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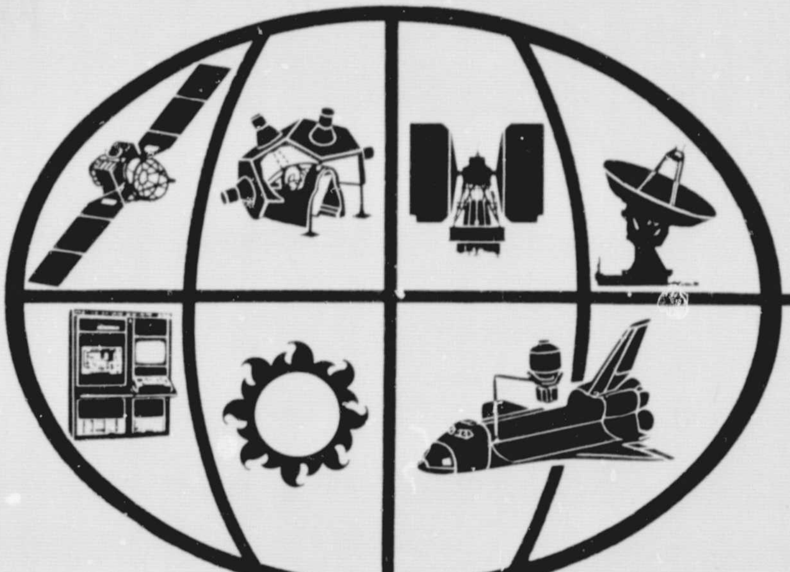
FINAL REPORT
DESIGN, FABRICATION, TEST, QUALIFICATION AND PRICE ANALYSIS OF "THIRD-GENERATION" DESIGN SOLAR CELL MODULES

JPL CONTRACT NO. 955401



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FINAL REPORT

DESIGN, FABRICATION, TEST, QUALIFICATION AND PRICE ANALYSIS OF "THIRD GENERATION" DESIGN SOLAR CELL MODULES

JPL CONTRACT NO. 955401

PREPARED BY: N. F. SHEPARD

REPORT DATE: MARCH 31, 1980

The JPL Low-Cost Solar Array Project is sponsored by the U.S. Department of Energy and forms part of the Solar Photovoltaic Conversion Program to initiate a major effort toward the development of low-cost solar arrays. This work was performed for the Jet Propulsion Laboratory, California Institute of Technology by Agreement between NASA and DOE.

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ACKNOWLEDGEMENT

The author wishes to gratefully acknowledge the contribution of Mr. W. C. Yager in the optical analysis of improved internally reflective coverplate geometries that might be applied to flat-panel photovoltaic systems. The contributions of Messrs. M. Cerza and J. Wright are also acknowledged for their efforts in performing the SAMIS/SAMICS price analysis and for the supervision of the module assembly process, respectively.

ABSTRACT

This design, development, fabrication and qualification testing of a "third-generation" solar cell module for residential applications is reported. This Block IV shingle-type module makes it possible to apply a photovoltaic array to the sloping roof of a residential building by simply nailing the overlapping hexagon-shaped shingles to the plywood roof sheathing.

This "third-generation" shingle module design consists of nineteen series-connected 100 mm diameter solar cells which are arranged in a closely packed hexagon configuration to provide in excess of 75 watts/m^2 of exposed module area under Standard Operating Conditions which include a calculated NOCT of 64°C.

The solar cells are individually bonded to the embossed underside of a 4.4 mm thick thermally-tempered piece of ASG Sunadex glass. An experimental GE silicone pottant, which is identified by the number 534-044, was used as the transparent bonding adhesive between the cells and glass. The encapsulant between the underside of the glass superstrate and a rear protective sheet of Mead Pan-L board is GE Silglaze SCS 2402. The semi-flexible portion of each shingle module is a composite laminate construction consisting of an outer layer of B.F. Goodrich FLEXSEAL bonded to an inner core of closed cell polyethylene foam. Uniroyal Silaprene M6338 is used as the substrate laminating adhesive.

The module design has satisfactorily survived the JPL-defined qualification testing program which includes 50 thermal cycles between -40 and +90°C, a seven day temperature-humidity exposure test and a wind resistance test per UL997.

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SUMMARY

SECTION 1

SUMMARY

The "third-generation" shingle-type module shown in Figure 1-1 has been designed and developed to meet the requirements of a Block IV residential application. A total of 62 pre-production modules of this design were fabricated for delivery to JPL. Six of these modules were assembled into two simulated roof sections, one of which is shown in Figure 1-2. The first of these roof sections was delivered to JPL for qualification testing while the second was retained by GE for the performance of a similar sequence of environmental exposures consisting of 50 thermal cycles between the extremes of -40 and +90°C, a seven-day temperature humidity exposure, and a wind resistance test per the requirements of UL997. The measured electrical performance degradation as a result of these environmental exposures was 1.4 percent, which is within the expected accuracy of the illumination test.

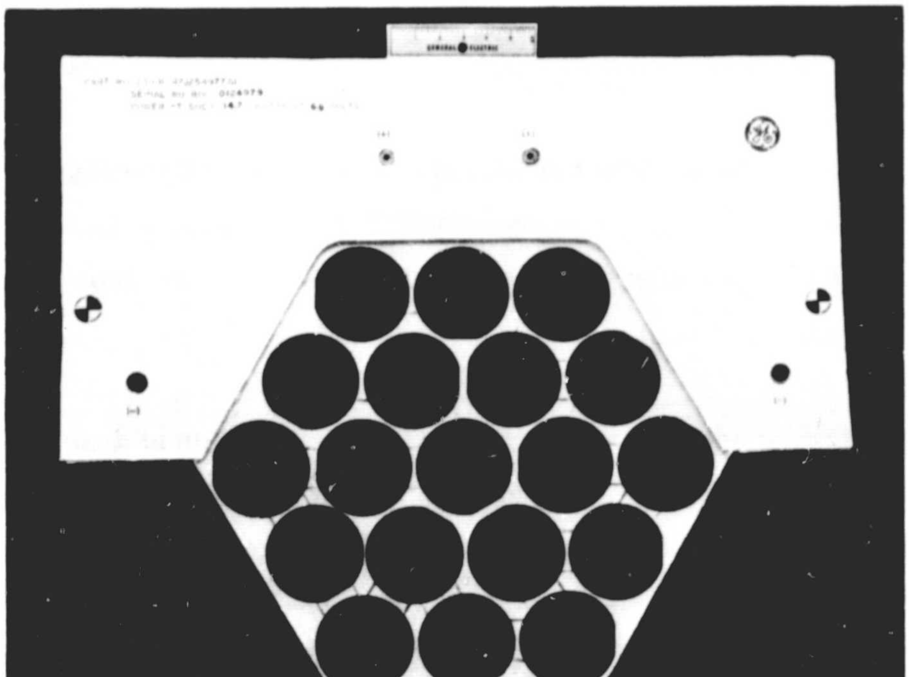


Figure 1-1. Block IV Shingle Module

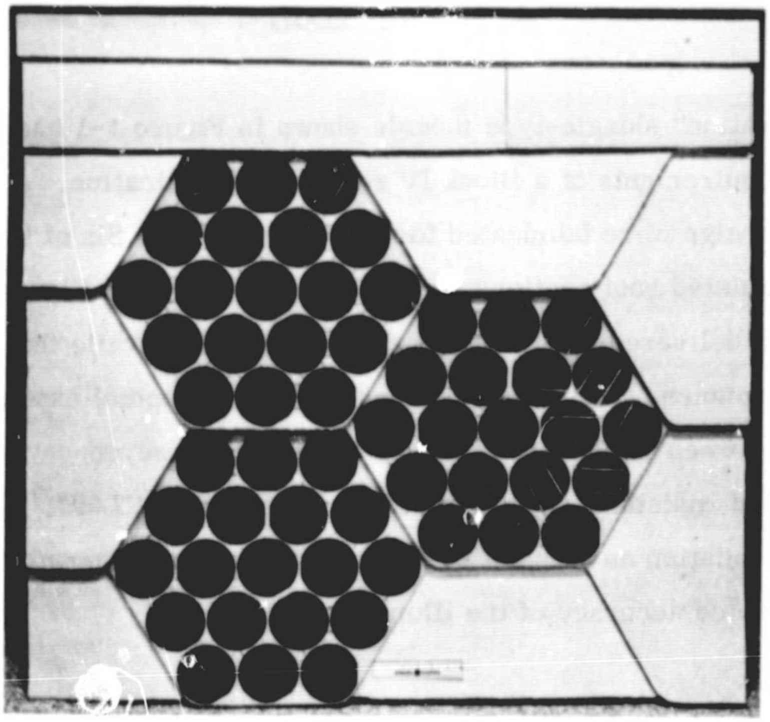


Figure 1-2. Simulated Roof Section Consisting of Three Shingle Modules

An average module electrical output of 14.7 watts of Standard Operating Conditions was established based on the measured performance of the first eleven modules fabricated. In this case the Standard Operating Conditions reflect a Nominal Operating Cell Temperature (NOCT) of 64°C.

A SAMICS/SAMIS price analysis was performed for this module at annual production rates of 10, 100, and 1000 peak kW. The resulting prices of $ 24.82, $17.09, and $15.38 per peak watt reflect the influence of production rate over this range. The cost of the solar cells, which were considered to be a purchased commodity for this analysis, has a major impact on the price analysis results. At the highest production rate considered, the cost of the solar cells represents 67 percent of the calculated price of the modules.

SECTION 2

INTRODUCTION

SECTION 2
INTRODUCTION

The scope of work under this contract involved the design, development, fabrication, qualification, testing and price estimation of a "third-generation" solar cell module which was specifically intended for residential applications. The design of the module shall conform to the requirements of JPL Document No. 5101-83 dated November 1, 1978 and entitled "Block IV Solar Cell Module Design and Test Specification for Residential Applications." A roof shingle type module was proposed to meet these requirements. This Block IV module design represents an extension of designs previously developed under JPL Contract No. 954607 and DOE Contract No. DE-AC04-78ET23056.

This program activity was organized into four major tasks as described below:

Task Number	Description
1	Detailed Design
2	Fabrication and Inspection
3	Shingle Module Testing
4	Price Estimation

This contract activity was started on June 1, 1979, the delivery of 900 watts of pre-production modules was completed on March 7, 1980 and the Final Design Review was held on March 31, 1980.

The Task 1 Detailed Design effort embodied the detailed design and supporting analysis of the "third-generation" module and included an investigation of optical designs for the transparent module coverplate to achieve an enhancement of the electrical output due to improved entrapment and subsequent photovoltaic conversion of the reflected light from the interstices. This study was general in nature in that it was not specifically constrained by the geometry of the proposed shingle module design.

The Task 2 Fabrication and Inspection covers the activity associated with the fabrication and delivery of at least 900 watts of module output under Standard Operating Conditions. This task included the assembly of two simulated roof structures, one of which was shipped to JPL for qualification testing while the other was retained by GE for qualification testing under Task 3. An Inspection System Plan, which defines the detailed inspection requirements for the pre-production modules, was written as part of this task activity.

The Task 3 Shingle Module Testing activity involved subjecting a representative sample of the pre-production modules to the qualification testing sequence shown in Figure 2-1 as taken from JPL Document 5101-83. In this case the qualification test article consisted of a segment of a simulated roof structure comprising three active shingle modules surrounded by suitable dummy shingles to electrically terminate and seal the roof surface. Each module produced was subjected to an illuminated test, using a JPL supplied reference solar cell to establish its output at Optional Test Conditions, and subsequently converted to performance at Standard Operating Conditions using temperature-dependent scaling coefficients supplied by JPL.

The Price Estimation performed under Task 4 made use of the SAMIS/SAMICS analysis code developed by JPL. This code was accessed through the NCSS system and an industry simulation was performed for annual production rates of 10, 100, and 1000 kW.

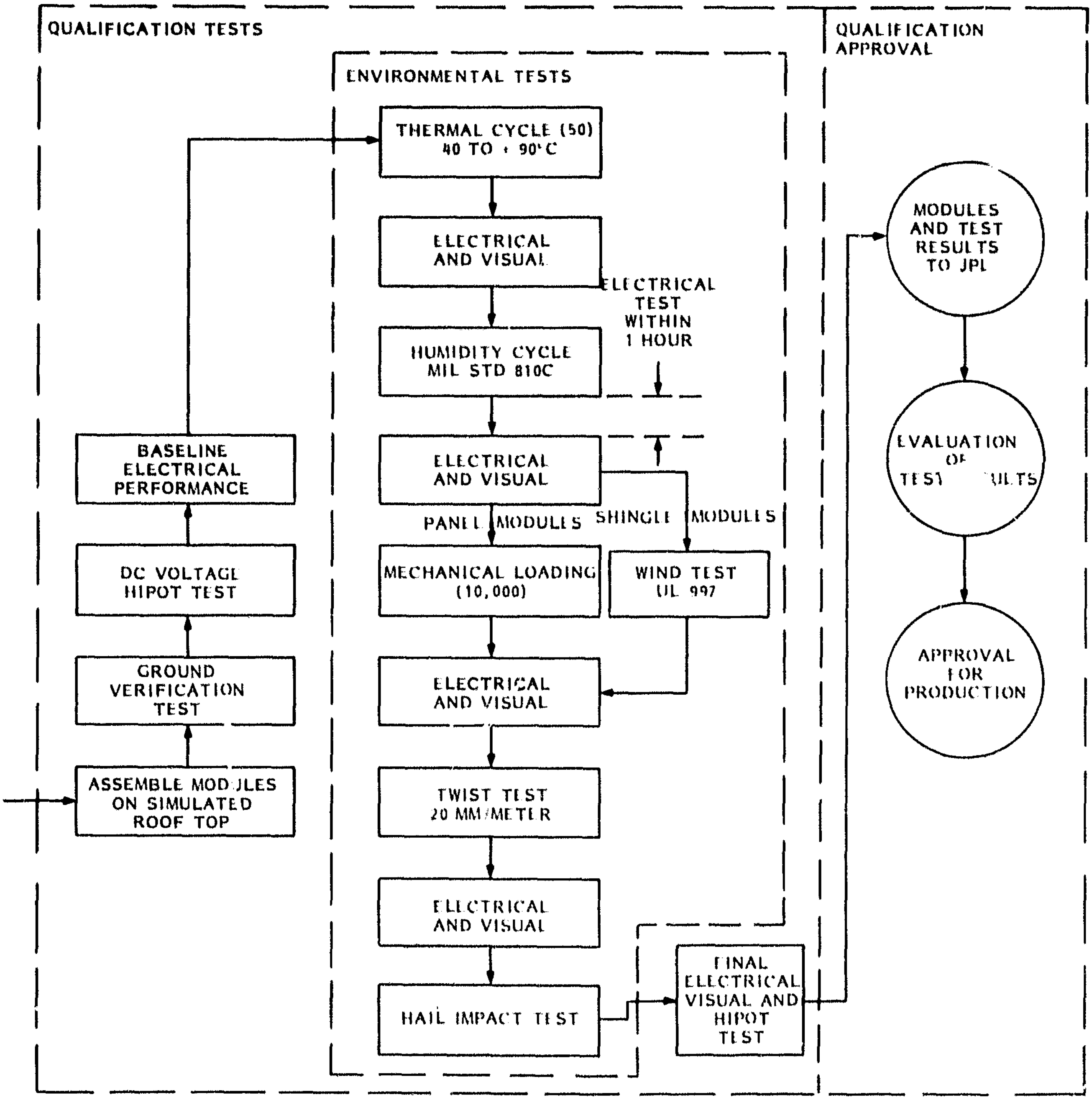


Figure 2-1. Module Qualification Testing Sequence

SECTION 3

TECHNICAL DISCUSSION

SECTION 3

TECHNICAL DISCUSSION

3.1 DETAILED DESIGN

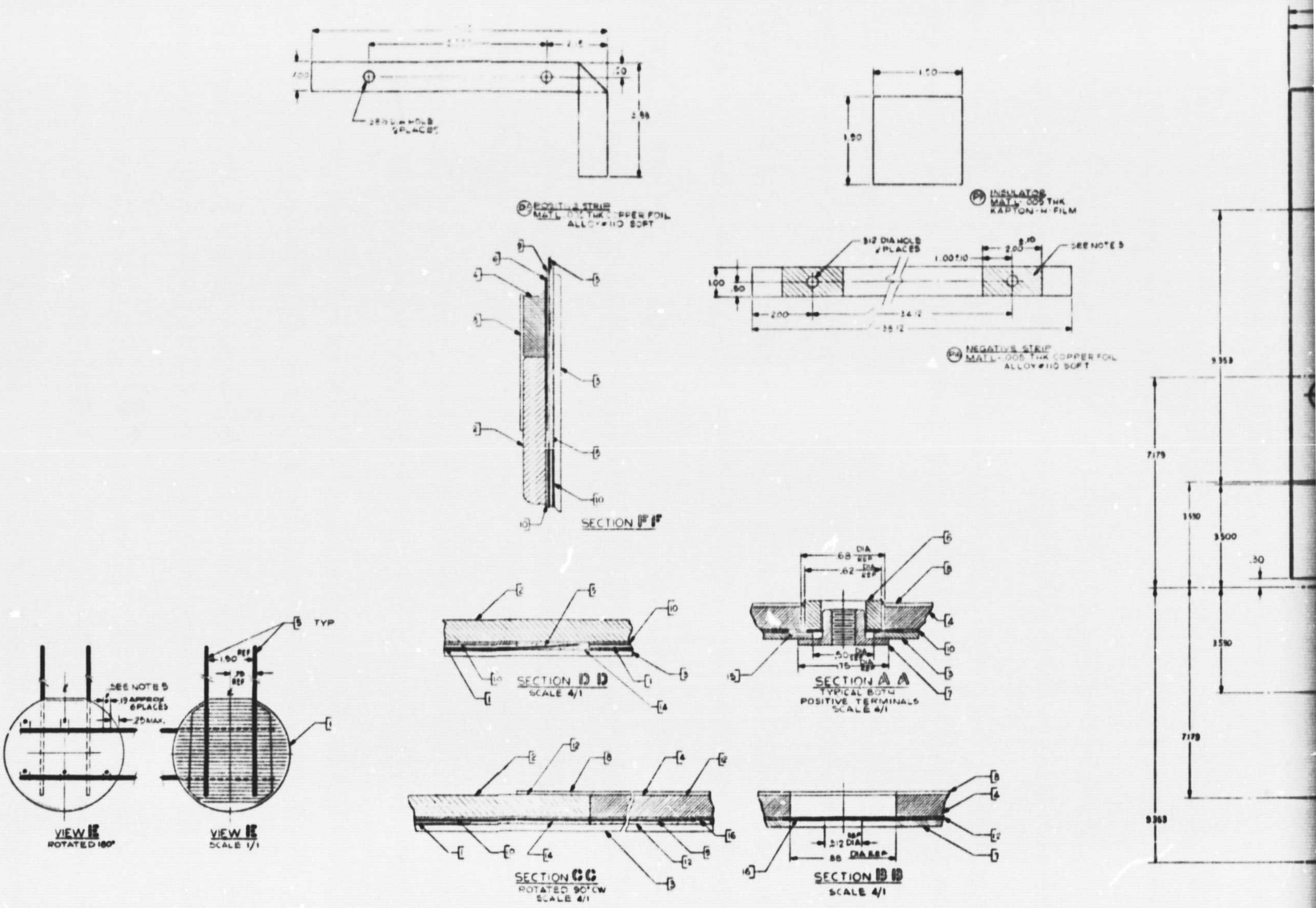
3.1.1 DESIGN DESCRIPTION

The design of the "third-generation" shingle solar cell module is depicted on GE Drawing number 47J254977 which is reproduced as Figure 3-1. This assembly drawing, along with the lower tier drawings listed in Table 3-1, represent the complete design definition of this module.

