DOE/JPL-1012-78/14
Distribution Category UC-63b

Low-Cost Solar
Array Project

5101-83

Block IV Solar Cell Module Design and Test Specification For Residential Applications

November 1, 1978

(NASA-CR-158117) BLOCK 4 SOLAR CELL MODULE DESIGN AND TEST SPECIFICATION FOR RESIDENTIAL APPLICATIONS Low-Cost Solar Array Project (Jet Propulsion Lab.) 31 p HC A03/MF A01 CSCL 10A G3/44
N79-18453
Unclas
16126

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Pasadena, California

Prepared by the Jet Propulsion Laboratory, California Institute of Technology, for the Department of Energy by agreement with the National Aeronautics and Space Administration.

The JPL Low-Cost Solar Array Project is sponsored by the Department of Energy (DOE) and forms part of the Solar Photovoltaic Conversion Program to initiate a major effort toward the development of low-cost solar arrays.

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Block IV Solar Cell Module Design and Test Specification For Residential Applications

LSA Engineering Area

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

PREFACE

This specification was prepared by the Engineering Area of the Low-Cost Solar Array Project. Inquiries related to details of the document or requests for additional information should be directed to Dr. R. G. Ross, Jr., Engineering Area Manager, or Mr. J. C. Arnett, Cognizant Module Design Engineer.

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SECTION I

INTRODUCTION

A. SCOPE

This specification provides near-term design, qualification and acceptance requirements for terrestrial solar cell modules suitable for incorporation in photovoltaic power sources (2 kW to 10 kW) applied to single family residential installations. Requirement levels and recommended design limits for selected performance criteria have been specified for modules intended principally for rooftop installations. Modules satisfying the requirements of this specification fall into one of two categories, residential panel or residential shingle, both meeting general performance requirements plus additional category peculiar constraints.

B. APPLICABLE DOCUMENTS

The following documentation is applicable to the extent specified:

(1) Military: MIL-STD-810 C, Environmental Test Methods, March 10, 1975.

(2) Energy Research and Development Administration: TM 73702, ERDA/NASA/1022-77/16 "Terrestrial Photovoltaic Measurement Procedures" June 1977, Lewis Research Center, Cleveland, Ohio, 44135.

(3) Underwriters Laboratory, Inc.: UL Standard No. UL 997, Wind Resistance of Prepared Roof Covering Materials," Latest Revision.

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SECTION II

DESIGN AND PERFORMANCE REQUIREMENTS

Solar cell modules meeting the requirements of this document will be installed in roof-top arrays intended for residential applications ranging from 2 kW to 10 kW. In general these are intended as single-family dwelling applications. The use of concentrators or hybrid (combined thermal and photovoltaic) systems shall not be considered in meeting these requirements. The module designs shall satisfy the following general design considerations. Environments to be considered in assessing possible degradation of module electrical performance and physical properties include: solar exposure (particularly UV); thermal conditions, including freezing and thawing; effects of wind, rain, snow, ice, hail, salt mist, and atmospheric oxidants; dust and debris accumulation, especially nonremovable stains or contamination; and dynamic loading effects of wind, snow and hail. In addition to these general considerations, the following specific performance and design requirements shall be met by the modules.

A. PERFORMANCE REQUIREMENTS

The following standard performance measurement requirements shall be used:

(1) Average Module Output Power - Average module output power P_{avg}) shall be determined for a suitably sized sample quantity of modules (not less than 10), at Standard Operating Conditions (SOC) and at Nominal Operating Voltage (V_{no}). Standard Operating Conditions (SOC) are defined as an AM1.5 irradiance level of 100 mW/cm^2 and cell temperature equal to the Nominal Operating Cell Temperature (NOCT). The power output (P) of individual modules shall be determined per Section IV, paragraph A.

(2) Minimum Individual Module Power Output - The minimum acceptable power output (P_{min}) for production modules shall be not less than 90 percent of the predetermined P_{avg}.

(3) Nominal Operating Voltage - The Nominal Operating Voltage (V_{no}) is the reference voltage at which modules are designed to provide maximum power output at Standard Operating

Conditions (100 mW/cm^2, NOCT). For purposes of standardization, V_{no} shall be 15.0 Vdc, or a convenient fraction or multiple of 15 volts. In no case shall V_{no} exceed 60 Vdc.

(4) Nominal Operating Cell Temperature - The Nominal Operating Cell Temperature (NOCT) is the module cell temperature under ambient conditions equivalent to the Standard Thermal Environment (STE) which is defined as:

Insolation = 100 mW/cm^2

Air temperature = 20°C

Wind average velocity = 1 m/s

Mounting = Oriented normal to solar noon, mounted on structure typical of application

Electrical Load = Open circuit

The NOCT shall be determined by the procedure provided in Appendix A.

B. ELECTRICAL DESIGN REQUIREMENTS

The electrical design of the module shall meet the following requirements:

(1) Electrical Voltage Isolation - All module circuitry, including output terminations, shall be insulated from electrically conductive external surfaces. The voltage isolation design shall provide capability to withstand an operating voltage resulting from series connection of modules to obtain a system voltage of 250 Vdc. This capability shall be demonstrated by successful completion of the 1500 Vdc high voltage withstanding test of Section III, paragraph B.2.

(2) Electrical Grounding and Safety - In order to minimize electrical hazard to personnel, all modules shall be provided with an external grounding terminal or stud serving as a common grounding point for all exposed external conductive surfaces not part of the module circuitry. A grounding connection is not required for modules without exposed conductive surfaces, unless removal of covers, mounting hardware, or adjacent modules, will expose such surfaces.

(3) Module Electrical Interface - Each module shall be provided with redundant output terminations. The polarity of each termination shall be clearly marked in a permanent and legible manner. The terminations shall provide redundant

connection to the module internal circuitry (cell strings) and shall have current handling capability compatible with module short circuit current. If pigtails are selected as the output termination, they shall be of sufficient length to provide interconnection with adjacent modules. Output termination redundancy is not a requirement when direct module-to-module interconnection capability is provided.

