heliotek

CR 114476

AVAILABLE TO THE PUBLIC

PART SPECIFICATION
SOLAR CELLS, SILICON N-ON-P
SOLDERLESS LOW TEMPERATURE OPERATION
FOR JUPITER MISSIONS

Prepared under Contract No. NAS2-5519

for

AMES RESEARCH CENTER

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

3 April 1972

Heliotek, Division of Textron Inc.

12500 Gladstone Avenue

Sylmar, California 91342

heliotek

A Division of textron Inc.

PART
SPECIFICATION

SOLAR CELLS, SILICON N-ON-P

SOLDERLESS LOW TEMPERATURE OPERATION

FOR JUPITER MISSIONS

DATE: 3 April 1972 NO. FINAL

PREPARED BY: A. Payne

APPROVAL SIGNATURES: E. Ralph 3 April 1972
DATE

Q. Ham 3 APR 1972
DATE

REV.	DATE	BY	REVISION DESCRIPTION	APPROVED
1.	4-3-72		Final Specification based upon results of pilot line.	E.R.

CONTENTS

PRELIMINARY

PART SPECIFICATION

SOLAR CELLS, SILICON N-ON-P, SOLDERLESS LOW TEMPERATURE OPERATION

FOR JUPITER MISSIONS

1.0 SCOPE

This specification covers the requirements for 10 ohm cm N-ON-P, silicon solar cells, for use on solar panel assemblies for space flight applications.

2.0 APPLICABLE DOCUMENTS

2.1 CONFLICTING REQUIREMENTS.

In the event of conflict between this specification and any of the referenced documents, this specification shall govern.

2.2 GOVERNMENT DOCUMENTS.

The following documents of the issue in effect on the date of the invitation for bids or request for proposal, form a part of this specification to the extent specified herein. Later issues of these documents may be used at the option of the supplier providing no degradation of the product ensues.

Federal

QQ-S-571	Solder, Lead Alloy, Tin-Lead Alloy, Tin Alloy, Flux covered Ribbon and Wire, and Solid Form

Military

MIL-S-19500	Semiconductor Devices, General Specification for

2.3 OTHER PUBLICATIONS.

The following documents of the issue noted form a part of this specification to the extent specified herein.

PUBLICATIONS

The Solar Constant, F.S. Johnson,
Journal of Meteorology, Vol. 11,
No. 6, December 1954, pp. 431-439.

3.0 REQUIREMENTS

3.1 DESIGN AND CONSTRUCTION.

Solar cells supplied to this specification shall be of the design, construction, and physical dimensions as specified below and in Figure 1.

3.1.1 Cell Material.

The solar cells shall be produced from single crystal, P-type silicon of 6 to 14 ohm cm range base resistivity.

3.1.2 Anti-Reflective Coating.

The N side of the solar cells will have an anti-reflective coating. Such coating shall not deteriorate, delaminate from the cell, as specified herein.

3.1.3 Contacts and Gridlines

Electrical contacts on the cells shall be of sintered titanium-silver. The P side contact shall be a P+ type contact or be deposited on a P+ silicon surface.

3.1.4 Uniformity of Product.

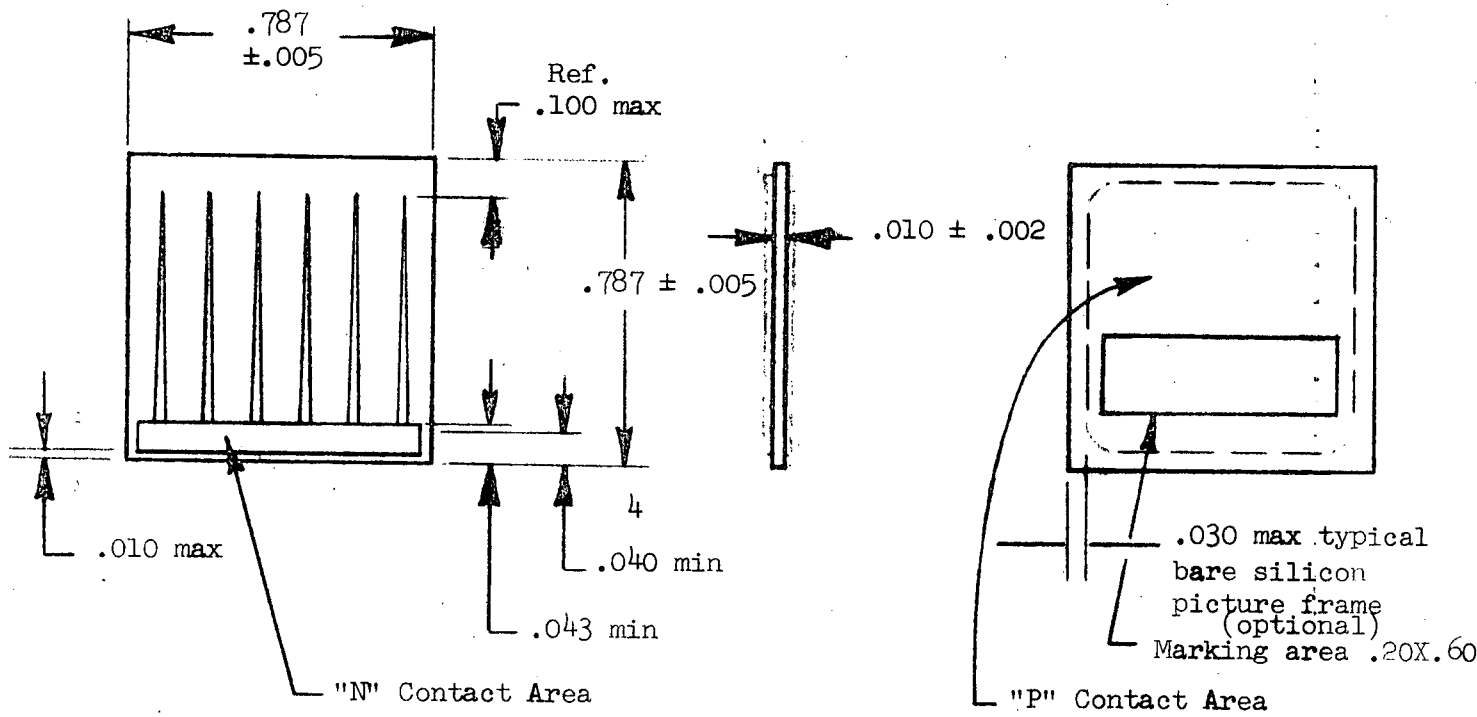
All solar cells shall be fabricated identically in procedure and material to the units which successfully pass the qualification testing as specified in 4.1. No major changes in materials, fabrication techniques or procedures, assembly, inspection, or testing shall be made for subsequent units.