Table 3-1. Drawing List for the "Third-Generation" Shingle Solar Cell Module

GE Drawing Number	Title
47J254977	Shingle Solar Cell Module, Block IV
47D254978	Coverplate
47D252772	Substrate Skin
47C252769	Substrate Core
47C252770	Rear Cover
47B252771	Interconnector, Cell-to-Cell
47B252768	Boss, Positive Terminal
47B252767	Nut, Positive Terminal

This module consists of two basic functional parts: an exposed rigid portion which contains the solar cell assembly, and a flexible portion which is overlapped by the higher courses of the roof installation. The design of the shingle module provides a closely-packed array of 19 series-connected 100 mm diameter solar cells. The position of the four output terminals of the module has been established to permit the connection of the negative terminals of one



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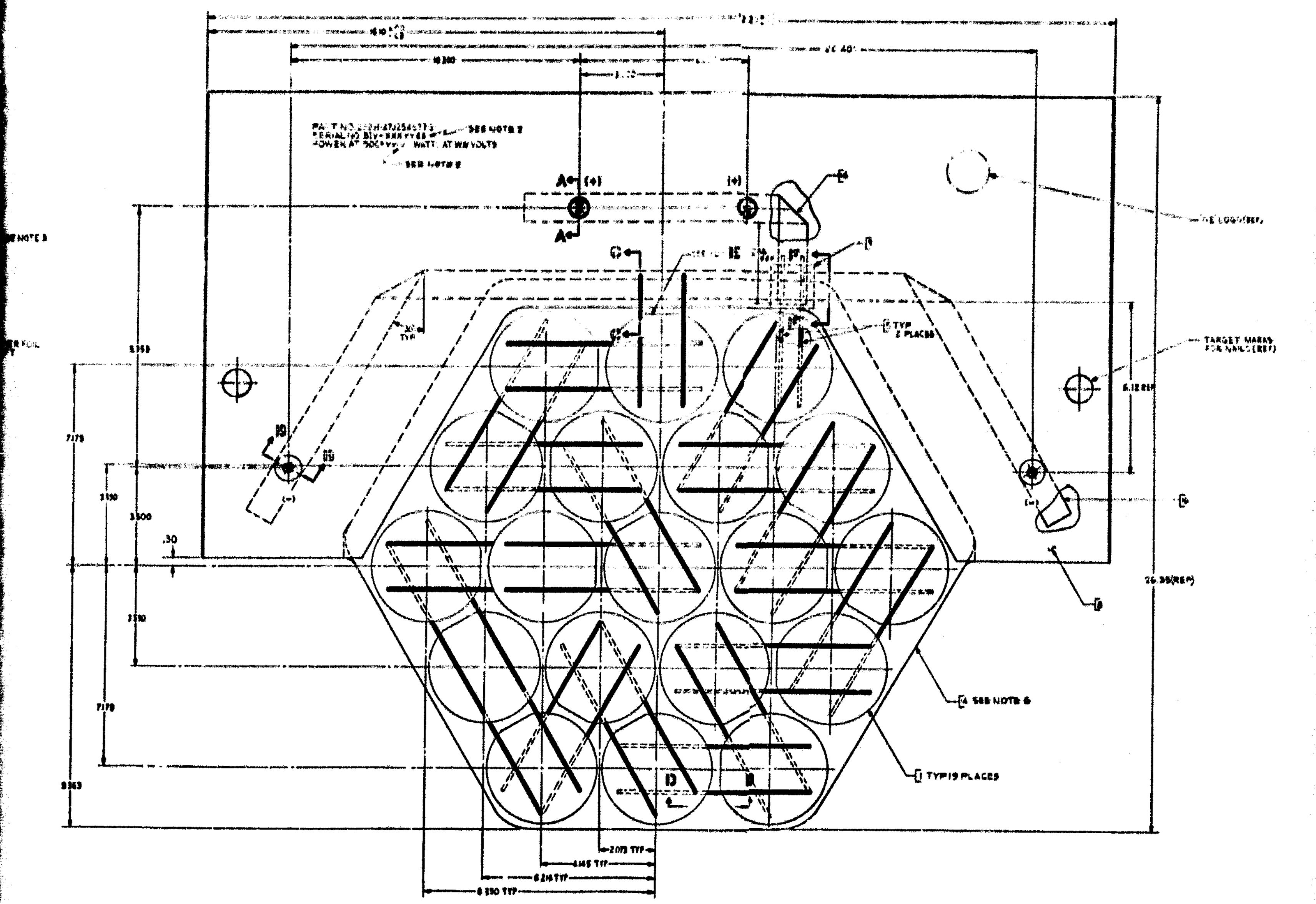


Figure 3-1. Assembly Drawing of the "Third-Generation" Shingle Solar Cell Module

course on the roof directly to the positive terminals of the course below. The method of connection, which uses a machine screw and flat washer, is discussed in Section 3.1.2.5.

As shown in Figure 3-2, the outer substrate FLEXSEAL skin overlaps, and is bonded to, the glass coverplate to form a weather-tight joint around the upper three sides of the hexagon. The rear side of the module is covered with Mead Pan-L board which is cut to the shape of the module outline. The module electrical termination conductors are laminated within the substrate between the rear cover and the foam core. GE Silicone Construction Sealant "Silglaze" 2402 is used as the module encapsulant and occupies the space between the solar cells and between the solar cells and the rear cover.

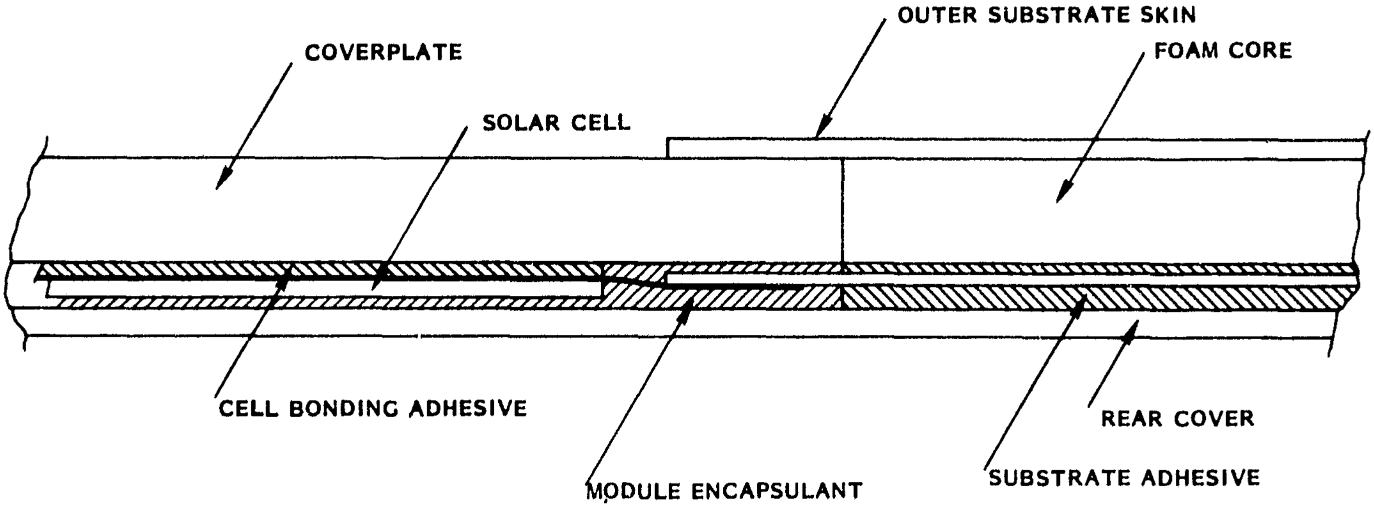


Figure 3-2. Shingle Module Construction Details

The pertinent design parameters for this module are summarized in Table 3-2. The maximum power output of this module is rated at 14.7 watts based on the average of the first ten modules produced. This power rating is at Standard Operating Conditions (SOC) as defined in JPL Document 5101-83 and includes a calculated Nominal Operating Cell Temperature (NOCT) of 64°C. This value for the NOCT is based on extrapolations of measurements made by JPL on the "second-generation" shingle module which was developed under a PRDA-38 Phase I contract.

The values for the voltage and current temperature coefficients were supplied by JPL based on measurements made on 2 x 2 cm reference solar cells. Values of -0.0494 V/^{o}C and +0.00070 A/^{o}C were employed to translate the module performance at Optional Test Conditions (OTC) to SOC.

Table 3-2. Pertinent Design Features of the "Third-Generation" Shingle Module

Parameter	Value
Total Solar Cell Area	1480 cm^2
Exposed Module Area	1955 cm^2
Packing Factor	0.757
Module Weight	3.9 kg
NOCT at 100 mW/cm^2	64^{o}C
P_{avg} at SOC	14.7 watts
V_{no}	6.6 volts

Thus, this shingle module is expected to have an average areal power density of 75.2 watt/m^2 at exposed module area at SOC. The nominal operating voltage (V_{no}) under these conditions is 6.6 volts.

3.1.2 DESIGN DETAILS

3.1.2.1 Solar Cell Selection

The solar cells for this program were procured to the requirements of GE Specification No. SVS10011 which was later changed to SVS10010 to cover the addition of integral interconnectors on the front surface. ARCO-Solar was selected as the cell supplier based on the results of a request for quotation which was solicited early in the program. An order for 1260 solar cells was placed on June 29, 1979. The first shipment of 250 cells was received November 5, 1979.

This shipment was rejected for the following reasons: (a) improper front contact geometry with only three solder pads per interconnector strip, (b) low contact pull strength at these interconnector strips, and (c) cell breakage along a line coinciding with the front contact strips.

At this time it was reported that ARCO-Solar was experiencing problems with the transition of their cell production operations from the Chatsworth to the Camerillo facility. Significant changes in the cell design and processing were incorporated at this time in an attempt to overcome the problems which were apparent on the first shipment. The second shipment of cells received had incorporated a change to 17 solder pads on each interconnector strip as opposed to the 25 pads specified in the original cell design. The contact pull strength on this second shipment was still apparently lower than the minimum standard established by ARCO-Solar. An I-V characteristic for a typical cell from this second shipping lot is shown in Figure 3-3. These cells were used to assemble modules through serial number BIV-0114879.

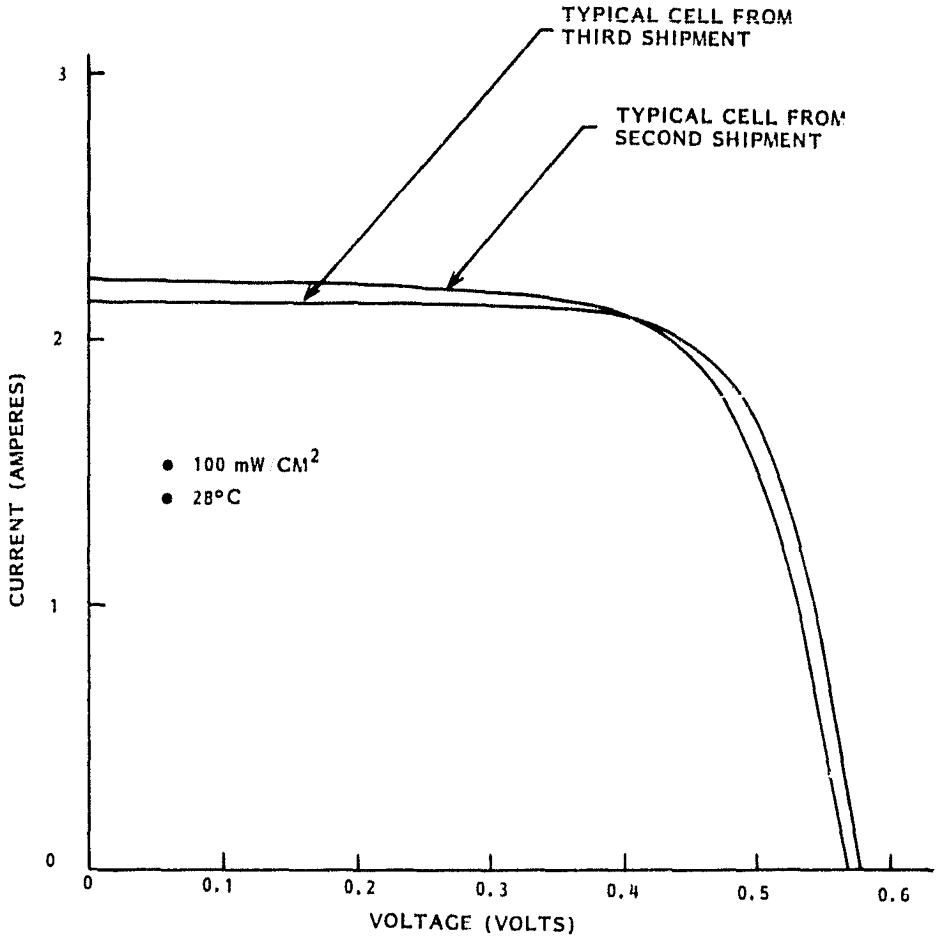


Figure 3-3. Typical Bare Cell I-V Characteristics

At this time it was again reported that cell production at ARCO-Solar had been stopped pending resolution of the low contact adhesion problem. Upon the resumption of cell production about one month later, a third and subsequent shipments of cells were received. These cells exhibited improved contact adhesion to the silicon. The rear contact geometry had also been changed to eliminate metallization directly behind the solder pads on the front surface. As shown in the second I-V characteristics on Figure 3-3, these cells also exhibited an enhanced open-circuit voltage and an improved curve fill factor.

3.1.2.2 Coverplate

The glass coverplate, which is the rigid exposed portion of the shingle module, is 4.4 mm thick ASG SUNADEX glass. This embossed low-iron soda-lime glass is cut to the required hexagon shape and thermally tempered to achieve a mean modulus of rupture in bending of 138 M Pa (20,000 psi). The solar cells are bonded to the embossed surface of the glass.

3.1.2.3 Cell Bonding Adhesive

A transparent bond between the cells and the glass coverplate was achieved by the use of an experimental silicone pottant developed by GE Silicone Products Department specifically for photovoltaic applications of this type. Designated by the number 534-044, this pottant requires no primers to achieve adequate adhesion to the glass and to the solar cell and can be cured at room temperature. Pertinent property data for this experimental pottant is given in Table 3-3.

3.1.2.4 Outer Substrate Skin

The outer substrate skin of B. F. Goodrich FLEXSEAL which is a 6 x 6 polyester scrim reinforced white HYPALON roofing membrane. HYPALON is a synthetic rubber with excellent weathering characteristics, low moisture vapor transmission rate, good oil and chemical resistance, and good abrasion and puncture resistance. The scrim reinforcement provides excellent tear resistance to prevent roofing nail tearout under wind loading conditions.

Table 3-3. Properties of GE Experimental Pottant 534-044

534-044 Experimental Photovoltaic Pottant

Product Description

GE 534-044, experimental photovoltaic pottant is a two-component, low viscosity, low modulus, RTV silicone rubber. After the addition of the curing agent, 534-044 may be cured at room temperature or with mild heat to a flexible rubber. Good adhesion to many substrates is achieved without a primer.

Product Data

Typical Uncured Properties

Color 534-044A	Clear, Colorless
534-044B	Clear, Pale Yellow
Viscosity, cps	900 - 1500

Typical Cured Properties (72 hrs. at 25°C and 50% R.H.)

Catalyst Level	5%	4%	2%
Work Time @ 25°C, min.	15	30	60
Tack Free @ 25°C, hrs.	1	1.25	2
Cure Time @ 25°C, hrs.	4	4	6

Color	Clear, Colorless
Refractive Index	1.4075
Specific Gravity	0.98
Durometer, Shore A	21
Dielectric Strength, v/mil	500
Dielectric Constant, 1 k Hz	2.89
Dissipation Factor, 1 k Hz	.002

3.1.2.5 Foam Core

The foam core of the shingle substrate is 4.8 mm (0.188 inch) thick L-200 closed cell polyethylene foam manufactured by Rodgers Foam Corporation. This foam provides a low-cost, low-density filler material to maintain a nearly uniform shingle thickness. Material screening tests have indicated that this foam is the lowest cost material available with the required high temperature (95°C) survivability.

3.1.2.6 Rear Cover

The rear cover, which covers the entire rear surface of the shingle module, is cut from 1.5 mm thick "Pan-L-Board" manufactured by Mead Paperboard Products.

Pan-L-Board is a weather-proofed, fire-resistant, pressed paperboard panel which Mead claims has endured 17 years of outdoor weathering in Wisconsin. This rear cover provides a low cost barrier against the entry of water and moisture from the underside and also provides some degree of protection against penetration by sharp objects during handling.

3.1.2.7 Substrate Adhesive

The adhesive used to laminate the various layers of the substrate is M6338 Super White Silaprene manufactured by Uniroyal. This material is a blend of high solid elastomeric compounds which provides excellent bond strength to most surfaces without priming, heating or mixing.

3.2.1.8 Module Encapsulant

The space between the solar cells and between the solar cells and the module rear cover is occupied by an encapsulant whose primary function is to prevent moisture from reaching the solar cells. A GE silicone construction sealant which is identified as Silglaze SCS2402 has been selected for this application. This material, which is a one-component construction sealant, has excellent adhesion to glass and provides the white diffusely reflective medium in the interstitial spaces.

3.1.2.9 Bus Strips

The bus strip conductors within the flexible shingle substrate are fabricated by folding 24.5 mm (1.00 inch) wide strips of 0.13 mm (0.005 inch) thick soft copper foil in the required pattern. These copper foil strips are sandwiched between the foam core and the pressed board rear cover. The single cross-over point of these two strips is insulated with a 31.8 mm (1.25 inch) square of 0.13 mm (0.005 inch) thick Kapton H film.

3.1.2.10 Module-to-Module Interconnection

The electrical connection between the two negative terminals on one module to the two positive terminals of the modules in the lower course form a series/parallel matrix interconnection of the array as shown in Figure 3-4. Each of these interconnections, which are represented as a dot in Figure 3-4, consists of a screw and washer which electrically mates a positive copper boss of one module to a negative copper strip of another module as shown in Figure 3-5. The high contact pressure developed at the top of the ridges of the solder-plated copper boss assures a low resistance contact when mated with the solder-plated copper foil strips. This joint should maintain its electrical integrity over long periods of outdoor exposure.

An internally threaded nylon nut which is held captive within the copper boss provides the mating thread for the interconnector screw.

3.1.3 MODULE INTERFACE DEFINITION

The module interface information is contained on GE Drawing No. 47E254979 which is reproduced as Figure 3-6. This drawing defines the overall outline and mounting dimensions for the module and provides the basic information needed to assemble these modules into an array. The exact arrangement of modules in an array in size and application dependent. Figure 3-7 can be used to obtain an approximate overall roof size for a given electrical arrangement of shingle modules. Thus, for example, an array of shingle modules which is configured as a matrix of 25 series by 13 parallel modules would require a roof surface of 6.391 m (251.6 inches) in slant height and 11.135 m (438.4 inches) in overall width for a total required roof area of 71.16 m^2.