(4) Cell String Circuit Reliability/Redundancy - Circuit redundancy features shall be incorporated where cost effective to enhance the reliability and manufacturing yield of completed modules. Design features may include, but are not limited to the following:

(a) Redundant interconnections between solar cells, including redundant cell attachment points

(b) Series/parallel interconnection of cells within the module

(c) Integral bypass diodes within each module

The decision to incorporate redundancy features shall be based on the expected percent improvement in lifetime/yield and replacement cost as contrasted with the percent increase in module cost/watt. Series/parallel circuit arrangements, when used, shall be designed so that "hot-spot" cell heating does not lead to further module degradation under worst-case-single-cell-failure conditions defined as follows:

(a) The module output is short circuited

(b) A single representative solar cell is open circuited to represent a single cell failure

(c) The incident irradiance is 100 mW/cm^2, AM1.5

(d) The thermal boundary conditions are adjusted so that the equilibrium solar cell temperature outside of the hot-spot region is equal to NOCT + 20°C

C. MECHANICAL DESIGN REQUIREMENTS

The mechanical design of the module shall meet the following requirements:

(1) Module Geometry - To meet the array/system requirements for mounting, each module shall meet the envelope, mechanical, and interface requirements specified by an Interface Control

Drawing to be prepared by the manufacturer/contractor, providing as a minimum the following information:

(a) Maximum envelope dimensions and tolerances

(b) Location and configuration of output terminations

(c) Mounting hole or attachment provisions, dimensions, and tolerance

(d) Illuminated (active) surface dimensions and shadowing or view angle constraints

(e) Nominal electrical performance (P_{avg})

(f) Maximum weight

(g) Dimensioned cross-sectional view through cells and terminations

(h) Drawing of roof-top installation showing interface constraints

(i) Details of labeling and identification

To allow for convenient handling and testing of modules, no individual panel module shall exceed 1.2 meters x 1.2 meters (47.244 inches x 47.244 inches). Shingle modules shall be sized such that an integral number of modules will fit efficiently on a 1.2 m x 1.2 m mounting structure.

(2) Interchangeability - All modules from a given manufacturer shall be physically and functionally interchangeable. Tolerances on all external module dimensions shall be maintained at a level consistent with module interchangeability. Surfaces, mounting holes, and any attachment hardware associated with the attachment interfaces, shall be maintained within tolerance specified in the interface control drawing.

(3) Optical Surface Soiling - The illuminated optical surface(s) of the module shall be smooth, and generally free of projections which could promote entrapment of dust and other debris. Particular attention shall be given to selection of materials for the optical surface(s) which will minimize the accumulation of nonremovable contaminants, particulate matter and stains, and will promote self-cleaning by natural processes such as wind and rain.

(4) Module Labeling and Identification - Each module shall be identified in a permanent and legible manner with suitable labels or markings specifying the manufacturer's module

model number (or drawing) and revision, sequential serial number, year and week of manufacture, and maximum system operating voltage for which the module is designed. Additional information may include the Nominal Operating Voltage and power of the module. The polarity of each electrical termination shall be marked in a permanent and legible manner in a position which is visible when accessing the electrical terminations in a completed array.

D. ENVIRONMENTAL DESIGN REQUIREMENTS

Environments to be considered in assessing possible degradation of module electrical performance and physical properties include: solar exposure (particularly UV); thermal conditions, including freezing and thawing; effects of wind, rain, snow, ice, hail, salt mist, and atmospheric oxidants; dust and debris accumulation, especially nonremovable stains or contamination; and dynamic loading effects of wind, snow, and hail. As a minimum, the module design shall be capable of withstanding exposure to the following test environments:

(1) Thermal cycling from -40°C to +90°C per the test procedure in Section V, paragraph A.

(2) Humidity per the test procedure in Section V, paragraph B.

(3) Mechanical cyclic loading per the test procedure in Section V, paragraph C. The test load level shall be ±1.7 kPa (±35 pounds per square foot). This test is applicable only to panel type modules.

(4) Wind resistance test per the procedure in Section V, paragraph D. Shingle type modules only shall be capable of withstanding a test level equivalent to an uplift loading of 1.7 kPa (35 pounds/ft^2).

(5) Twisted mounting surface of 20 mm/m (1/4 inch per foot) per the test procedure in Section V. Paragraph E.

(6) Hail impact testing per the test procedure in Section V, paragraph F. The module shall be capable of withstanding 20.0 mm (3/4 inch) diameter hailstone impact.

SECTION III

CHARACTERIZATION, QUALIFICATION AND ACCEPTANCE REQUIREMENTS

A. PERFORMANCE CHARACTERIZATION TEST REQUIREMENTS

The tests included in this section will be performed to characterize the module electrical and thermal performance. The characterization testing will be performed in the sequence shown in the flow diagram in Figure 3-1.

(1) Determination of Nominal Operating Cell Temperature - For purposes of providing a measurement of module performance that is representative of the anticipated terrestrial application, all module performance measurements shall be referenced to the Nominal Operating Cell Temperature (NOCT). NOCT is defined as the average cell temperature in the module under ambient conditions equivalent to the Standard Thermal Environment (STE). The Standard Thermal Environment is characterized by 100 mW/cm^2 insolation, ambient air temperature of 20°C, average wind velocity of 1.0 m/s, with the module installed in an open-frame panel assembly. Electrical output terminations are open-circuited. Actual cell temperatures shall be taken at conditions approximating STE in order to obtain the solar cell NOCT. The approved techniques for performing the NOCT characterization test are included in Appendix A.

(2) Initial Electrical Measurement - An appropriate size sample quantity of the prototype modules will be used to determine initial electrical performance per Section IV, paragraph A. Measurements shall be referenced to the NOCT determined per paragraph III.A.1, and at Nominal Operating Voltage (V_{no}). In addition to obtaining an initial I-V characteristic curve for each module at SOC, the average output power (P_{avg}) at nominal operating voltage shall be calculated from measurements of all prototype samples tested. When these electrical measurements are to be made at conditions other than SOC, the temperature correction coefficients required to correct measurements to NOCT shall be previously determined in accordance with Appendix B.

