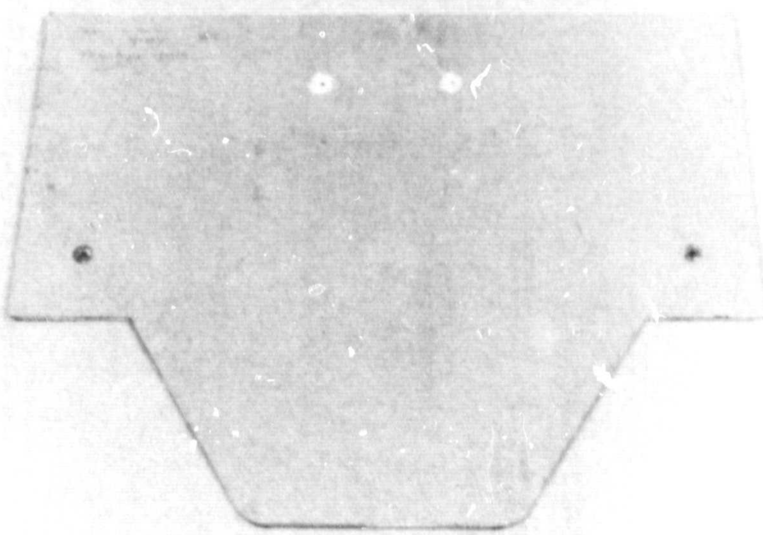

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Figure 8. GE Module (Residential): Photographic Views

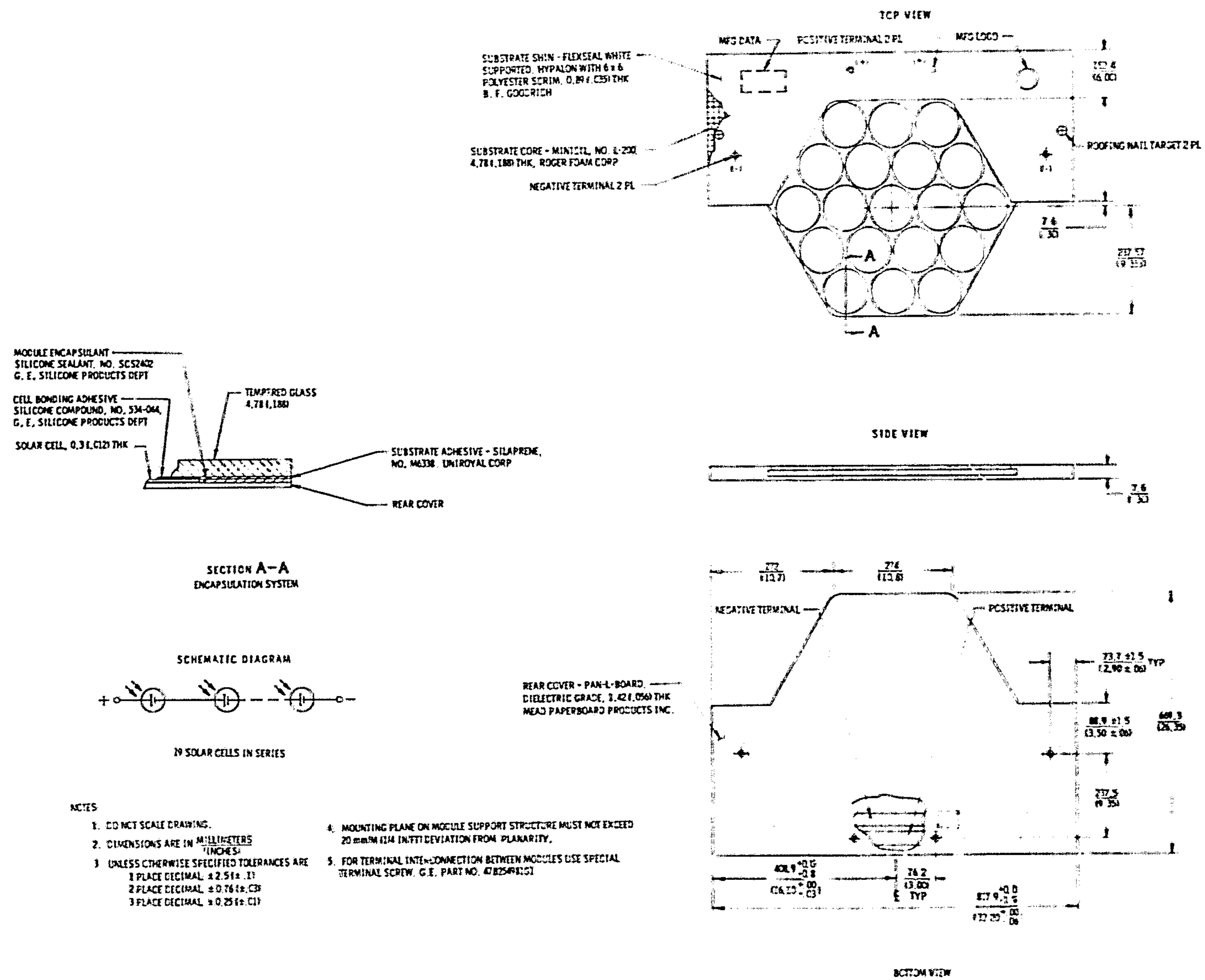

Figure 9. GE Module (Residential): Drawing

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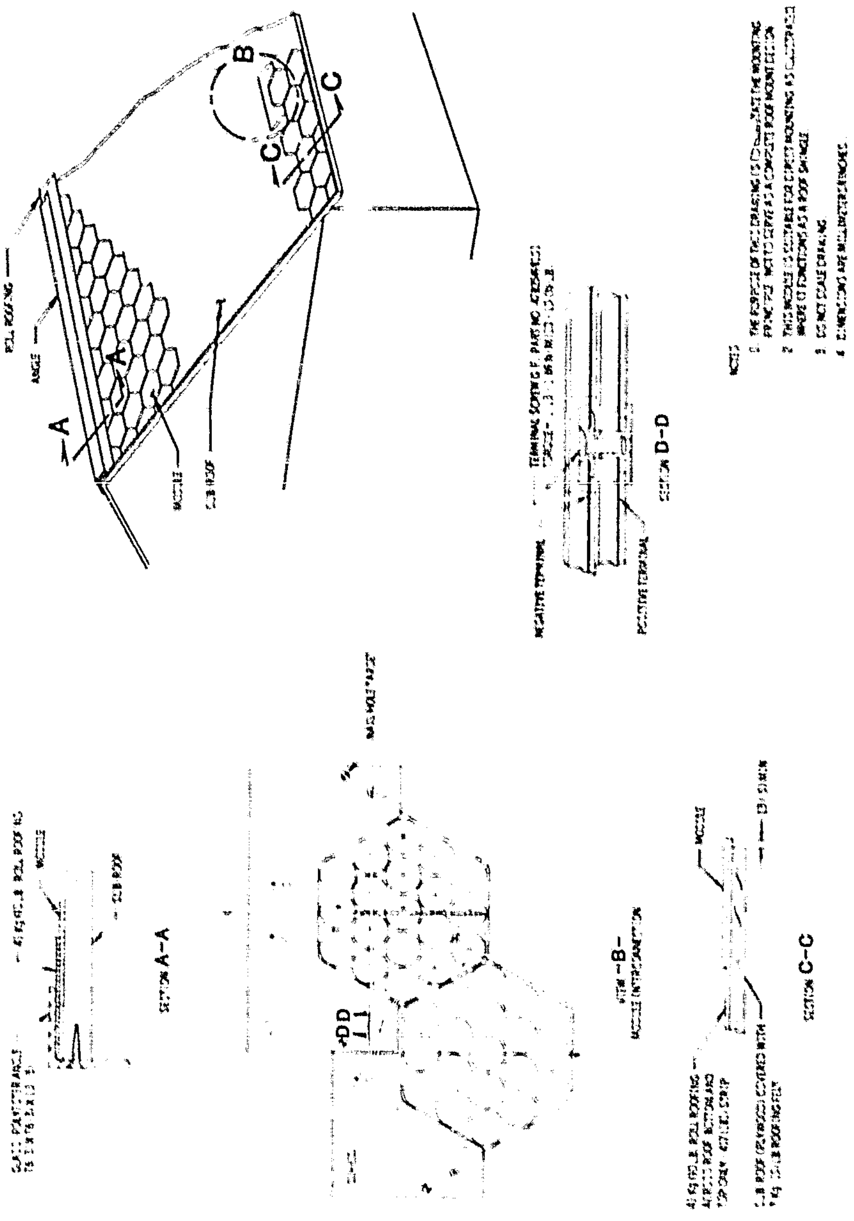

Figure 10. GE Module (Residential): Installation

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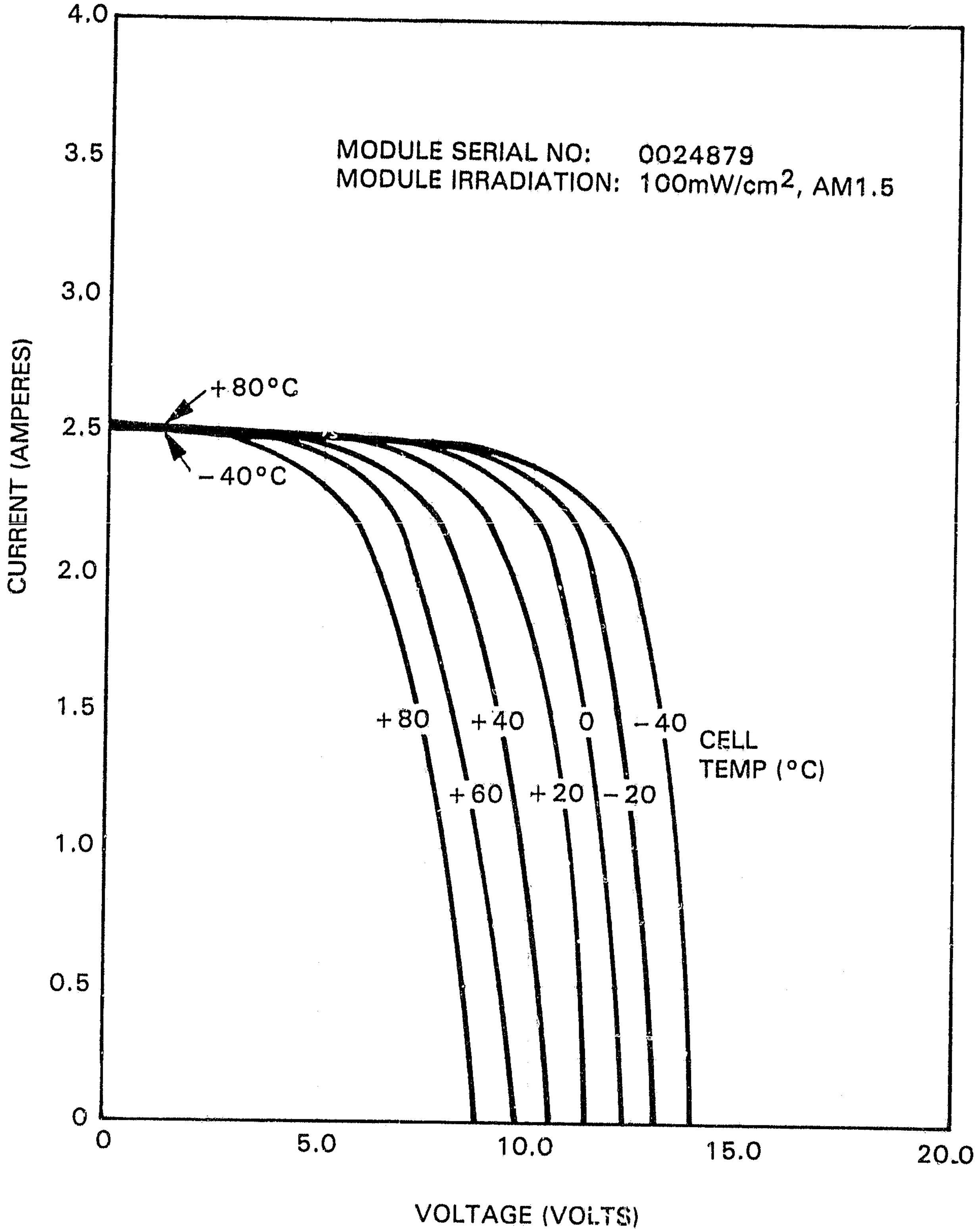

Figure 11. GE Module (Residential): I-V Curves

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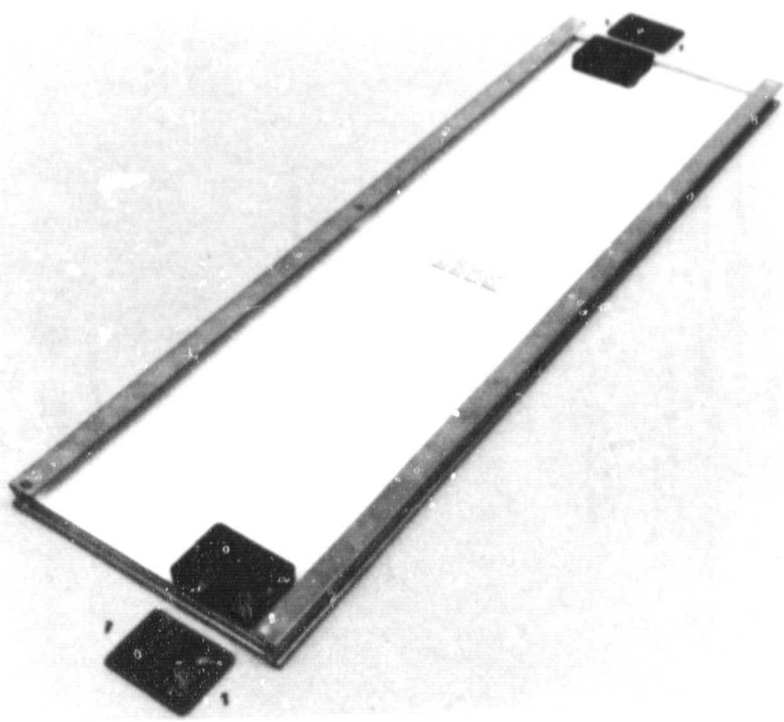

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Figure 12. Motorola Module: Photographic Views