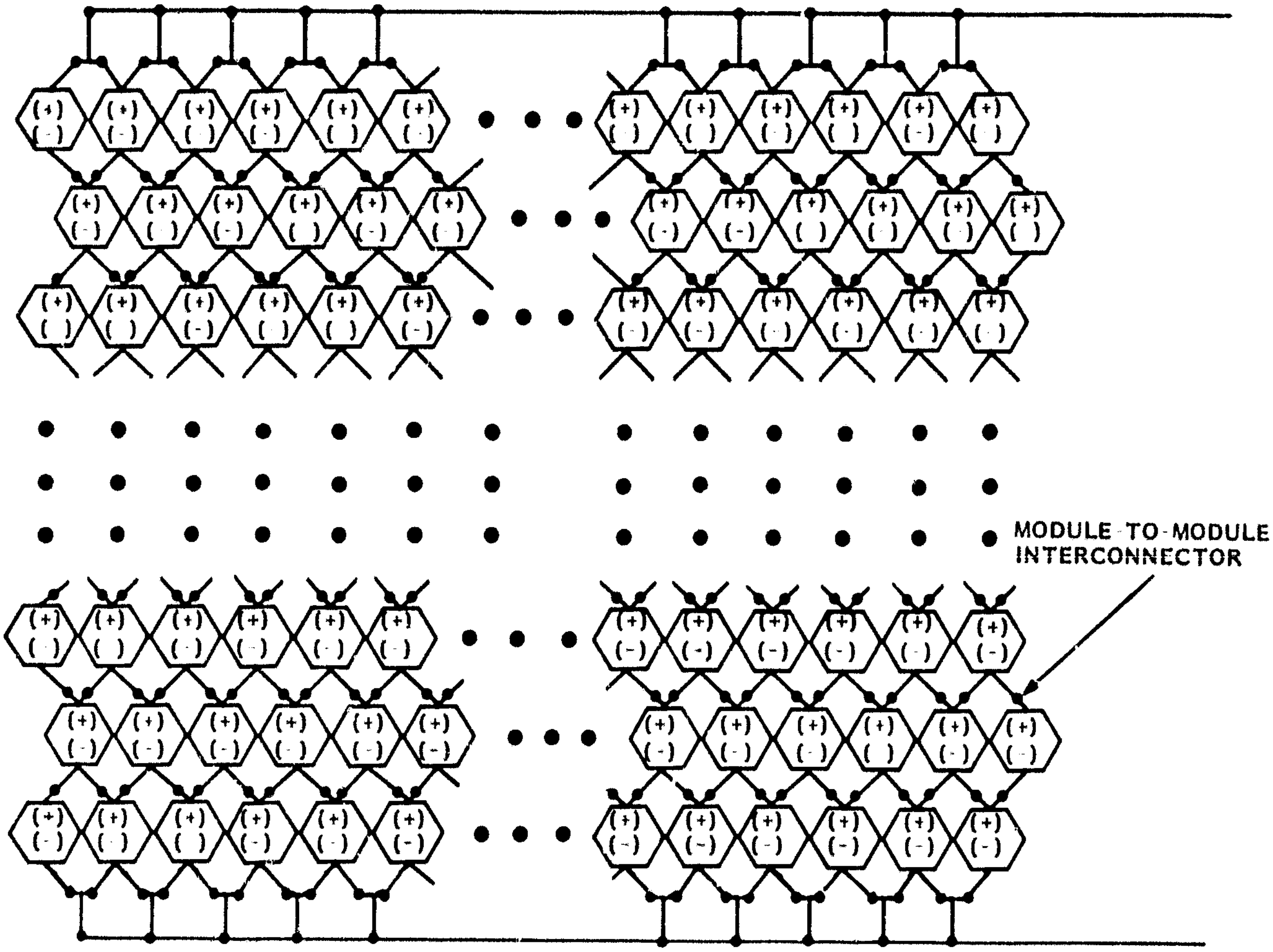


Figure 3-4. Module Interconnect Electrical Schematic

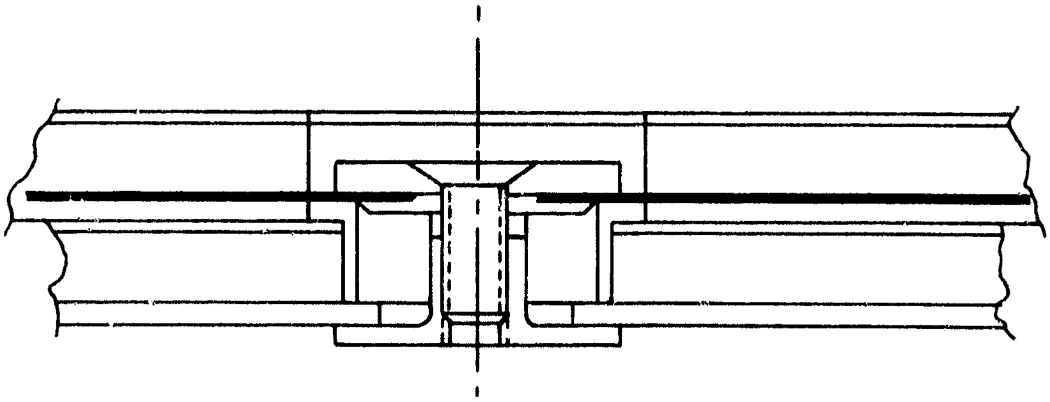
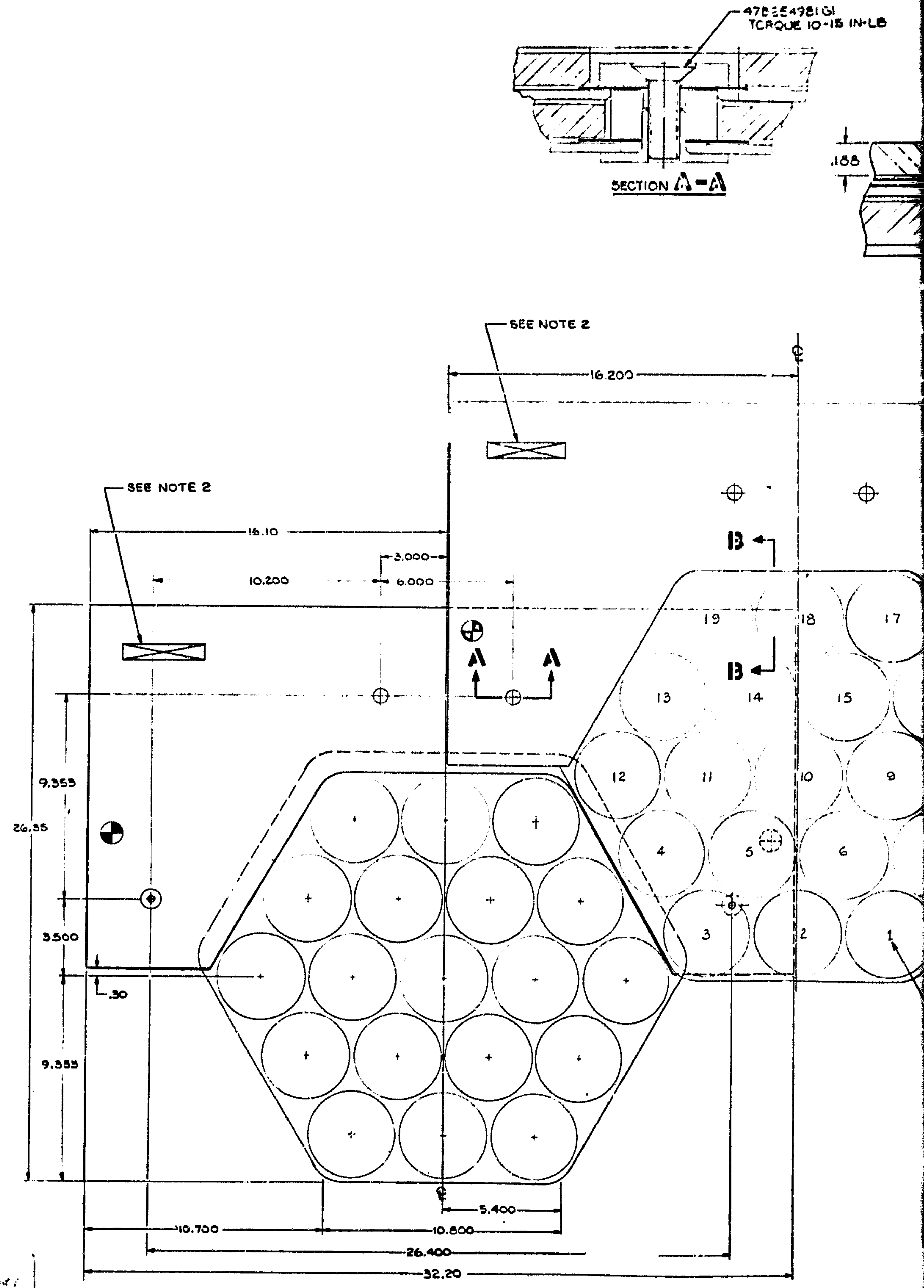


Figure 3-5. Module-to-Module Interconnection



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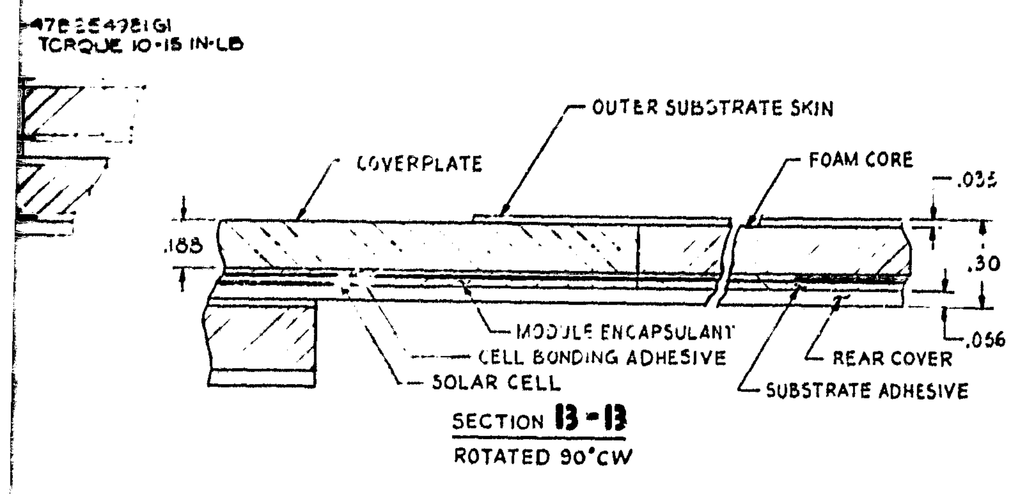
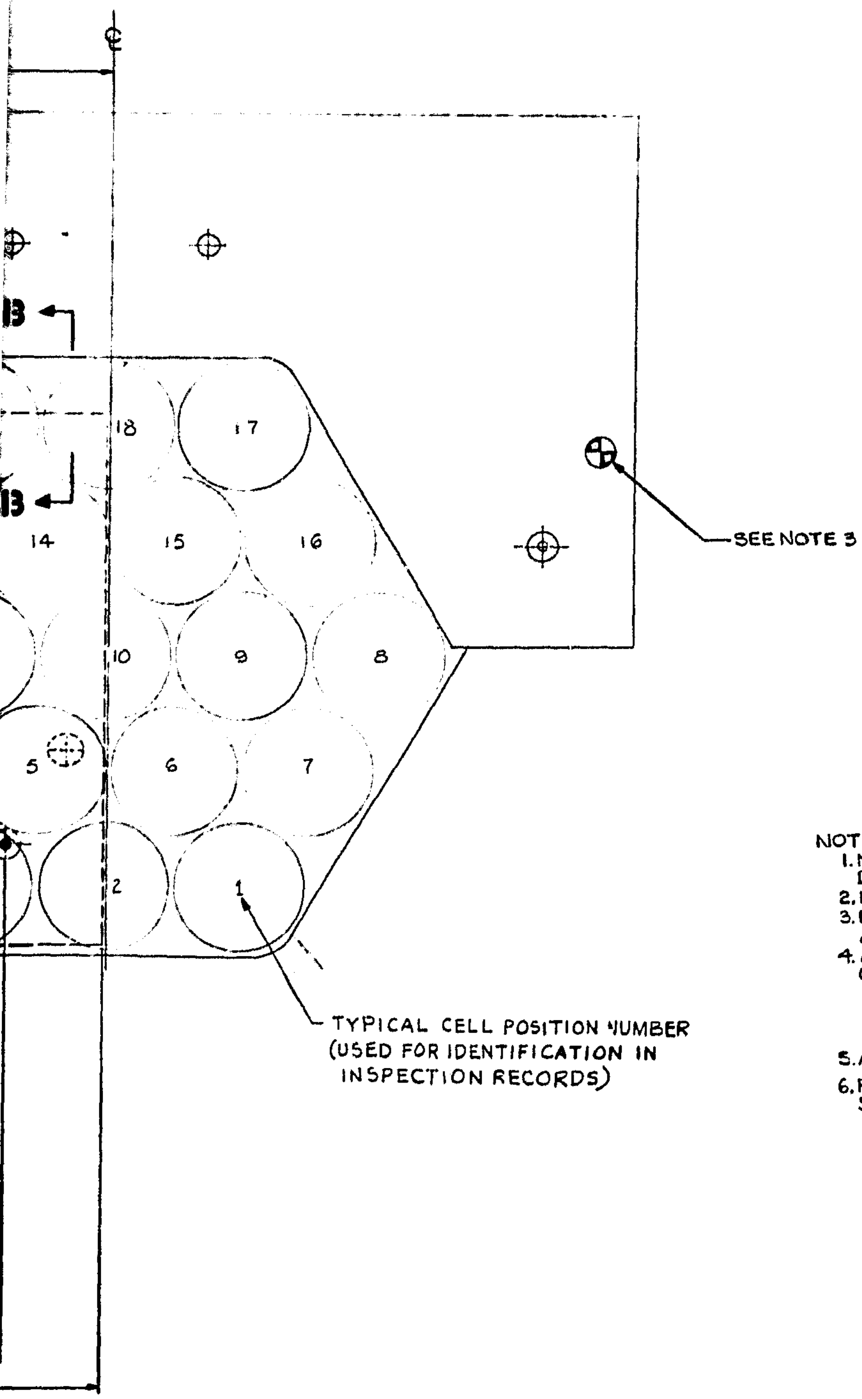




NOTES:

1. MODULES SHALL CONFORM TO THE REQUIREMENTS OF JPL DOCUMENT NO. 5101-83.
2. MANUFACTURER'S PART NO. & SERIAL NO. IN AREA INDICATED.
3. ROOFING NAILS MUST BE WITHIN OUTLINE OF TARGET AREAS SHOWN. 2 PER MODULE.
4. AVERAGE MODULE ELECTRICAL PERFORMANCE AT STANDARD OPERATING CONDITIONS.

   P_{MAX} = 14.7 WATTS

   V_{NO} = 6.6 VOLTS
5. AVERAGE MODULE WEIGHT = 3.9 kg.
6. FOR INSTALLATION DETAILS REFER TO APPLICABLE SITE-SPECIFIC INSTALLATION DRAWINGS.

Figure 3-6. Block IV Shingle Module Interface Control Drawing

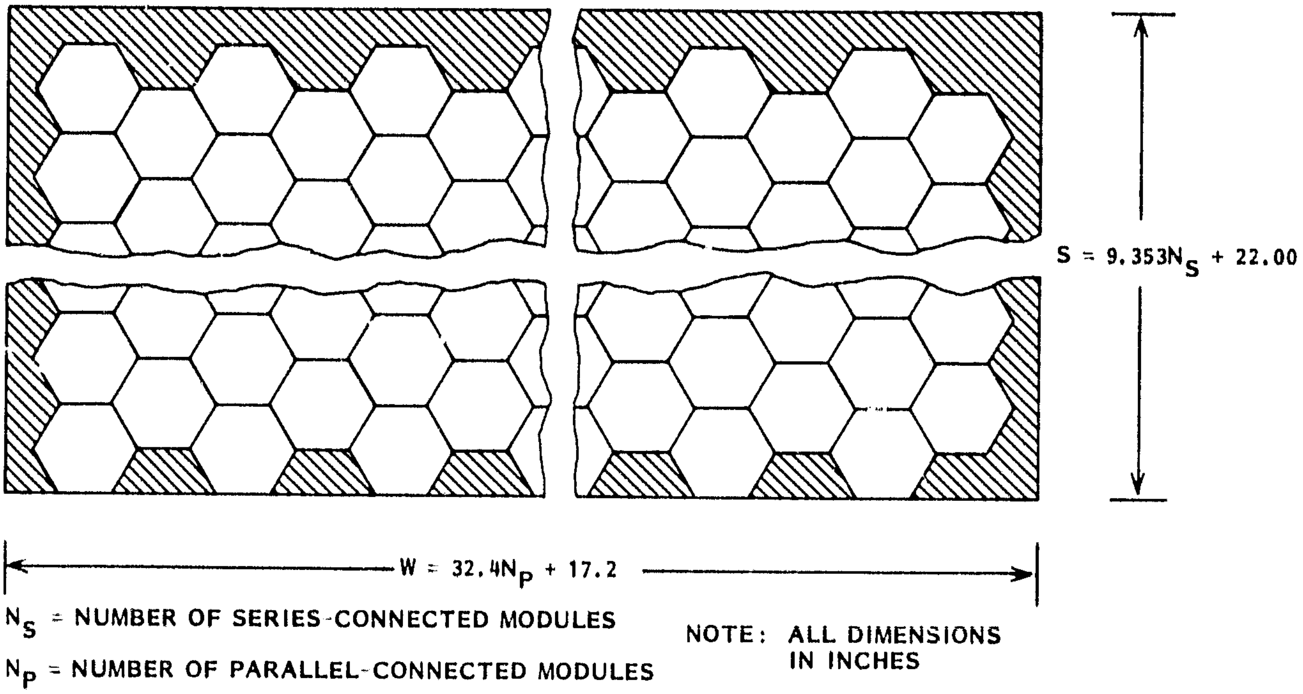


Figure 3-7. Shingle Module Arrangement on a Rectangular Roof Surface

3.1.4 OPTICAL ENHANCEMENT STUDY

3.1.4.1 Background

The optical enhancement of the output from a flat-panel photovoltaic module has been previously described and analyzed in Reference 1. During the course of this earlier work it became obvious that a further improvement in flat-panel module output could be achieved by shaping the undersurface of the transparent coverplate in such a way as to function as an specular reflector instead of as an diffuse scatterer. The present task was intended to be a first look at the possibilities inherent in this approach.

1. DOE/JPL - 954607-79/4, "Final Report - Development and testing of Shingle-Type Solar Cell Modules," February 29, 1979.

3.1.4.2 Specular Surface Patterns

A reflective surface is called <u>specular</u> when its mathematical description is simple enough to allow its reflective properties to be treated deterministically. On the other hand, a reflective surface is <u>random</u> or <u>diffuse</u> when its mathematical description is too complex to allow deterministic treatment. A specular reflective surface is characterized by a limited variety of reflective facets in some regular order or by a continuous surface definable in terms of a few parameters.

Five types of specular surfaces were given some attention in this task. Illustrated in Figure 3-8, these included:

1. continuous reflector
2. Fresnel reflector
3. dihedral mirror
4. trihedral mirror
5. dimpled mirror

The continuous reflector was not considered in detail because it required an unacceptable thickening of the module coverplate. The Fresnel reflector was similarly eliminated from consideration because it entailed large shadowing losses. The trihedral mirror and the dimpled mirror are considered promising, but time did not permit their analysis. This effort was therefore limited to consideration of the dihedral mirror.