3.2 PERFORMANCE

Solar cells supplied to this specification shall meet all of the performance requirements contained herein.

3.2.1 Electrical Output

Each solar cell shall be capable of converting artificial or natural radiant solar power as found outside the earth's atmosphere under the spectrum specified in the applicable document



6 Shape and number of gridlines optional

5 Marking per spec. paragraph 3.3.8, .12 high min. characters

4 Area to be free of antireflective coating

3 Minimum "N" contact width of .033 min x .775 min long

2 Finished cell shall be capable of seating flat within a square cavity of .7930 max by .7930 max and an angularity of ± 0°-2'.

1 All dimensions are in inches.

NOTES:

Figure 1. Dimensions of Solar Cell

section into the minimum electrical power required below. Each solar cell shall be grouped by its electrical output as shown. Where a minimum average electrical output of any shipping lot is required it shall be based upon the quantity of cells in each electrical output group. Actual measured output of individual cells shall not be used.

3.2.1.1 Electrical Output at 28°C.*

Maximum Solar Intensity	5.0 mW/cm^2
Minimum Cell Temperature	28°C
Cell Voltage	0.350V ± 0.002V
Minimum Cell Output Current at cell voltage:	3.5 mA

*This measurement optional, except where called for in IP, Qualification, and Acceptance Tests.

3.2.1.2 **Electrical Output at Low Temperature.**

Maximum Solar Intensity	5.0 mW/cm^2
Minimum Temperature	-135°C
Minimum Open Circuit Voltage	0.850 mV
Cell Voltage	.800 ±0.005V

Minimum Cell Output current at Cell Voltage

Group 1	3.00 mA
2	3.20 mA
3	3.40 mA
4	3.60 mA
5	3.80 mA

The minimum acceptable average output of any shipping lot is 3.40 mA at 5.0 mW/cm^2.

3.2.2 Radiation Resistance

Exposure of solar cells unprotected by cover slips to a normally incident charged particle flux as specified shall not degrade their output characteristic below that shown.

Radiation Resistance

Energy and Particle:	1 Mev electrons
Fluence:	1×10^{14} e/cm^2
Average current: *	
Minimum current: *	
Test conditions:	Paragraph 3.2.1

*Values to be specified and agreed upon based on most recent studies available.

3.2.3 Vacuum

Each solar cell shall be capable of meeting all requirements of this specification after exposure for 3 years to a condition of a temperature range specified in 3.2.5 and pressure of 1×10^{-8} mm Hg or less.

3.2.4 Temperature Cycling

Each solar cell shall be capable of meeting all requirements including the electrical output per 3.2.1; and contact and grid line integrity, 3.3.2 of this specification after being subjected to 20 temperature cycles between -140°C and +85°C with a cooling rate or heating rate of at least 10°C per minute except that the permissible current output degradation at 0.350 volts shall not exceed 2.5% for any single cell, and 1.5% average for any

sample of cells based on 5 mW/cm^2, 28°C measurements in an AMO spectrum before and after the temperature cycling and after corrections are made for measurement errors.

3.3 CHEMICAL AND PHYSICAL PROPERTIES

3.3.1 Chemical and Physical Compatibility

The solar cells shall be capable of construction into sub-assemblies using normal assembly techniques without exceeding degradation limit specified in 3.2.5.

3.3.2 Contact and Grid Line Integrity

After evaporating and sintering the silver-titanium contacts, the contacts shall be capable of withstanding the tape peel test of 4.5.2.

3.3.3 Solder Contact Appearance

There shall be no pinholes or voids in the N or P contact in excess of 2.5% of the total contact area. Pinholes or voids within this limit shall not impair the contact peel strength requirements of Paragraph 4.5.3. "Partial pinholes" or voids at the edges of solder contacts ("ragged edges") shall not be considered under this pinhole or void requirement.

3.3.4 Contact Solderability

Each solar cell shall be capable of being soldered according to the method specified below.

3.3.4.1 Assembly Solderability

Each solar cell shall be capable of having four (4) pull tabs soldered to it using a solder preform.

3.3.4.2 Solder, Contact Mechanical Integrity

Each contact shall be capable of being soldered according to the method described in 3.3.4.1 and thereafter possessing a contact peel strength of 500 grams (17.6 ounces) minimum.

3.3.5 Magnetic Materials.

Magnetic materials shall not be used in the manufacture or processing of the solar cells.

3.3.6 Radio-Active Materials.

Radio-active materials shall not be used as parts of the solar cell, or in the manufacture or processing of the solar cells.

3.3.7 Fluorescent or Phosphorescent Materials.

All solar cells shall be free of materials which emit visible light of any wavelength immediately after illumination with any wavelength light or during illumination with invisible light (UV or IR).

3.3.8 Identification of Product.

Identification of individual solar cells shall be as follows:

(a) Evaporation lot number (defined in Paragraph 6.3.9 of this specification.

(b) Current output group according to Paragraph 3.2.1 of this specification.

The marking shall be affixed to the rear of the solar cells in the area indicated in Figure 1. This identification shall be clearly readable after cell assembly and cleaning with water and alcohol, and shall not degrade the specified mechanical, electrical, or environmental properties of the cell. The marking shall comply with 3.3.1 and all other requirements of this specification. Rubber Stamping with independent 73X ink, available from Independent Ink Co., Gardena, California is acceptable. This ink must be air dried for at least 24 hours at room temperature or for 30 minutes at 65°C ±3°C before cleaning. Cleaning fluid is isopropyl alcohol.

3.4 DIMENSIONS AND WEIGHT

3.4.1 Dimensions.

The solar cell dimensions shall be as given in Figure 1.

3.4.2 Weight.

The average weight of solar cells in each shipping lot shall not exceed 0.300 grams.

3.5 COLOR AND FINISH

The appearance of each solar cell shall conform to the requirements specified below.

3.5.1 Color and Appearance.

The N side of the cells shall be of the color typical of coated silicon cells. All cells shall be reasonably uniform in color and appearance.

3.5.2 Mechanical Imperfections.

3.5.2.1 Chips.

The quantity and size of chips shall be:
Edge chip: 0.025 inch x 0.150 inch maximum
Corner chip: 0.075 inch hypotenuse maximum
No limit on quantity.

3.5.2.2 Nicks

The quantity and size of nicks shall be:
Edge chip: 0.025 inch x 0.150 inch maximum
Corner chip: 0.075 inch hypotenuse maximum
No limit on quantity.