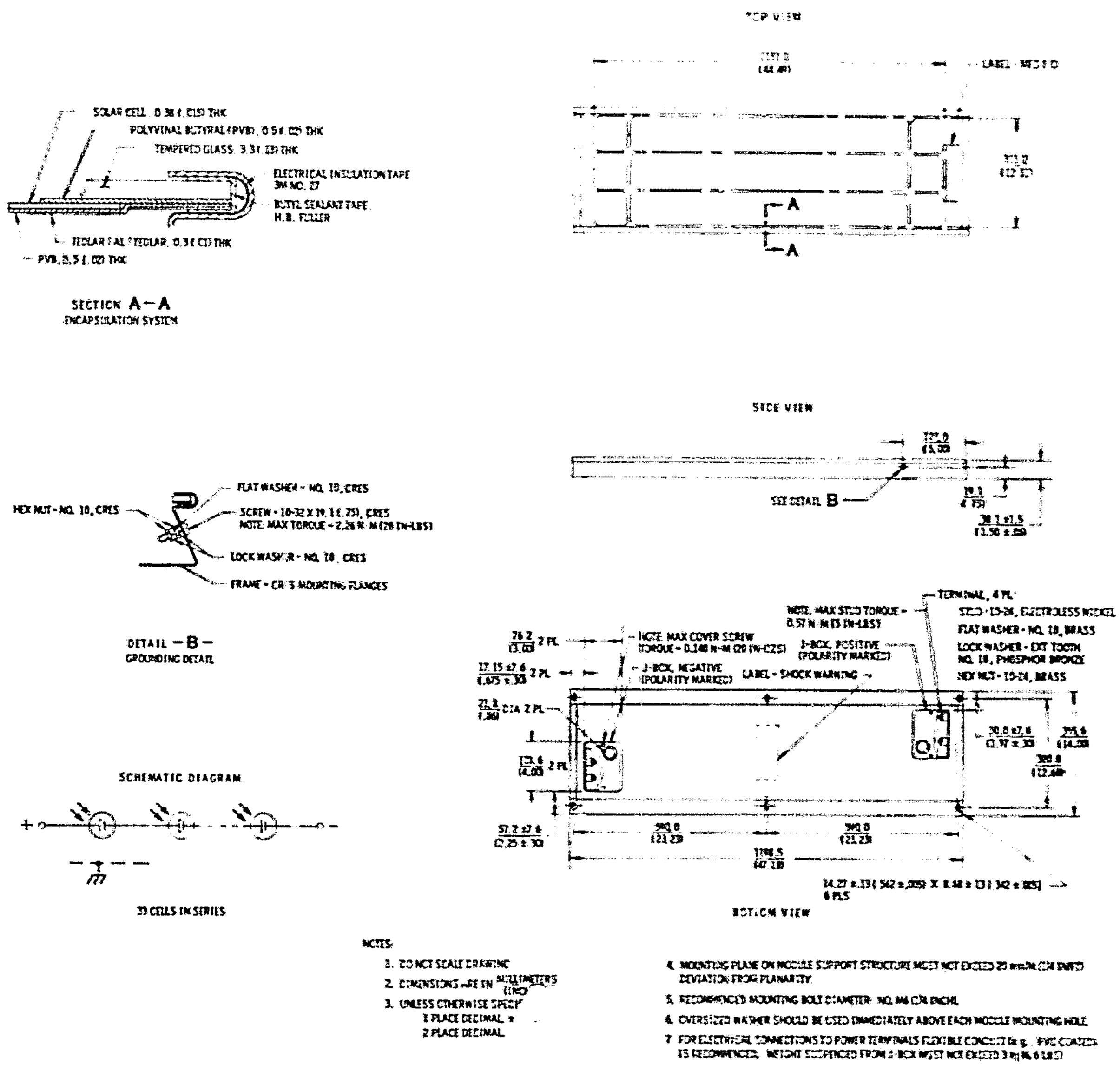

Figure 13. Motorola Module: Drawing

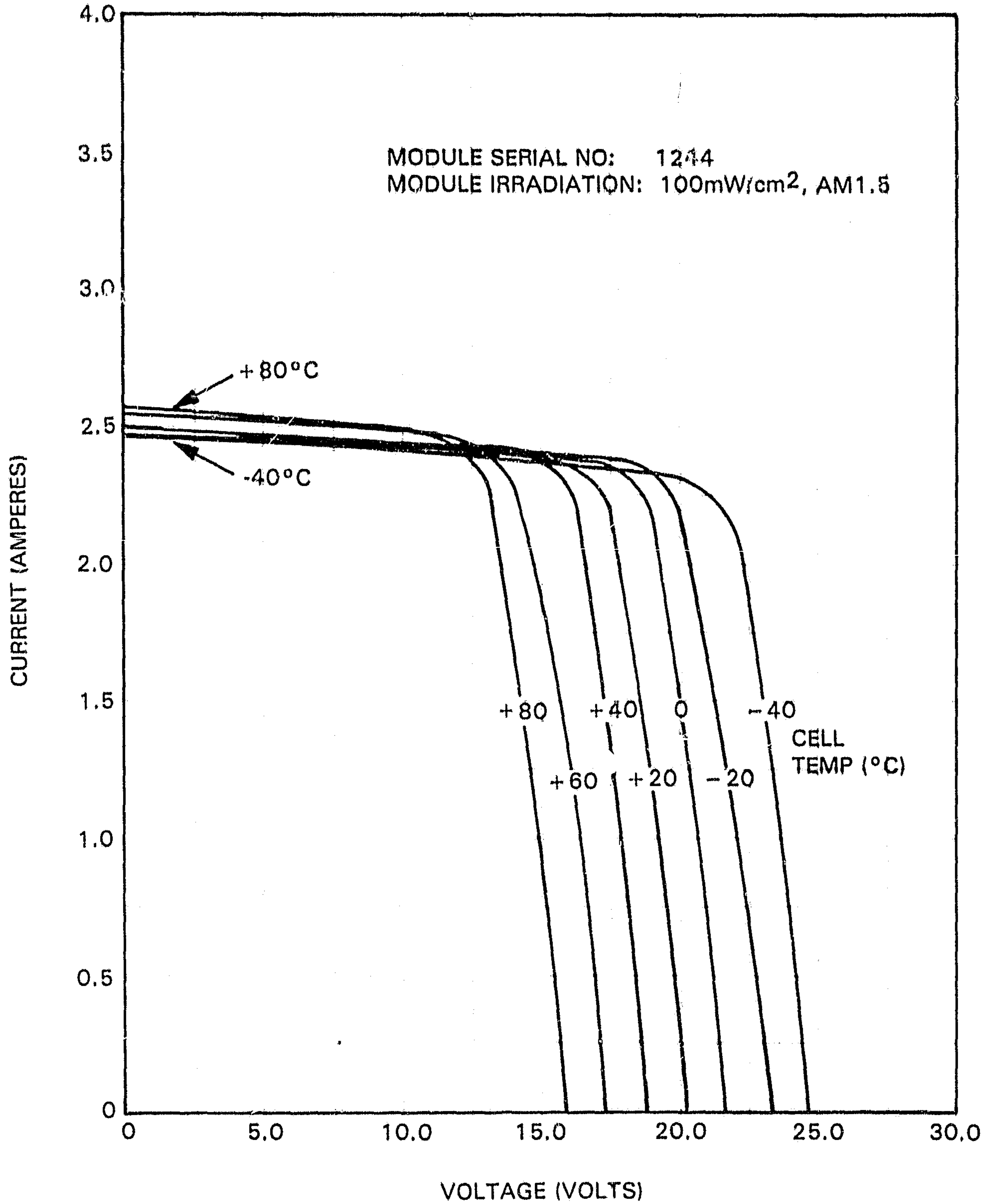

Figure 14. Motorola Module: I-V Curves

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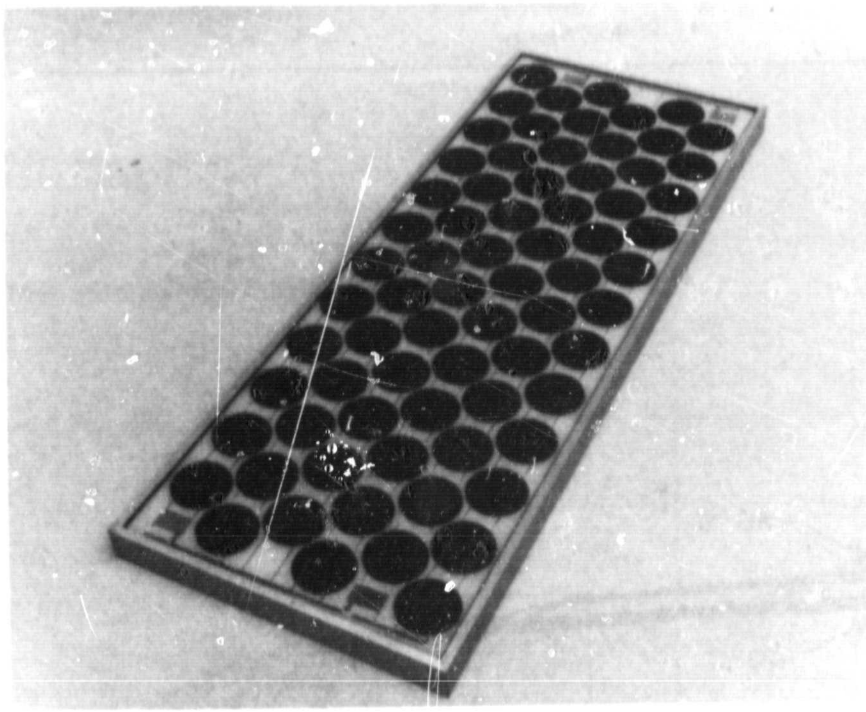

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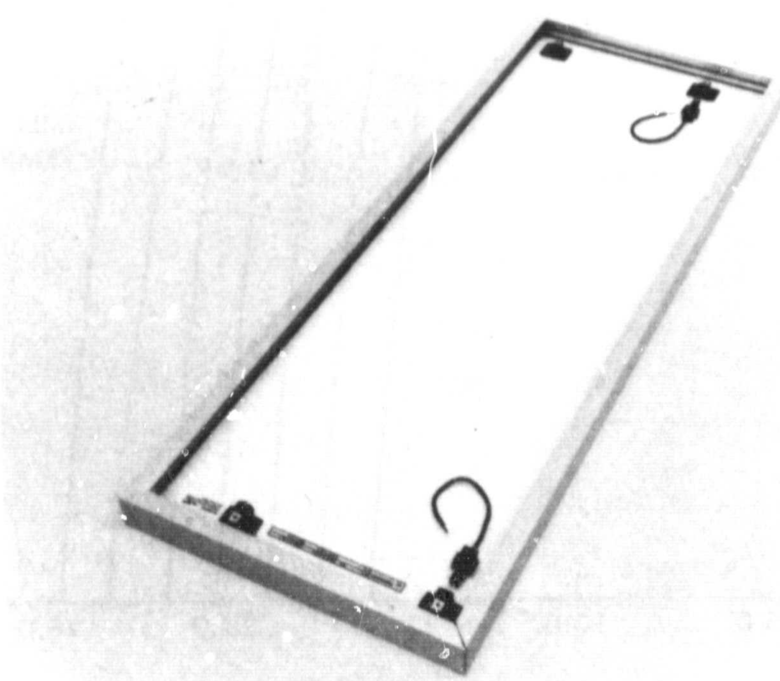

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Figure 15. Photowatt Module: Photographic Views

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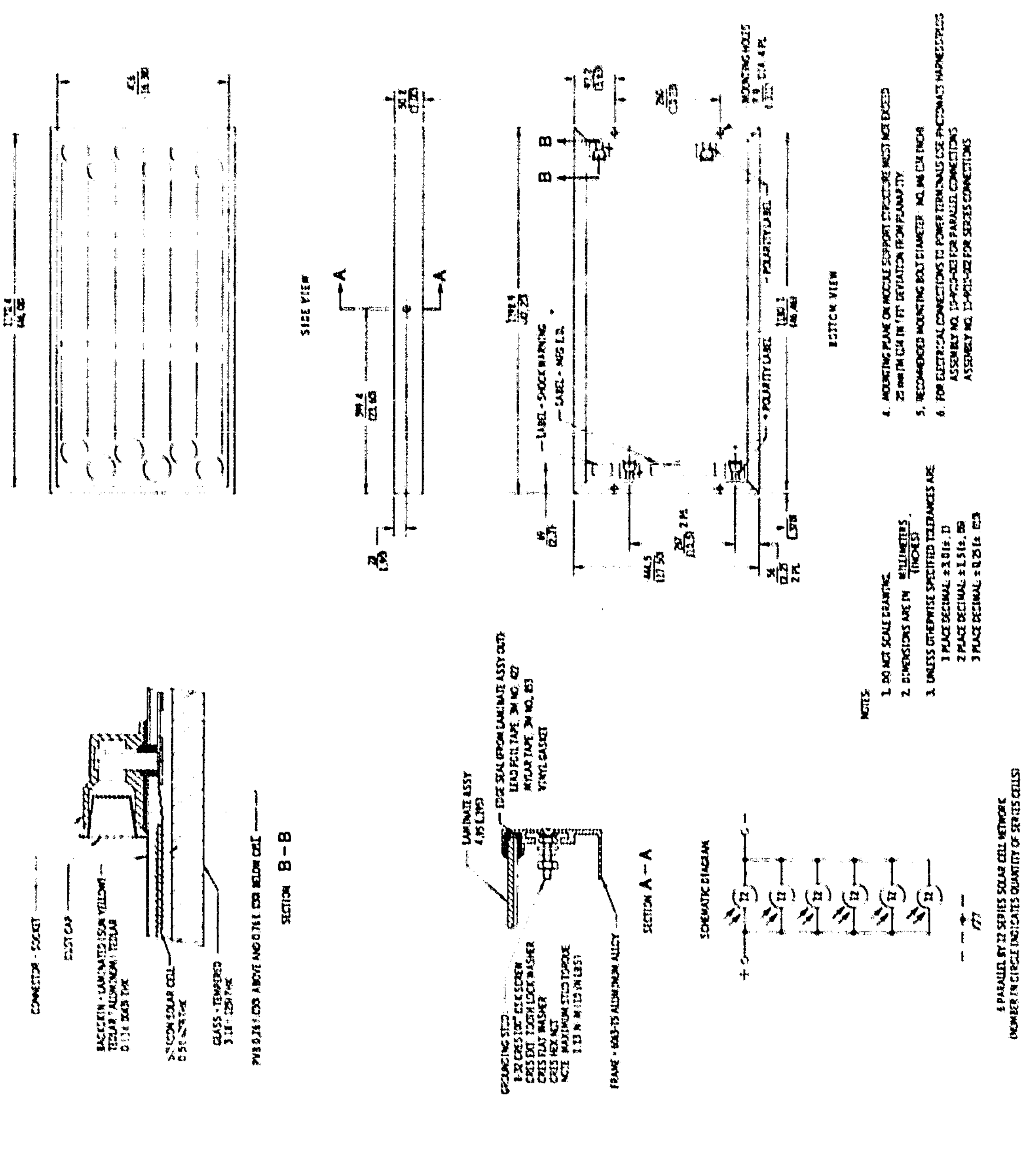


Figure 16. Photowatt Module: Drawing

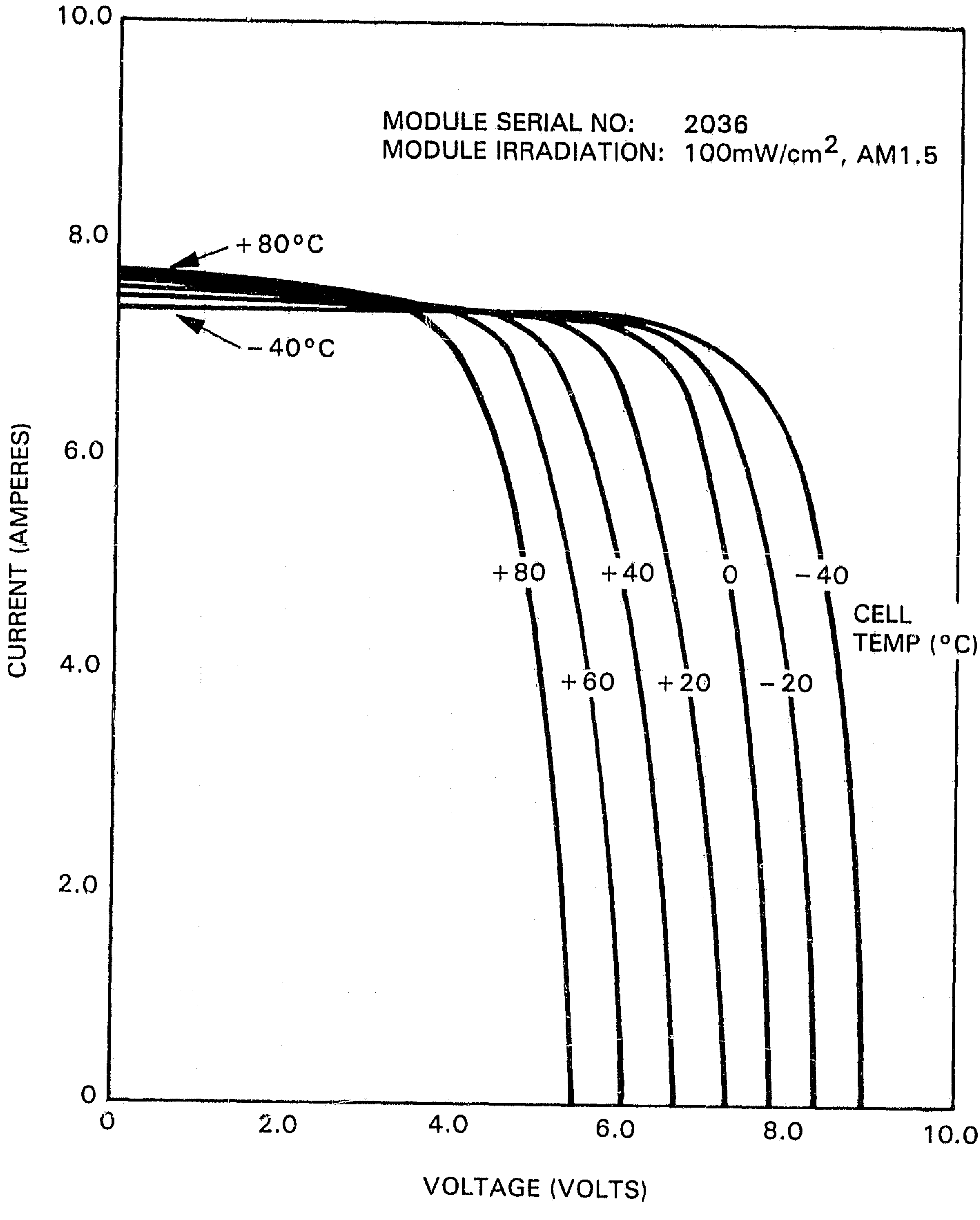
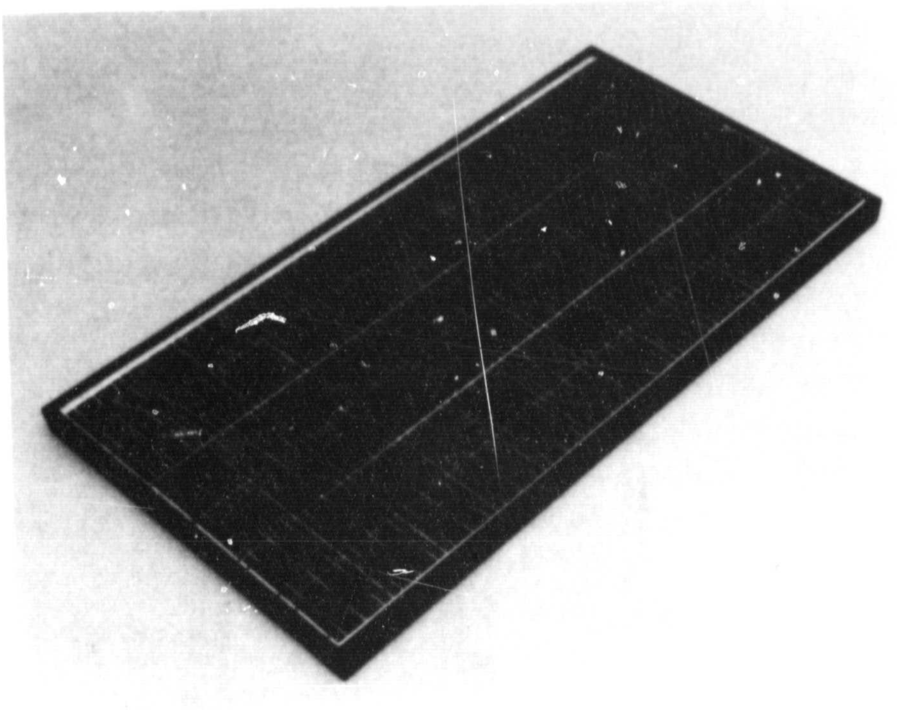