3.1.4.3 Incident Light

The concern of this investigation is with usefully redirecting light that is incident on the undersurface of the glass coverplate or superstrate after having entered the upper surface and passed through the glass. Because of refraction at the upper surface, such light can be incident on the undersurface only over a limited range of incidence angle. Two cases are of particular interest: (1) the case where light can fall on the upper surface from any direction in the hemisphere, and (2) the case where light can fall on the coverplate only from directions consistent with

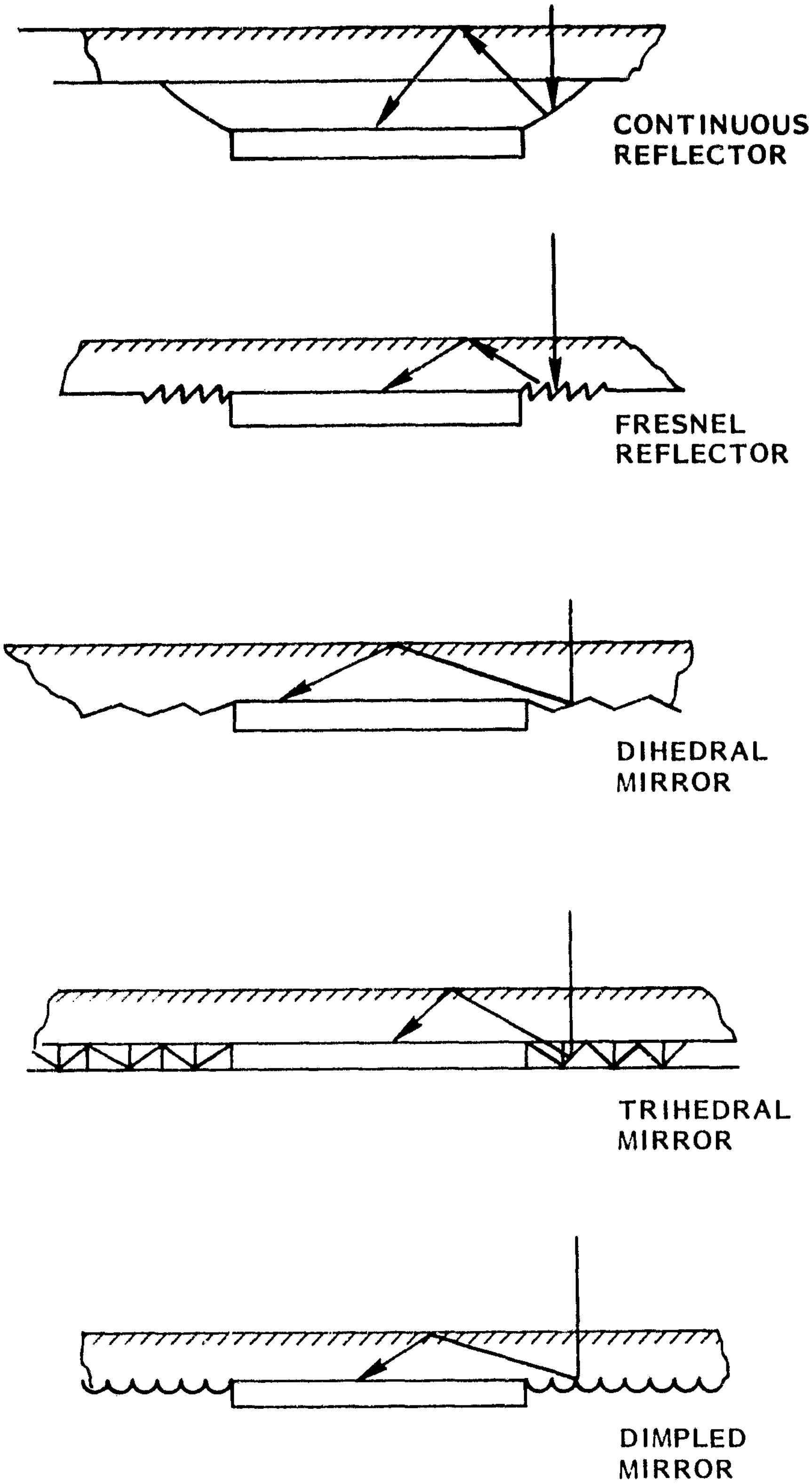


Figure 3-8. Specular Surfaces Considered in Study

the apparent direction of the sun when the module is optimally oriented at a fixed slope and azimuth orientation.

In the first case, shown in Figure 3-9, light can be regarded as incident on the undersurface within a cone of half angle

$$\theta' = \sin^{-1}\left(\frac{1}{N}\right) = \sin^{-1}\left(\frac{1}{1.52}\right) = 41.14^{\circ}$$

where the factor N = 1.52 is the index of soda lime glass. Such a model is physically unrealistic, but allows one to study performance when the orientation of the flat-panel module is completely uncontrolled.

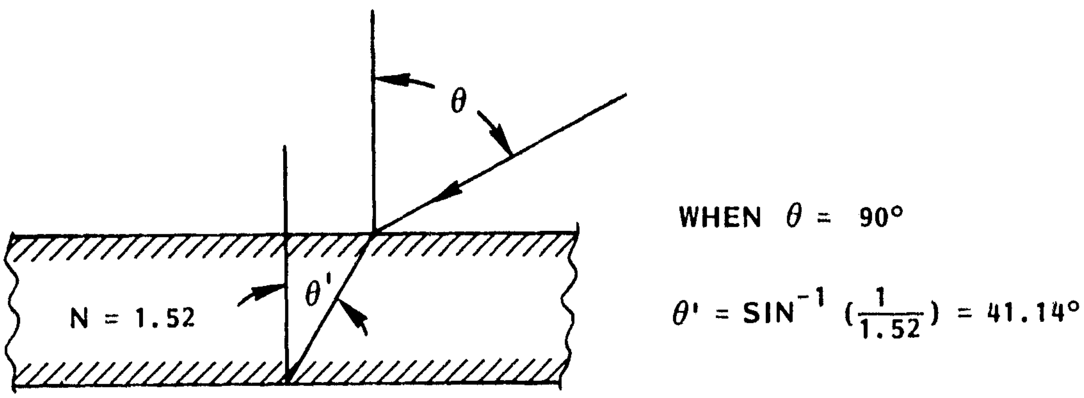
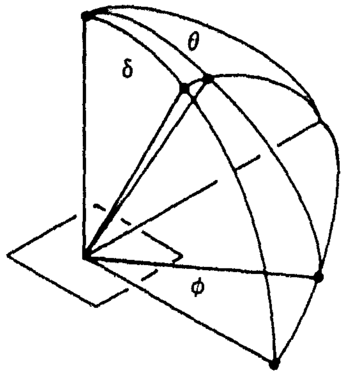


Figure 3-9. Refraction of Incident Light by a Glass Coverplate

In the second case, an optimally oriented module is defined as one whose normal is directed at the sun in the equinoctial noon position: that is, at the intersection of the local meridian and the celestial equator. This would normally be considered the optimal position for collection of solar energy. For this case, shown in Figure 3-10, the internal incidence angle can be predicted from solar declination and local azimuth measured in the module. Daily incidence angles so calculated are shown in Figure 3-11 for three particular solar declinations.



δ SOLAR DECLINATION

ϕ : SOLAR AZIMUTH IN MODULE

θ EXTERNAL INCIDENCE ANGLE

θ' = INTERNAL INCIDENCE ANGLE

$$\theta' = \mathrm{SIN}^{-1} \left(\frac{1}{1.52}\right) \mathrm{SIN}\ \mathrm{TAN}^{-1} \left(\frac{\mathrm{TAN}\,\delta}{\mathrm{COS}\,\phi}\right)$$

Figure 3-10. Internal Incidence Angle for a Fixed Slope Module

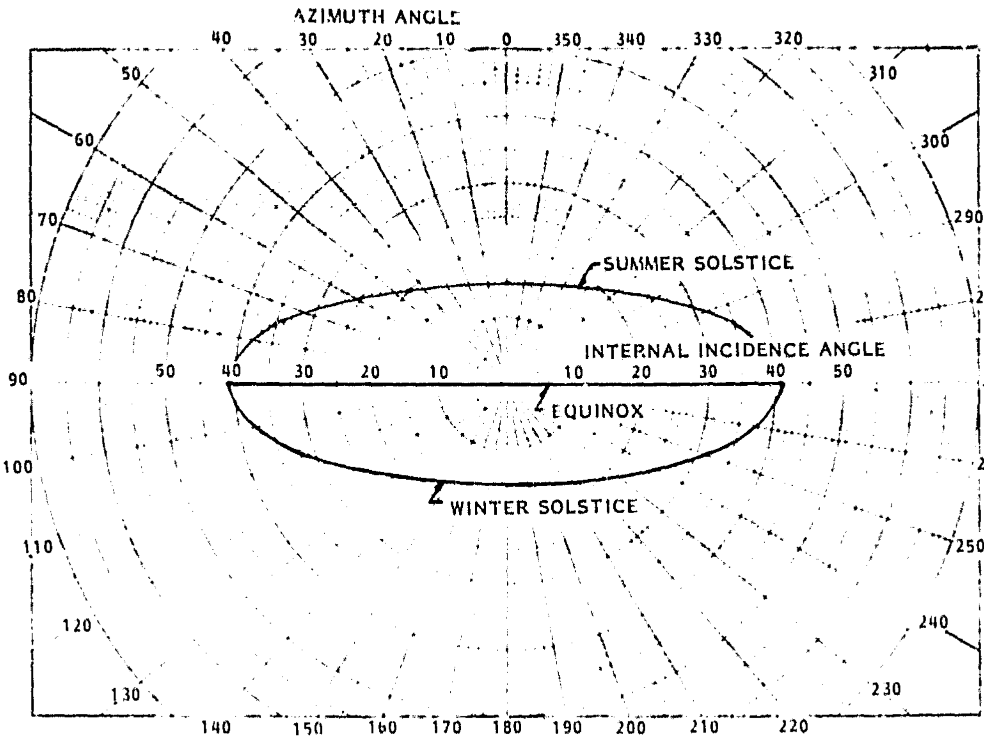


Figure 3-11. Internal Solar Incidence Angles for Optimally Oriented Module

3.1.4.4 Choice of Dihedral Angle

The first objective is to trap as much of the internally incident light on the first bounce as possible. If the module normal is pointed toward the intersection of local meridian and celestial equator (equinoctial noon), the declination of the sun relative to that normal, in the meridional plane, cannot vary by more than $\pm$ 23.5° over the course of the year. After refraction at the outer surface, the internal angle of incidence in the meridional plane cannot vary by more than

$$\theta = \pm \sin^{-1} \left(\frac{\sin 23.5^{\circ}}{1.52}\right) = \pm 15.2^{\circ}$$

over the course of the year.

If the dihedral mirror is oriented so that the two mirror normals lie in the meridional plane, Figure 3-12 shows the situation that exists. In vector notation the law of reflection is

$$\hat{t}' = \hat{t} \cdot (\mathrm{II} - 2\hat{n}\hat{n}) \quad \begin{cases} \hat{t}, \ \hat{t}, \ \hat{n} \equiv \text{unit vectors} \\ \mathrm{II} = \text{unit dyadic} \end{cases}$$

in which $\hat{t}$ and $\hat{t}'$ are the ray directions before and after reflection and $\hat{n}$ is the direction of the mirror normal. Whether a reflected ray is captured or not depends entirely on whether

$$(\hat{t}' \cdot \hat{k}) < \cos \theta_{cr} = \cos 41.2^{\circ}$$

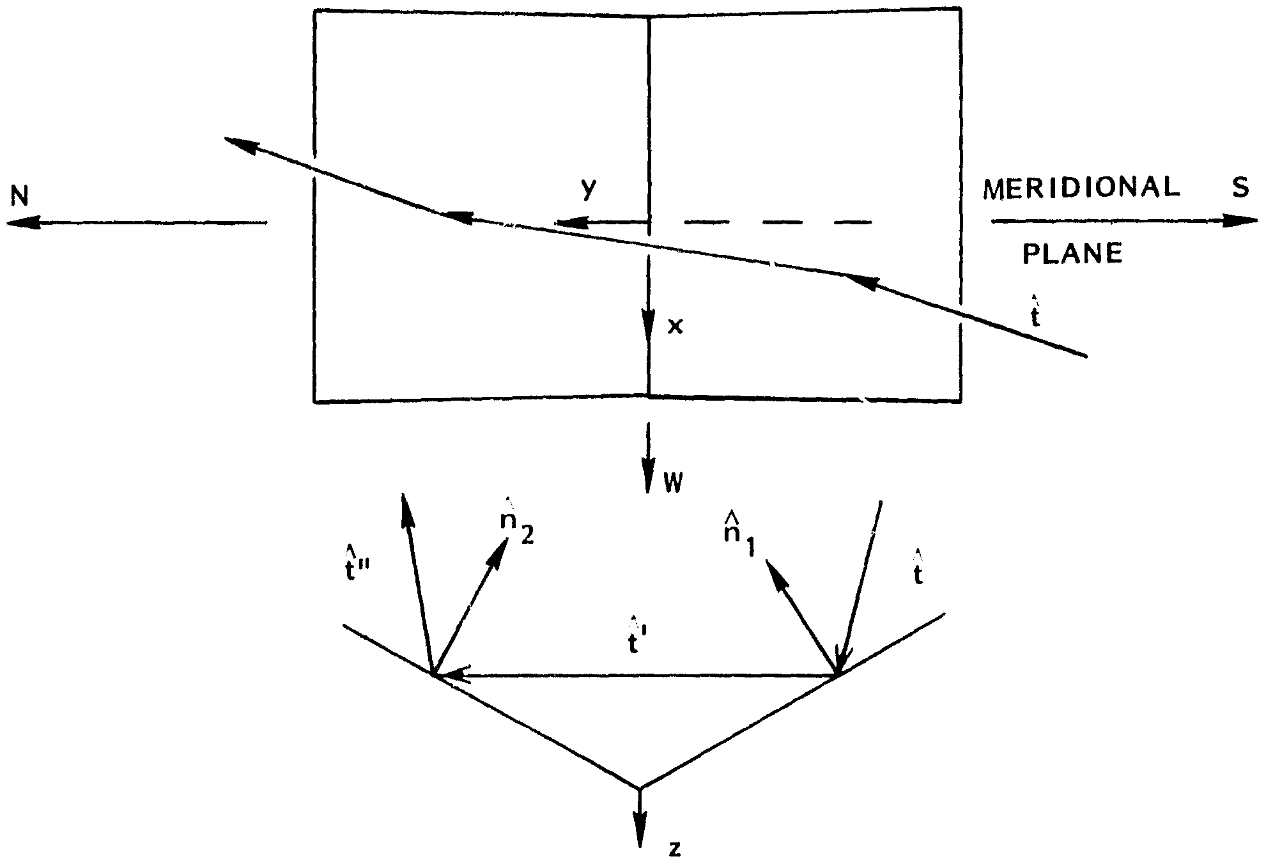


Figure 3-12. Orientation of the Dihedral Mirror Normals in the Meridional Plane

But from the law of reflection

$$(\hat{t}' \cdot \hat{k}) = (\hat{t} \cdot \hat{k}) - 2(\hat{t} \cdot \hat{n})(\hat{n} \cdot \hat{k})$$

Hence, the problem of capture can be studied entirely in terms of action in the $(\hat{n}, \hat{k})$ plane. All cases of reflection can be projected onto the $(\hat{n}, \hat{k})$ plane. Of all those cases, the most critical, for capture, is that one in the $(\hat{n}, \hat{k})$ plane for which $(\hat{t}, \hat{n})$ is the maximum as shown in Figure 3-13.

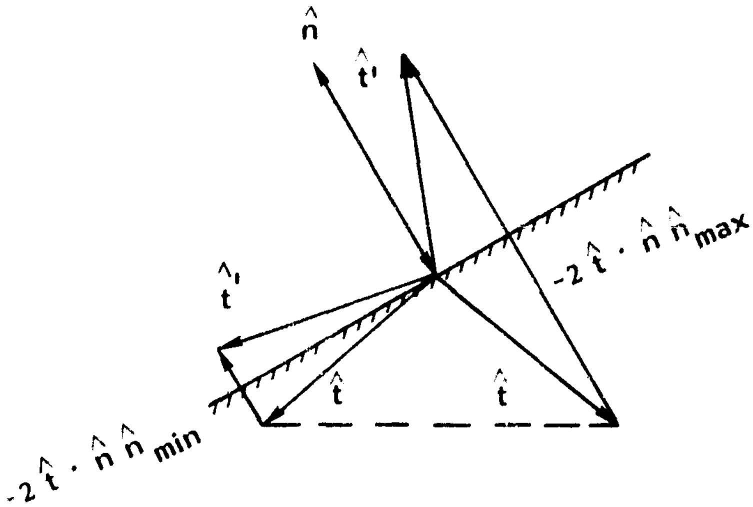


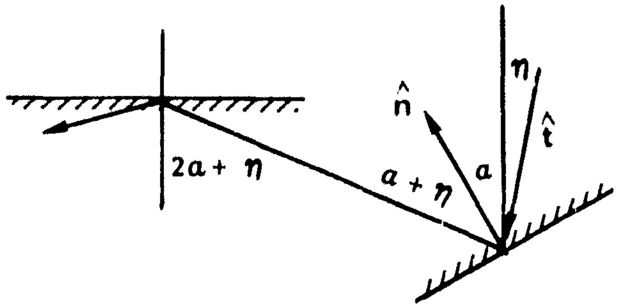
Figure 3-13. Reflection From a Dihedral Mirror Surface in the $(\hat{n}, \hat{k})$ Plane

It is now necessary to ascertain whether mirror slope angles exist that effect capture of the incident light. Referring to Figure 3-14, both singly and doubly reflected light must be considered. From the calculations displayed it can be concluded that to ensure capture of light experiencing only one reflection, the constraint on slope angle is

$$\alpha > 28.2^{\circ}$$

On the other hand, to ensure capture of light experiencing two reflections the constraint is

$$\alpha < 30.9^{\circ}$$

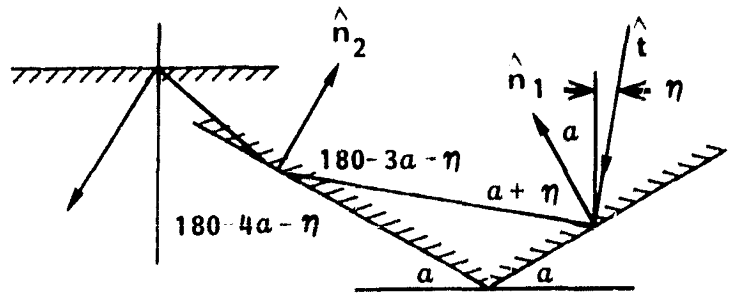


$2a + \eta > 41.2$

$a > \dfrac{41.2 - \eta}{2}$

FOR $\eta = -15.2$ (CRITICAL)

$a > 28.2°$



$180 - 4a - \eta > 41.2$

$a < \dfrac{180 - \eta - 41.2}{4}$

FOR $\eta = 15.2$ (CRITICAL)

$a < 30.9°$

Figure 3-14. Single and Double Reflections From a Diehedral Mirror at the Critical Angles for Internal Capture

There exists, then, a narrow range of slope angles permitting first bounce capture of all incident light. If it is further required, for balanced design, that the leaving incidence angle be the same for both singly reflected and doubly reflected light, then it can be shown, as indicated in Figure 3-15, that the required slope angle is 30°.

The aforementioned arguments show that a 120° dihedral mirror on the underside of the module coverplate will effect first-bounce capture of all internally incident light, if the module normal is directed at the equinoctial noon position of the sun and if the mirror normals lie in the meridional plane. For this reason, and because of the symmetry of its action, the 120° dihedral mirror was selected for further study.