B. DESIGN QUALIFICATION TEST REQUIREMENTS

This section specifies the minimum tests that shall be performed in order to verify that the modules will satisfy the design requirements

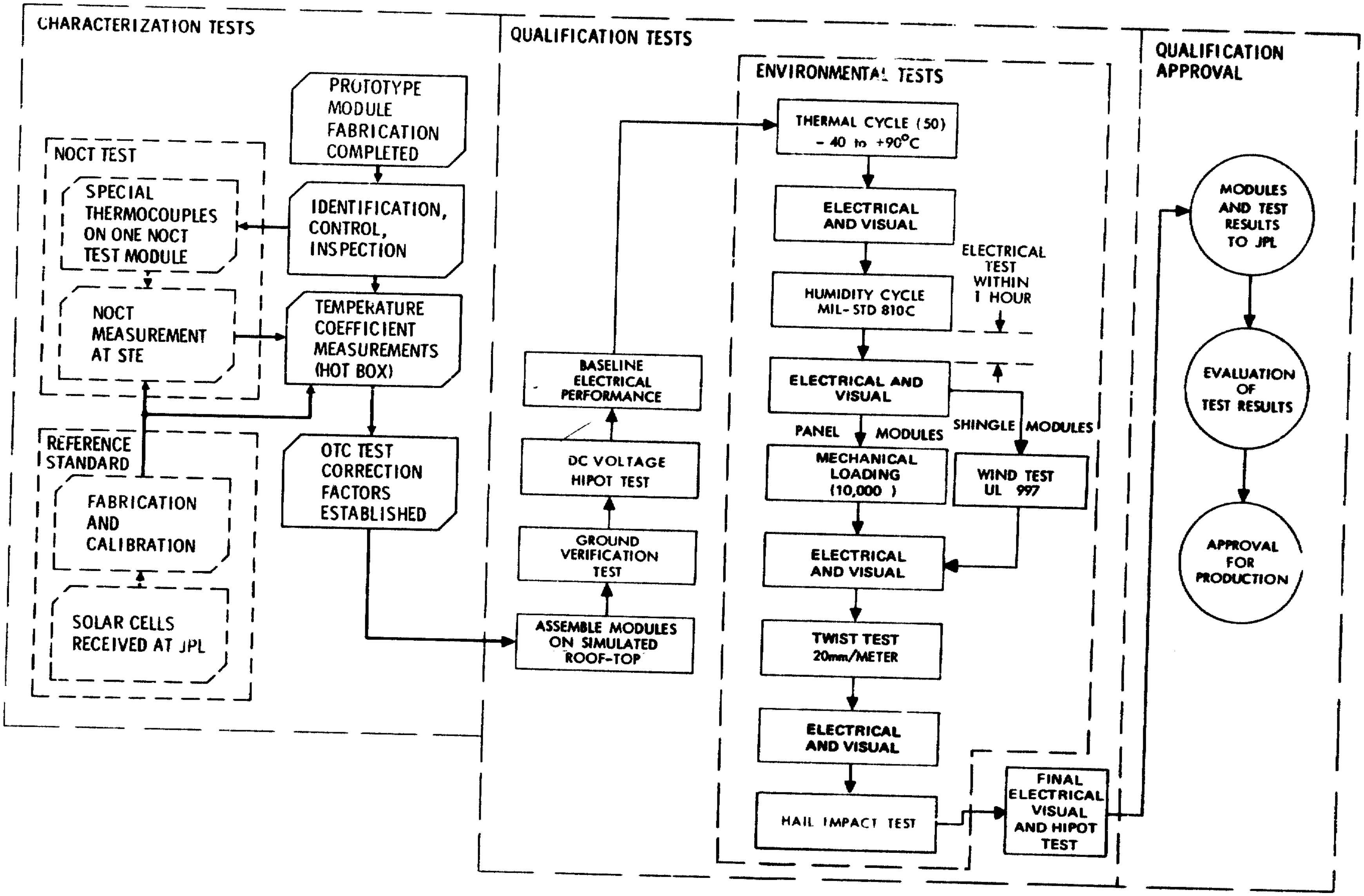

Figure 3-1. Characterization and Qualification Test Flow Plan

of this specification and to provide confidence that production modules will function within the specified performance requirements. Modules shall be mounted on rigid structural test frames simulating the selected mounting interface and configuration for all design qualification testing. The mounting arrangement shall be representative of the rooftop installation shown on the manufacturer's Interface Control Drawing. Modules shall be provided with suitable thermocouple or circuit monitoring instrumentation. As a minimum, the following qualification tests shall be performed in the order described below. For clarification, the test sequence is shown in the flow chart (Figure 3-1).

(1) Ground Continuity Test - Each module having exposed external conductive surfaces (i.e., frame or structural members) shall be tested using a suitable continuity tester to verify that electrical continuity exists between all such surfaces and the module grounding point. The maximum resistance to ground shall be 50 milliohms.

(2) Electrical Isolation Test - Each module shall be subjected to a 'Hi-Pot' test conducted with the output terminations short-circuited. Test leads from a suitable dc voltage power supply shall be connected with the positive lead on the terminals and the negative lead on the module grounding stud.

In the case of modules not required to provide a grounding stud, the mounting structure shall be used as the second test point. Voltage shall be applied at a rate not to exceed 500 V/sec up to the test voltage of 1500 Vdc, and then held at the required test voltage for 1 minute. The module shall be observed during the test and there shall be no signs of arcing or flashover. Leakage current shall be monitored during the test and shall not exceed 50 microamps.

(3) Baseline Electrical Measurement - Subsequent to assembly in the structural test frame, each module shall be remeasured to establish a baseline electrical output power which will serve as the comparison value for determination of the effects of qualification testing on electrical performance. The measurement shall be made per Section IV, Paragraph A.

(4) Visual Inspection - Each module shall be visually inspected to obtain a baseline identification of the presence or absence of any defects in the module for purposes of detecting any changes following environmental exposure. Pertinent sections of the applicable acceptance/rejection criteria or workmanship specification shall provide a guide for this inspection.

(5) Environmental Tests - Each module shall be subjected to the following exposures. Module electrical performance measurements and visual inspection shall be conducted after each exposure. The tests shall be conducted in the order indicated:

(a) Thermal cycling test

(b) Humidity cycling test

(c) Mechanical cycling test, if applicable

(d) Wind resistance test, if applicable

(e) Twisted mounting surface test

(f) Hail impact test

(6) Qualification Pass/Fail Criteria - The output power degradation of each tested module determined after completion of all qualification tests, shall not exceed 5 percent of the baseline electrical performance determined per Section III, paragraph B.3. The module shall pass the electrical isolation test when retested at completion of qualification tests. There shall be no occurrences of open circuit or short circuit conditions during tests in which the module circuitry is instrumented. The allowable level of observable cracks or other mechanical degradation (such as delamination of coatings) shall be determined by the JPL-approved manufacturer's module acceptance testing plan. Acceptable performance under the qualification testing requirements is a prerequisite for JPL approval of the module design.