Figure 17. Photowatt Module: I-V Curves



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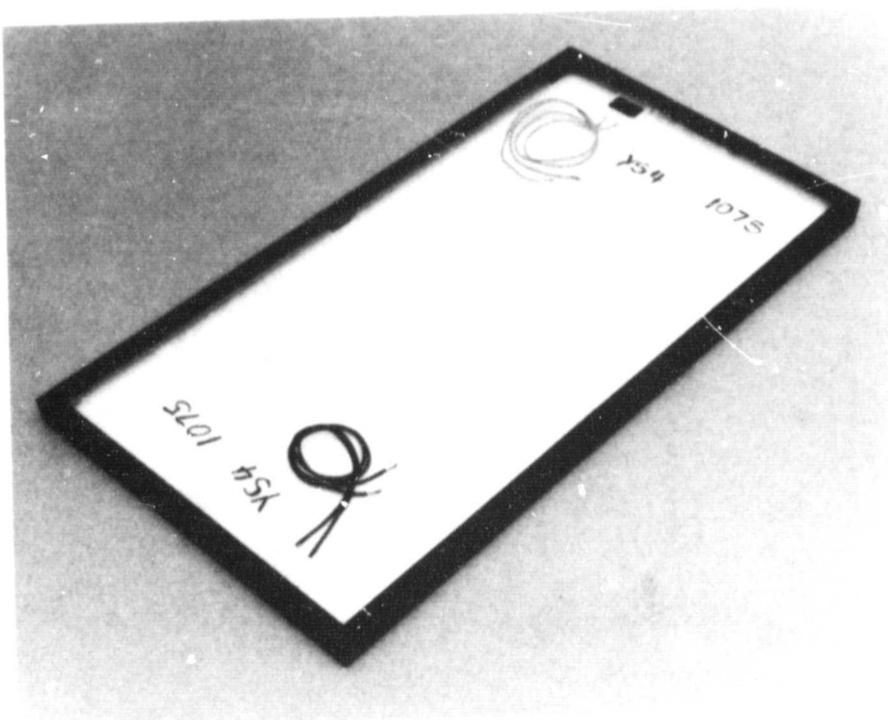

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Figure 18. Solarex Module: Photographic Views

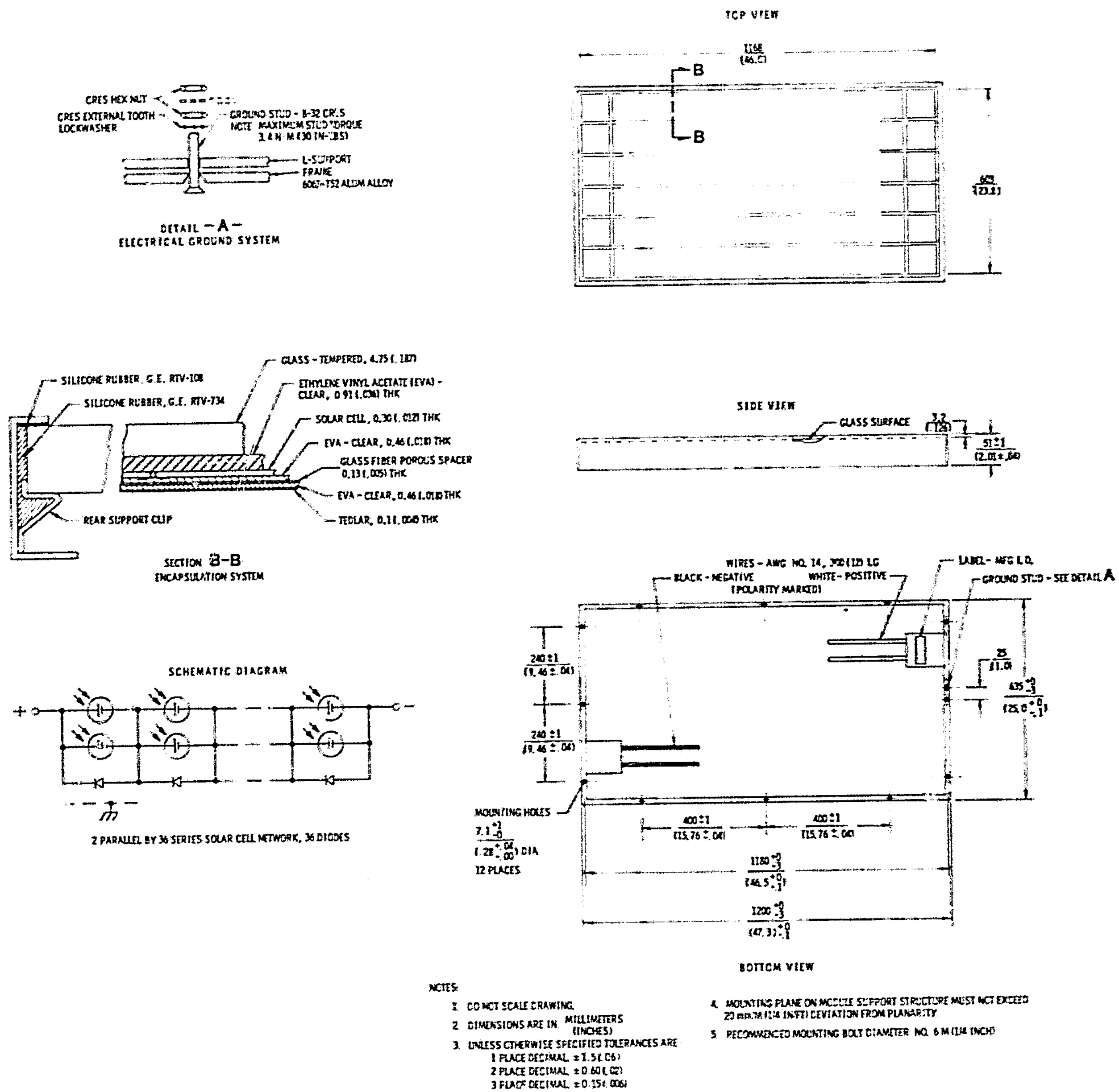

Figure 19. Solarex Module: Drawing

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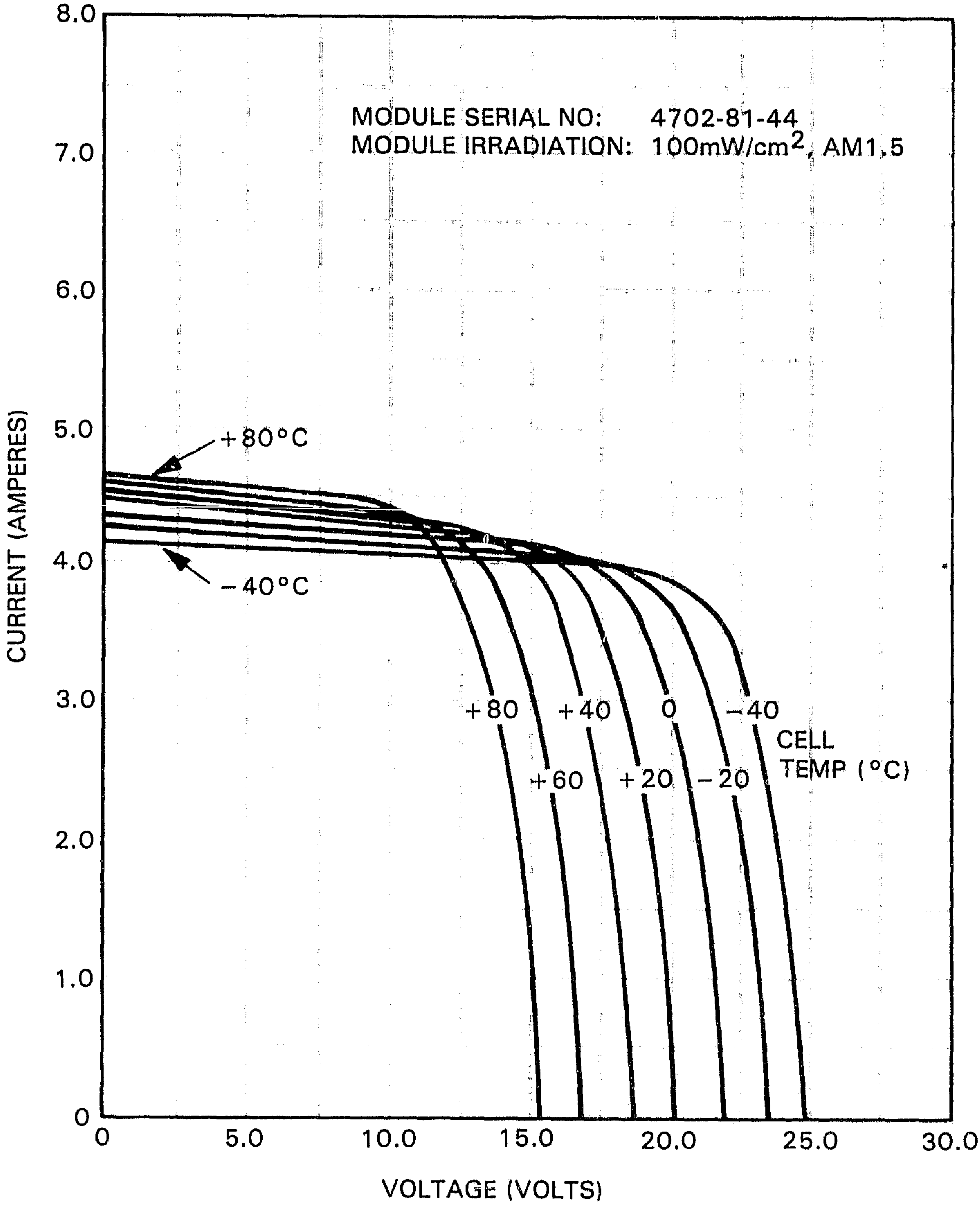
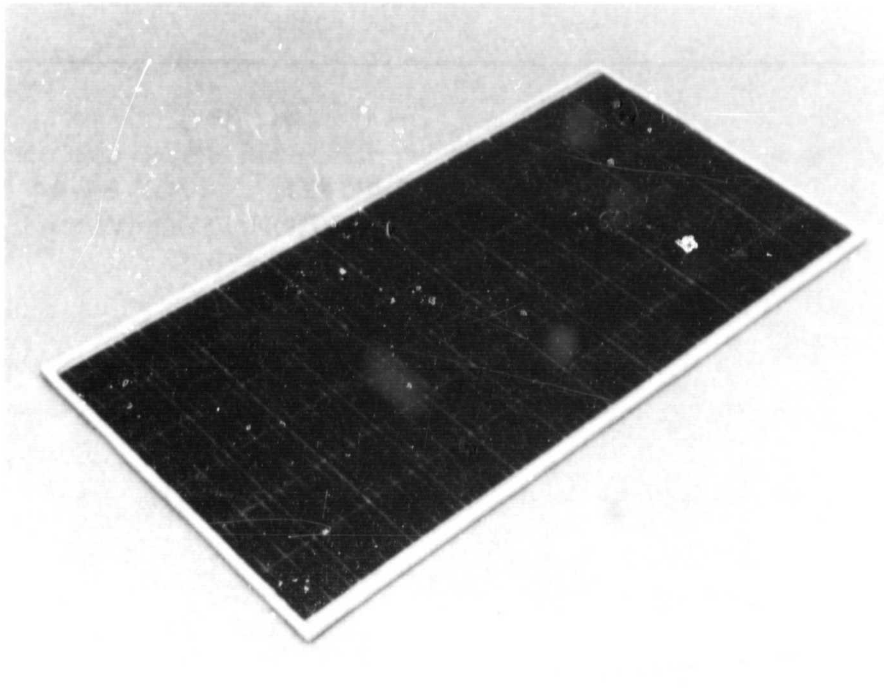


Figure 20. Solarex Module: I-V Curves



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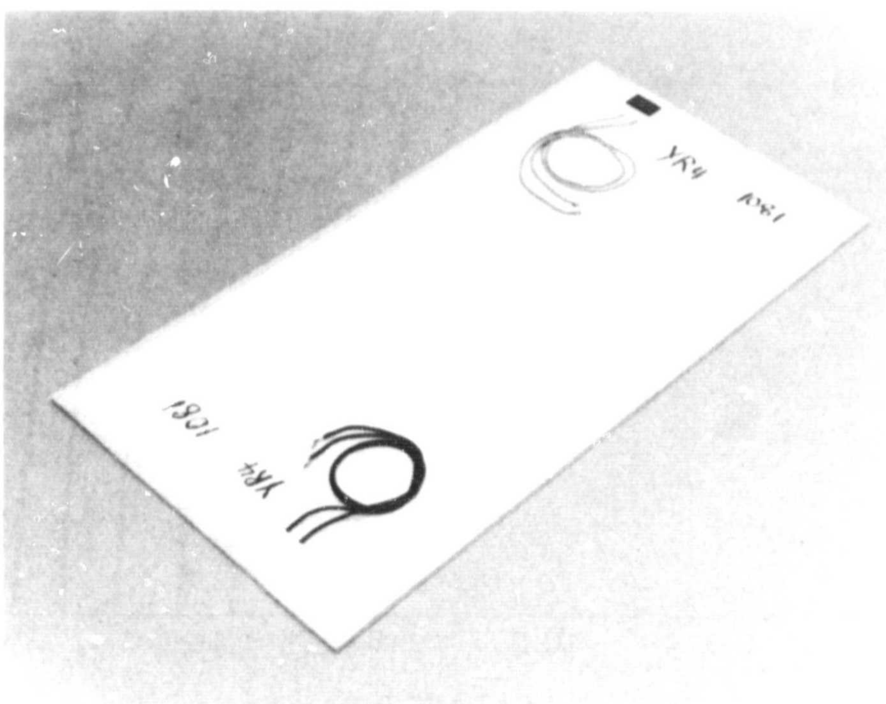

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Figure 21. Solarex Module (Residential): Photographic Views