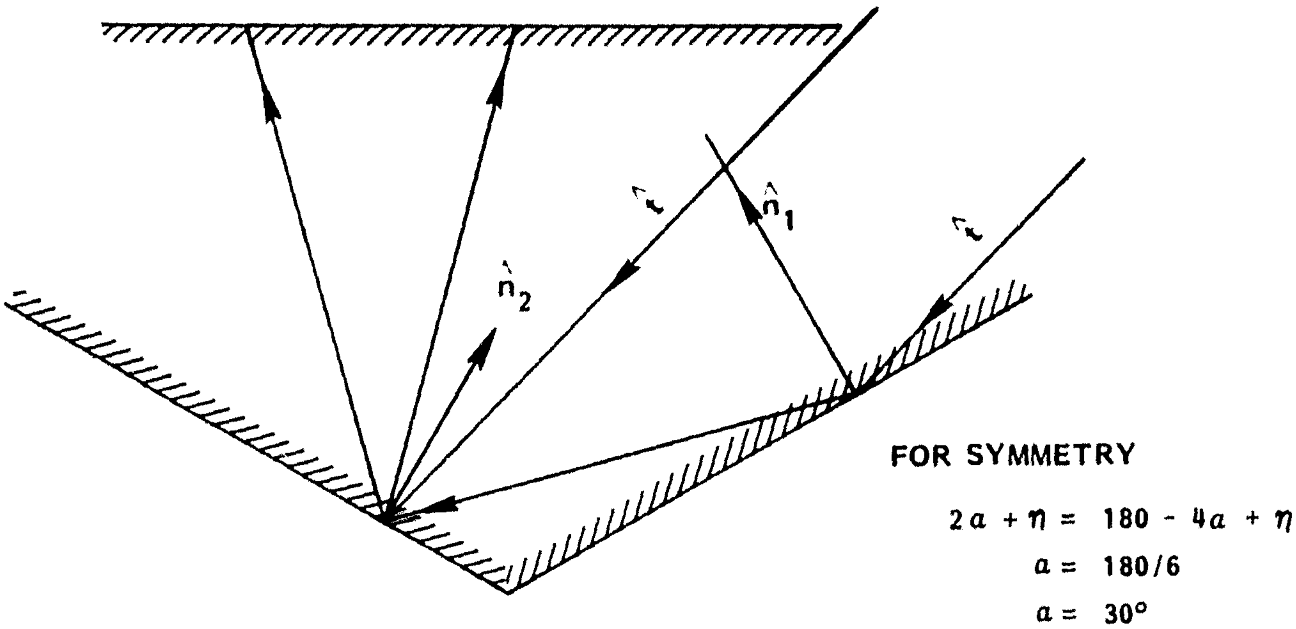


Figure 3-15. Required Dihedral Mirror Slope Angle for Symmetry

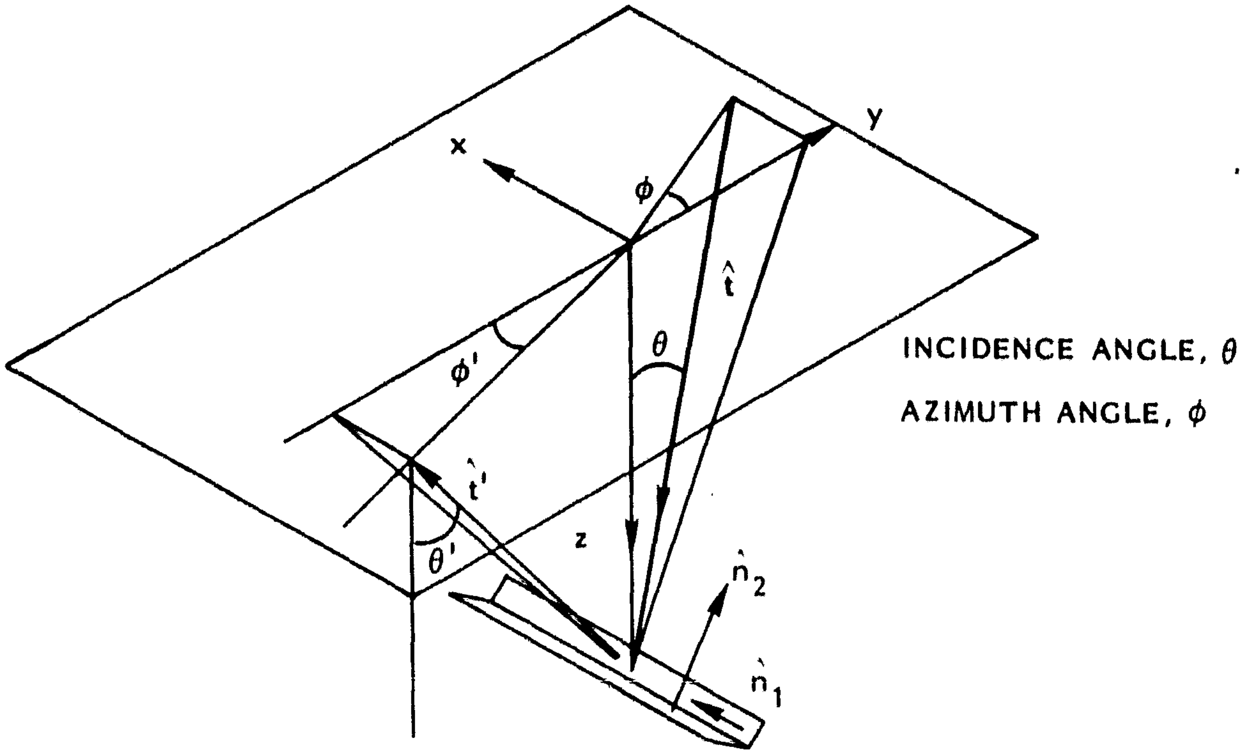
3.1.4.5 General Scattering Pattern

Although the 120° dihedral mirror, if suitably oriented, is capable of trapping on the first bounce all internally incident sunlight, the problem is more than just the mirror's first-bounce properties. It is necessary, therefore, to calculate the complete scattering pattern for light incident internally from any azimuth and at any incidence angle. This calculation can be set up conveniently using vector algebra.

The geometry of the problem to be studied is shown in Figure 3-16. Given light internally incident on the mirror at azimuth ϕ and incidence angle θ, the problem is to find the leaving angle θ' and the leaving azimuth ϕ'. Since the interest is in light trapped by total internal reflection and therefore incident again on the mirror surface, a further quantity of interest is the reach

$$r = 2\, t \tan \theta'$$

where t is the thickness of the glass coverplate. A plot of (r, ϕ') as a function of (θ, ϕ') represents a kind of footprint of scattered light that is most informative in seeking ways to use the dihedral mirror effectively.



$$\hat{t} = -(\mathrm{SIN}\ \theta\, \mathrm{SIN}\ \phi)\ \hat{i} - (\mathrm{SIN}\ \theta\ \mathrm{COS}\ \phi)\ \hat{j} + \mathrm{COS}\ \theta\ \hat{k}$$
$$\hat{n}_1 = -0.5\ \hat{j} - 0.866\ \hat{k}$$
$$\hat{n}_2 = 0.5\ \hat{j} - 0.866\ \hat{k}$$
$$\hat{t}' = \hat{t} \cdot (\mathrm{II} - 2\ \hat{n}_1\hat{n}_1) \quad \text{(SINGLE REFLECTION)}$$
$$\hat{t}' = \hat{t} \cdot (\mathrm{II} - 2\ \hat{n}_1\hat{n}_1) \cdot (\mathrm{II} - 2\hat{n}_2\ \hat{n}_2) \quad \text{(DOUBLE REFLECTION)}$$
$$\theta' = \mathrm{COS}^{-1}\ (\hat{t}' \cdot \hat{k})$$
$$\phi' = \mathrm{TAN}^{-1}\ \left(\frac{t \cdot \hat{i}}{t \cdot \hat{j}}\right) \qquad \mathrm{II} = (\hat{i}\hat{i} + \hat{j}\hat{j} + \hat{k}\hat{k})$$

Figure 3-16. Geometry of Reflection From a 120° Dihedral Mirror

The footprint (r, ϕ') has been calculated for the full range of possible azimuth and incidence angles, taking into account both singly and doubly reflected light. The resulting pattern has four-fold symmetry; one quadrant of which is shown in Figure 3-17.

The quadrant receiving the scattered light depends on which of the two mirror faces is first struck by the incident light.

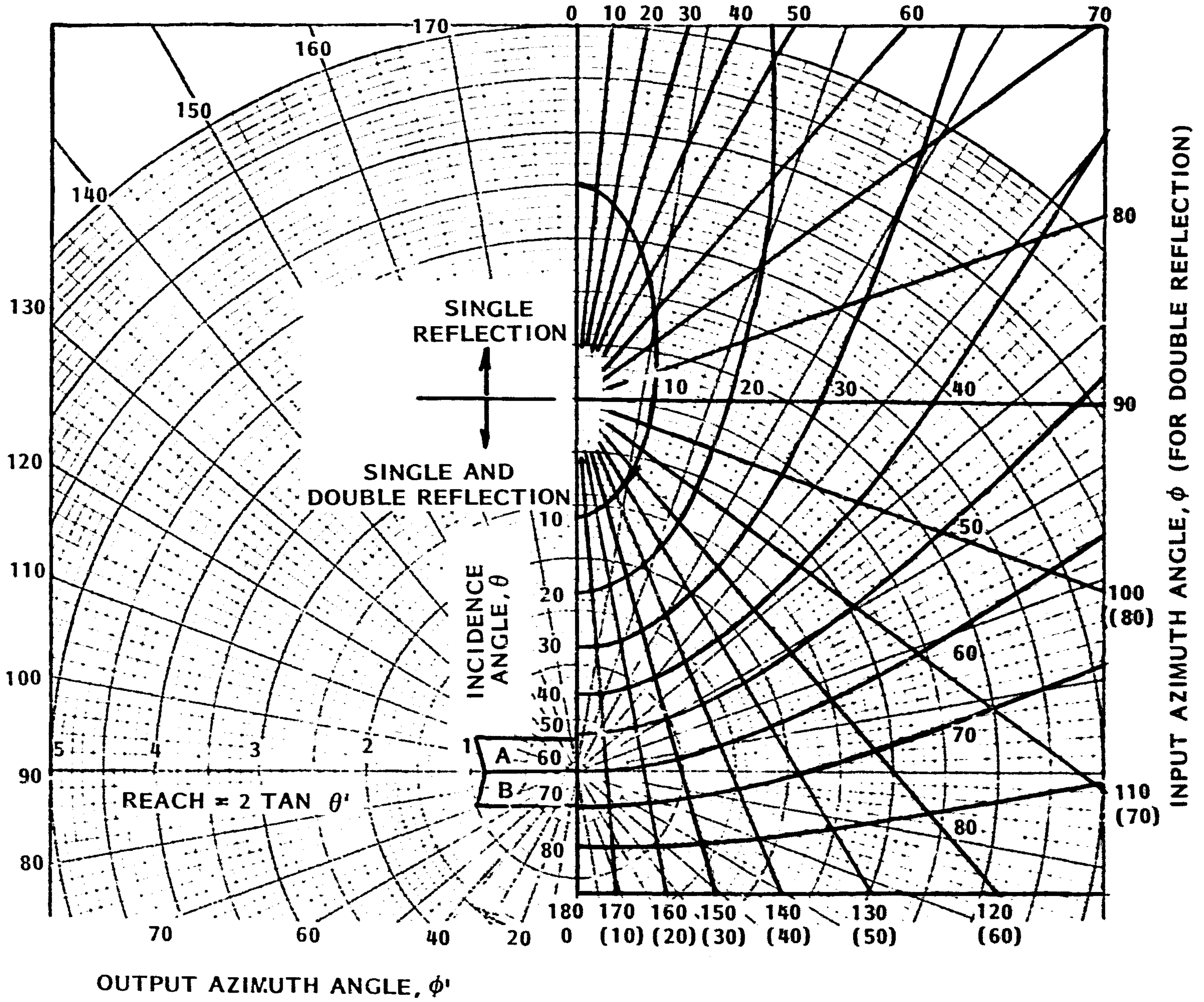


Figure 3-17. General Reflection Footprint for a 120° Dihedral Mirror

3.1.4.6 Scattering for an Hemispherical Input

One of the two cases of light incidence considered here is that of hemispherical input. A hemispherical input leads to an internally incident cone of semiangle 41.14°. On the footprint diagram the scattered input plots as shown in Figure 3-18. It should be noted that captured first-bounce light has a reach exceeding $r = 2(t) \tan 41.14°$, which plots on the footpring diagram as a circle of 1.75 units, as shown on Figure 3-18.

3.1.4.7 Scattering for Optimum Module Orientation

In the case of an optimally oriented module, the plot of this input on the footprint diagram as shown in Figure 3-19 reveals that 100 percent of the incident light is captured on the first bounce. The path of sunlight scattered from a small section of optimally oriented dihedral mirror is shown to have a minimum and maximum "reach" in the y-direction of 2 and 7.5 times the glass coverplate thickness, respectively. Thus, with the dihedral mirror pattern shown in Figure 3-20 it would be possible to capture all the energy incident on the optimally oriented fixed module for an effective concentration ratio of 1.27 (= 9.5/7.5). It should be noted that the units on Figure 3-20 are those of "reach" which can be converted to physical sizes if the glass coverplate thickness is given. Thus, for a typical thickness of 4.4 mm, the required cell width would be 33 mm with 8.8 mm of dihedral mirror width between cell rows.

3.2 FABRICATION AND INSPECTION

3.2.1 PRE-PRODUCTION MODULE ASSEMBLY

A total of 65 pre-production modules were assembled as part of this contract effort. The process flow sequence that was used for this assembly is shown in Figure 3-21. The extremely low production rate associated with this pre-production module assembly task dictated that all operations be labor intensive with little expenditure for special tooling or other labor-saving capital equipment.

The solar cells were received from ARCO-Solar with integral interconnector strips soldered to the N contacts of the cell. In the first process step, nineteen of these cells are positioned by hand on a glass coverplate which has been previously cleaned and covered with the

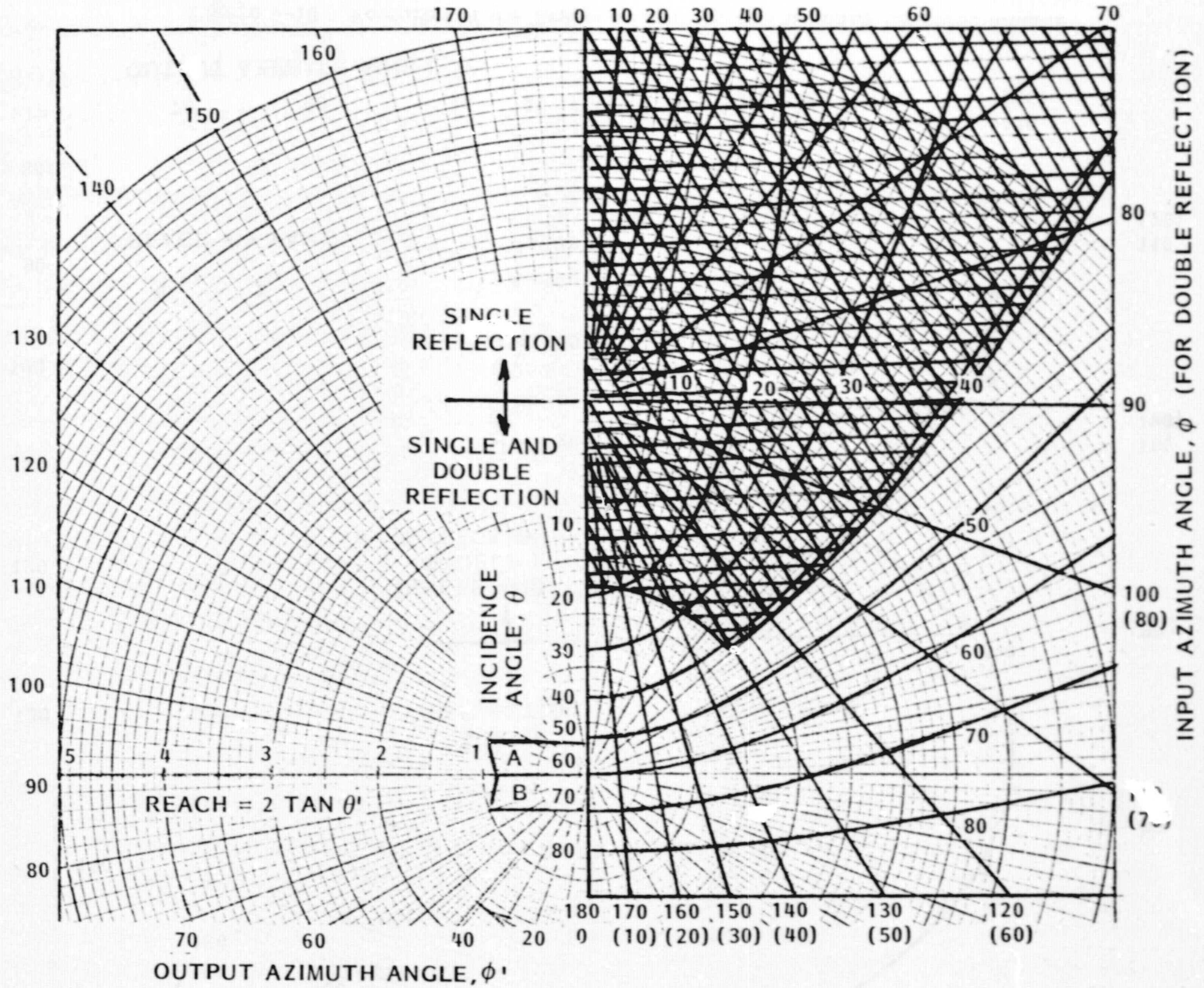


Figure 3-18. Footprint of Hemispherical Input Trapped on First Bounce

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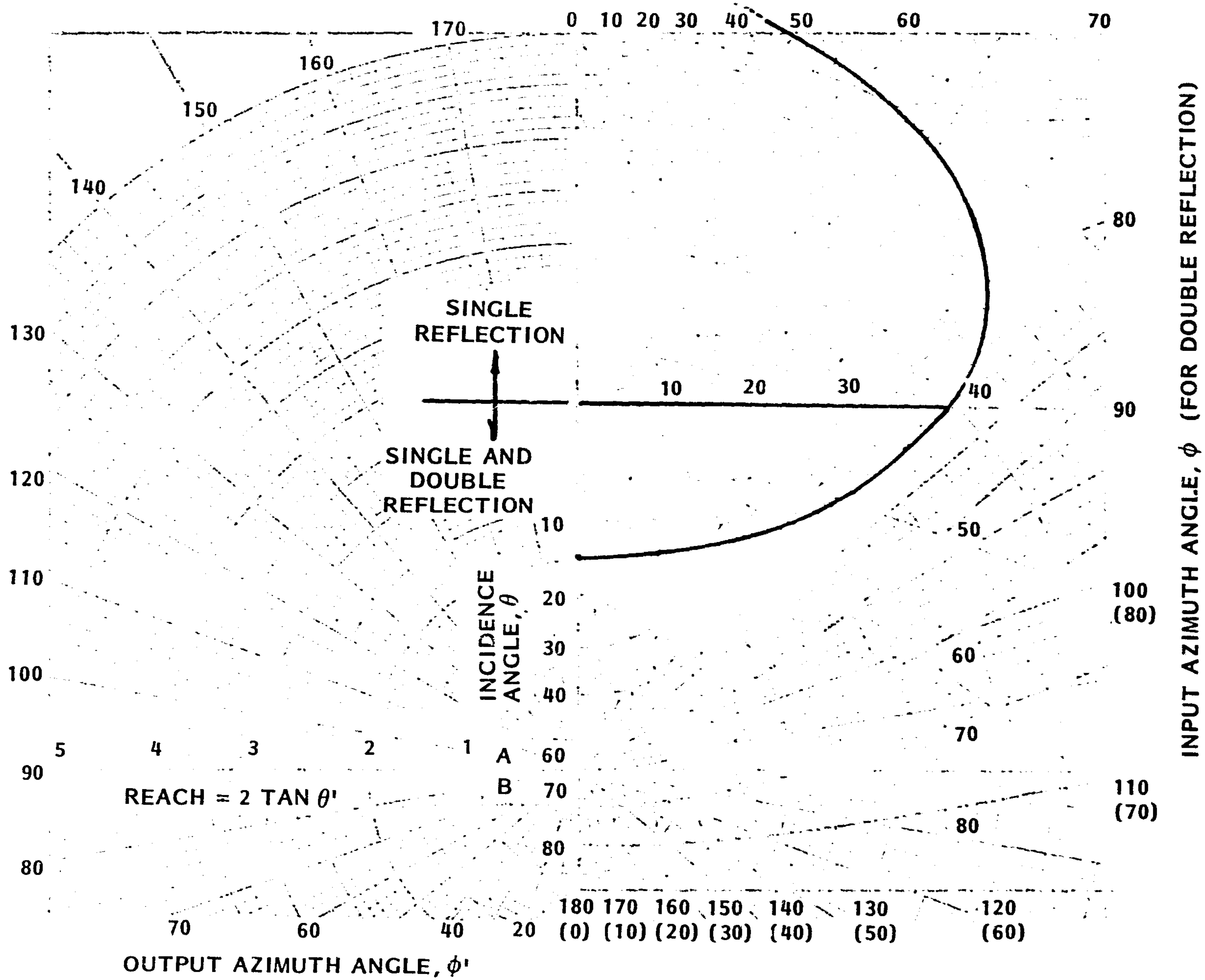