C. MODULE PRODUCTION ACCEPTANCE REQUIREMENTS

Module acceptance shall be based on meeting the following requirements:

(1) Electrical Performance - Each module shall be measured to determine its current-voltage characteristics (I-V curve). Measurement shall be made in accordance with paragraph A of Section IV. No module shall be accepted for delivery which produces less than 90 percent of the average module output power (P_{avg}) under Standard Operating Conditions.

(2) Electrical Isolation - Each module shall be subjected to a 1500 Vdc Hi-Pot test, per Section III, Paragraph B.2, to assure adequate electrical isolation for safety of operating personnel at system operating voltages.

(3) Mechanical and Visual Inspection - Modules shall be mechanically and visually inspected, on the basis of criteria developed by the manufacturer, and approved by JPL, defining acceptable/rejectable levels of workmanship and quality.

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SECTION IV

PEıFORMANCE MEASUREMENT PROCEDURES

A. ELECTRICAL PERFORMANCE

Electrical performance measurements shall be referenced to Standard Operating Conditions (SOC) defined as 100 mw/cm^2 AM1.5 irradiance, Nominal Operating Cell Temperature (NOCT). All procedures, equipment and standards related to measurements shall conform to the latest revision of NASA TM 73702, Terrestrial Photovoltaic Measurement Procedures. A reference cell which has spectral response representative of the cells in the module shall be the only irradiance reference used. Secondary standards or transfer modules shall not be used.

To provide for efficient module testing, module electrical performance may be based on measurements made at either Standard Operating Conditions (SOC) or at Optional Test Conditions (OTC) defined as 100 mW/cm^2 irradiance, and a cell temperature other than NOCT.

1. Module Output Power Measurements at SOC

When module performance is measured at SOC, the output power of individual modules shall be calculated as the product of V_{no} (15.0 Vdc unless otherwise specified) and the module current taken from the I-V characteristic curve at V_{no}:

$$P = V_{no} \cdot I_{SOC} \qquad (1)$$

where

V_{no} = Module nominal operating voltage at NOCT

I_{SOC} = Module current at NOCT and V_{no}

2. Module Output Power Measurements at OTC

When module performance is measured at Optional Test Conditions (OTC), the individual module output power must be determined by application of appropriate temperature correction coefficients to the voltage and current data obtained from the OTC I-V characteristic curve. Under these conditions the module output power is calculated directly from:

$$P = V_{no} (I_{OTC} + \Delta I) \qquad (2)$$

where

I_{OTC} = Current at V_{OTC} from OTC I-V curve

ΔI = Current temperature correction, amps

= $C_I (T_{NOCT} - T_{OTC})$

C_I = Current temperature coefficient, amps/°C

V_{OTC} = Voltage point on OTC I-V curve

= $V_{no} - \Delta V$

ΔV = Voltage temperature correction, volts

= $C_V (T_{NOCT} - T_{OTC})$

C_V = Voltage temperature coefficient, volts/°C

T_{NOCT} = Predetermined value of NOCT

T_{OTC} = Selected optional test temperature

Determination of the temperature coefficients shall be accomplished by the method described in Appendix B.

Alternate temperature correction procedures such as that provided by computer controlled Large-Area Pulsed Solar Simulator (Xenon source) may be used if approved by JPL.

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SECTION V

ENVIRONMENTAL TEST PROCEDURES

A. THERMAL CYCLING TEST PROCEDURE

The module shall be subjected to the thermal cycling procedure per Figure 5-1, consisting of 50 cycles with the cell temperature varying between -40°C and +90°C. The temperature shall vary approximately linearly with time at a rate not exceeding 100°C per hour and with a period not greater than 6 hours per cycle (from ambient to -40°C to +90°C to ambient). The module circuitry shall be instrumented and monitored throughout the test to verify that no open circuits or short circuits occur during the exposure.

B. HUMIDITY TEST PROCEDURE

The module shall be subjected to the humidity cycling procedure per Figure 5-2. The module shall be tested in the open circuit condition, but with terminations protected from water condensation. Electrical performance test, per paragraph IV.A, shall be performed within one hour after removal from the humidity chamber, or within another mutually agreed-upon time period if the testing is subcontracted.

C. MECHANICAL CYCLING TEST PROCEDURE

The module shall be subjected to a cyclic load test in which the module is supported only at the design support points and a uniform load normal to the module surface is cycled 10,000 times in an alternating negative and positive direction. Cycle rate shall not exceed 20 cycles/minute. The module circuitry shall be instrumented to verify that no open circuitry or short circuits occur during the test. JPL Document 5101-19 "Cyclic Pressure-Load Developmental Testing of Solar Panels," February 1977, describes techniques suitable to the performance of this test.

D. TWISTED MOUNTING SURFACE TEST PROCEDURE

The module shall be subjected to a twist test by deflection of the substrate to which it is mounted. The deviation from a true flat surface during the test shall be ±20 mm/m (±1/4 inch per foot) measured along either mounting surface as shown in Figure 5-3. The module circuitry shall be instrumented to verify that no open circuits or short circuits occur during the deflection test.

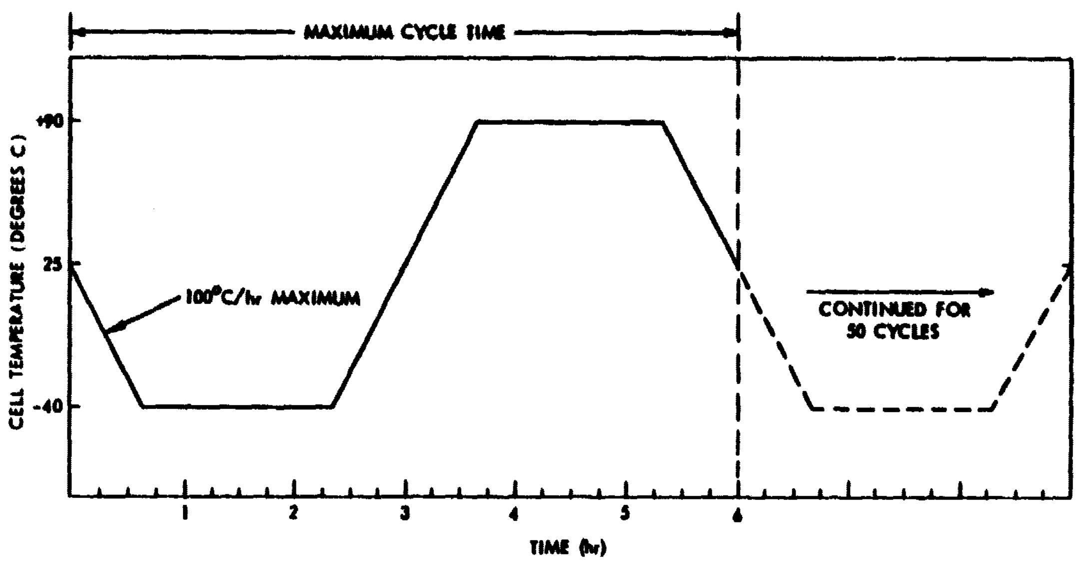

Figure 5-1. Thermal Cycle Test (Shorter cycle time is acceptable if 100°C/hr maximum rate of temperature change is not exceeded. Chamber may be opened at 25 cycles for visual inspection.)