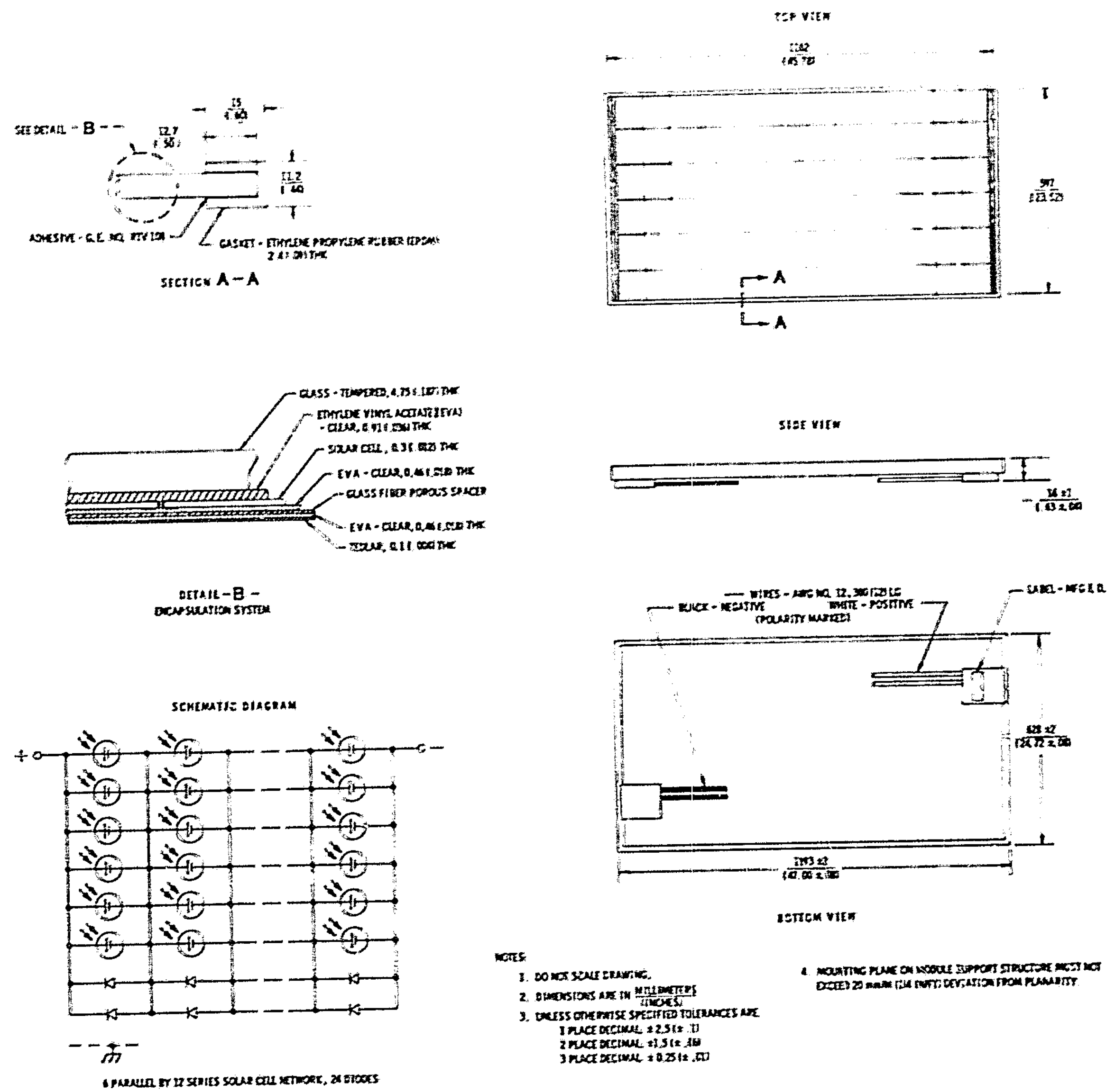
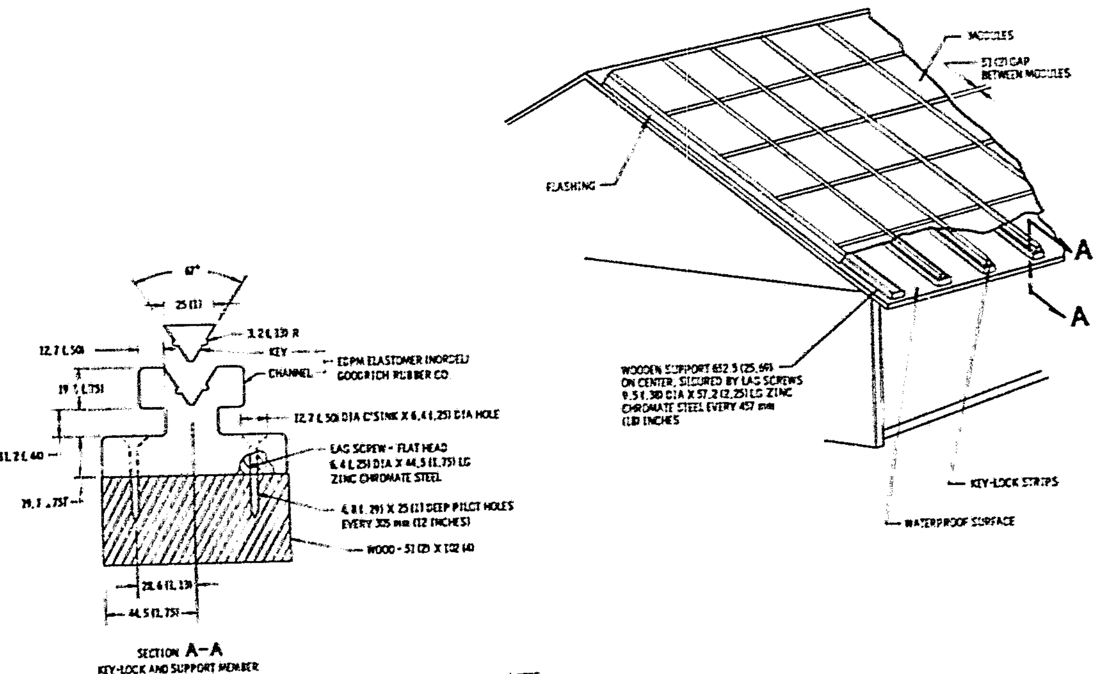


Figure 22. Solarex Module (Residential): Drawing



NOTES:

1. THE PURPOSE OF THIS DRAWING IS TO ILLUSTRATE THE MOUNTING PRINCIPLE, NOT TO SERVE AS A COMPLETE ROOF MOUNT DESIGN.
2. THIS MODULE IS SUITABLE FOR STANDOFF MOUNTING, AS ILLUSTRATED HERE.
3. DO NOT SCALE DRAWING.
4. DIMENSIONS ARE MILLIMETERS (INCHES)

Figure 23. Solarex Module (Residential): Installation

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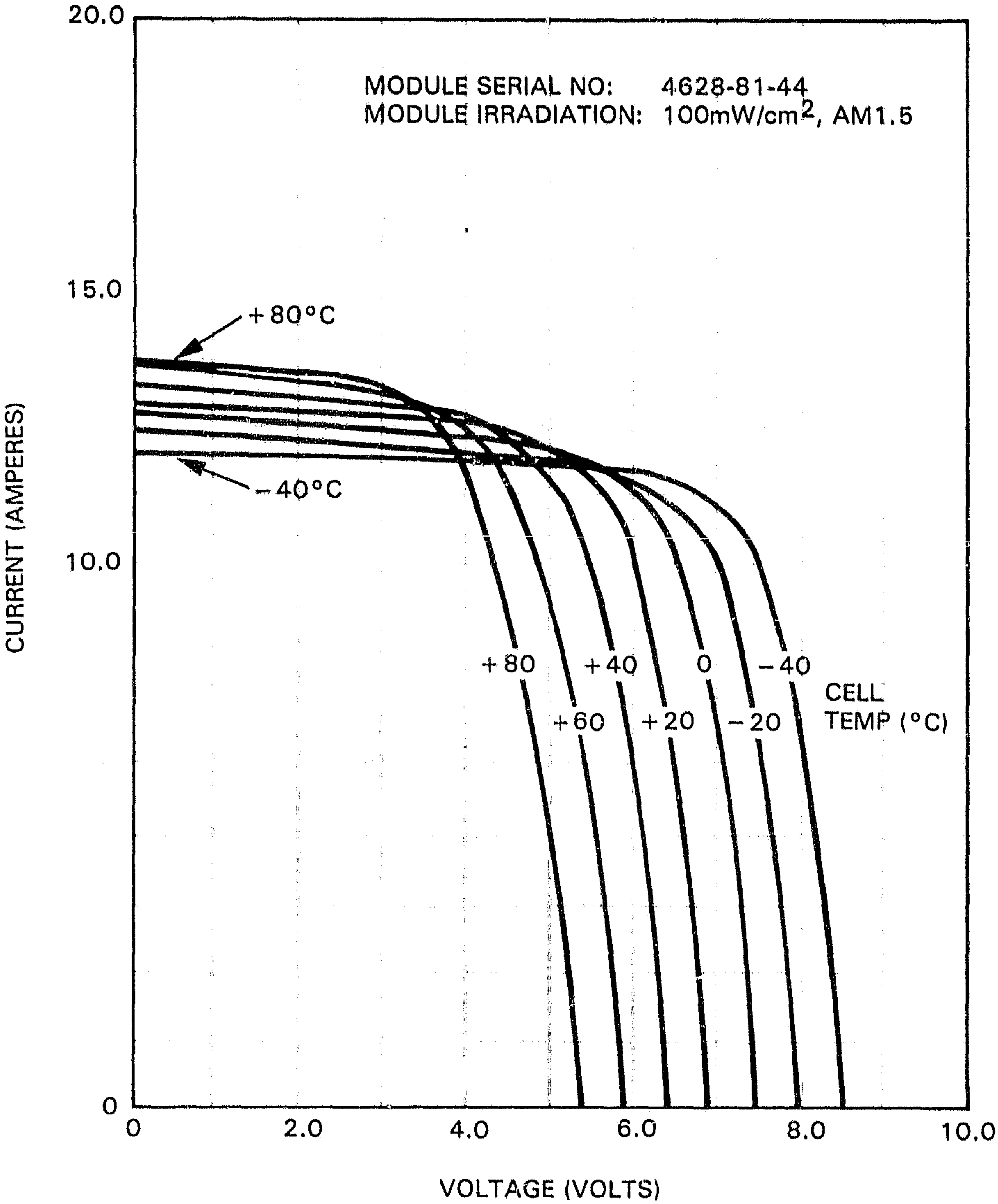
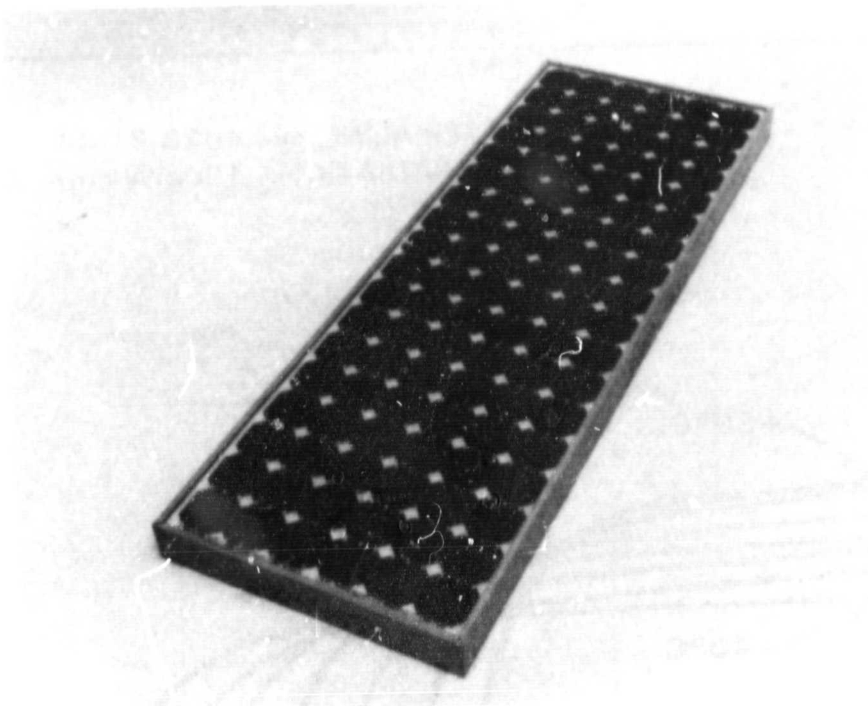


Figure 24. Solarex Module (Residential): I-V Curves



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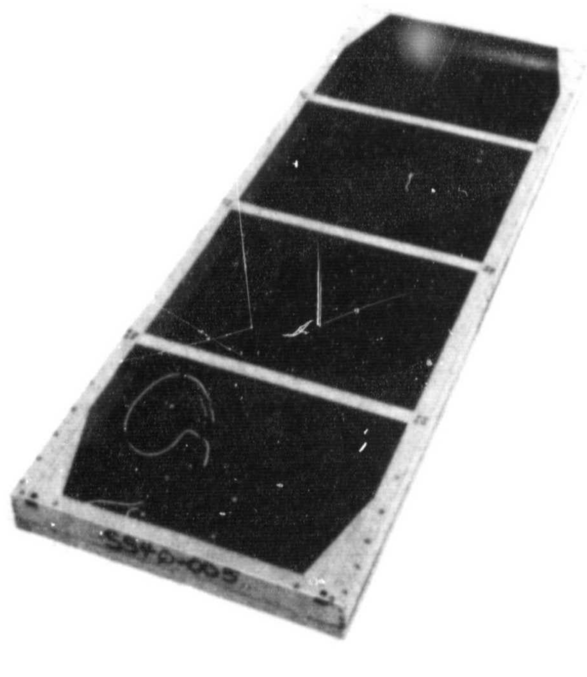

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Figure 25. Spire Module: Photographic Views

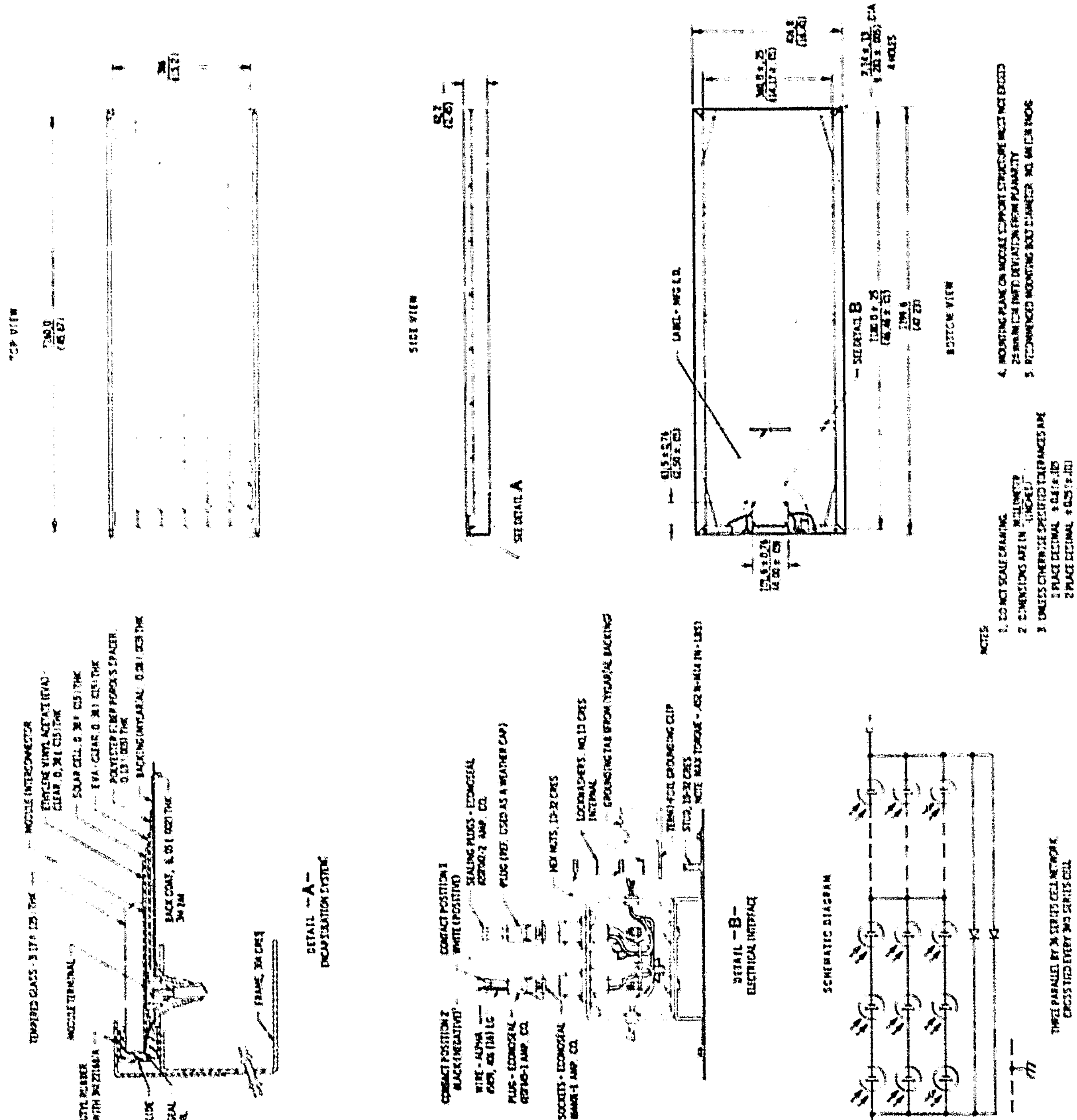

Figure 26. Spire Module: Drawing

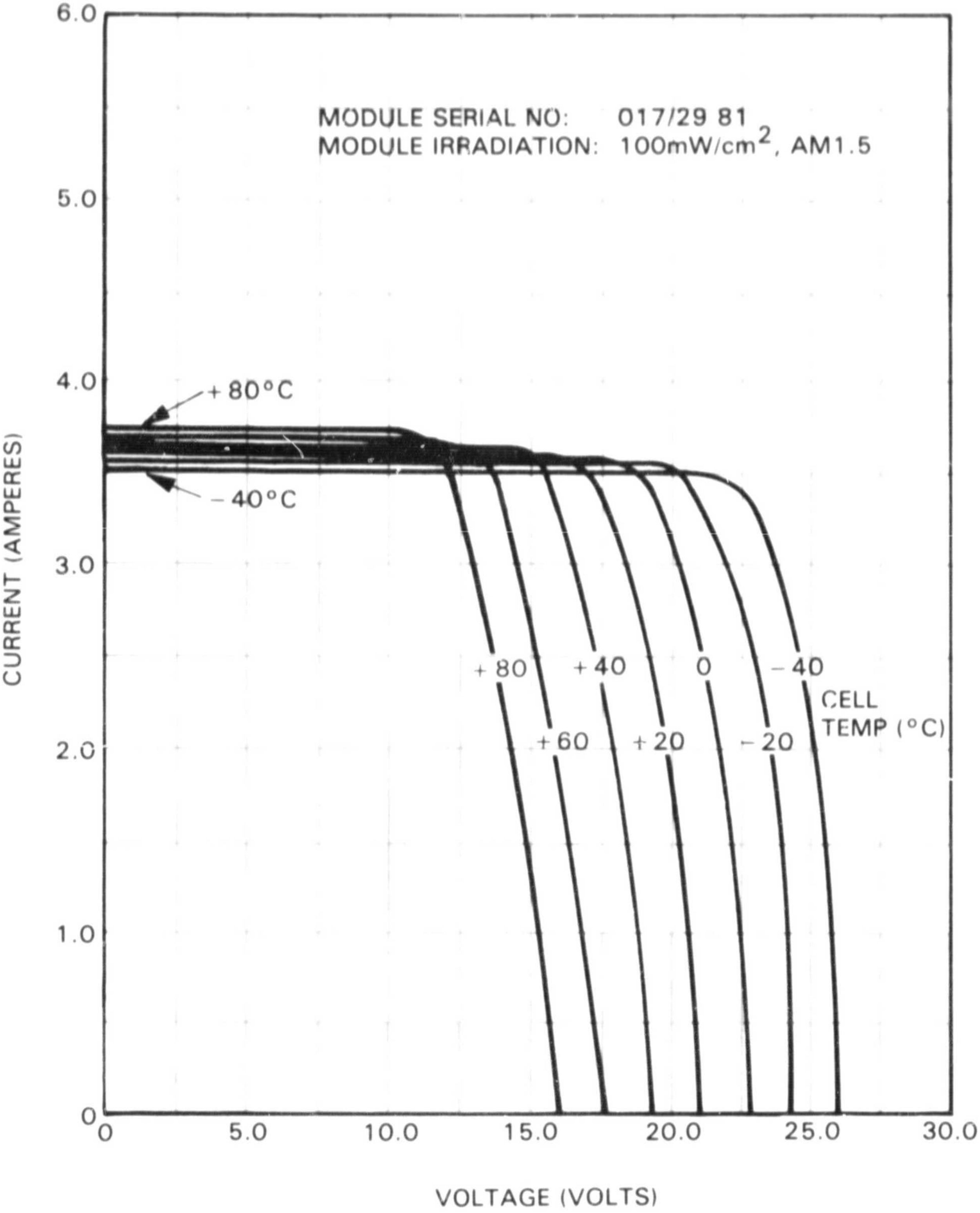

Figure 27. Spire Module: I-V Curves

REFERENCES

1. Smokler, M., User Handbook for Block II Silicon Solar Cell Modules, JPL Document No. 5101-36, Jet Propulsion Laboratory, Pasadena, California, October 15, 1977.