3.5.2.3 Grid Line Discontinuities

The maximum total linear length of breaks in the grid lines per cell and the total permissible number of cells with this condition,

is as follows: accumulated grid line discontinuity per cell 0.150 inch maximum. Linear breaks of 0.010 inch (0.25 mm) or less in the grid line shall be discounted. There is no limit to the number of cells with these conditions.

4.0 QUALITY ASSURANCE PROVISIONS

4.1 QUALIFICATION

All parts furnished to this specification shall be products which have been tested and qualified at the beginning of the program.

4.1.1 Qualification Basis.

Qualification shall be based on certified evidence that the specimens submitted have successfully demonstrated conformance to all of the provisions of this specification and that the specimens were fabricated using normal production run materials and processes. Unless otherwise indicated this evidence shall consist of the following:

(a) Certification of Conformance by the vendor as defined in Table I, Qualification by Certification of Conformance. In the event that this Certification is based upon data obtained from a source other than the vendor, the source and the data shall be subject to approval. A copy of the test data, data reduction and analysis shall accompany the Certificate of Conformance.

(b) Certification by the vendor of the results of In-Process Tests performed by the vendor as defined in Table II, In-Process Tests.

(c) Qualification Testing per 4.1.3 and Table III, Qualification Tests.

Table I. Qualification by Certification of Conformance

Compliance with the following requirements shall be certified, unless the vendor elects to verify compliance by testing:

Item		Requirement
1	3.1.4	Contacts and Gridlines
2	3.1.5	Uniformity of Product
3	3.2.2	Radiation Resistance
4	3.2.3	Vacuum
5	3.3.1	Chemical and Physical Compatibility
6	3.3.5	Magnetic Materials
7	3.3.6	Radio-Active Materials
8	3.3.7	Fluorescent and Phosphorescent Materials

Table II. In-Process Tests and Test Sequences

Item		Requirement	Test Method	Test Sequences for Sampling Plans (per 4.2.3.1) IP-1	IP-2	IP-3
1	3.1.1	Cell Material	4.5.1	1		
2	3.3.2	Contact and Gridline Integrity	4.5.2		1*	
3	3.1.2	Anti-Reflective Coating	4.5.4		3	
4	3.5.1	Color and Appearance	4.5.5			1
5	3.5.2	Mechanical Imperfections	4.5.6			2
6	3.4.1	Dimensions	4.5.7			3
7	3.2.1	Electrical Output	4.5.8.1			4
8	3.3.8	Identification of Product	4.5.5			5

*The vendor may elect to perform this test on all cells 100 percent, provided the evaporation lot identity is maintained.

TABLE III. Qualification Tests and Test Sequences

Item		Requirement	Test Method	Test Sequences for Test Samples (sampled per 4.1.2) Group A	Group B	Group C
1	3.1.2	Anti-Reflective Coating	4.5.4	12		
2	3.5.1	Color and Appearance	4.5.5	2,9	1	1
3	3.3.8	Identification of Product	4.5.5	7	5	4
4	3.5.2	Mechanical Imperfections	4.5.6	3	2	2
5	3.4.1	Dimensions	4.5.7	4		
6	3.2.1.1	Electrical Output	4.5.8.2	5,10	3,7	3
7	3.2.1.2	Electrical Output, Low Temp.	4.5.8.2	6,11	4,8	
8	3.2.5	Temperature Cycling	4.5.10	8		
9	3.2.2	Charged Particle Irradiation	4.5.12		6	
10	3.4.2	Weight	4.5.13	1		

4.1.2 Qualification Sampling.

4.1.2.1 Sample.

The number of cells to be tested shall be chosen (independent of lot size) by the vendor in conformance with paragraph 50.2 of Appendix C to MIL-S-19500 such that the Qualification Test LTPD Level is 7% for all groups. This shall apply to each group of cells to be tested (A through C).

4.1.2.2 Selection of Qualification Lot.

The qualification inspection lot shall be chosen by the vendor from typical production lots and shall contain cells from at least two (2) evaporation lots of approximately equal proportions. All cells shall have passed the In-Process Tests of Table II and the Acceptance Test Sampling Plan A of Table IV.

4.1.2.3 Qualification Lot Size.

The qualification inspection lot shall contain at least twice the number of cells required for qualification.

4.1.2.4 Selection of Samples.

Initial samples shall be randomly selected from the qualification inspection lot. When the qualification inspection lot is composed of two or more sublots such as mA output groups, the number of samples from each sublot shall be approximately proportional to the corresponding sublot size.

4.1.3 Qualification Testing.

Qualification testing shall be performed as specified below on cells selected according to 4.1.2.

4.1.3.1 Responsibility for Qualification Testing.

Unless otherwise specified on the contract or purchase order the vendor shall be responsible for the performance of qualification testing. The vendor may utilize his own facility or any qualified commercial laboratory.

TABLE IV Acceptance Tests and Test Sequences

Item	Para.	Requirement	Test Method	Test Sequences for Sampling Tests (per 4.2.3) Plan A	Plan B
1	3.1.2	Antireflective Coating	4.5.4	7	
2	3.5.1	Color and Appearance	4.5.5	1	1, 5
3	3.3.8	Identification of Product	4.5.5	5	
4	3.5.2	Mechanical Imperfections	4.5.6	2	2
5	3.4.1	Dimensions	4.5.7	3	
6	3.2.1.1	Electrical Output	4.5.8.1	4	3
7	3.2.1.1	Electrical Output	4.5.8.2		6
8	3.2.1.2	Electrical Output	4.5.8.2		7
9	3.2.6	Temperature Cycling	4.5.10		4
11	3.4.2	Weight	4.5.13	6	

4.1.3.2 Qualification Tests

Qualification tests shall consist of all the tests (Group A through D) specified in Table III and in the order indicated. They shall demonstrate compliance with the respective requirements as shown in the Table.

4.1.3.3 Disposition of Tested Lots

The lot from which the qualification samples are selected may be offered for shipment under contract after qualification status has been granted.

4.1.4 Qualification Test Conditions

4.1.4.1 Qualification Test Methods

Qualification tests shall be performed in compliance with 4.5, Test Methods, of this specification.

4.1.4.2 Qualification Test Procedure.

The vendor shall submit a complete qualification test procedure for approval prior to commencement of the test.

4.1.5 Destructive Tests.

Certain qualification tests are destructive tests. Destructively tested cells shall not be submitted as partial fulfillment of any order.

4.1.6 Qualification Status and Requalification.

4.1.6.1 Qualification Status.

After successful completion of all qualification testing and compliance with 4.1.1, vendor will be granted qualified status.