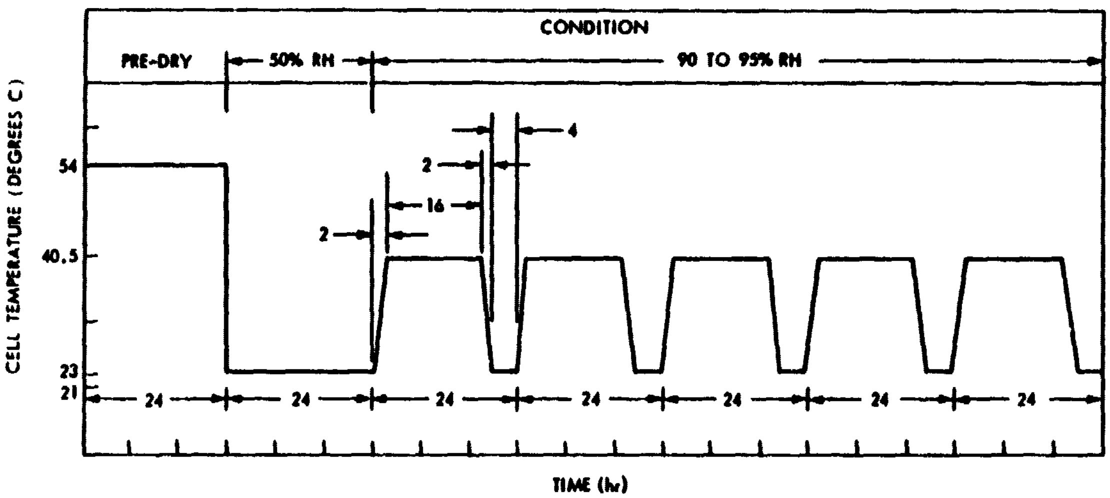

Figure 5-2. Humidity Cycle Test (Suitable procedures for accomplishing this test are described in MIL-STD-810C, Method 507.1, Procedure V.)

E. TWISTED MOUNTING SURFACE TEST PROCEDURE

The module shall be subjected to a twist test by deflection of the substrate to which it is mounted. The deviation from a true flat surface during the test shall be ±20 mm/m (±1/4 inch per foot) measured along either mounting surface as shown in Figure 5-3. The module circuitry shall be instrumented to verify that no open circuits or short circuits occur during the deflection test.

F. HAIL IMPACT TEST PROCEDURE

The module shall be subjected to normal impact loading with 20 mm (3/4 inch) diameter iceballs traveling at terminal velocity of 20.1 m/sec (45 mph) specified size. At least three different points of impact shall be selected to include the test specimen's most sensitive exposed point, and each point will be struck at least 3 times (a minimum of 9 impacts). The most sensitive exposed point on a test specimen must be determined experimentally through destructive testing of a sample panel. Iceballs of 38 mm (1-1/2 in.) diameter shall be fired at candidate sensitive points with increasing velocity until the panel is broken. Several different points on the panel should be broken, and the points broken at the lowest velocities should be used for subsequent testing.

The candidate points selected should include (where applicable) the following:

(1) Corners and edges of the module

(2) Edges of cells, especially around electrical contacts

(3) Points of minimum spacing between cells

(4) Points of support for any superstrate material

(5) Points of maximum distance from points of support in (4) above

Some scatter is expected in hitting a location on a module. Three repeated impacts are required to ensure that a sensitive point has been struck. Error of up to 13 mm (1/2 in.) in the location hit is acceptable. Either pneumatic or spring-actuated guns for projecting the iceballs against the modules are acceptable. However, iceball velocity at impact must be controlled to within ±5 percent of terminal velocity for the required hailstone size. Iceballs shall be generally spherical in shape with a maximum deviation in diameter of ±3 mm (±1/8 in.). The iceballs shall be cooled to -10°C ±2°C as measured in the compartment where they are stored. The module shall be mounted in a manner representative of that used for actual installation of the module in the array. After each impact, the module shall be inspected for evidence of visible damage. Note that iceballs are the only acceptable hailstone simulation. Dropped steel balls, for example, shall not be used.