2. Smokler, M., User Handbook for Block III Silicon Solar Cell Modules, JPL Document No. 5101-82, Jet Propulsion Laboratory, Pasadena, California, February 1, 1979.

3. Block IV Solar Cell Module Design and Test Specification for Intermediate Load Center Applications, JPL Document No. 5101-16, Revision A, Jet Propulsion Laboratory, Pasadena, California, November 1, 1978.

4. Block IV Solar Cell Module Design and Test Specification for Residential Applications, JPL Document No. 5101-83, Jet Propulsion Laboratory, Pasadena, California, November 1, 1978.

APPENDIX A

MISCELLANEOUS MODULES

The main body of the User Handbook for Block IV Silicon Solar Cell Modules describes all modules meeting two conditions: they were purchased under the Block IV procurement, and they have successfully completed the Block IV qualification tests. This Appendix describes four additional modules that were purchased by JPL but which do not meet, at this time, one or both of the above conditions. The designs are of interest, however, in the context of Block IV technology, so it was considered useful to publish the available data as an Appendix to this User Handbook.

Two of the designs, by ARCO Solar and GE, are of modules that were part of the Block IV procurement. The ARCO Solar module was purchased under a Block IV development contract. The GE module was purchased under a Block IV production contract, but was enough different from the design that had been supplied under the preceding development contract that the design could not be considered qualified until the production modules could be submitted to qualification tests. The other two modules, by Solar Power and Solenergy, were purchased as commercial units specifically for the purpose of submitting them to the complete set of Block IV qualification tests, in contrast with other commercial modules purchased by JPL only for exploratory testing.

Of the four designs, the Solar Power module has successfully completed the qualification tests and the other three have not, at this time, progressed to completion. The qualification test program is typically an iterative process involving detection of problems, consequent redesign of the module or of the manufacturing process, and subsequent submission of modules for a repeat of the qualification tests. Since an essential part of this sequence of events is an option of the manufacturer, it cannot be predicted whether the sequence will, for any of the latter three designs, be pursued to the point of successful completion of the qualification tests. Should the manufacturer of any of these three designs elect to pursue the sequence fully, his final module design may differ from that shown here.

A detailed description of each of the four modules is given in Table A-1, Module Characteristics. Some of these details are given in the form of references to photographs, drawings, and I-V curves, all of which are included in this Appendix.

Table A-1. Miscellaneous Module Characteristics

	Manufacturer	ARCO Solar	GE	Solar Power	Solenergy
IDENT	MFR's Part No.	012431-F	47E258296G1-NC	LG12-361-G	0444-Q HEM
	Module Type[a]	RES	RES	INT	INT
PHYSICAL	Photographic Views	Figure A-1	Figure A-5	Figure A-9	Figure A-12
	Overall Dimensions [mm (in.)]				
	Length	1200 (47.2)	818 (32.2)	1199 (47.2)	1198 (47.2)
	Width	583 (23.0)	628 (24.7)	302 (11.9)	454 (17.9)
	Height	19 (0.8)	7.6 (0.3)	60 (2.4)	44 (1.7)
	Weight kg(lbs)	5.2 (11.4)	4.0 (8.8)	6.0 (13.2)	13.0 (28.6)
	Support Structure Planarity Rqmt [mm/m (in./ft)][b]	note c	note c	20 (0.25)	note c
	Module Drawing and Materials	Figure A-2	Figure A-6	Figure A-10	Figure A-13
	Module Installation	Figure A-3	Figure A-7	Figure A-10	Figure A-13
	Electrical Connections	Figure A-2	Figure A-6	Figure A-10	Figure A-13
	Cells				
	Quantity	60	19	36	44
	Size [mm (in.)]	Dia: 102.9 (4.05)	Dia: 100 (3.94)	Dia: 100 (3.94)	100 x 100 (3.9 x 3.9)
	Packing factor	0.79	0.76	0.76	0.81
	Base material	Cz	Cz	Cz	HEM
	Junction	n/p	n/p	p/n	p/n
	Front metallization	Printed Ag	Printed Ag	Ni-Solder	Au-Ni-Solder
	Back metallization	Printed Al, Ag	Printed Ag	Ni-Solder	Au-Ni-Solder
ELECTRICAL	Nominal Performance[d]				
	Power, rated (watts)	49.0	15.0	27.3	33.8
	Voltage, rated (volts)	7.7	7.0	15.0	4.0
	Current Amps	6.4	2.14	1.82	8.4
	SOC Performance[d,e,f]				
	Power, maximum (watts)	48.8	15.5	27.3	32.2
	Voltage at max power (volts)	7.8	6.81	15.0	3.81
	Current at max power (amps)	6.26	2.27	1.82	8.46
	Voltage, open circuit (volts)	10.2	9.40	19.9	5.30
	Current short circuit (amps)	7.0	2.59	2.04	9.68
	Fill factor	0.68	0.64	0.67	0.63
	Efficiency, Module (%)	8.0	7.9	7.5	5.9
	Eff., encapsulated cell (%)	10.1	10.4	9.9	7.3
	$28^{o}C$ Performance[f]				
	Power, maximum (watts)	59.5	20.0	30.9	38.4
	Voltage at max power (volts)	9.4	8.9	13.3	4.52
	Current at max power (amps)	6.36	2.25	1.78	8.50
	Voltage, open circuit (volts)	11.6	11.1	21.8	6.04
	Current, short circuit (amps)	6.94	2.60	2.03	9.55
	Fill factor	0.73	0.69	0.70	0.66
	Efficiency, module (%)	9.7	10.2	8.5	7.0
	Eff., encapsulated cell (%)	12.3	13.4	11.2	8.6
	I-V Curves[f]	Figure A-4	Figure A-8	Figure A-11	Figure A-14
	Circuit Diagram	Figure A-2	Figure A-6	Figure A-10	Figure A-13
	Breakdown Voltage, Min. (V_{dc})[b,g]	note c	note h	2000	note c

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Table A-1. Miscellaneous Module Characteristics (Cont'd)

		ARCO Solar	GE	Solar Power	Solenergy
THERMAL	Nominal Operating Cell Temperature, NOCT (°C)[e]				
	At 100 mW/cm² insolation	65	68	54	58[j]
	At 80 mW/cm² insolation	55	58	47	50
	Temperature Coefficients[i]				
	ΔV/ΔT (Volts/°C)	-0.047	-0.047	-0.078	-0.027
	ΔI/ΔT (Amps/°C)	+0.0009	+0.0009	+0.0011	+0.0059
ENVIRONMENT	Temperature range (°C)[b]	note c	note c	-40 to +90	note c
	Humidity, max relative (%)[b]	note c	note c	90	note c
	Wind load, max [kPa (lbs/ft²)][b]	note c	note c	+2.4 (+50)	note c
	Hail impact, max hailstone [mm (in.)][b]	note c	note c	20.0 (0.75)	note c

NOTES

[a]INT = Module intended for use in intermediate-load centers, defined here as installations providing 20 kW to 500 kW.
RES = Module intended for use on single-family residence in installations providing 2 kW to 10 kW.

[b]The data given are tested limits, not module limits. For details see Appendix B (Qualification Test Program).

[c]Qualification (see Appendix B) not completed at this time.

[d]Each module is expected to produce not less than 90% of rated power when loaded to provide rated voltage under Standard Operating Conditions (SOC), i.e.:

1. Module irradiated with 100 mW/cm² insolation at air mass 1.5 (AM1.5) spectrum.
2. Cell temperature equal to NOCT (per Block IV Specifications; see note e).

[e]The Block IV Specifications define NOCT (Nominal Operating Cell Temperature) as the cell temperature with the module in the Standard Thermal Environment defined as follows:

Insolation	=	100 mW/cm²
Air temperature	=	20°C
Average wind velocity	=	1 m/s
Electrical load	=	open circuit
Mounting	=	normal to solar noon on structure typical of application

Practice at the time of publication is to measure NOCT with the module in the Nominal Thermal Environment, which is the same as the Standard Thermal Environment except that the insolation level is 80 mW/cm².

[f]The data presented here for each module design were obtained by measurement and extrapolation of the performance of one sample module of that design. The radiation source was a Large-Area Pulsed Solar Simulator calibrated by use of a calibrated reference cell of the same spectral response as the module to irradiate the module with the equivalent of 100 mW/cm² at AM1.5. Module temperature was approximately 20°C. Extrapolation was performed by computer, based upon a set of measured temperature coefficients (voltage, current, and series resistance) for each module design. The resultant families of I-V curves for the sample modules are given in Figures A-4, A-8, A-11, and A-14.

[g]Modules should not be series-connected to obtain system voltages under worst-case conditions (100 mW/cm² insolation, 0°C cell temperature, open circuit) exceeding:

500 volts for intermediate load modules
250 volts for residential modules

[h]Not applicable. This module has no exposed conductive surface and is intended for installation in a non-conductive assembly.

[i]These coefficients are for use in the neighborhood of the maximum power points on the module I-V curves. They are useful for determining power output at a selected voltage and temperature when the available I-V curve was made at a different temperature. For details see Reference 3, Appendix B.

[j]Estimate; based on small data sample

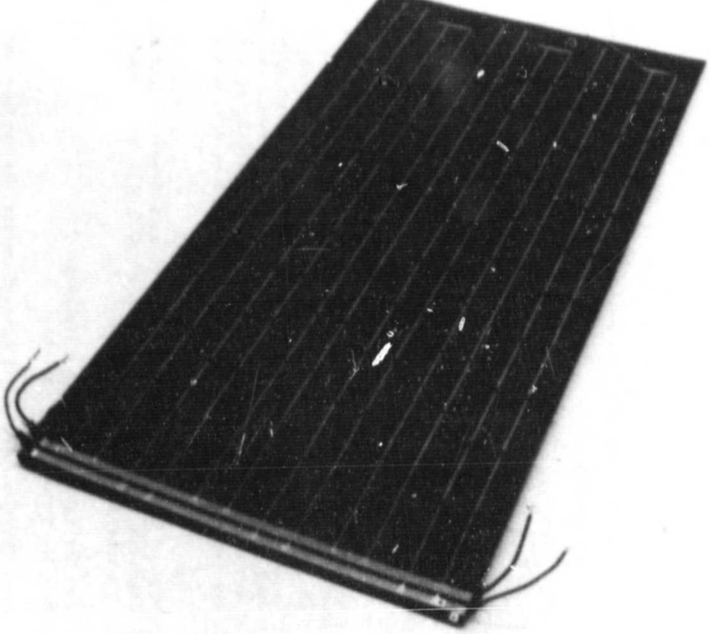

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Figure A-1. ARCO Solar Module (Residential): Photographic Views