4.1.6.2 Qualification Test Rejection.

Failure to meet or out of tolerance performance of any group during Qualification Testing shall be considered evidence of inability to supply solar cells in accordance with this specification.

4.1.6.3 Requalification.

4.1.6.3.1 Changes.

Changes in cell manufacturing processes and/or procedures or changes in requirements imposed by detail specification changes which may effect cell performance as defined in this Specification and/or the applicable detail specification change shall be sufficient cause to require partial or complete requalification.

4.1.6.3.2 Loss of Qualified Status.

When a previously qualified supplier has been removed from the qualified status for one of the reasons specified below, requalification consisting of compliance with 4.1.1 through 4.1.4, inclusively, shall be required prior to additional procurement. Qualified vendors may lose qualified status for:

(a) Failure to meet acceptance test provisions for two (2) consecutive lots, or

(b) Failure to notify in advance of proposed changes to materials, manufacturing processes, or inspection procedures connected with the manufacture of solar cells supplied to this specification.

4.2 ACCEPTANCE

Acceptance shall consist of compliance with all provisions specified below. Each shipping lot shall successfully pass all in-process tests (sampled per Paragraph 4.2.3.1) and all Plan A tests in Table IV (sampled per Paragraph 4.2.3.2).

4.2.1 Acceptance Certification.

A certificate of compliance shall accompany each shipment. The certificate shall provide evidence that all of the acceptance provisions of this specification have been complied with.

4.2.2 Responsibility for Inspection and Testing.

Unless otherwise specified in the contract or purchase order, the vendor shall be responsible for the performance of all inspection requirements and testing specified herein. Except as otherwise specified, the vendor may utilize his own facilities or any qualified commercial laboratory. A summary of all final examinations and tests relating to cells within a shipment shall accompany the shipment of the cells. Test and inspection records of all inspection and tests shall be complete, shall be maintained in the vendors files, and shall be readily available upon request.

4.2.3 Acceptance Sampling.

4.2.3.1 Sampling for In-Process Tests

Units shall be selected for in-process tests according to Table II and by the sampling plans below.

4.2.3.1.1 Sampling Plan IP-1

Each full or partial ingot or block of silicon from which solar cells are to be manufactured shall be selected 100 percent.

4.2.3.1.2 Sampling Plan IP-2

Cells shall be selected from each evaporation lot. These cells may be selected at random or from units rejected for characteristics independent of those for which they are to be tested. The sample size shall be determined by the vendor according to 4.2.3.4 and the LTPD of 50 percent. For the purpose of identification and sampling the vendor may at his risk combine relatively small evaporation lots into manufacturing lots of 400 units maximum.

4.2.3.1.3 Sampling Plan IP-3

All completed cells shall be selected 100 percent.

4.2.3.2 Sampling Plan A

Sample solar cells shall be selected at random from each shipping lot which has passed the in-process tests in Table II, In-Process Tests, and shall be subjected to the tests listed in Table IV and described under 4.5, Test Methods. Statistical sampling shall be in accordance with 4.2.3.4 and to the Lot Tolerance Percent Defective (LTPD) level of 10 percent. In the event cells are damaged prior to completion of scheduled test, each damaged cell may be replaced by a new unit chosen at random from the lot under test. Each new unit shall be subjected to all the environmental tests in the test sequence. Any accidentally damaged cell which has been replaced by a new unit, shall not be included in determining the acceptance or rejection of the sample.

4.2.3.3 Sampling Plan B

Sample solar cells shall be selected at random from the first quarter and last quarter shipping lots of the production span. They shall be subjected to the tests listed in Table IV and described under 4.5, Test Methods. The sample size shall be the same as that determined by 4.2.3.2. In the event cells are damaged prior to completion of the scheduled test, each damaged cell may be replaced by a new unit chosen at random from the lot under test. Each new unit shall be subjected to all the environmental tests in the test sequence. Any accidentally damaged cell which has been replaced by a new unit shall not be included in determining the acceptance or rejection of the sample. Shipping lots from which Plan B sample cells have been selected shall be retained by the vendor until all Plan B tests have been successfully completed.

4.2.3.4 Sampling Method.

Statistical sampling shall be in accordance with Section 30 and Table C-II of Appendix C to MIL-S-19500 for lots of 200 cells or less, and in accordance with Table C-1 of the same for lots greater than 200 cells. Samples shall be randomly selected from the shipping lot. When the shipping lot is composed of two or more mA output groups, the number of samples from each output group shall be approximately proportional to the corresponding output group size.

4.2.4 Acceptance Testing.

Acceptance of a shipment shall be made only after successful completion of acceptance testing according to Table IV on units selected in accordance with 4.2.3 to demonstrate compliance with the respective requirements shown in Table IV.

4.2.4.1 In Process Tests.

The in-process tests listed in Table II and described in 4.5. shall be part of the total acceptance tests. The results of these tests shall be reported in compliance with 4.2.1.

4.2.4.2 Records of Rejected Lots.

Adequate records of all rejected lots shall be maintained including: lot number, quantity of solar cells, test date, type of test, reason for rejection and disposition, as a minimum. Two copies of each lot rejection record shall be submitted to the contractor when disposition is made.

4.2.4.3 Destructive Tests.

Certain acceptance tests are destructive tests. Destructively tested cells shall not be submitted as partial fulfillment of any order.

4.2.5 Acceptance Test Conditions.

4.2.5.1 Acceptance Test Methods.

Acceptance tests required by Table IV shall be performed in compliance with 4.5, Test Methods.

4.2.6 Inspection of Preservation, Packaging and Marking.

Inspection of the preservation, packaging, packing and marking for shipment and storage shall be in accordance with the requirements of Section 5, or the documents specified therein and shall be carried out by contractor inspection. Containers with visual damage shall be rejected. The reading displayed by the visual humidity indicator card shall be recorded. In the event that this humidity indicator shows a humidity level greater than 40 percent the units shall be rejected.

4.2.7 Rejection and Resubmittal.

4.2.7.1 Rejection.

Any cell which does not meet any one or more requirements of any individual test specified shall be rejected.

4.2.7.2 Rejection of Evaporation Lot.

When an evaporation lot fails the lot shall be scrapped and shall not be used to formulate any subsequent lot. An evaporation lot shall have failed if any of the following tests were failed:

(a) 4.5.2 Contact and Grid Line Integrity

(b) 4.5.3 Solder Contacts

4.2.7.3 Rejection and Retest.

When a lot fails to meet the specified LTPD, all items in the lot shall be rejected. Any lot so rejected by Sampling Plan B shall require the testing of the immediate prior and next untested lots to the condition of Sampling Plan B. Contractor shall be immediately notified of any rejected lot.