Figure 3-19. Footprint of the Trapped Light for an Optimally Oriented Module

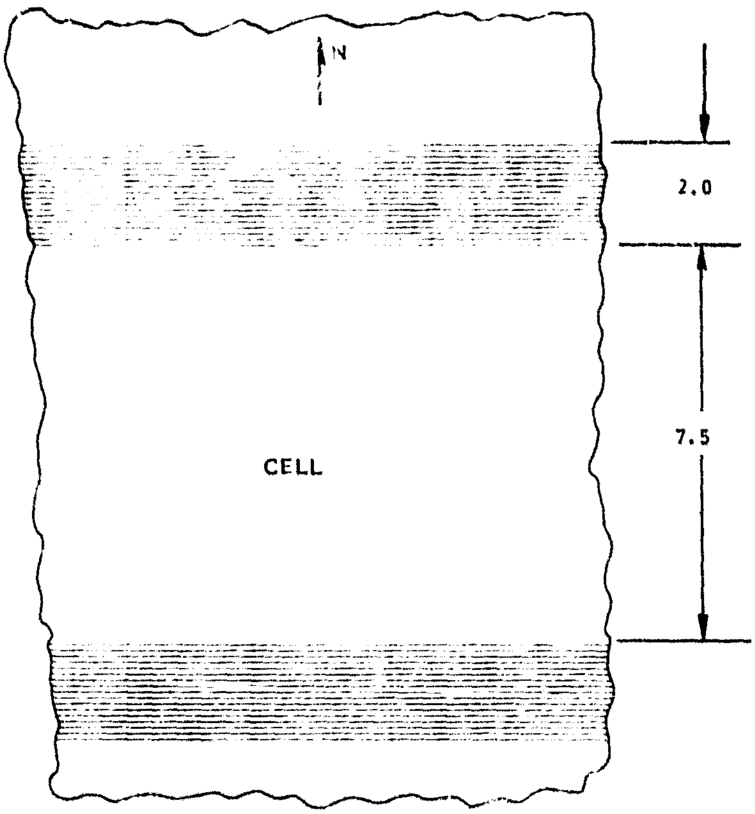


Figure 3-20. Efficient One-Dimensional Mirror/Cell Array

GE534-044 silicone pottant at the appropriate spots. A full size drawing of the glass coverplate and cells, which is placed under the coverplate, is used as an aid to correctly position the cells. Weights are individually applied to the back of each cell and the assembly is allowed to cure for at least eight hours. Following cure of the pottant excess material is removed from the spaces between the solar cells and the coverplate/solar cell subassembly is cleaned. The second process in the sequence involves the soldering of the interconnector strips on the rear side of the cells to connect all nineteen in series. Each interconnector strip is soldered in three places: one joint at the nearest point of contact with the rear side metallization, one joint at the end of the strip and one joint midway between the other two. After the "P" contact soldering operating the completed coverplate/solar cell subassembly is inspected for cracked cells, proper solder joints, bubbles and void in the cell-to-glass bonding adhesive, and proper positioning of the solar cells. If necessary, rework is performed at this point to correct any defects which were discovered during the in-process inspection. The remaining steps in the module assembly sequence can be described with the aid of Figure 3-22 which depicts the

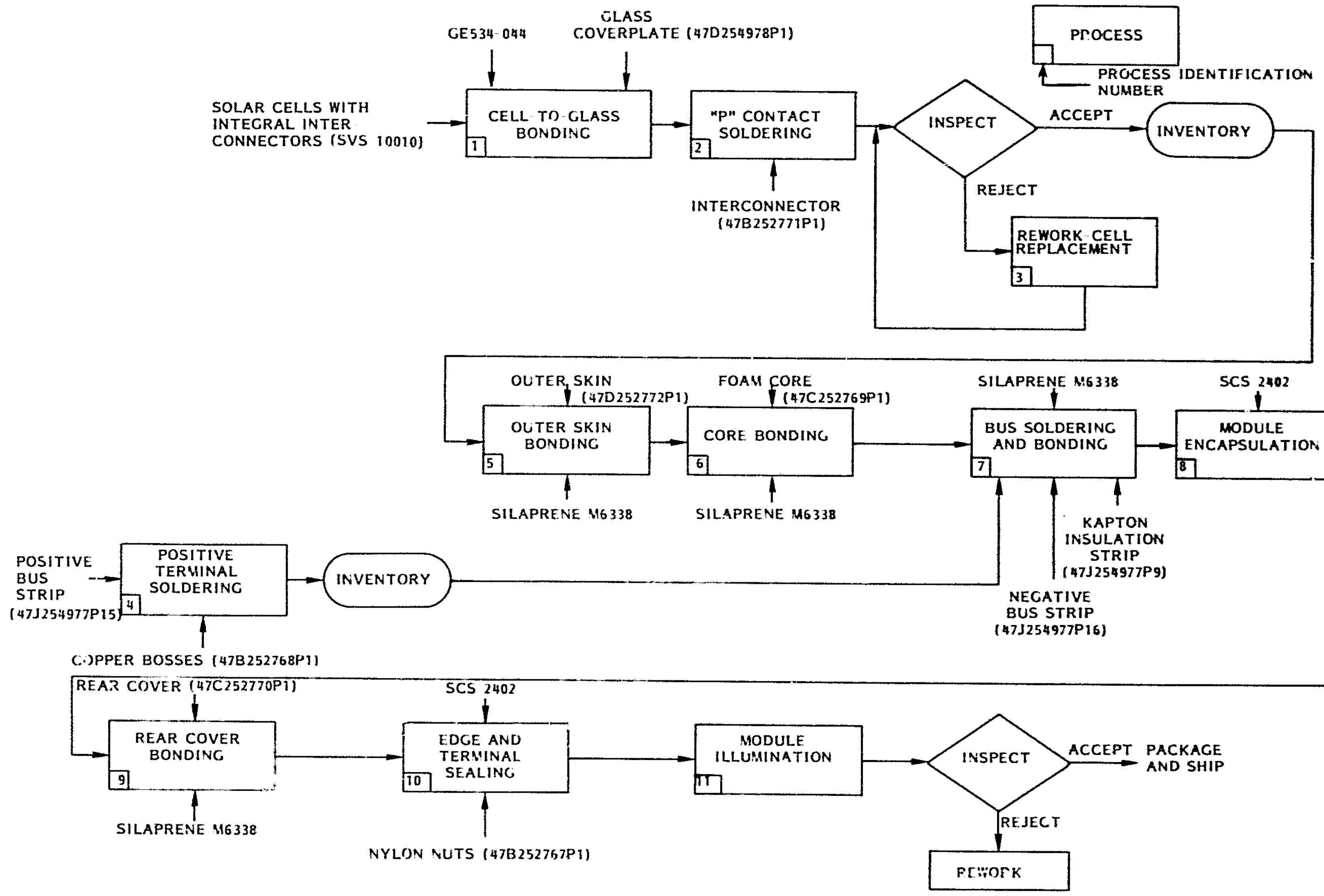
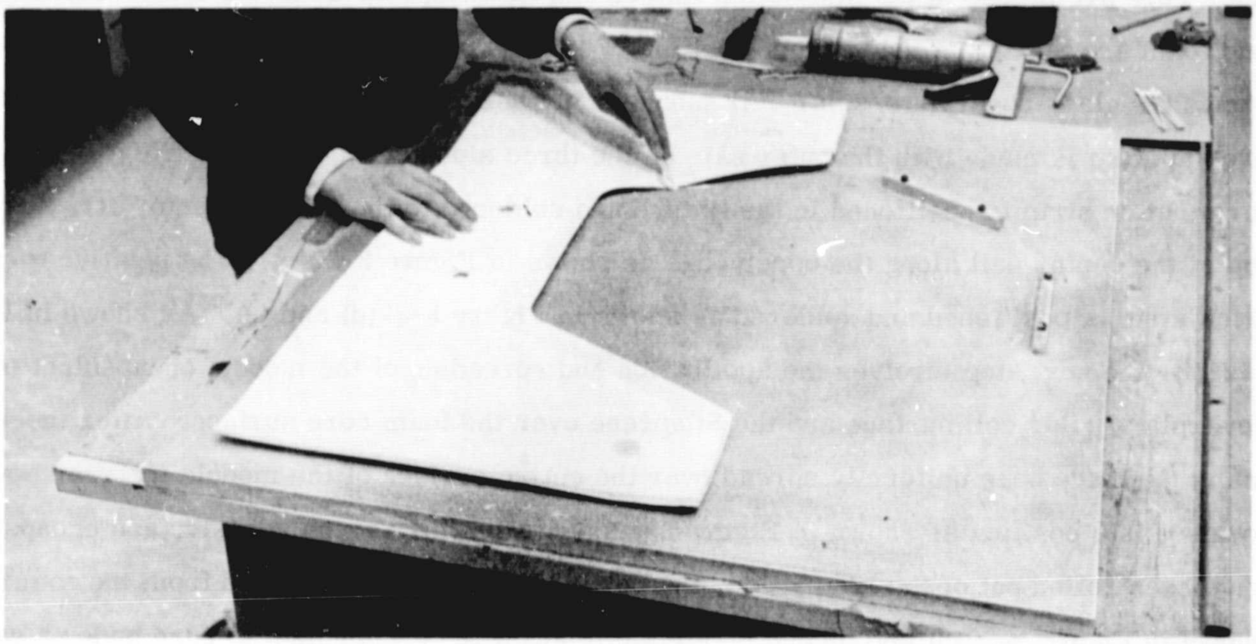


Figure 3-21. Process Flow Diagram for the Block IV Shingle Solar Cell Module

various stages in the lamination of a module. In Figure 3-22(a), the outer substrate skin and foam core are placed in the lamination fixture and the Silaprene adhesive is spread. The skin and foam are located in the correct position by two nylon plugs in the fixture. Figure 3-22(b) shows the glass coverplate/solar cell subassembly being positioned in the fixture so that the overlap joint is made with the outer skin on the three sides of the hexagon. Next the negative termination strip is positioned in the fixture and soldered to the interconnector strips from the top of the center cell along the upper edge as shown in Figure 3-22(c). The positive termination strip is positioned and soldered as shown in Figure 3-22(d) and (e). As shown in Figure 3-22(f), the next step involves the application and spreading of the module encapsulant over the coverplate/solar cell surface and the Silaprene over the foam core surface. After these two materials have been uniformly spread over the entire surface of the module the rear cover is lowered into position as shown in Figure 3-22(g). After the excess adhesive and encapsulant have been rolled out of the lamination, the completed module is removed from the fixture as shown in Figure 3-22(h) and placed on a table to allow the encapsulant to cure under a weighted condition.

Table 3-4 summarizes pertinent data concerning the 65 modules that were assemblied under this contract. Each module is identified by a serial number which begins with "BIV" which designates the Block IV program. The seven digit serial number begins with a three digit sequence number which is followed by four digits which identify the week and year that the cell-to-glass bonding operation was performed. As indicated in Table 3-4, the early modules (through serial no. BIV-0064979) were fabricated using SCS1202 as the module encapsulant. This material was replaced with SCS2402 on subsequent serial numbers when it became apparent that the acetic acid cure by-product of the SCS1202 was causing a tarnishing of the interconnector strips. Beginning with serial number BIV-0094979, this rear cover design was modified to add a series of holes to allow air to reach the module encapsulant during the cure period.

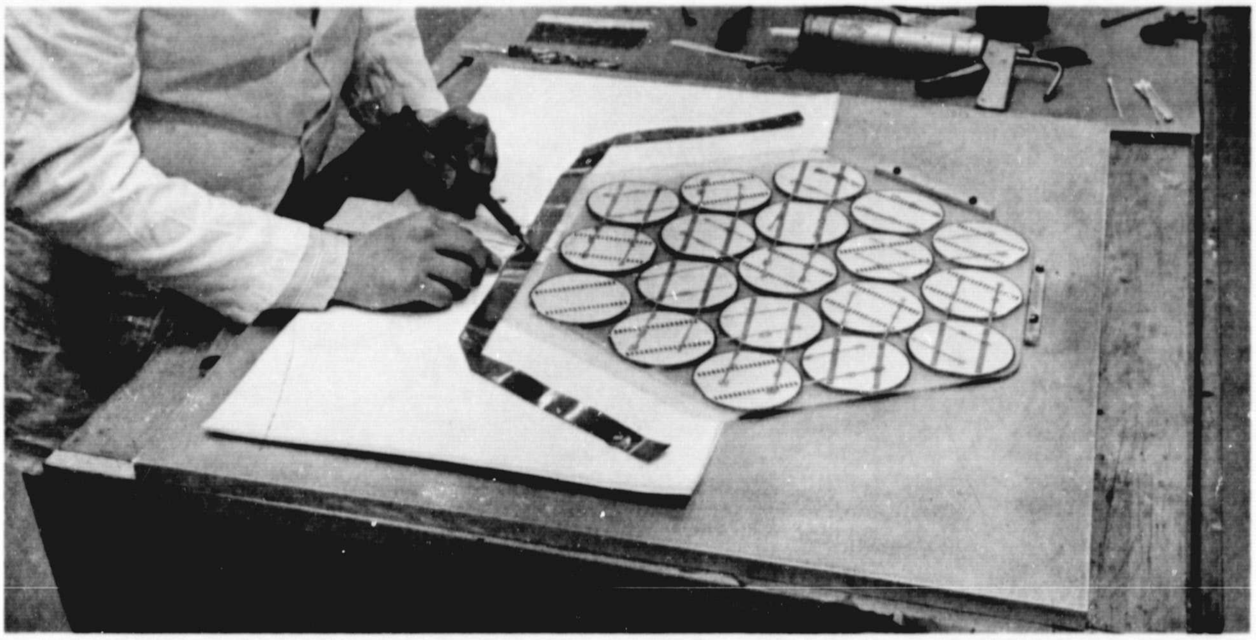
Two simulated roof structures, each consisting of three active modules and associated termination shingles and edge dummy shingles, were assemblied as depicted in Figure 3-23. One of these simulated roof sections was immediately shipped to JPL for testing while the other was



(a) Coating Substrate Skin

(b) Positioning Coverplate Subassembly

Figure 3-22. Pre-production Module Lamination Sequence

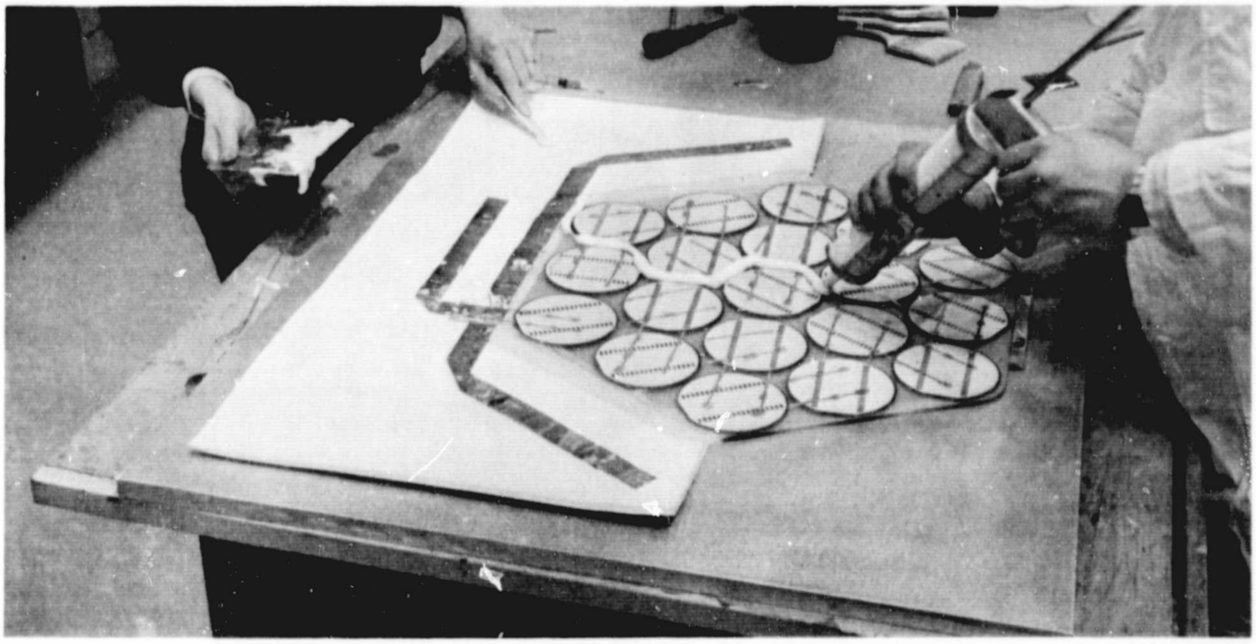


(c) Soldering Negative Termination Strip

(d) Positioning Positive Termination Strip

Figure 3-22. Pre-production Module Lamination Sequence (Cont)

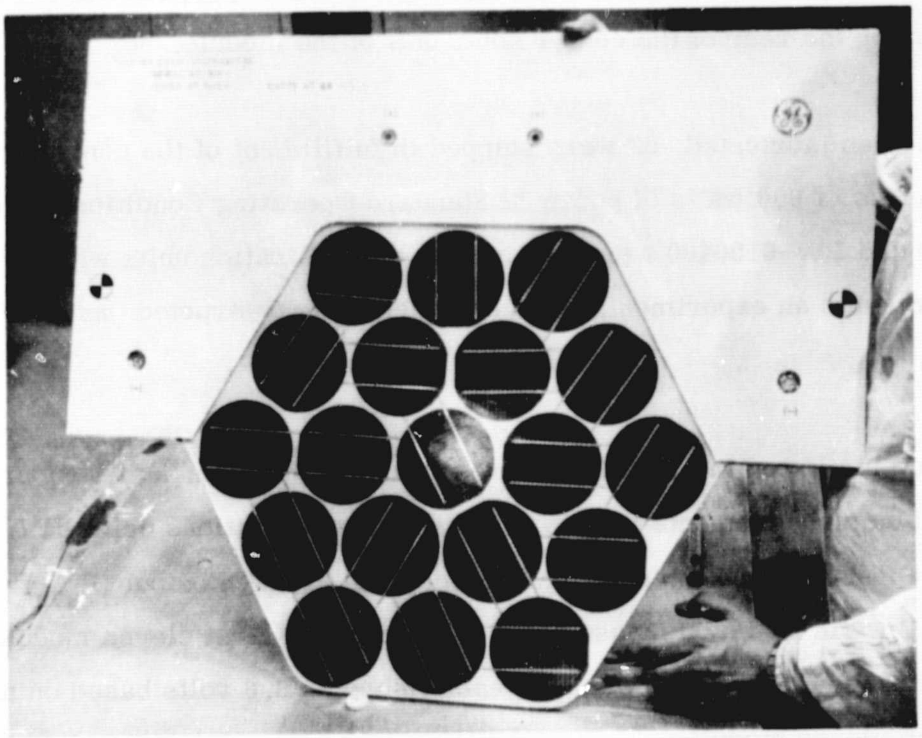
(e) Soldering Positive Termination Strip



(f) Spreading Module Encapsulant and Substrate Adhesive

Figure 3-22. Pre-production Module Lamination Sequence (Cont)

(g) Positioning Rear Cover



(h) Completed Module

Figure 3-22. Pre-production Module Lamination Sequence (Cont)

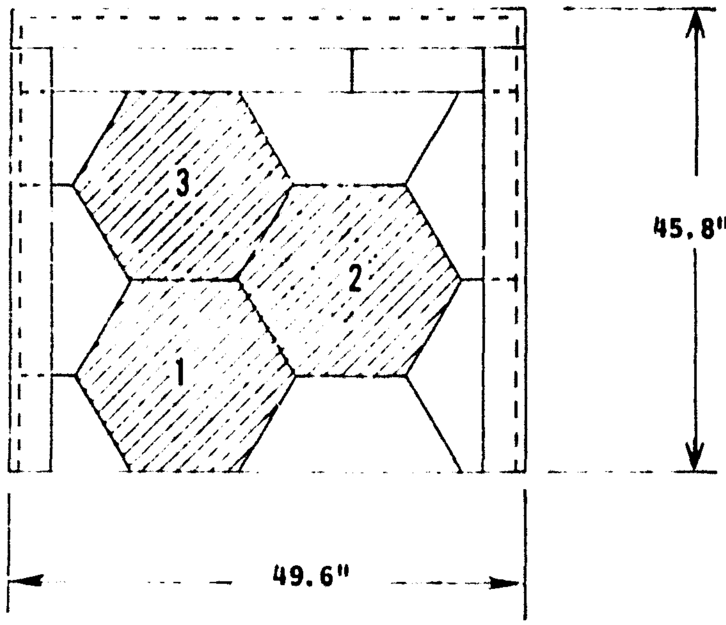


Figure 3-23. Simulated Roof Test Article

retained by GE for qualification testing as described in Section 3.3.2. Table 3-4 also indicates the identification and location of each module which was installed on these two test articles. In each case, the module installed at location number 2 was equipped with two thermocouples which were mounted on the rear of the center solar cell of the module.