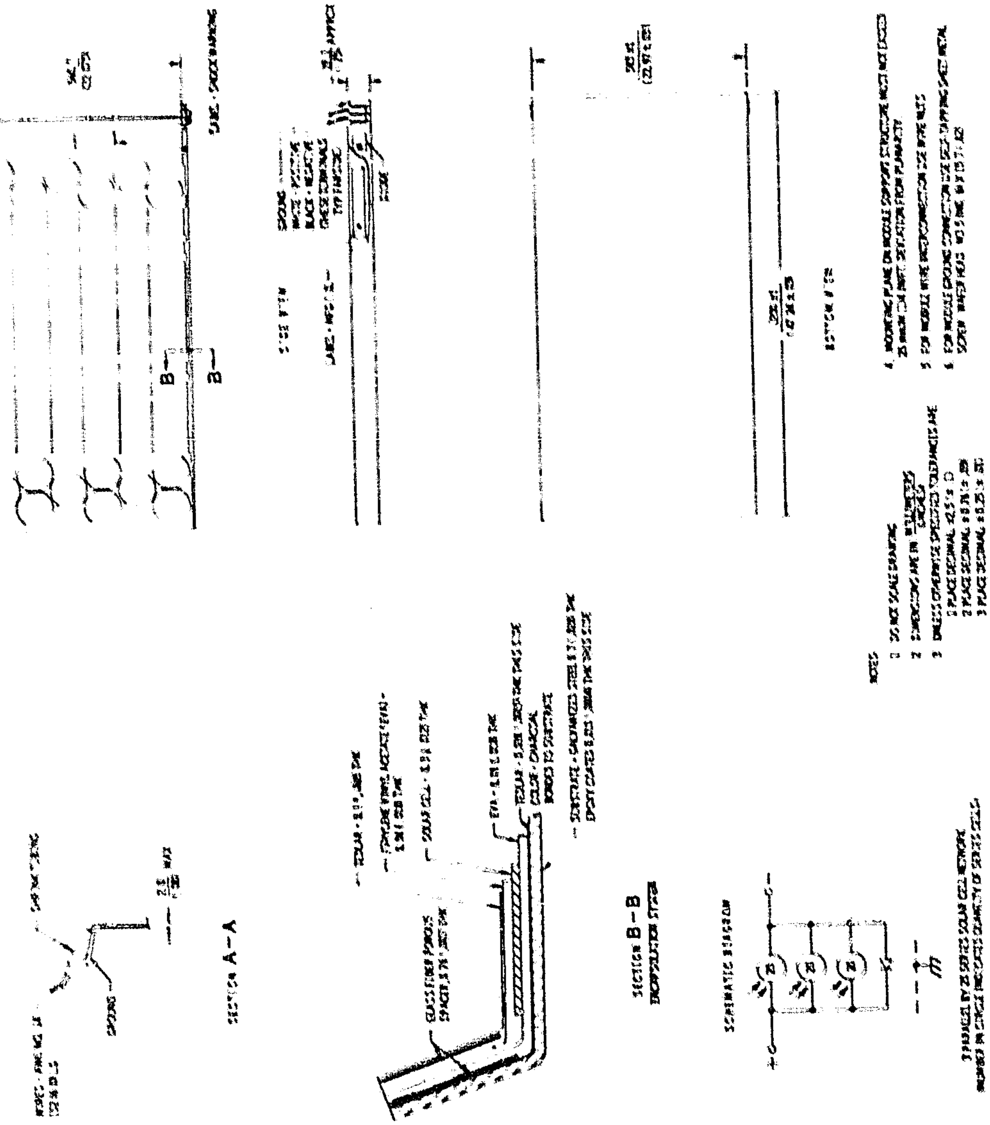


Figure A-2. ARCO Solar Module (Residential): Drawing

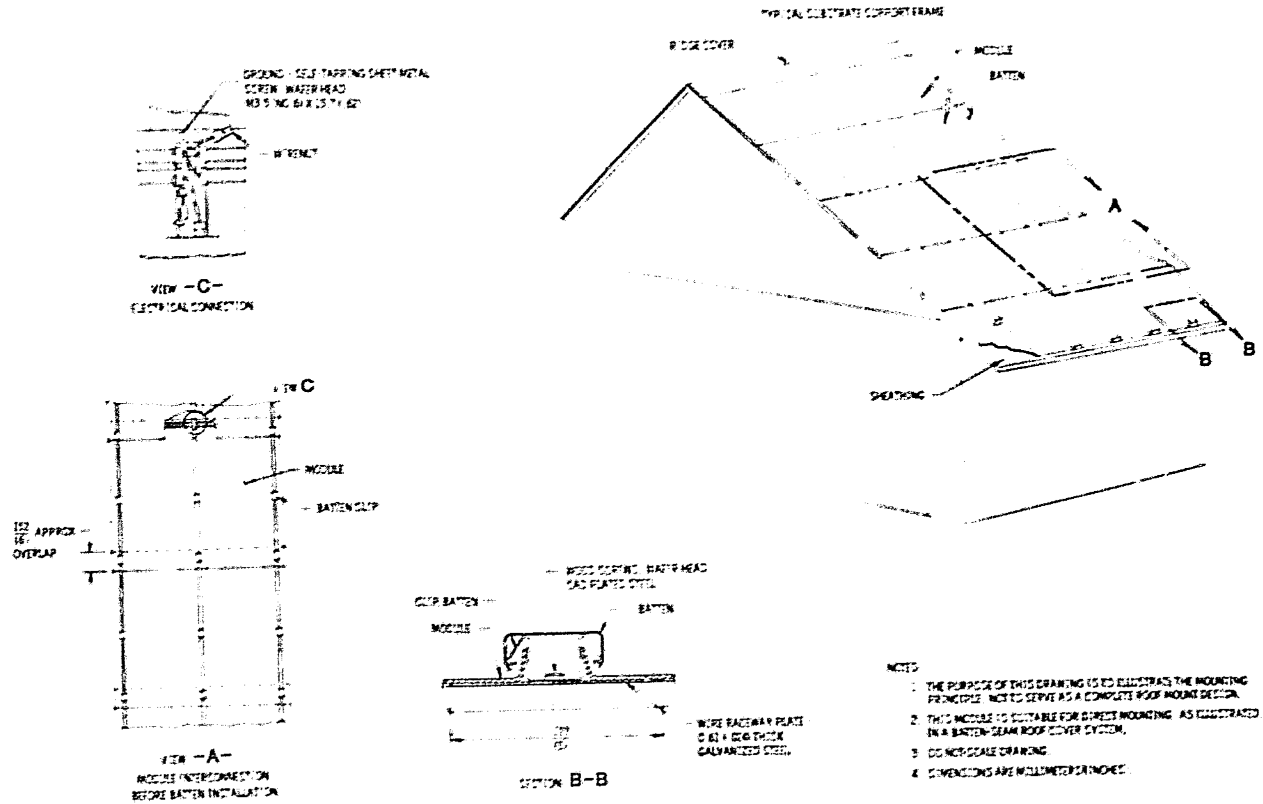


Figure A-3. ARCO Solar Module (Residential): Installation

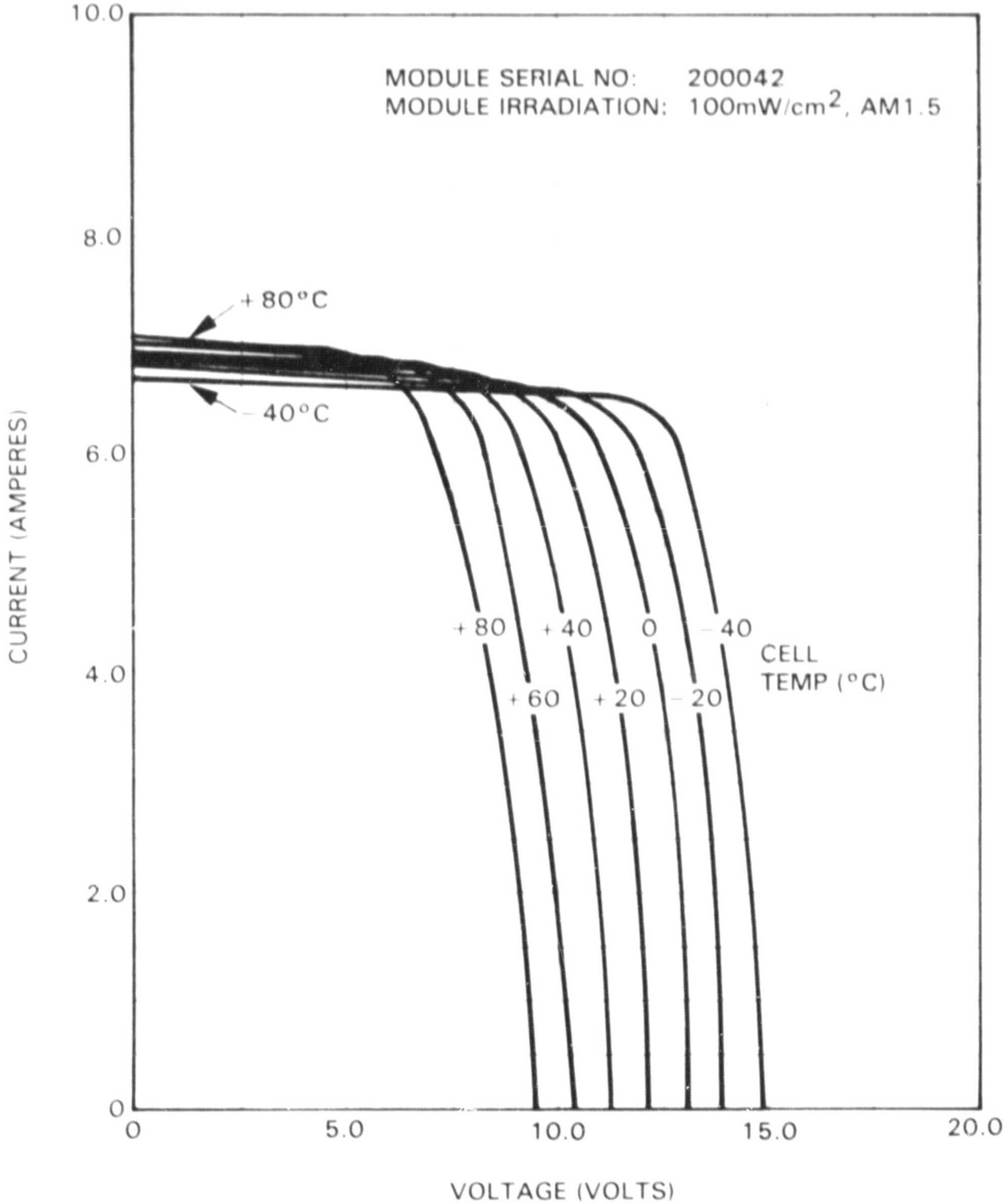
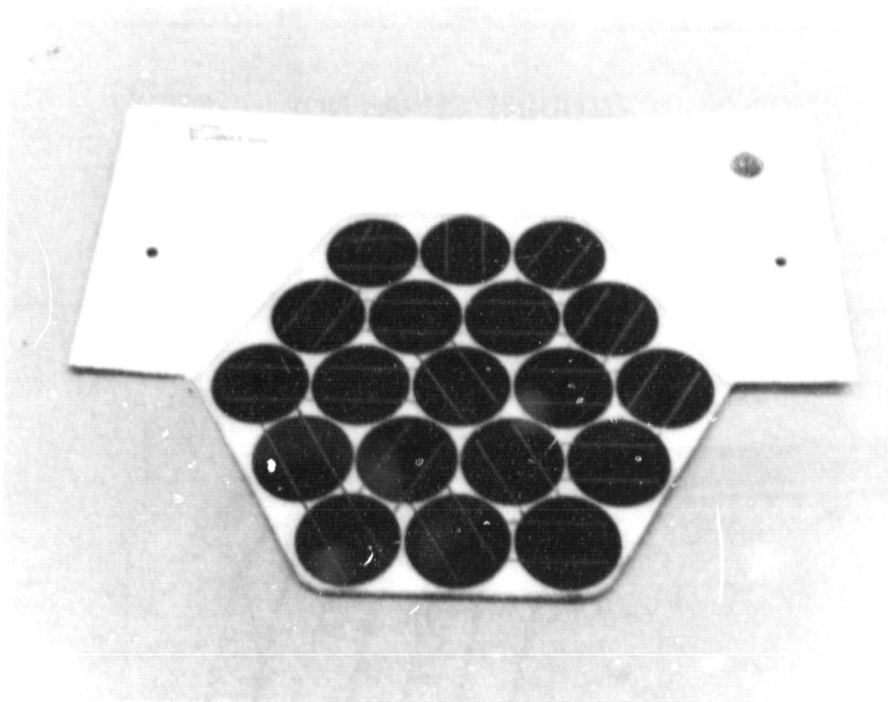


Figure A-4. ARCO Solar Module (Residential): I-V Curves



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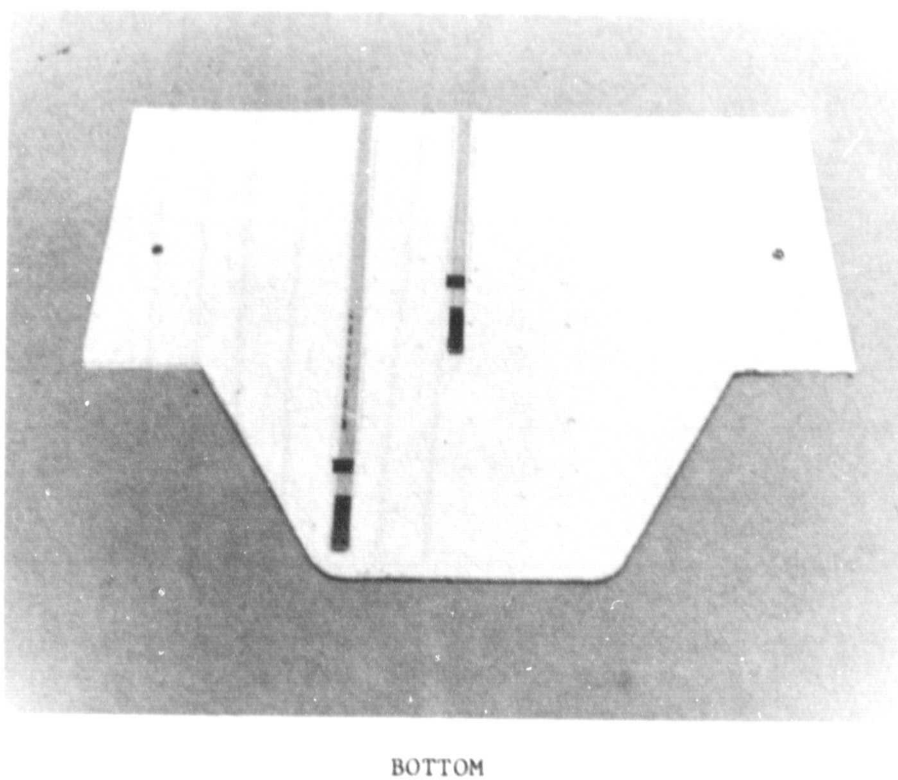

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Figure A-5. GE Module (Residential): Photographic Views