4.2.7.4 Disposition of Rejected Lot.

The disposition of rejected lots shall be in accordance with applicable QA and MRB procedures.

4.2.7.5 Resubmittal

Resubmittal shall be in accordance with 4.3.5 of MIL-S-19500. Tightened inspection for lots which have been resubmitted shall be in accordance with Appendix C of MIL-S-19500.

4.2.7.6 Disposal of Samples.

Solar cells subjected to destructive in-process tests and to tests under Sampling Plans A and B, shall be submitted to the contractor for disposition. These cells shall not be shipped on the contract or purchase order.

4.2.7.7 Defects in Items Already Accepted.

The investigation of a test failure could indicate that defects may exist in items already accepted. If so, the vendor shall fully advise the contractor of all defects likely to be found and methods of correcting them.

4.3 RELIABILITY OR FAILURE RATE PROVISIONS. N/A.

4.4 INSPECTION LEVEL PROVISIONS. N/A.

4.5 TEST METHODS

The in-process, qualification and acceptance tests required

by Tables II, III, and IV for solar cells manufactured according to this specification shall be performed according to test methods and under the test conditions stated below.

4.5.1 Cell Material.

Each full or partial ingot (block) of silicon from which solar cells are to be manufactured shall be measured with a calibrated four-point probe resistivity apparatus with an accuracy of at least ±10 percent.

4.5.2 Contact and Grid Line Integrity Test. (Tape Peel Test).

The solar cell shall be subjected to the following tests (before solder application):

(a) The solar cell shall be heated in an oven to a temperature of 215 ± 5°C and maintained at this temperature for at least 15 minutes. The solar cell shall then be allowed to naturally cool to room temperature.

(b) N Side. The solar cell is placed N side up on a flat surface. Adhesive tape Scotch Brand No. 810 or direct equivalent is then placed over the cell to completely cover the cell surface. The tape shall be firmly rubbed until the cloudy appearance of the tape disappears, assuring firm adherence of the tape to the cell. The tape is then stripped from the cell at a 45 to 90 degree angle to the cell surface starting at the trailing edge of the grid line, peeling toward the contact strip.

(c) P Side. The solar cell is placed P side up on a flat surface. Adhesive tape Scotch Brand No. 810 or direct equivalent is then placed over the cell to completely cover the cell surface. On cells that have approximately the same contact void area on each long edge, the tape shall cover the entire cell surface. The tape shall be firmly rubbed until the cloudy appearance of the tape disappears, assuring firm adherence of the tape to the cell. The tape is then stripped from the cell at a 45

to 90 degree angle to the cell surface, peeling toward the contact strip edge of the cell.

4.5.3 Solder Contacts.

The requirements of 3.3.4 shall be verified by performing all the following tests in the sequence given:

4.5.3.1 In-Process Solder Contact Test Sequence.

This paragraph is applicable only for solar cells selected according to Sampling Plan IP-2 (Table II) and readied for the Solder Contact Test (Test Sequence 2 of Table II). Each cell shall be exposed to the following tests in the sequence given below:

(a) Attach copper pull tabs to cells per 4.5.3.6.
(b) Perform non-limited 90° pull test per 4.5.3.7.

4.5.3.2 Solder Contact Test Sequence for Qualification and Acceptance Testing.

This paragraph is applicable only to solar cells selected according to Sampling Plan "Group C" (Table III) or "Plan A" (Table IV) and readied for the Solder Contact Test. Each cell shall be exposed to the tests in the sequence given below:

(a) Inspect solder contact areas per 4.5.3.3.
(b) Measure electrical output per 4.5.8.2.
(c) Attach all four (4) Kovar tabs to cells per 4.5.3.8.
(d) Inspect solder joints per 4.5.3.3.
(e) Repeat electrical output measurement per 4.5.8.2. If necessary, carefully bend pull tabs such that interference with test fixture and illuminating light source is minimized.
(f) Calculate degradation between (b) and (d) per 4.5.3.5.
(g) Perform limited pull test per 4.5.3.9.

4.5.3.3 Solder Contact Appearance.

Compliance with the requirements of 3.3.3 shall be verified by visual inspection using a stereo microscope of 5 to 10 power magnification or an optical comparator with equivalent magnification.

4.5.3.6 Soldering of Copper Pull Tabs.

This soldering shall be performed by the vendor with any soldering method selected by the vendor.

4.5.3.7 **Non-Limited 90° Pull Test.**

4.5.3.7.1 **Test Procedure.**

(a) Each group of cells (a sample) to which pull tabs are to be attached, shall be randomly divided into 2 subgroups. One copper pull tab each, as shown in Figure 2 of this specification, shall be soldered to the P contacts of cells of the one subgroup, as shown in Figures 3 and 4.

(b) Pull tabs shall be soldered according to 4.5.3.6.

(c) The cell shall be clamped in the pull tester. The pull force shall be applied to the tab normal to the face of the cell at a rate not exceeding 100 grams (3.52 ounces) per second.

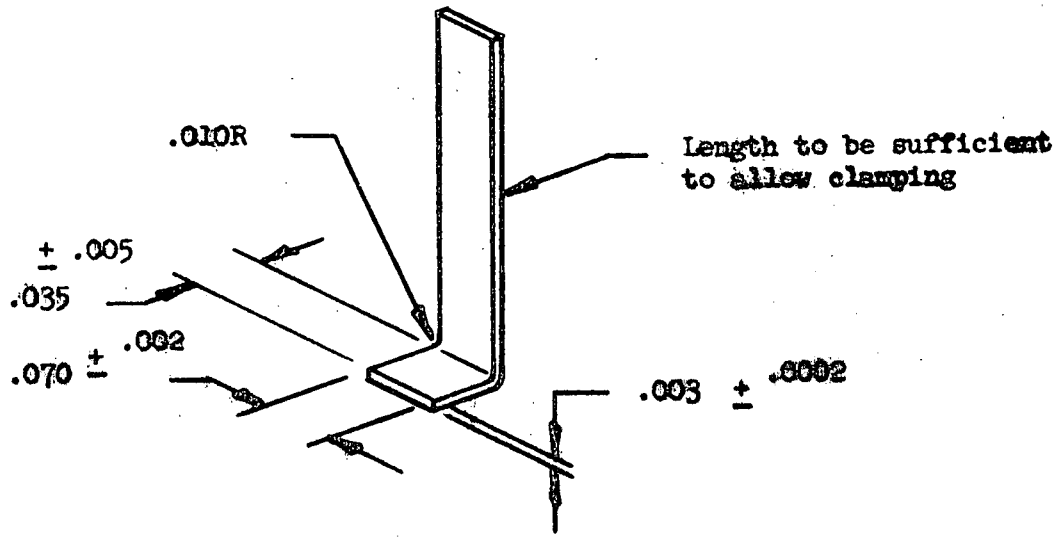
(d) The reading of the pull force indicator shall be recorded at the instant of separation of the tab from the cell.