Of the 65 modules fabricated, 62 were shipped in fulfillment of the contract requirement to deliver in excess of 900 watts of power at Standard Operating Conditions. Serial numbers BIV-0124979 and BIV-0190480 were retained as demonstration units while serial number BIV-0130280 represents an experimental module which was constructed using a patterned glass coverplate.

The power outputs listed in Table 3-4 represent calculated values at Standard Operating Conditions based on measurements made at Optional Test Conditions using JPL-supplied standard cell number GR-416 as the intensity reference. The average output (P_{avg}) at SOC was established as 14.7 watts based on measurements made on the first eleven modules produced. The nominal operating voltage (V_{no}) was also established as 6.6 volts based on measurements made on these same eleven modules.

Table 3-4. Summary of Module Performance and Processing Attributes

MODULE SERIAL NO.	POWER AT Vno (WATTS)	ENCAPSULANT		HOLES IN REAR COVER		REMARKS
		SCS1202	SCS2402	YES	NO	
BIV-0014879	14.9	X			X	GE Roof-Position No. 1
BIV-0024879	14.6	X			X	
BIV-0034879	14.5	X			X	
BIV-0044879	14.7	X			X	GE Roof-Position No. 3
BIV-0054979	14.8	X			X	JPL Roof-Position No. 2 2 T/C's installed
BIV-0064979	14.9	X			X	JPL Roof-Position No. 1
BIV-0074979	14.3		X		X	JPL Roof-Position No. 3
BIV-0084979	14.7		X		X	
BIV-0094979	14.7		X	X		
BIV-0104979	14.6		X	X		GE Roof-Position No. 2 2 T/C's installed
BIV-0114979	14.7		X	X		
BIV-0124979	-		X	X		Non-functional demonstration unit - Not delivered
BIV-0130280	15.4		X	X		Experimental module with patterned glass coverplate - Not delivered
BIV-0140480	14.1		X	X		
BIV-0150480	14.3		X	X		
BIV-0160480	14.2		X	X		
BIV-0170480	14.3		X	X		
BIV-0180480	14.3		X	X		
BIV-0190480	14.0		X	X		Demonstration Unit - Not Delivered
BIV-0200480	14.3		X	X		
BIV-0210480	14.1		X	X		
BIV-0220480	14.0		X	X		
BIV-0230580	14.4		X	X		
BIV-0240580	14.4		X	X		
BIV-0250580	14.3		X	X		
BIV-0260580	14.5		X	X		
BIV-0270580	14.5		X	X		
BIV-0280580	14.2		X	X		
BIV-0290580	14.4		X	X		
BIV-0300580	14.5		X	X		
BIV-0310580	14.5		X	X		
BIV-0320680	14.6		X	X		

BIV-0250580	14.3		X	X		
BIV-0260580	14.5		X	X		
BIV-0270580	14.5		X	X		
BIV-0280580	14.2		X	X		
BIV-0290580	14.4		X	X		
BIV-0300580	14.5		X	X		
BIV-0310580	14.5		X	X		
BIV-0320680	14.6		X	X		
BIV-0330680	14.5		X	X		
BIV-0340680	14.5		X	X		
BIV-0350680	14.5		X	X		
BIV-0360680	14.6		X	X		
BIV-0370680	14.4		X	X		
BIV-0380680	14.4		X	X		
BIV-0390680	14.5		X	X		
BIV-0400680	14.4		X	X		
BIV-0410680	14.7		X	X		
BIV-0420680	14.9		X	X		
BIV-0430680	14.8		X	X		
BIV-0440680	14.9		X	X		
BIV-0450680	14.9		X	X		
BIV-0460780	14.9		X	X		
BIV-0470780	14.7		X	X		
BIV-0480780	14.7		X	X		
BIV-0490780	14.9		X	X		
BIV-0500780	14.8		X	X		
BIV-0510780	15.0		X	X		
BIV-0520780	14.9		X	X		
BIV-0530780	14.8		X	X		
BIV-0540880	14.6		X	X		
BIV-0550780	14.8		X	X		
BIV-0560780	14.8		X	X		
BIV-0570780	14.9		X	X		
BIV-0580780	14.9		X	X		
BIV-0590780	14.6		X	X		
BIV-0600780	14.8		X	X		
BIV-0610880	14.9		X	X		
BIV-0620880	14.9		X	X		
BIV-0630880	14.7		X	X		
BIV-0640880	14.7		X	X		
BIV-0650880	14.9		X	X		

3.2.2 INSPECTION SYSTEM PLAN

An Inspection System Plan was formulated to define the inspection and acceptance test requirements for the pre-production modules. This plan defines the rejection criteria to be employed at both in-process and final inspection and covers areas such as cracked or broken solar cells, voids in cell-to-glass bonding adhesive, voids in module encapsulant and critical module dimensions. The crack-tolerant solar cell and interconnector design, which reduces the likelihood that a cell crack will reduce the cell or module output, has made it possible to define many cracked cell patterns which are acceptable in a completed module. In general any rim-to-rim crack is considered acceptable if it does not remove a significant portion of the cell from the electrical circuit thereby potentially causing a module power output less than the minimum acceptable value. A terminated crack is acceptable if the termination lies within the area formed by the intersection of the projections of both the top and bottom interconnects on a common plane or if the terminated crack has passed through this area. However no more than two acceptable cracked cells per module are allowed.

The acceptance criteria which were applied to the cell-to-glass bonding adhesive, module encapsulant and substrate lamination are summarized in Table 3-5.

3.3 SHINGLE MODULE TEST

3.3.1 ACCEPTANCE TESTING

Acceptance testing of the completed modules consisted of an illumination test using the Large Area Pulse Solar Simulator (LAPSS) as the source. A JPL-supplied standard cell No. GR-416 was used as the reference to establish the 100 mW/cm^2 intensity level. The module was mounted in the LAPSS test plane as shown in Figure 3-24 with copper straps connecting the two terminals of the same polarity.

Figure 3-25 shows the I-V characteristic obtained under Optional Test Conditions for module serial number BIV-0044879. This module performance is typical of that measured on the first seven pre-production modules fabricated. The calculated I-V characteristic at SOC is plotted on this same figure using temperature coefficients for voltage and current of -0.0494 V/^{o}C and +0.00070 A/^{o}C, respectively. These values were specified by JPL based on

Table 3-5. Module Inspection Criteria

- **<u>Bubbles, Voids or Delaminations in Cell-to-Glass Bond</u>**

  Reject if
  - > 0.5 cm^2 on a single cell
  - > 5.0 cm^2 per module
  - > 4 mm across largest dimension for a single defect

- **<u>Bubbles, Voids or Delaminations in Module Encapsulant</u>**

  Reject if
  - > 3 cm^2 per module
  - > 1 cm^2 for a single defect

- **<u>Substrate Blistering</u>**

  Oven Bakeout at 64 ± 4°C for 1 hour

  Reject if
  - > 25 cm^2 total per module
  - > 10 cm^2 for a single blister
  - > 3 mm height above surface

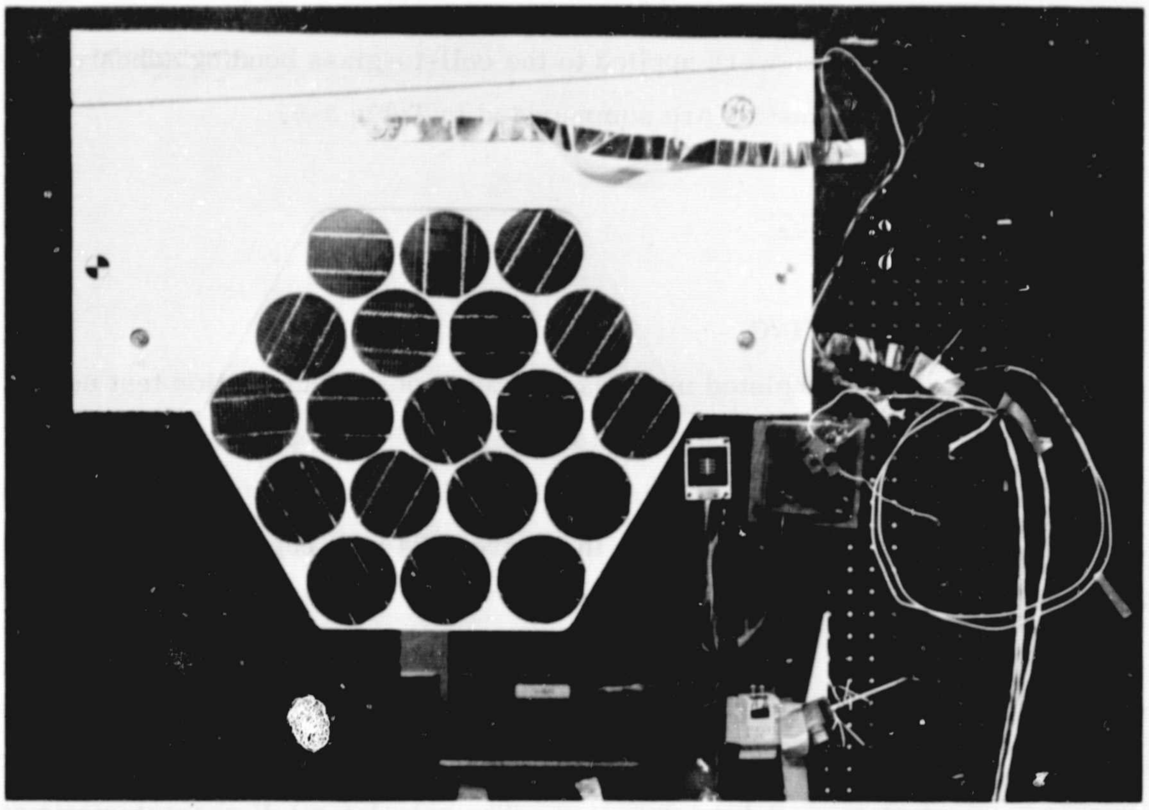


Figure 3-24. Shingle Module Set-up for the Acceptance Illumination Test

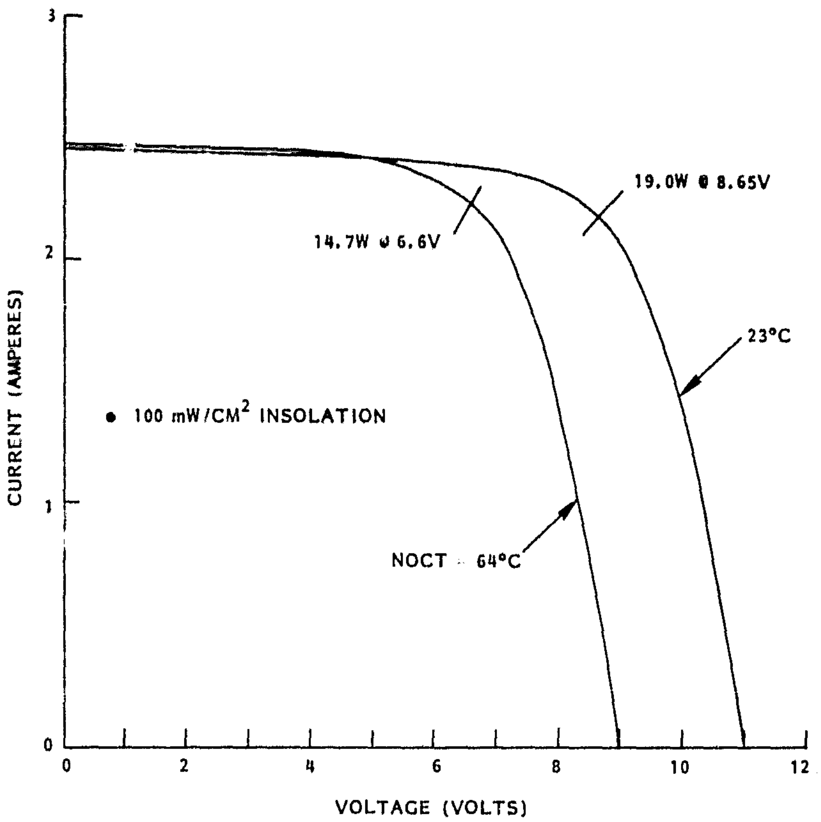


Figure 3-25. I-V Characteristics for Module Serial No. BIV-0044879

measurements made on the reference solar cells. Thus, the measured maximum power output of 19.0 at 8.65 volts is reduced to 14.7 watts at 6.6 volts when translated to SOC using the coefficients given.

As noted earlier in Section 3.1.2.1, the solar cells delivered after the resumption of production at ARCO-Solar exhibited an enhanced voltage output compared to the cells used to assemble the first eleven modules. This is reflected in the module I-V characteristics shown in Figure 3-26, where serial no. BIV-0450680 is typical of those modules made with the newer cells. This module has a maximum power voltage at the Optional Test Conditions which is approximately 0.6 volts higher than the earlier modules which are represented by module serial no. BIV-0044879.

This change in basic solar cell I-V characteristic, which resulted in a higher open-circuit and maximum power voltage in those cells delivered after January 1, 1980, is of significance since

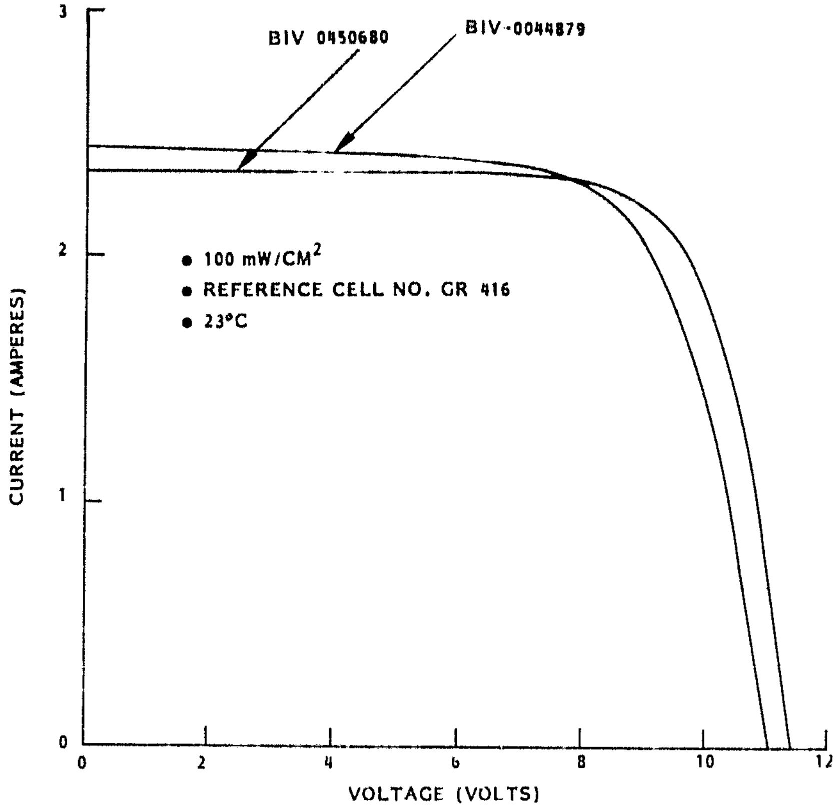


Figure 3-26. Typical Module I-V Characteristics

the values of P_{avg} and V_{no} were established based on measurements made on the first eleven modules assembled. As shown in Figure 3-27, the calculated I-V characteristic of module serial no. BIV-0450680 at SOC differs significantly from the corresponding curve for serial no. BIV0044879 as given in Figure 3-25. In other words, the choice of 6.6 volts for V_{no} based on the first eleven modules fabricated results in a low output rating for the majority of the modules produced since the calculated maximum power voltage of these later modules is 0.6 volts higher at SOC. In particular for module serial no. BIV-0450680, the calculated maximum power output is 15.4 watts at 7.2 volts as compared to 14.9 watts at the selected 6.6 volt value for V_{no}.

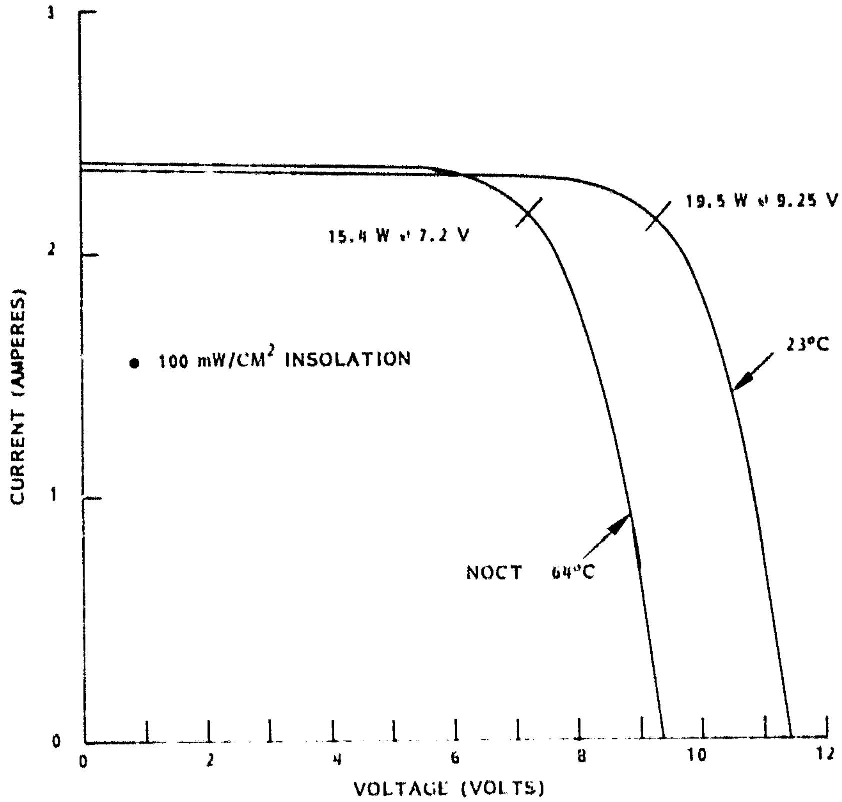


Figure 3-27. I-V Characteristic for Module Serial No. BIV-0450680

3.3.2 QUALIFICATION TESTING

3.3.2.1 Introduction

The qualification program conducted by GE followed the testing sequence given in Figure 2-1 except that a dc voltage HIPOT test was not performed since the shingle modules have no exposed conductive parts. Also, the hail impact test was not performed as part of the GE testing sequence.

Module serial numbers BIV-0014879, BIV-0044879 and BIV-0104979 were assembled into the simulated roof structure shown in Figure 1-2. Positive and negative termination shingles and dummy edge shingles were installed to complete the simulated roof test article. The three active modules on this roof section are connected in series by the module-to-module interconnectors. Positive and negative termination shingles at the top and bottom of this array are used to connect the module terminals to a current collection bus bar at each end. Two power leads from each bus bar exit from the rear of the roof section to permit the electrical performance testing of the array consisting of three series-connected modules.