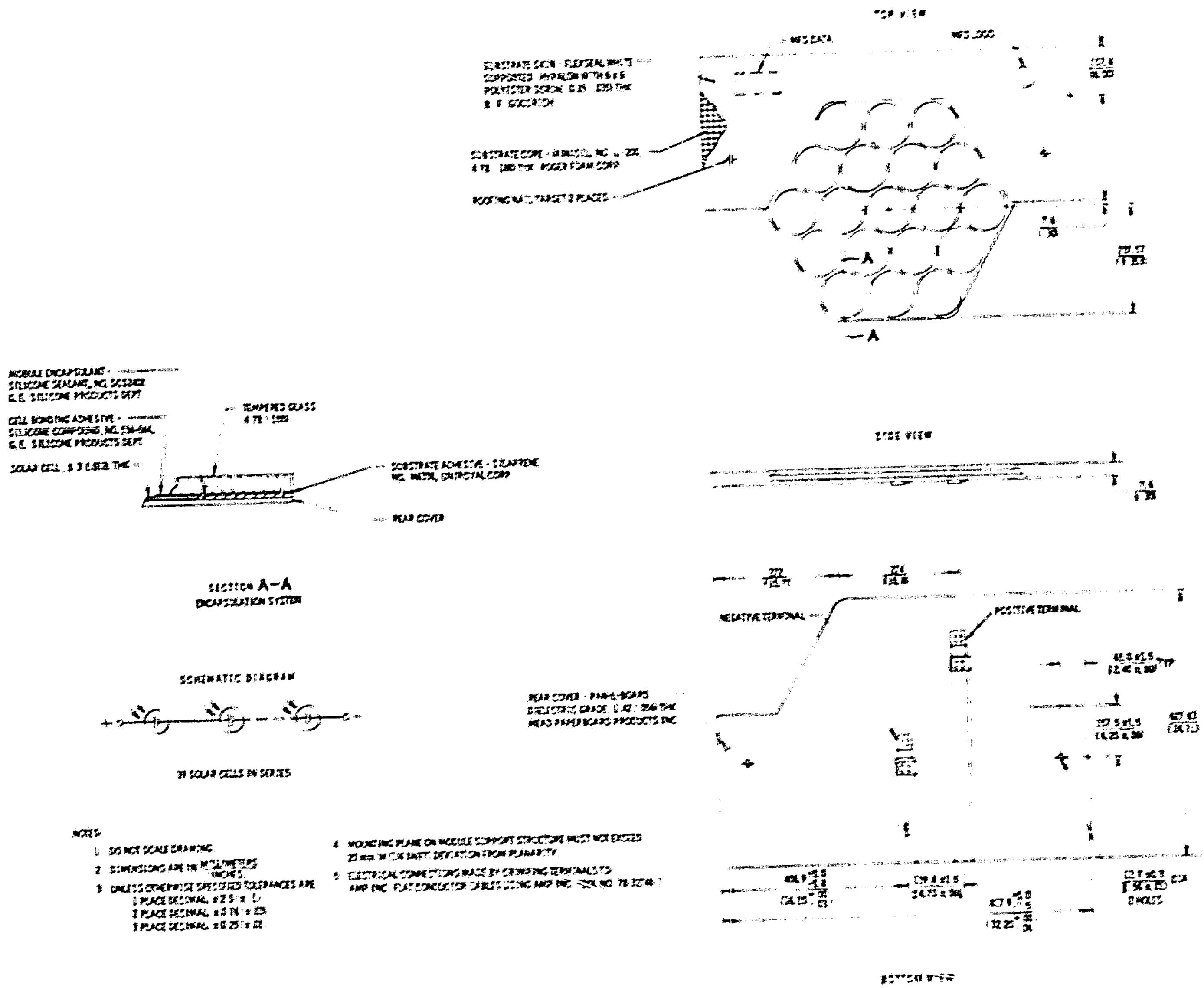

Figure A-6. GE Module (Residential): Drawing

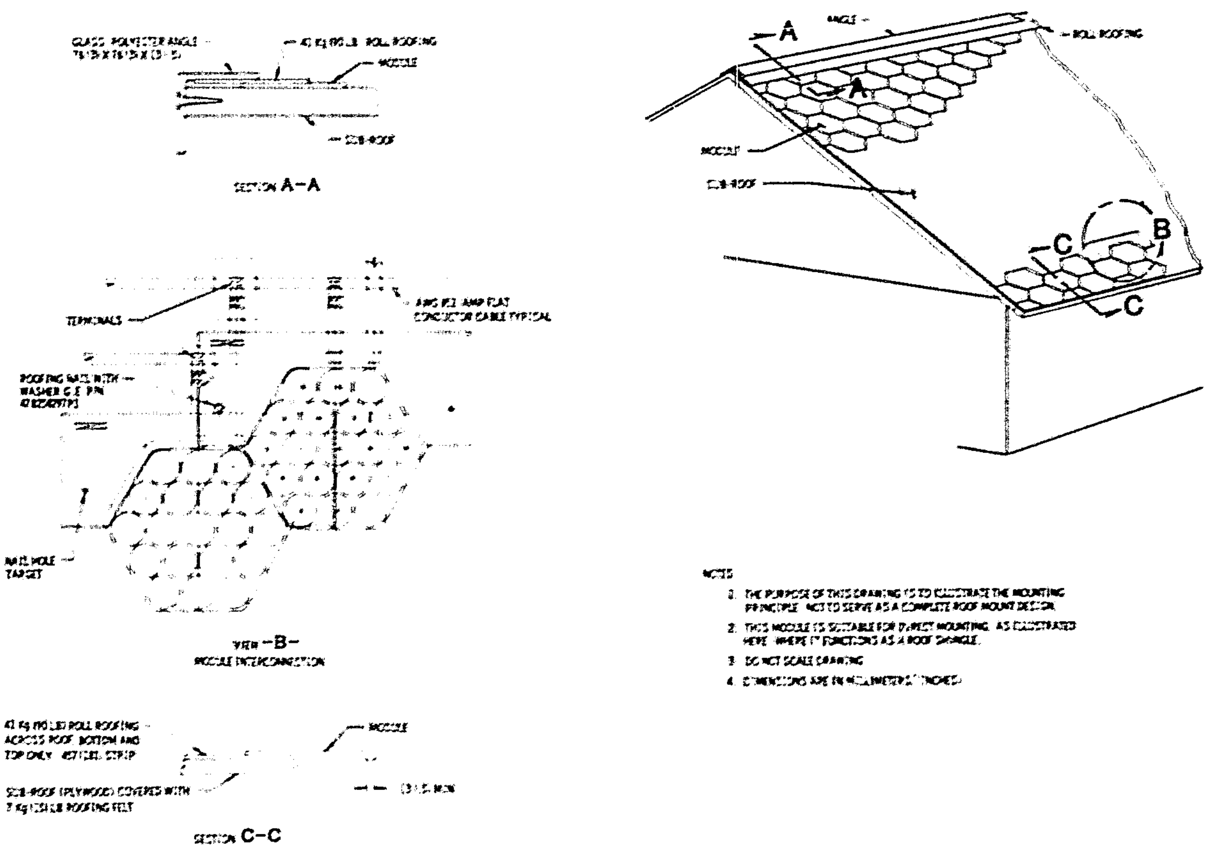

Figure A-7. GE Module (Residential): Installation

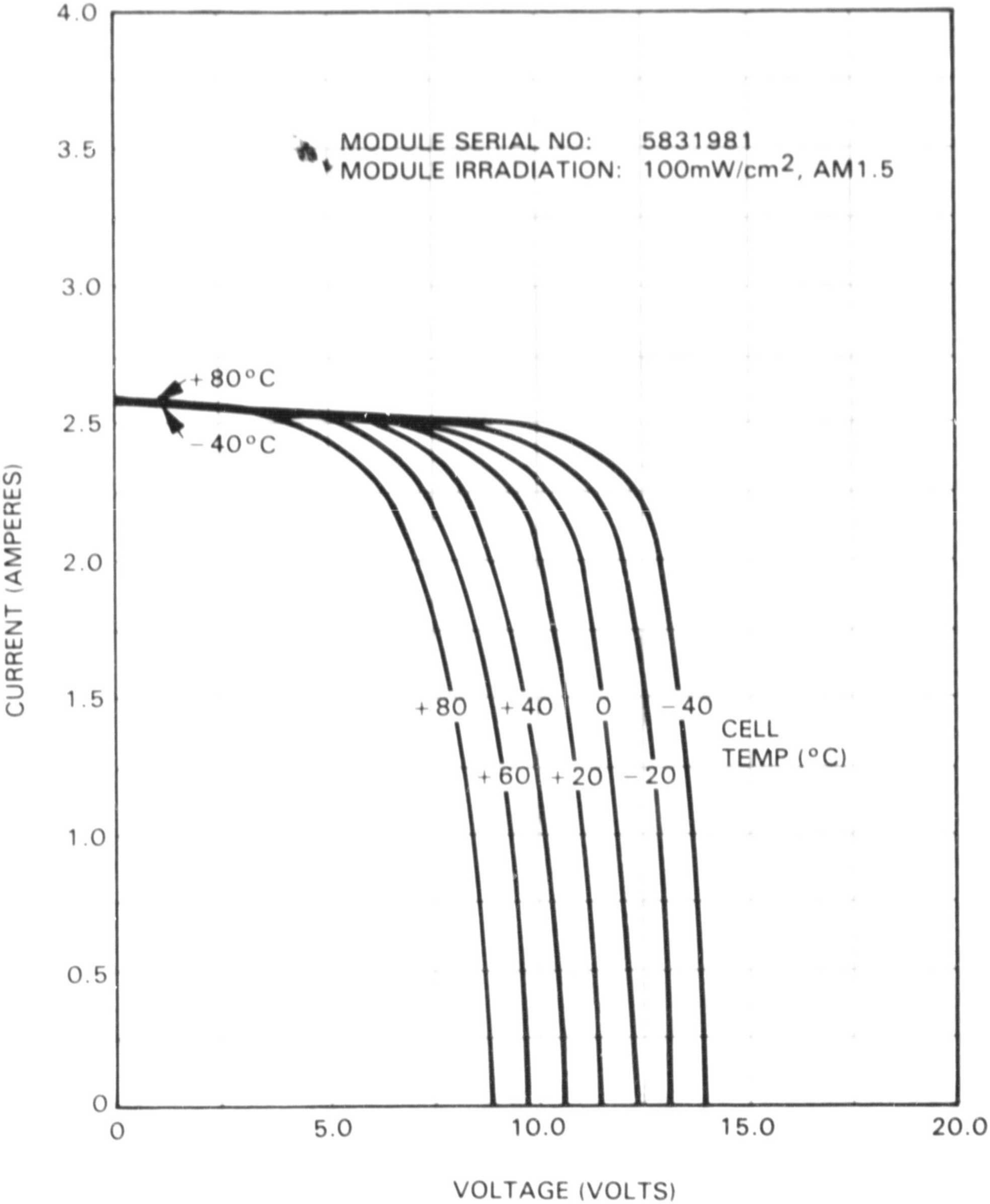

Figure A-8. GE Module (Residential): I-V Curves

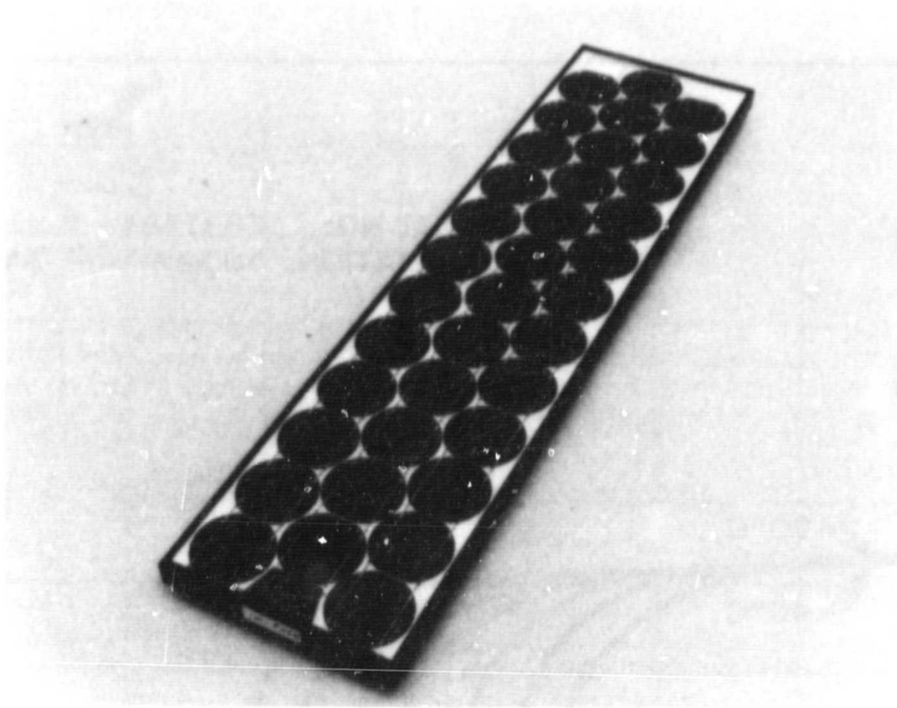

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Figure A-9. Solar Power Module: Photographic Views

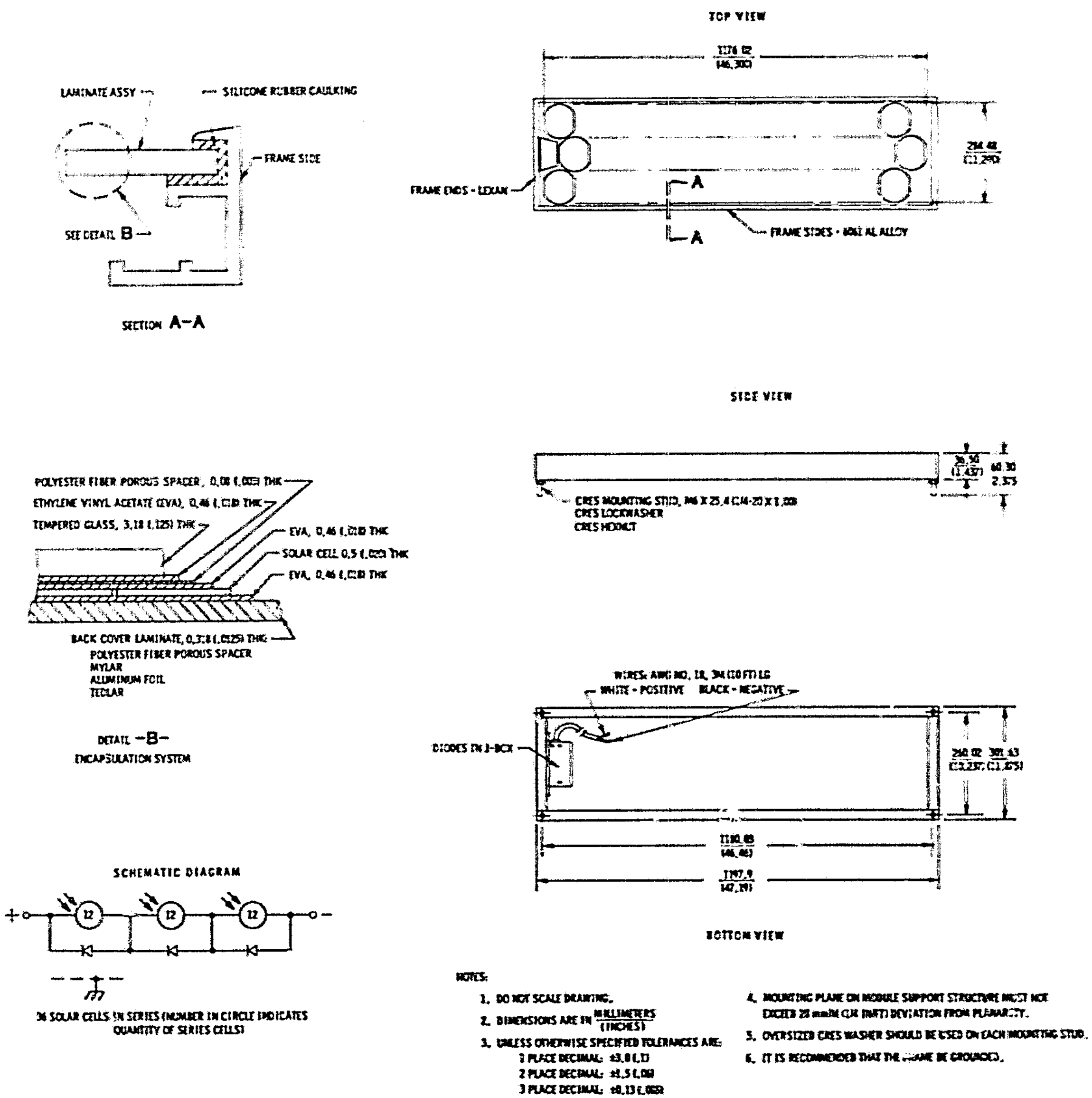


Figure A-10. Solar Power Module: Drawing

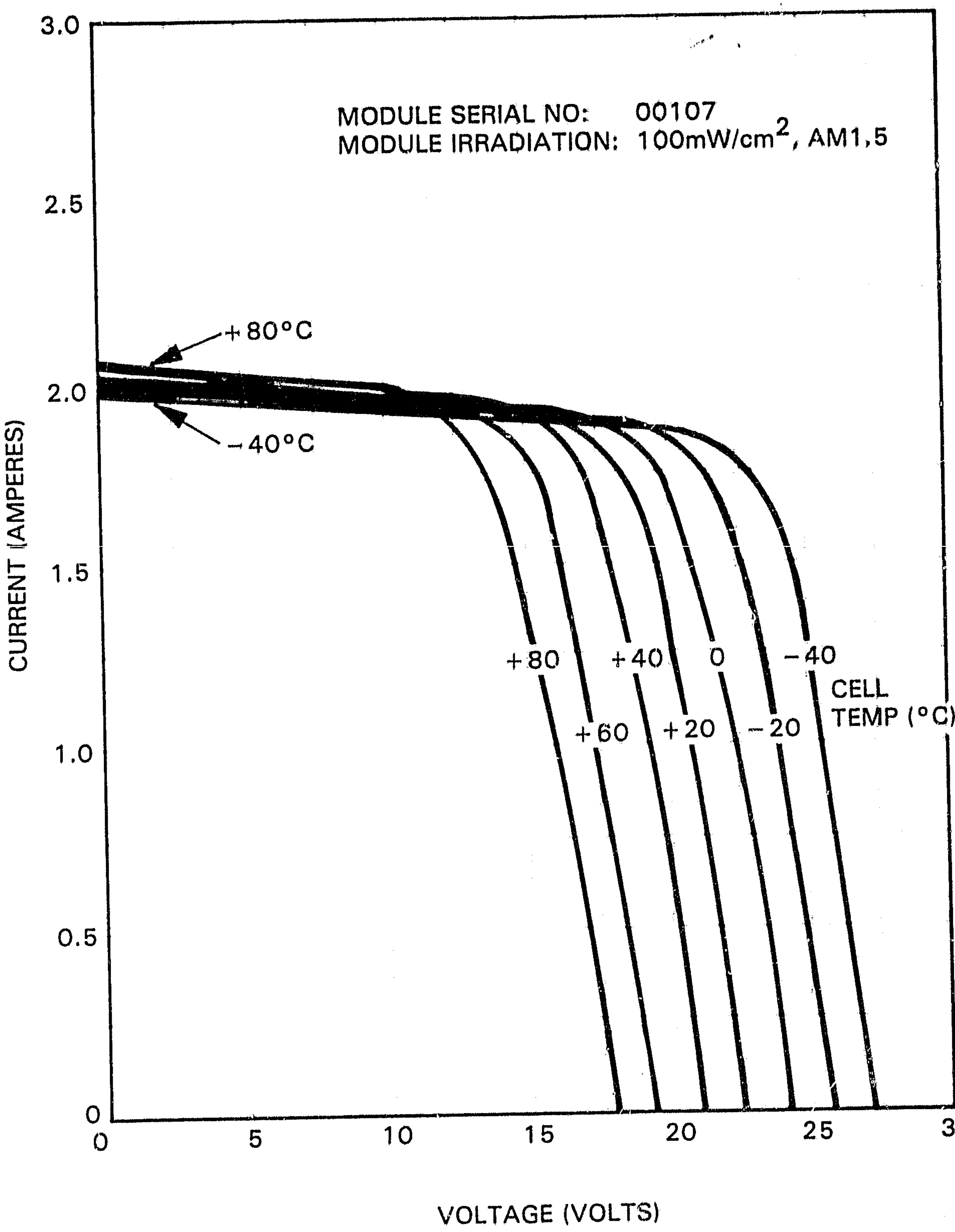
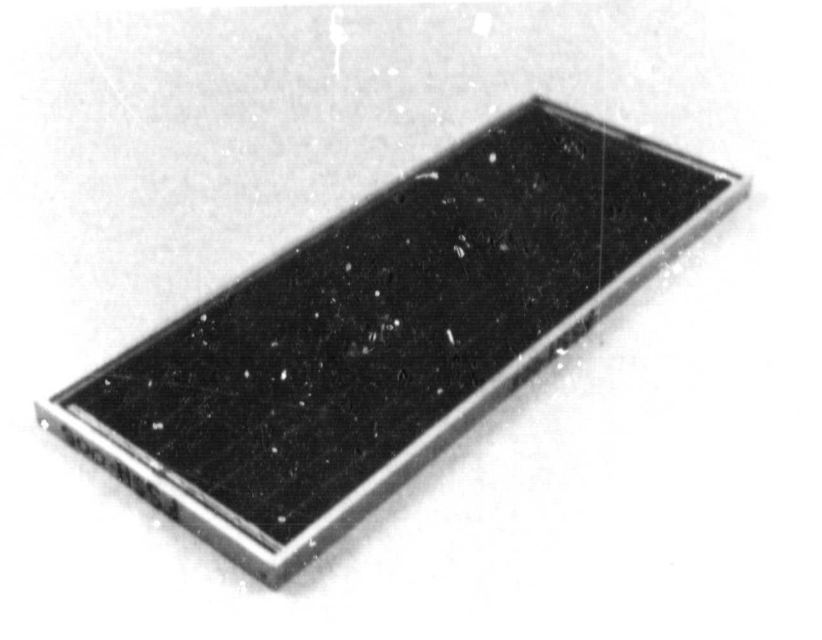


Figure A-11. Solar Power Module: I-V Curves



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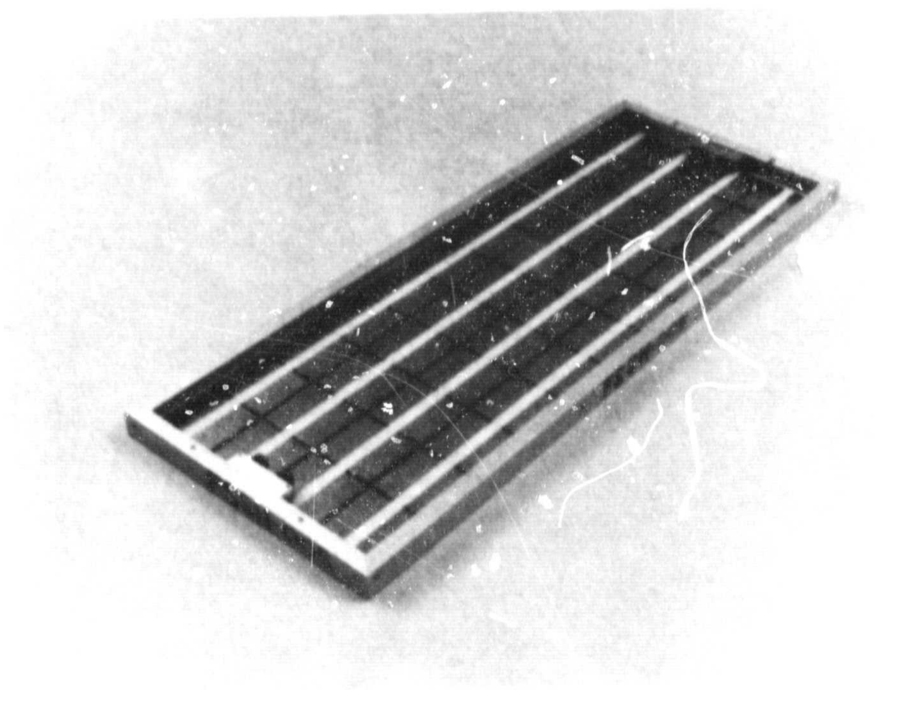

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Figure A-12. Solenergy Module: Photographic Views