(e) Steps (b) through (d) shall be repeated on the reverse side of the cell.

(f) The separated solder joints shall be inspected with the unaided eye to determine whether or not a tested cell has failed the test according to 4.5.3.7.2. If a cell had not failed according to 4.5.3.7.2, this cell shall be considered to have complied with the requirement of 3.3.4.

4.5.3.7.2 Failure Criteria.

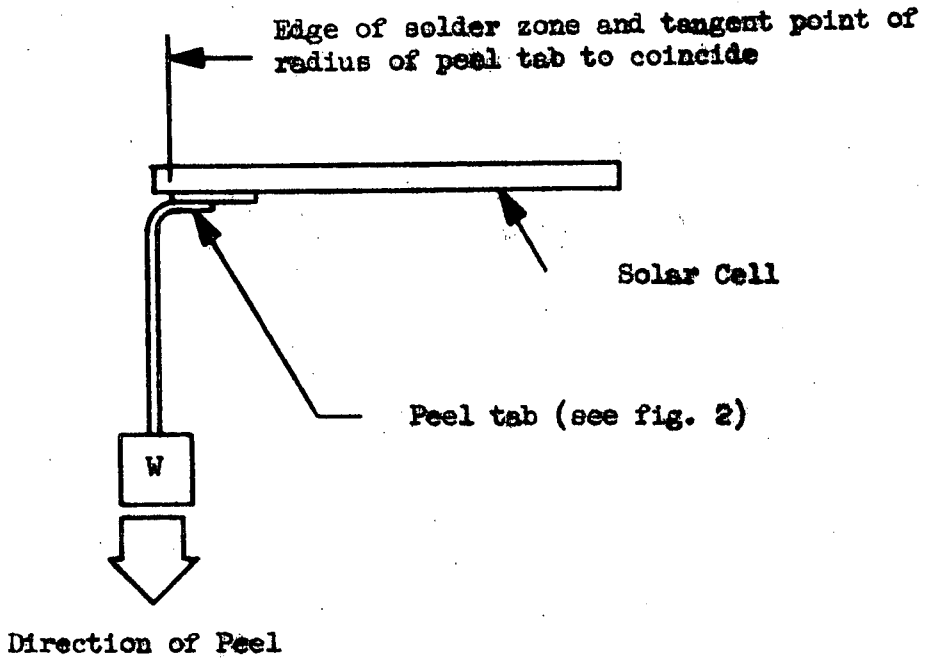
Mode	(Applicable only if pull force was 500 (17.6 ounces) grams or lower)	Disposition
a)	Tab with solder pulled from cell leaving either silver, titanium, or the bare silicon cell surface exposed.	F
b)	Tab pulled out of test fixture, tab broke, or tab cell contact fully solder covered.	R
c)	Cell broke near or away from solder joint.	N or R
d)	Solder joint separated, removing silver titanium from contact, and pulled out some silicon now adhering to tab.	R
e)	Tab pulled off, leaving some solder on solder joint area but also pulled some contact material (silver, titanium, or solder)	P



NOTES: 1. Tab material to be copper CR½ hard or ¼ hard per QQ-C-576 tin plated per MIL-T-10727 Type I and fused, .00005/0 0.00020.

2. All dimensions in inches.

Figure 2. Contact Pull Tab



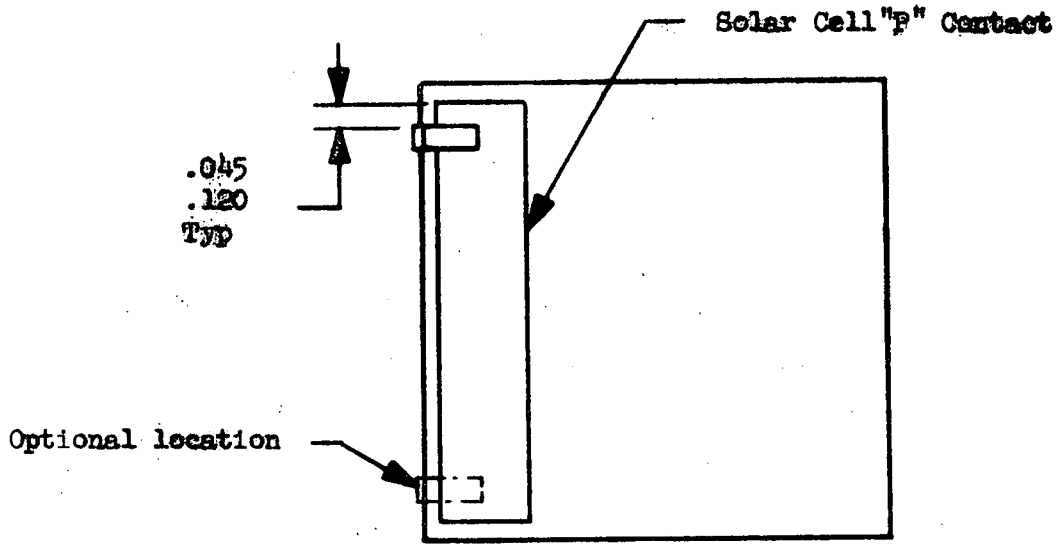
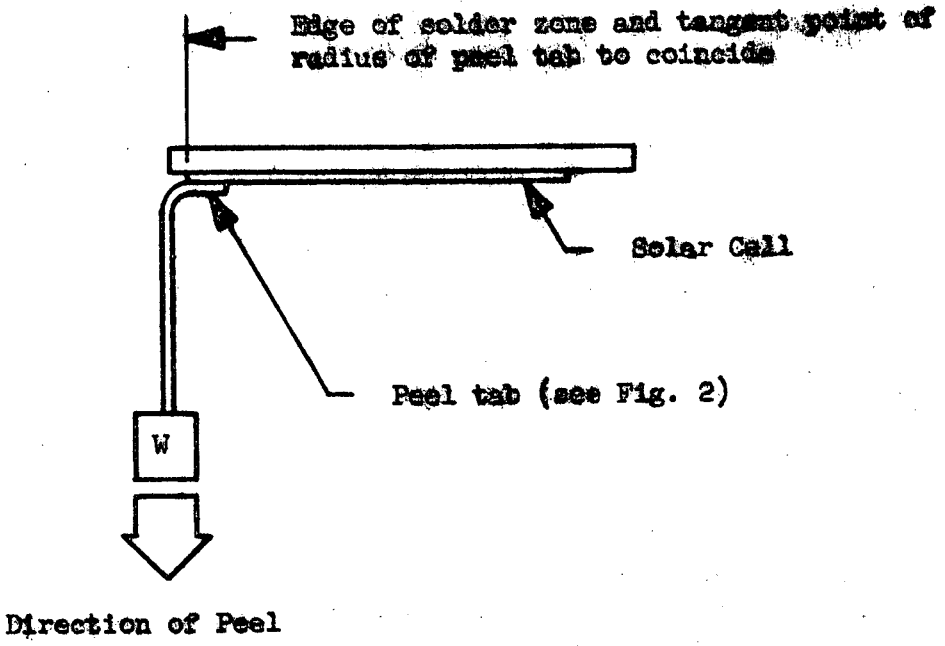