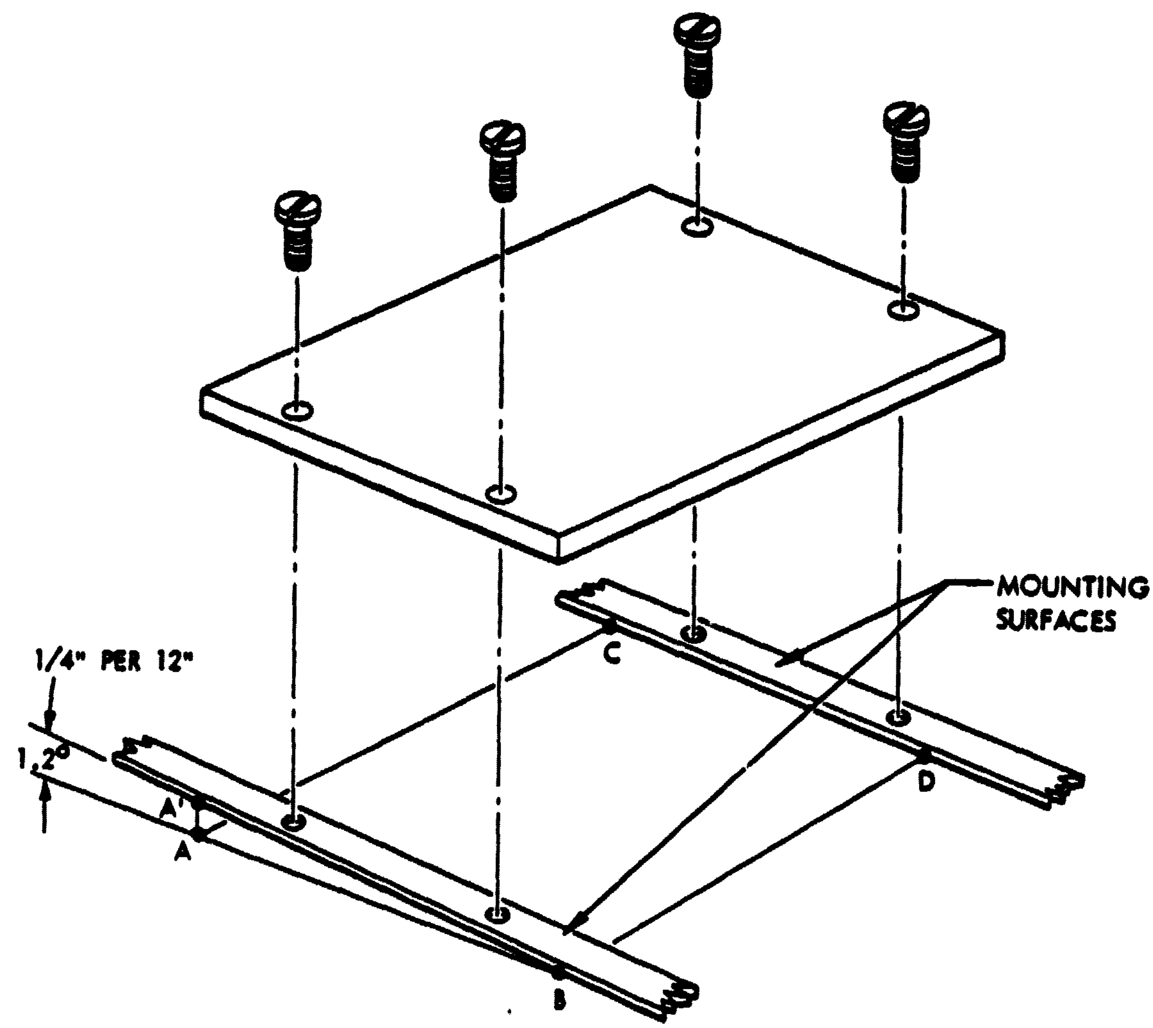

Figure 5-3. Graphical Representation of "Twisted Mounting Surface" Requirement
- Points A, B, C, D are in a Plane
- Point A' is out of Plane the Amount Shown

APPENDIX A

APPENDIX A

DETERMINATION OF NOMINAL OPERATING CELL TEMPERATURE

1. Purpose

The purpose of this test is to acquire sufficient data to allow an accurate determination of the nominal operating temperatures of the solar cells of a terrestrial solar array module.

By definition, the Nominal Operating Cell Temperature (NOCT) is the module cell temperature under operating conditions in the Standard Thermal Environment (STE) which is defined as:

Insolation = 100 mW/cm^2

Air temperature = 20°C

Wind average velocity = 1 m/s

Mounting = oriented normal to solar noon, open back

Electrical load = open circuit

The NOCT test procedure is based on gathering actual measured cell temperature data via thermocouples attached directly to the cells of interest, for a range of environmental conditions similar to the STE. The data are than presented in a way that allows accurate and repeatable extrapolation of the NOCT temperature.

2. Determination of NOCT

The temperature of the solar cell (T_{cell}) is primarily a function of the air temperature (T_{air}), the average wind velocity ($\overline{V}$), and the total solar insolation (L) impinging on the active side of the solar array module. The approach for determining NOCT is based on the fact that the temperature difference ($T_{cell}-T_{air}$) is largely independent of air temperature and is essentially linearly proportional to the insolation level. Analyses indicate that the linear assumption is quite good for insolation levels greater than about 40 mW/cm^2. The procedure calls for plotting ($T_{cell}-T_{air}$) against the insolation level for a period when wind conditions are favorable. The NOCT value is then determined by adding T_{air} = 20°C to the value of ($T_{cell}-T_{air}$) extrapolated for the STE insolation level of 100 mW/cm^2, i.e., NOCT = $(T_{cell}-T_{air})\,|\,STE + 20°C$.

The plot of ($T_{cell}-T_{air}$) vs L shall be determined by conducting a minimum of two field tests in which the module being characterized is tested under terrestrial environmental conditions approximating the STE in accordance with the testing guidelines which follow. Each test shall consist of acquiring a semi-continuous record of ($T_{cell}-T_{air}$) over a one- or two-day period, together with other measurements as required to characterize the terrestrial environment during the testing period. Acceptable data shall consist of measurements made when the average wind velocity is 1 m/s $\pm$0.75 m/s and with gusts less than 4 m/s for a period of 5 minutes prior to and up to the time of measurement. Local air temperature during the test period shall not differ by more than 5°C and shall lie in the range of 20°C $\pm$15°C. Using only acceptable data as so defined, a plot shall be constructed which defines the relationship between ($T_{cell}-T_{air}$) and the insolation level (L) for L $\geq$ 40 mW/cm^2.*

When ($T_{cell}-T_{air}$) is plotted as a function of L for average wind velocities less than 1.75 m/s, results similar to those shown in Figure A-1 are obtained. For the data shown, the local air temperature was 15.6°C $\pm$4.5°C and the wind speed varied from zero to less than 4 m/s with an average of 1 m/s. Using the plot of ($T_{cell}-T_{air}$) vs L, the value of ($T_{cell}-T_{air}$) at STE is determined by extrapolating the average value of ($T_{cell}-T_{air}$) for L = 100 mW/cm^2. Using the data in Figure A-1 as an example, ($T_{cell}-T_{air}$) at STE is determined to be 25.1°C. The preliminary value of NOCT is thus 25.1°C + 20°C = 45.1°C.

3. Air Temperature and Wind Correction

A correction factor to the preliminary NOCT for average air temperature and wind velocity is determined from Figure A-2. This value is added to the preliminary NOCT and corrects the data to 20°C and 1 m/s. $\overline{T}_{air}$ and $\overline{V}$ are the average temperature and wind velocity for the test period.

For the test data shown in Figure A-1, $\overline{V}$ is 1 m/s and $\overline{T}_{air}$ is 15.6°C. From Figure A-2, the correction factor is 0°C. The NOCT is, therefore, 45.1°C.