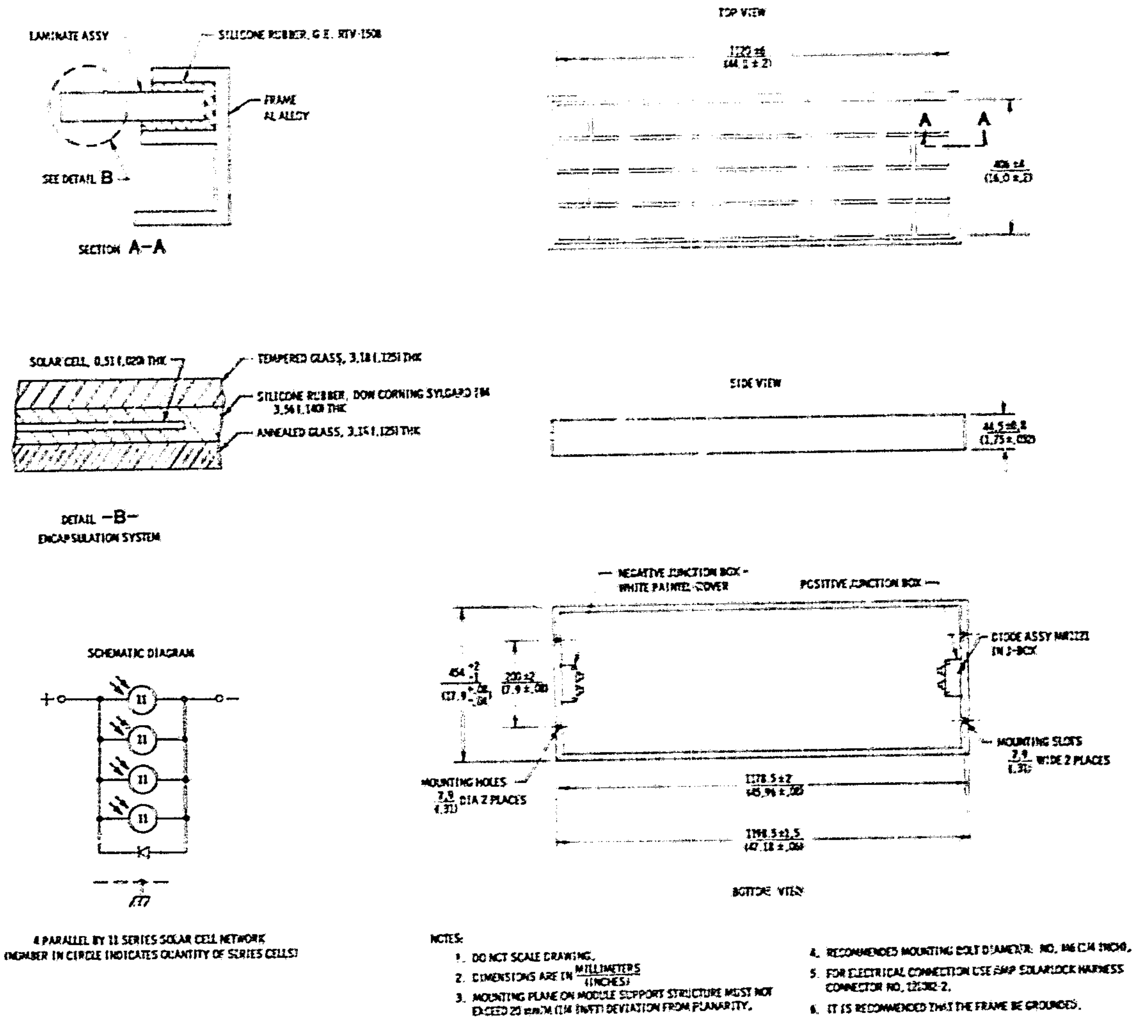

Figure A-13. Solenergy Module: Drawing

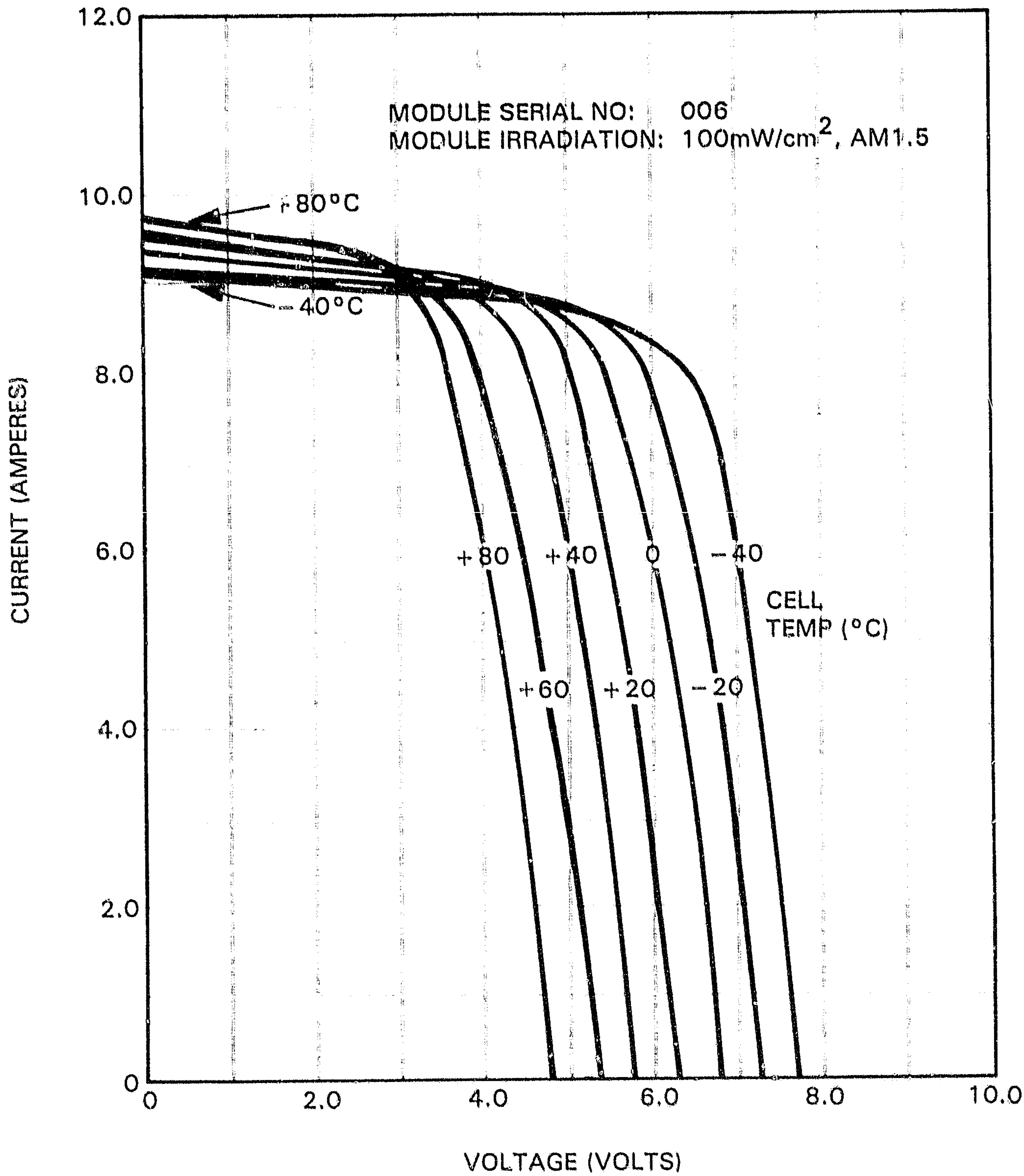

Figure A-14. Solenergy Module: I-V Curves

APPENDIX B

QUALIFICATION TEST PROGRAM

Each Block IV design was subjected to a series of qualification tests to prove compliance with the required ranges of environmental exposure. Typically, four modules were used for most tests. Qualification of a design means that modules of that specific detailed design and processing have been shown capable of withstanding the stresses of the test program without more than 5% power degradation, without visible degradation exceeding preselected criteria, and without failure of a dielectric breakdown test.

The Block IV qualification tests are defined in References 3 and 4. A simplified description of the tests is presented here for convenience in understanding the data in this User Handbook.

The block diagram in Figure B-1 shows the qualification test sequence with the names of individual tests given in blocks that are alphabetically coded to key them to the descriptions below. 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 exceeding preselected criteria for that module design. The criteria reflect a judgment of degradation that threatens continued successful performance of the module. Such degradation may appear as breaks, cracks, delamination, spalling, etc.

B. Ground Continuity

This test verifies that, in a module with exposed external conducting surfaces (such as a metal frame), electrical continuity exists between all such surfaces and the module grounding point, with resistance to the grounding point not greater than 50 milliohms.

C. Dielectric Breakdown

This test verifies that the insulation between the (shorted-together) output terminals of the module and module metal frame or ground will not suffer dielectric breakdown when subjected to 2000 Vdc for an intermediate-load module or 1500 Vdc for a residential module. The voltage is applied at a rate not exceeding 500 V/s up to the test value and then held constant for 1 min. Failure is defined as arcing, flashover, or leakage current exceeding 50 A. For modules not required to have a grounding point, the test is done with the module installed in a mounting structure, with the test voltage negative connection contacting the mounting structure. For residential modules, the test does not apply if the module is intended to be mounted in a non-conductive assembly.

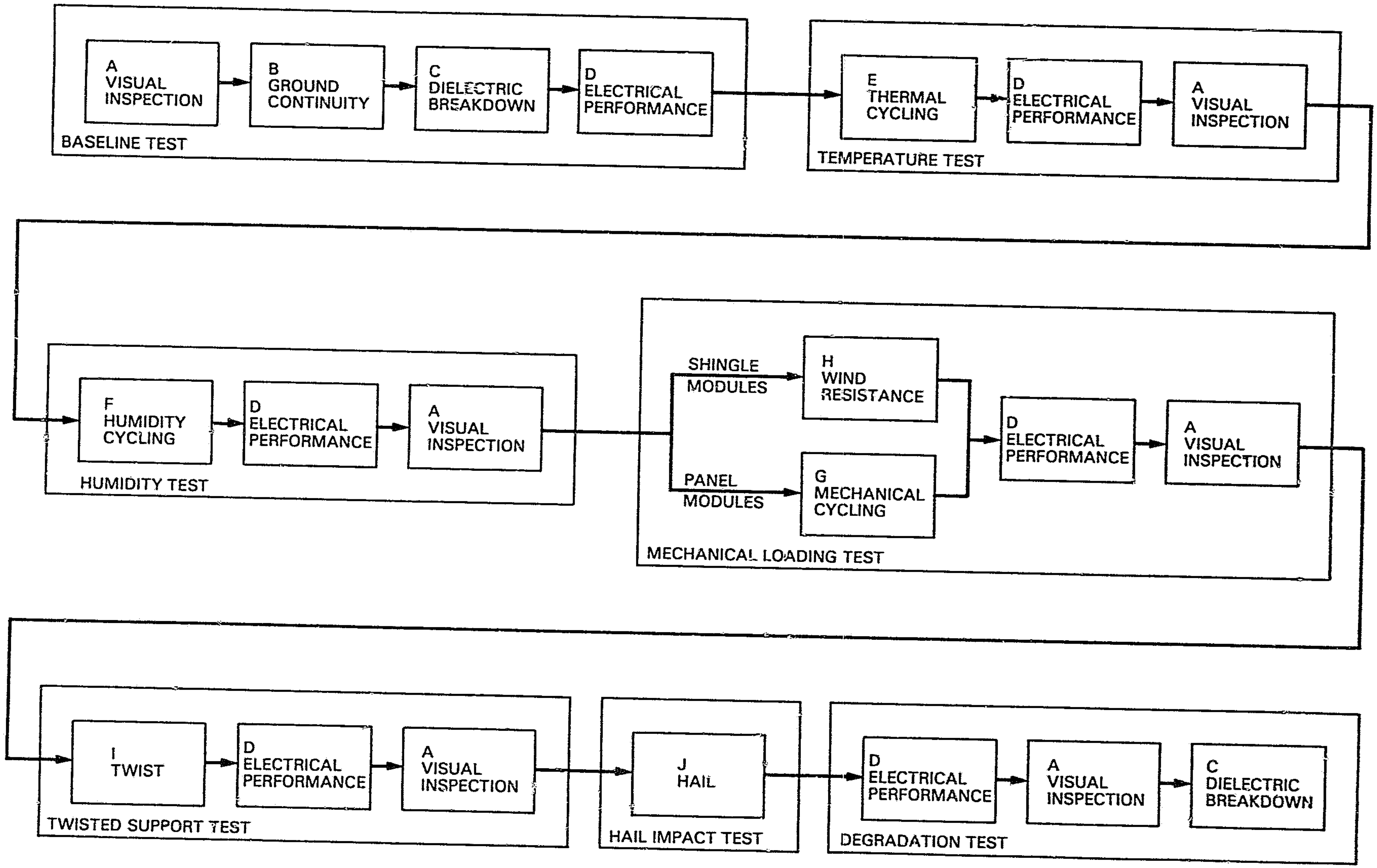

Figure B-1. Qualification Test Sequence

Although not part of the qualification test specification, by agreement with the Block IV manufacturers an additional dielectric breakdown test was done with the polarity reversed, i.e., with negative voltage on the module output terminals and positive voltage on the grounding point or mounting structure as applicable.

D. 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 resulting from the stresses of the qualification tests. The criteria for excess degradation is a reduction in maximum power (measured at 100 mW/cm^2, AM1.5 input and 28°C cell temperature) exceeding 5%.

An additional purpose of the baseline electrical performance test is to verify that the module power output is acceptable, defined as not less than 90% of the nominal power expected from the module at its stipulated nominal output voltage and at 100 mW/cm^2, AM1.5 input, with cell temperature equal to Nominal Operating Cell Temperature (NOCT). For this purpose the module I-V curve is measured at the same irradiance but with the cells at room temperature. The room-temperature data are then extrapolated, using module temperature coefficients, to calculate module power at NOCT at the nominal output voltage.

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 B-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 a wind that produces peak mechanical loading amplitudes of ±2.4 kPa (±50 lbs/ft^2) on intermediate-load modules or ±1.7 kPa (±35 lb/ft^2) on panel-type residential modules will not result in mechanical or electrical degradation. The test is performed by applying 10,000 cycles of mechanical load, normal to the module surface. This test is not applicable to shingle-type modules.

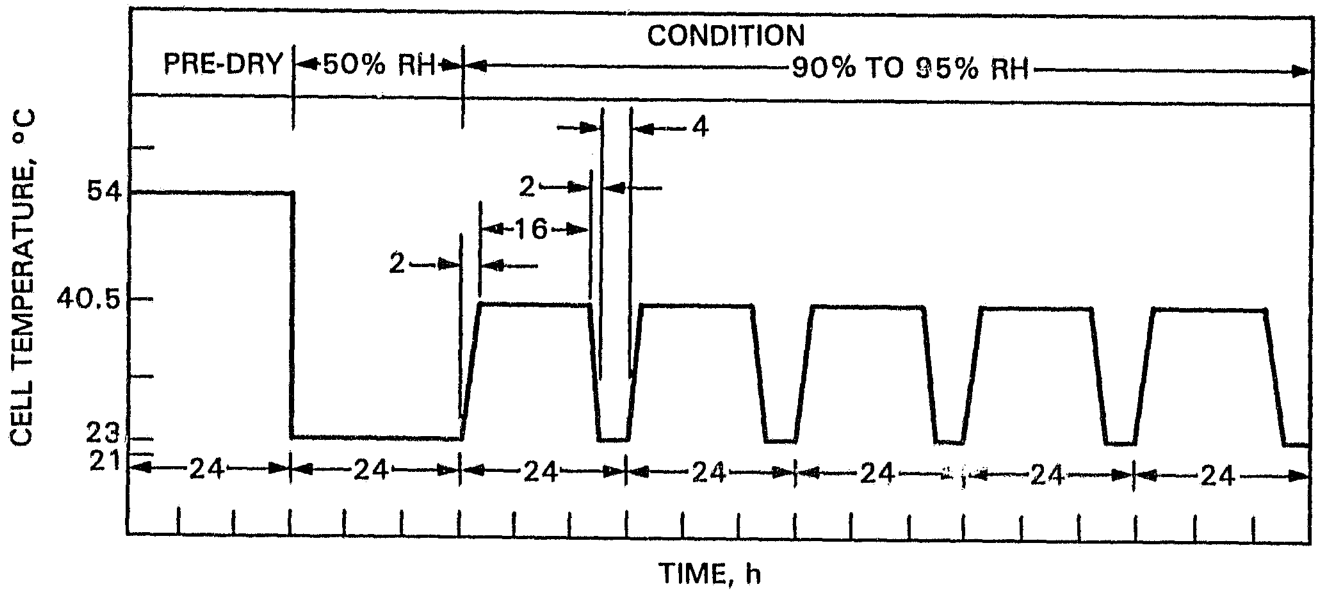

Figure B-2. Humidity Cycle Regime

H. Wind Resistance

This test verifies, by use of a wind machine providing uplift force, that shingle-type residential modules will withstand an uplift pressure of 1.7 kPa (35 lb/ft^2).

I. Twist

This test verifies that mounting the module on a twisted mounting surface with planarity deviation of $\pm$20 mm/m ($\pm$1/4 in./ft) will not cause module damage.

J. Hail

This test verifies that the module will not be damaged by impact of simulated hailstones (ice balls) 20 mm (3/4 in.) in diameter, travelling at 20.1 m/s (45 mi/h). The test includes at least three impacts at each of at least the three points on the module most sensitive to impact, as determined experimentally.