Figure 3. "P" Contact Pull Test



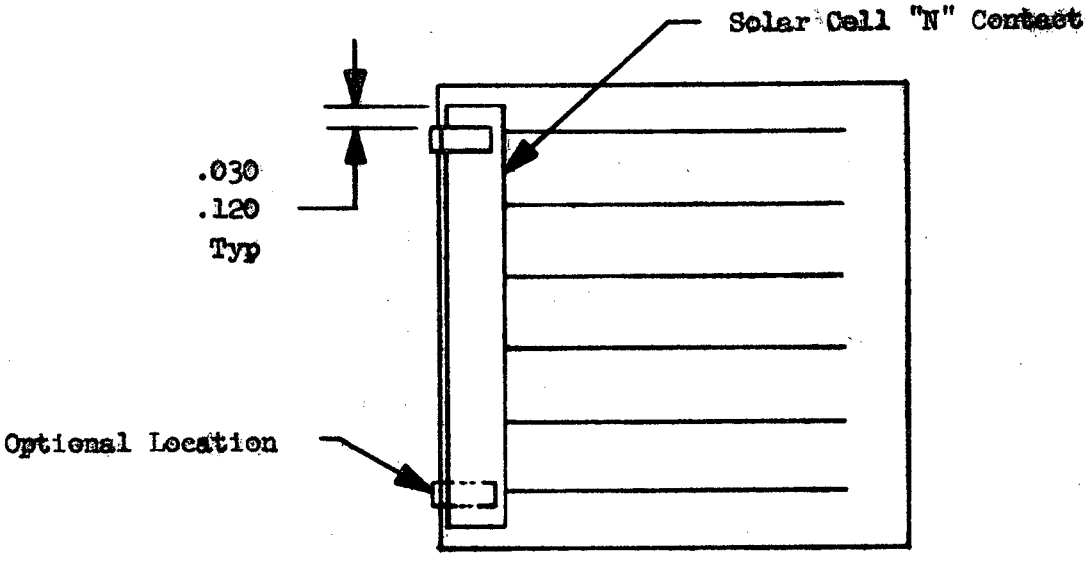


Figure 4. "N" Contact Pull Test

f) Tab pulled off with solder, leaving some silver or titanium on contact and pulled out some silicon now adhering to tab. P

(Applicable only if pull force was 500 (17.6 ounces) grams or lower)

Mode Disposition

g) Tab pulled complete piece of silicon out of cell. P

Legend: F Failed test

R Disregard and repeat soldering and pull test at alternate tab location

N Disregard and pick a new cell from the inspection lot and repeat soldering and pull test

P Passed test (did not fail)

NOTE: If either an N-contact or P-contact fails the test as defined above and a contact on the opposite side passes the test, the cell shall be considered to have failed this test.

4.5.3.8 Soldering of "Kovar" Pull Tabs.

Four "Kovar" pull tabs shall be soldered to each solar cell to be tested (2 on the N-contact, 2 on the P-contact) at the location shown in Figures 3 and 4. Each tab shall be a flat ribbon of 0.030 $\pm$ 0.002 inches width, 0.001 $\pm$ 0.002 inches thickness, and sufficient length for clamping in the pull tester. The tab material shall be alloy of 54% iron, 28% nickel, and 18% cobalt, first copper plated per MIL-C14550 with 0.0003/0.0005 inch thickness and then tin plated per MIL-T-10727 type 1 with 0.00005/0.0002 inch thickness and fused. The soldering shall be performed as described in Section 4.5.3.6.

4.5.3.9 Limited 45° Pull Test.

4.5.3.9.1 Test Procedure.

(a) Pull tabs shall be soldered according to 4.5.3.8.

(b) The group of cells to be tested (the sample) shall be divided at random into 2 subgroups. One subgroup shall first undergo P-contact pulling, the other N-contact pulling. Only one (1) P and N contact tab each shall be pulled per cell.

(c) The cell shall be clamped in the pull tester. The tabs shall be bent up 45° and clamped. The pull force shall be applied to the tabs at an angle of 45° so the face of the cell (the angle enclosed by the 2 legs of the tab is 135°) at a rate not exceeding 100 grams (3.52 ounces) per second. The pull force shall be limited to 500 ± 50 grams (17.6 ± 1.7 ounces). The limit force shall be maintained for 20 ± 10 seconds and then released at a rate not exceeding 100 grams (3.52 ounces) per second.

(d) Step (c) shall be repeated on the reverse side of the cells.

(e) Separated solder joints shall be inspected with the unaided eye to determine whether or not a tested cell has failed the test according to 4.5.3.7.2. If a cell has not failed according to 4.5.3.7.2, this cell shall be considered to have complied with the requirement of 3.3.4.

4.5.4 Anti-Reflective Protective Coating.

The solar cell shall be placed in a beaker of boiling de-ionized water for 15 minutes. The solar cell shall then be removed and allowed to naturally cool to room temperature. It shall then be subjected to 20 complete cycles of eraser abrasion over the same area of anti-reflective coating with a continuous pressure of between 17 and 21.3 pounds per square inch. During the test, the eraser shall be normal to the face of the solar cell. The eraser face shall be clean, and shall be A. W. Faber Type No. 7107 alternatively Frankfort Arsenal Eraser or equivalent.

NOTE: Delamination of any of the coating, contacts, or grids from the solar cell shall be cause of rejection. Scuffing and/or scratching of the anti-reflective coating resulting from the test shall not constitute cause for rejection.

4.5.5 Visual Inspection.

Solar cells shall be inspected with the unaided eye to verify the respective requirements.

4.5.6 Examination of the Product.

The solar cells shall be examined visually using a stereo microscope of 5 to 10 power magnification or an optical comparator to verify the respective requirements.