4. Test Geometry

a. Tilt Angle. The plane of the module shall be positioned so that it is normal to the sun ($\pm$5°) at solar noon.

b. Height. The bottom edge of the module shall be 0.6 m (2 ft) or more above the local horizontal plane or ground level.

c. Panel Configuration. The module shall be located in the interior of a 1.2 m x 1.2 m (4 ft x 4 ft) panel designed to simulate the thermal boundary conditions of the expected field installation. For modules designed for free-standing, open-back installations, black aluminum plates or other modules of the same design shall be used to fill in any remaining open area of the panel surface. During testing

*If the air temperature varies by more than 5°C, the resulting effect appears as an increase in the scatter of the plotted data. As a result, the data will be more difficult to fit and a less accurate result is possible.

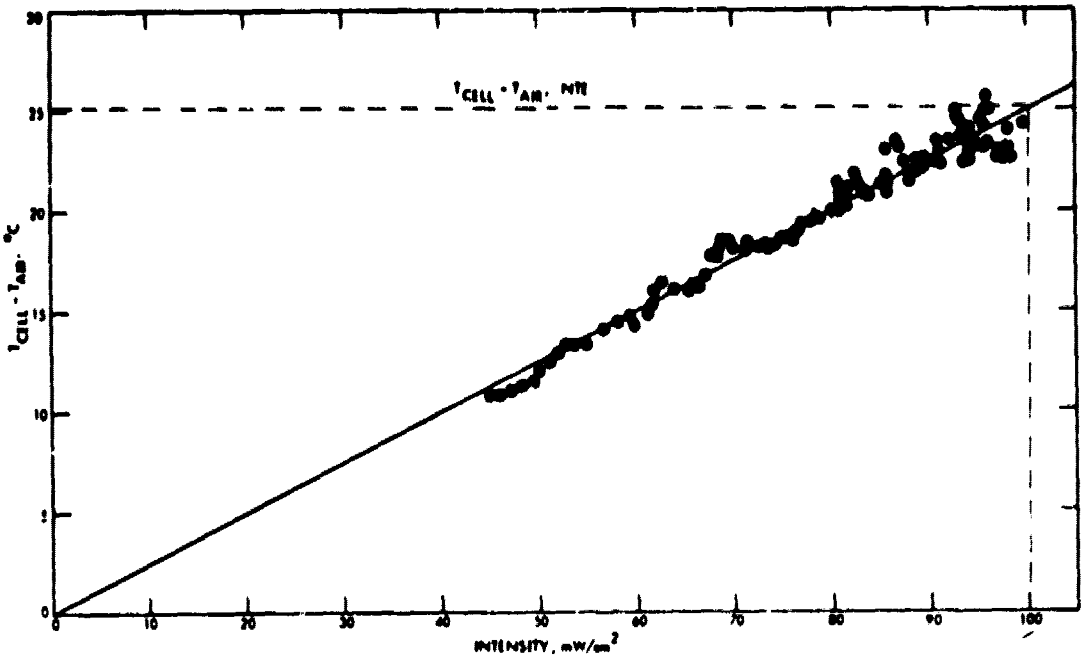

Figure A-1. Typical Cell Temperature Data

the panel should be supported in a manner which allows normal cooling of the rear surface. In the case of modules that are not self-supporting or have special mounting characteristics, such as shingle modules, the test module shall be centrally located in the panel and integrated with representative supporting structure and interfacing modules to simulate the thermal boundary conditions expected in field application.

d. Surrounding Area. There shall be no obstructions to prevent full irradiance of the module beginning a minimum of 4 hours before solar noon and up to 4 hours after solar noon. The ground surrounding the module shall not have a high solar reflectance and shall be flat and/or sloping away from the test fixture. Grass and various types of ground covers, blacktop, and dirt are recommended for the local surrounding area. Buildings having a large solar reflective finish shall not be present in the immediate vicinity. Good engineering judgment shall be exercised to ensure that the module is receiving a minimum of reflected solar energy from the surrounding area.

e. Wind Direction. The wind shall not be predominantly from due east or due west; flow parallel to the plane of the array is not acceptable and can result in a lower-than-typical operating cell temperature.

f. Module Electrical Load. In order to simplify testing, data shall be obtained for a module open-circuit condition corresponding to zero electrical power output.