4.5.7 Dimensions.

4.5.7.1 Overall Dimensions.

The overall dimensions of the cells shall be verified by seating the cells flat within a cavity of dimensions given in Figure 1. An optical comparator with overlay dimensions may be used.

4.5.7.2 Contact Dimensions.

The cell contact area dimensions shall be measured with an optical comparator, measuring microscope, or similar instrument.

4.5.8 Electrical Output.

4.5.8.1 Electrical Current Output Test Method.

The electrical current output shall be measured with the light source of 4.5.8.3 at the constant voltage level, cell temperature, and light intensity specified in 3.2.1. The cells shall be grouped into current output groups specified in 3.2.1.

4.5.8.2 Electrical I-V Curve Output Test Method.

The solar cell current-voltage characteristic shall be measured by illuminating the cell with the light source of 4.5.8.3, varying the load resistance across the cell, and plotting corresponding current-voltage data points. Short-circuit current is defined as current through a one-ohm load, or lower. Open-circuit voltage is defined as voltage at a current of one milliampere, or less.

4.5.8.3 Light Source.

The light source shall conform to the requirements of 4.6. This conformance shall be demonstrated as follows:

4.5.8.3.1 Spectrum.

The spectral content of the light shall be determined by at least one of the methods below:

(a) Direct measurement with a calibrated spectro-radiometer.

(b) Indirect (comparison) measurement with a number of sensors of different spectral response characteristics.

4.5.8.3.2 Intensity.

The light intensity at the test plane (plane of N-side of solar cell) shall be determined by measuring the short-circuit currents of at least two (2) Standard Solar Cells as defined in 4.5.8.3.3. The intensity shall be adjusted such that the sum of the measured short-circuit currents of the standard cells used for calibration is equal to the sum of the calculated short-circuit currents for the light intensity specified in 3.2.1.

The deviation in measured short-circuit current for any one standard cell from the calculated value shall not exceed 1.0%.

4.5.8.3.3 Standard Solar Cells.

All standard solar cells shall have the same characteristics as those solar cells which are to be delivered under this specification. The spectral similarity between the standard cells and production cells shall be demonstrated using xenon-tungsten ratios or similar generally employed methods.

A minimum of two secondary standard cells shall be used. They shall be of the enclosed temperature controlled type. They shall be calibrated and traceable to flight calibrated primary standard cells. Details of the procedures for the use by the vendor of these standard cells and the calibration of any working standards derived from these standard cells shall be approved by contractor.

4.5.9 Magnetic Field Test. N/A.

4.5.10 Temperature Cycling.

The solar cells shall be placed in a chamber at ambient temperature and pressure. The chamber temperature shall then be varied to alternately bring the cells to the lower and upper temperature limits specified in 3.2.5. The dwell times at the temperature limits shall be not less than 2 minutes each. The time-rate of temperature change shall be within the limits specified in 3.2.4. The number of cycles are also specified in 3.2.4. The solar cell temperatures shall be monitored during this test with suitable thermo-electric instrumentation.

4.5.11 Charged-Particle Irradiation.

The solar cell shall be subjected to a fluence as specified in 3.2.2. The flux density shall be uniform over the area of the solar cell to within ± 10%. The electron energy shall be 1 Mev ± 10%. During the irradiation and thereafter the cell shall be kept at a temperature of approximately -135°C, but not exceeding -130°C. Within 24 hours after irradiation, the solar cell shall be tested per 4.5.8.2.

4.5.12 Weight.

The average solar cell weight shall be determined by weighing groups of cells and dividing the group weight by the number of cells in the group. The weighing accuracy shall be ± 10 milligram per hundred cells.

4.6 LIGHT SOURCE REQUIREMENTS FOR SOLAR CELL TESTING.

Electrical output measurements shall be performed in natural or artificial sunlight which approximates natural sunlight spectrum under Air Mass Zero (AMO) conditions.

4.6.1 Spectral Distribution.

The AM0 solar spectrum shall be defined by Johnson's curve (Journal of Meteorology, 1954) in the range from 300 to 1200 nanometers.

The total energy in any wavelength band incident on the test plane shall not deviate from the same band of Johnson's curve by more than the following indicated percentage:

$\Delta\lambda$	$\pm$ %
200 Å (20 nanometer)	30
400 Å (40 nanometer)	25
600 Å (60 nanometer)	20
1000 Å (100 nanometer)	10

4.6.2 Intensity.

The intensity shall be adjustable to the test level required by paragraph 3.2.1.

4.6.3 Intensity Uniformity.

The intensity of any wavelength band specified in 4.6.1 shall not vary by more than $\pm$ 2% across an area which is at least as large in any direction as the cell under test (or the standard cell, if larger) plus twice the sum of the cell positioning accuracy and the uniformity test cell diagonal dimension.

4.6.4 Intensity Stability.

The intensity shall be stable within $\pm$ 1% during any measurement period. If intensity-compensating measuring circuits are used, their speed of response shall be at least ten (10) times higher than that of the light level fluctuations.

4.6.5 Intensity Measurement.

Intensity shall be measured by taking short-circuit readings of silicon solar cells. Intensity calibrations shall be made with standard solar cells as defined in 4.5.8.3.3.

5.0 PREPARATION FOR DELIVERY

5.1 PRESERVATION AND PACKAGING

The solar cells shall be shipped in containers of a design providing adequate protective packing materials to prevent damage or shock of the solar cells. Containers or bags with visual damage shall be rejected. Each container shall be heat-sealed in an airtight, water-vapor proof barrier bag together with sufficient bagged, activated, dry dessicant to prevent atmospheric or other contamination of the surfaces of the solar cells. Cells should be stored under these conditions when not being used.

One unit of dry dessicant is required for each 90 square inches of bag area (one side only). This material shall not adversely affect the mechanical or electrical properties of the cells and shall not come into immediate physical contact with the cells.

A card-type humidity indicator scaled 10 to 80 percent relative humidity shall be placed within each sealed bag in an easily viewed location. This indicator shall be inspected according to 4.2.6. Any packing material used shall not adversely affect the mechanical or electrical properties of the cells and shall not contaminate the surfaces of the solar cells.

5.2 MARKING OF SHIPPING CONTAINERS

Unless otherwise stated each container shall be clearly identified by the following:

a) Vendor name and specification number

b) Shipping lot number and quantity of cells

c) Month and year of manufacture

d) Cell current measured at a specified voltage. Current to be in current groups as specified.

5.3 DELIVERABLE DOCUMENTS

Each shipment of solar cells shall be accompanied by complete major inspection records of all examinations and tests per 4.1, pertaining to the lot from which the cell shipment is made.