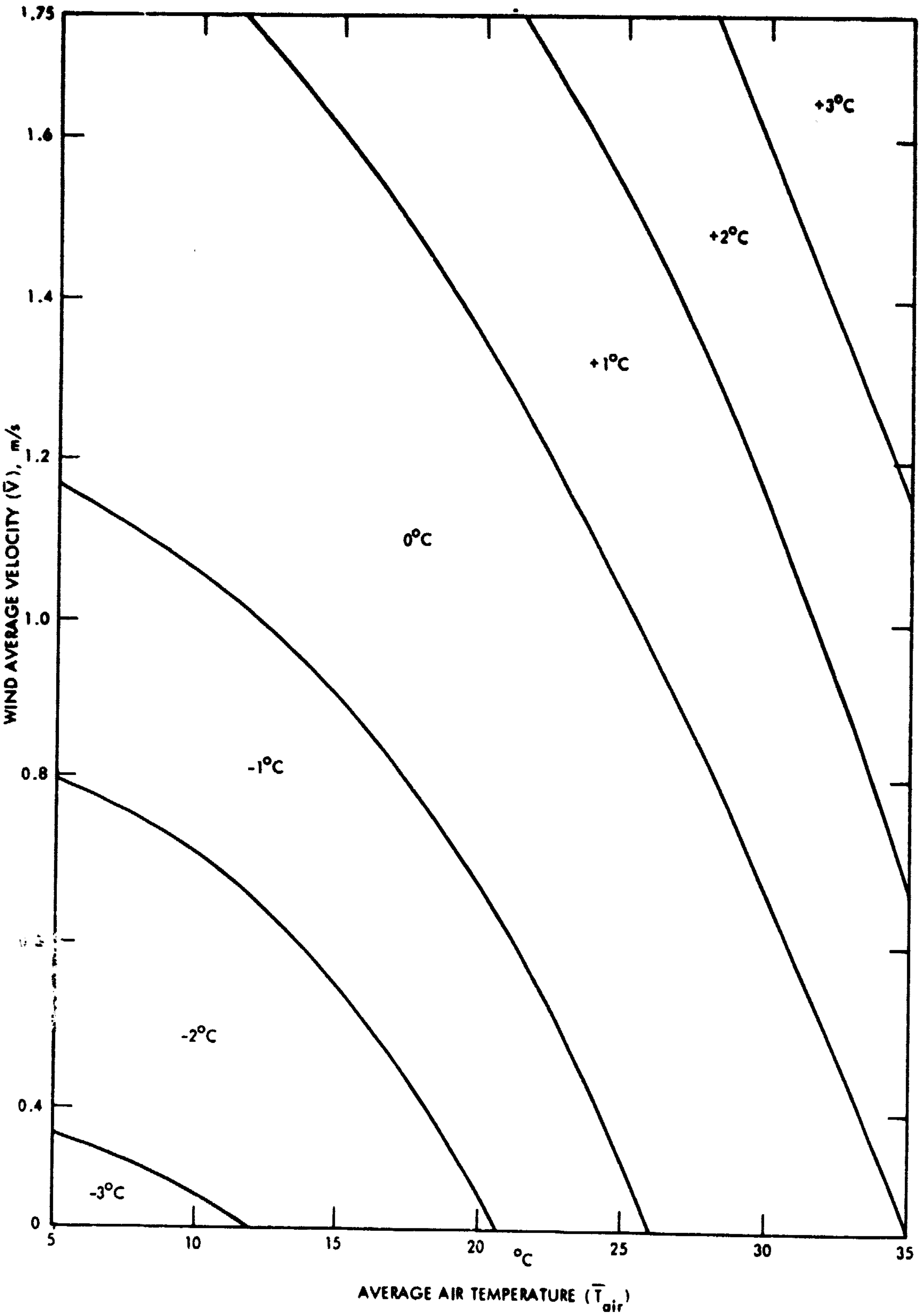

Figure A-2. NOCT Correction Factor

5. Test Equipment

a. Pyranometer. The total solar irradiance on the active side of the module shall be measured by a pyranometer mounted on the plane of the module and within .3 m (1 ft) of the array. The pyranometer used shall have a traceable annual calibration to a recognized standard instrument and shall be either (1) a temperature-compensated unit which has less than ± 1 percent deviation in sensitivity over the range -20°C to +40°C, or (2) a unit which incorporates a temperature sensor and has a sensitivity-temperature correction supplied with its calibration.

b. Wind Measurement. Both the wind direction and wind speed shall be measured at the approximate height of the module and as near to the module as feasible.

c. Air Temperature. The local air temperature shall be measured at the approximate height of the module. The measurement shall be made in the shadow of the module and shall be accurate to ±1°C. An average local air temperature is desired. This is obtained satisfactorily by increasing the thermal mass of the thermocouple by imbedding the thermocouple in a solder sphere of approximately 6 mm (1/4 in) diameter. The thermocouple must be appropriately shielded and vented.

d. Cell Temperature. The temperature of at least two representative interior solar cells shall be measured to ±1°C. Thermocouples shall be 36 gauge, and shall be soft-soldered directly to the back of the cells.

e. Substrate Surface Temperature. The exterior temperature of the rear of the solar module shall be measured to ±1°C beneath a representative cell and when practical beneath a representative space between cells. Thermocouples shall be 26 gauge, and shall be bonded down with aluminized epoxy adhesive or the equivalent.

6. Data Recording

All data shall be printed out approximately every 2 minutes. In addition, solar intensity, wind speed, wind direction, and air temperature shall be continuously recorded.

7. Cleaning

The active side of the solar cell module and the pyranometer bulb shall be cleaned before the start of each test. Dirt shall not be allowed to build up. Cleaning with a mild soap solution followed by a rinse with distilled water has proven to be effective.

8. Equipment Calibration

A calibration check shall be made of all the equipment prior to the start of the test.

APPENDIX B

APPENDIX B

DETERMINATION OF TEMPERATURE CORRECTION COEFFICIENTS

1. Purpose

The purpose of this test is to determine the temperature correction coefficients used in transforming module electrical performance measurements made at Optional Test Conditions to Standard Operating Conditions.

2. Approach

A photovoltaic I-V characteristic curve obtained at a given cell temperature and a fixed insolation level can be transformed by a point-by-point correction to an I-V curve at a different temperature. For purposes of translation from OTC to SOC the insolation is constant at 100 mW/cm^2. The region of the I-V curve of interest is near the maximum power point. The current and voltage points on the SOC I-V curve can be obtained from the coordinates of a point on the OTC I-V curve with the following equations:

$$I_{SOC} = I_{OTC} + C_I (T_N - T_O) \quad (1)$$

$$V_{SOC} = V_{OTC} + C_V (T_N - T_O) \quad (2)$$

where

V_{OTC}, I_{OTC}	are coordinates of a selected point on the curve obtained at OTC
V_{SOC}, I_{SOC}	are coordinates of the corresponding point on the SOC curve
T_N	is actual cell temperature, usually NOCT, ±2°C, during the SOC curve measurement
T_O	is actual cell temperature, during the OTC curve measurement
C_I	the current temperature coefficient, expressed as amps/°C
C_V	the voltage temperature coefficient, expressed as negative volts/°C

The values of C_I and C_V are to be determined empirically by a curve overlay procedure applied to I-V curve measurements of a minimum of 10 modules with cell temperatures approximating both OTC and SOC. The values of C_I and C_V for the 10 modules will be averaged to establish mean values to be used in calculating the power of production modules.

3. Procedure

To determine C_I and C_V, the following procedure shall be used:

(1) Install the module to be tested in a temperature controlled environment. After stabilizing the module temperature at the cell temperature selected for OTC within ±2°C obtain an I-V curve for OTC conditions. Record the actual temperature (T_O).

(2) Repeat step (1) for SOC with the module stabilized at NOCT ±2°C. Record the actual temperature (T_N).

(3) On the curve obtained at SOC, mark two points, near the maximum power point, and approximately equi-distant from it. For reference, these points should be approximately at 90% of I_{SC} and 60% of V_{OC}.

(4) Using a light box or similar equipment, superimpose the OTC curve on the SOC curve and translate the curve rectilinearly until the curves match closely at the marked points. Mark the overlayed curve at the same points.

(5) Separate the curves and determine the voltage ($V_{SOC} - V_{OTC}$) and current ($I_{SOC} - I_{OTC}$) shifts required to achieve the match.

(6) Calculate the C_I and C_V from the following:

$$C_I = \frac{I_{SOC} - I_{OTC}}{T_N - T_O}$$

$$C_V = \frac{V_{SOC} - V_{OTC}}{T_N - T_O}$$

C_V is negative.

(7) Determine the average values of C_I and C_V for the 10 modules.