The dummy shingles on the side and top edges of this roof section were constructed by laminating the FLEXSEAL outer skin to 0.25 inch thick tempered Masonite.

3.3.2.2 Thermal Cycling Test

As the first environmental exposure in the sequence the simulated roof section was subjected to the thermal cycling test described in Figure 3-28. This test was performed at AEL Industries, Product Testing Laboratory in Montgomeryville, PA beginning on January 22, 1980. The test set-up at this facility is depicted in Figure 3-29. The specimen was instrumented as shown in Figure 3-30. The two thermocouples on the rear of the center cell of module serial no. BIV-0104979 were recorded throughout the test. A constant current of 0.5 amperes was passed in the forward diode direction through the array and the voltage drop between the roof terminals was continuously recorded on a strip chart.

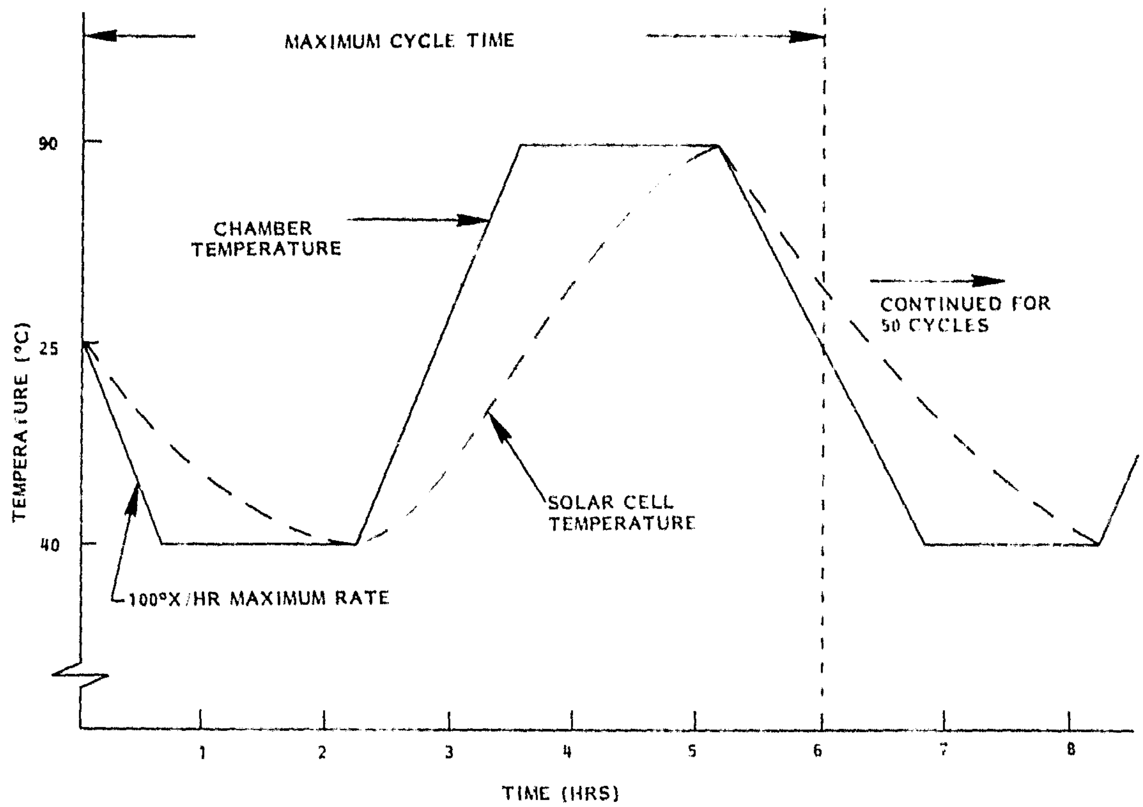


Figure 3-28. Temperature Cycling Profile

(a) Simulated Roof Structure in the Test Chamber

(b) Temperature and Forward Voltage Drop Instrumentation

Figure 3-29. Test Set-up for the Thermal Cycling Exposure

ORIGINAL PAGE IS OF POOR QUALITY

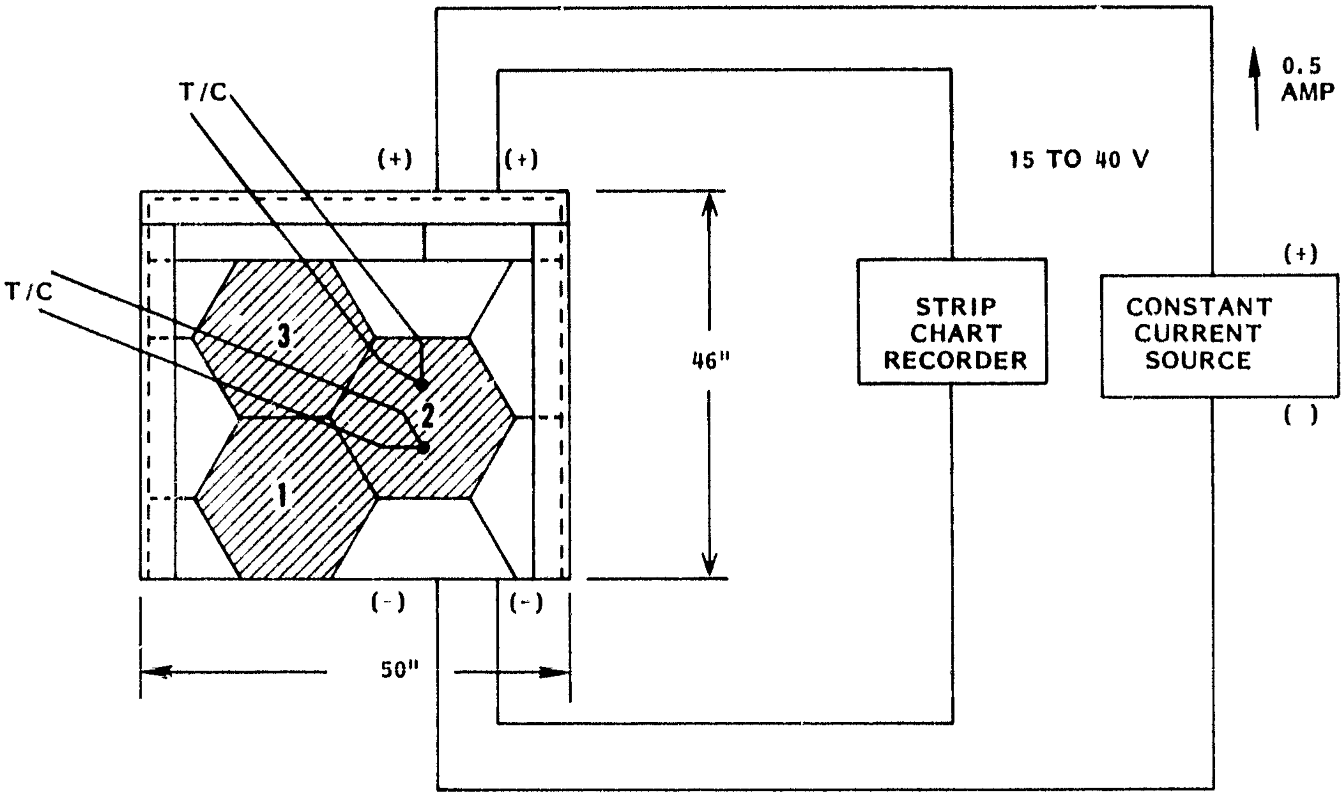


Figure 3-30. Simulated Roof Instrumentation

3.3.2.3 Humidity-Temperature Test

A seven-day humidity-temperature test was performed in accordance with the profile given in Figure 3-31. This test was performed at AEL Industries, Product Testing Laboratory in Montgomeryville, PA beginning on February 11, 1980. The instrumentation for this was identical to that used for the thermal cycling test as shown in Figure 3-30.

3.3.2.4 Wind Resistance Test

A wind resistance test was performed in accordance with the requirements of UL997. This test was conducted at the Underwriters Laboratories in Northbrook, IL, on February 22, 1980.

A roof slope of 22.6 degrees from the horizontal was maintained throughout this exposure as the direction of the 60 mph horizontal air stream with respect to the array was varied from head-on to 30 and then 90 degrees from head-on.

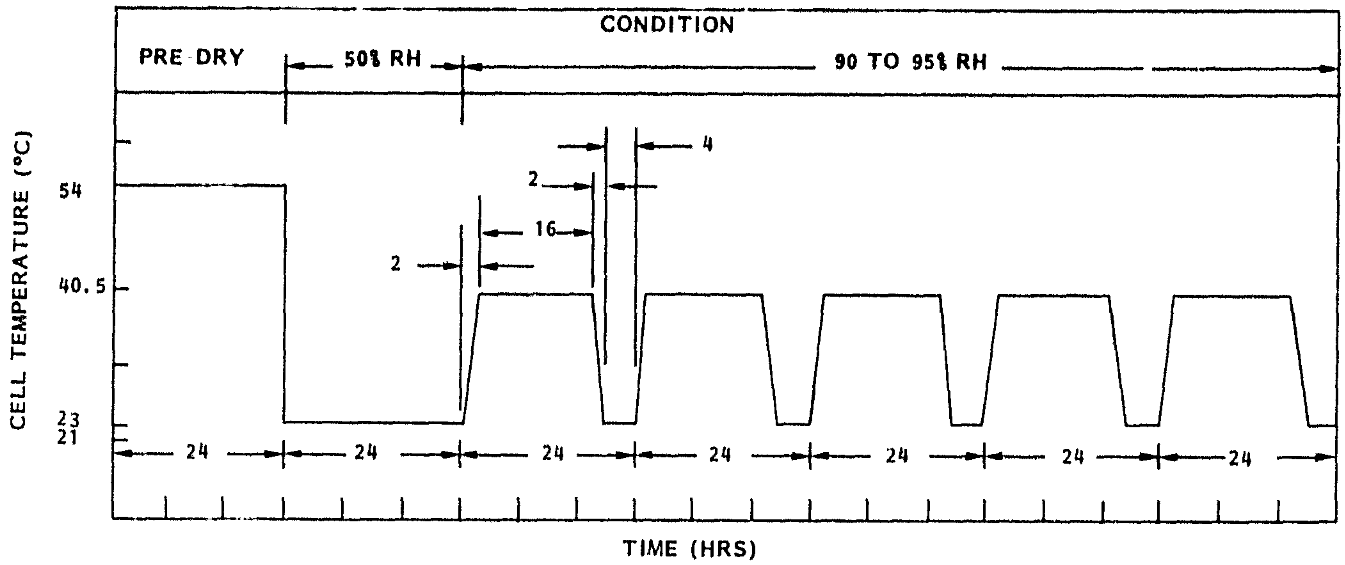


Figure 3-31. Humidity-Temperature Cycling Test Profile

3.3.2.5 Twisted Mounting Surface

A twisted mounting surface test was performed by placing the roof section on a smooth horizontal surface with a 1.0 inch thick block under one of the four corners and forcing the other three corners to touch the surface. The test was repeated with the block under each of the four corners.

3.3.2.6 Qualification Test Results

Table 3-6 summarizes the results of the electrical performance measurements which were made on the simulated roof section after each environmental exposure. In all cases, the measured changes in array electrical output are within the expected accuracy of the illumination test set-up. Figure 3-32 shows the I-V characteristic for this simulated roof section in the as-built condition and after the completion of the qualification testing program.

A photograph of the roof section taken after the completion of all qualification testing is shown in Figure 3-33. Changes in physical appearance which can be attributed to the testing program are noted below:

1. An increase in the amount of corrosion of the interconnector strips on the two modules which used SCS 1202 as the module encapsulant. This increased interconnector corrosion was noted after the thermal cycling exposure.

2. A warpage of the exposed edges of the bottom dummy shingles and the positive and negative termination shingles. This warpage was noted immediately after the humidity-temperature test and can be attributed to an expansion of the Mead Pan-L board rear cover of these laminated dummy shingles. The dummy shingles constructed with the tempered Masonite experienced no such warpage. These warped edges eventually returned to the original condition after several days of air drying.

Table 3-6. Electrical Performance of the Simulated Roof Structure*

	Isc (Amps)	V_{oc} (volts)	V_{mp} (volts)	P_{max} (watts)
Initial Measurement	2.455	33.2	26.2	56.8
After Thermal Cycle Test	2.433	33.6	26.5	56.9
After Humidity-Temperature	2.437	33.3	25.9	55.9
After Wind Resistance Test	2.459	33.2	26.3	56.3
After Twisted Mounting Surface Test	2.440	33.3	26.4	56.0
Net Change (%)	-0.6	+0.3	+0.8	-1.4

* At 100 mW/cm^2 and at 23°C

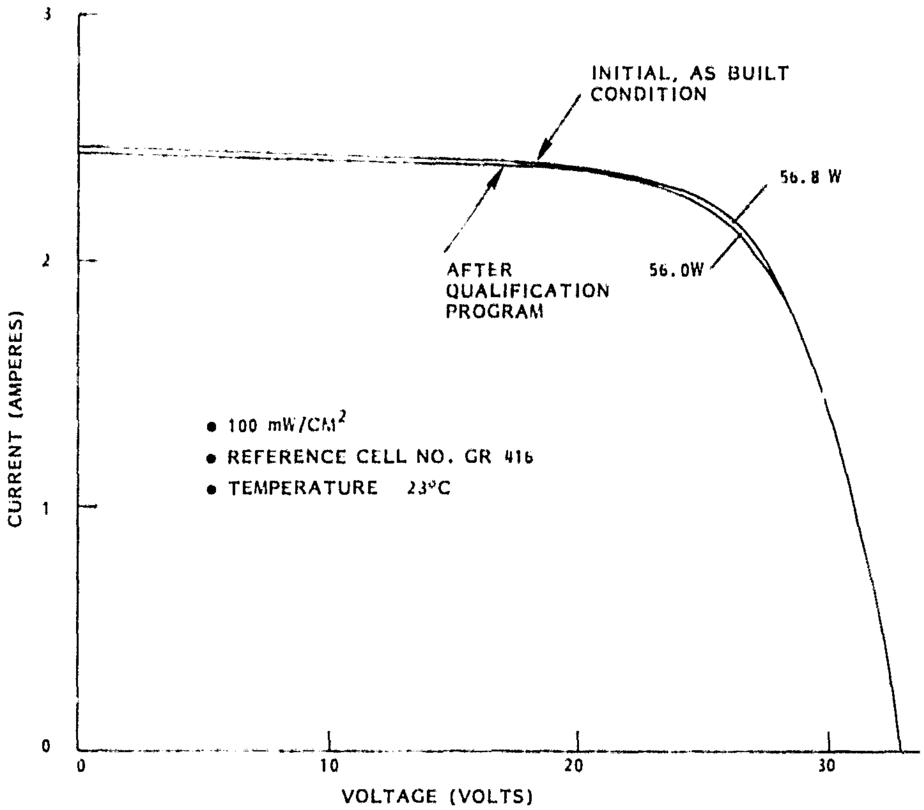


Figure 3-32. I-V Characteristics for the Simulated Roof Structure

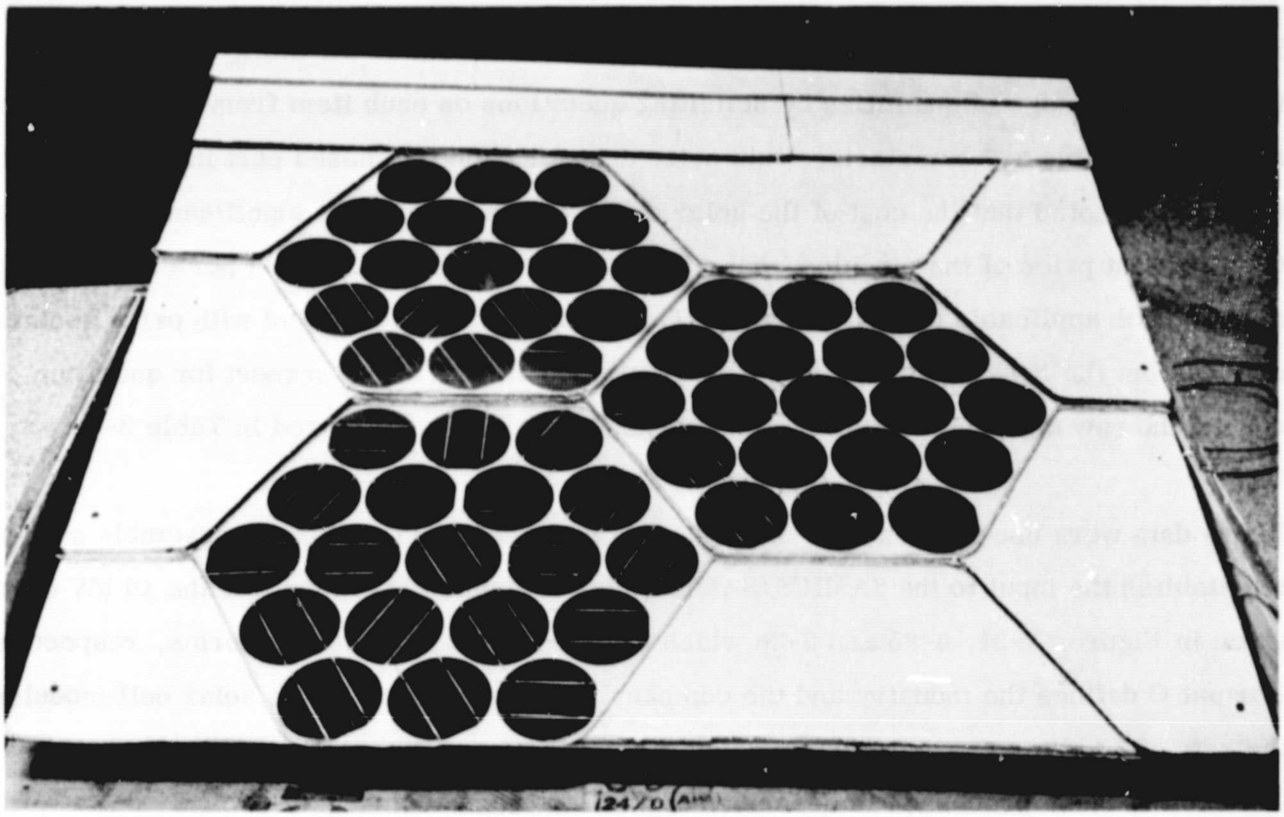


Figure 3-33. Simulated Roof Section After the Completion of All Qualification Testing

3.4 PRICE ESTIMATION

A SAMICS/SAMIS price estimate was performed for the production of shingle solar cell modules in annual quantities of 10, 100 and 1000 kW. This price estimate is reflected in 1980 dollars and was based on the following guidelines for the three cases considered. For the 10 kW case the estimate was based on equipment and processes which could be in place and functioning successfully at the time the estimate was prepared (i.e., February, 1980). Module electrical performance was based on actual measurements. For the 100 and 1000 kW cases the estimate was based on equipment and processes which could exist in some successful form by January 1, 1980 such that the supplier could, by that date, proceed with equipment procurement and emplacement and with process set-up without the need for further development. This production capability was considered as existent on January 1, 1980. That is, the lead time from the initiation of equipment procurement to the existence of the requisite production capability was assumed to be zero.

The cost of the purchased parts which are required to assemble the shingle module were obtained over a range of quantities by soliciting quotations on each item from established sources of supply. Table 3-7 summarizes this price data for each purchased part in the shingle module. It should be noted that the cost of the solar cells, which is of major significance in determining the resultant price of the modules, was assumed to be constant at $7.44 per cell over the range of quantities applicable to this analysis. This assumption is consistent with price quotations received from the lowest bidder among five responses received to a request for quotation. The cost of the raw material used in the module assembly are summarized in Table 3-8.

These data were used, along with the descriptions of each process in the assembly sequence, to establish the input to the SAMICS/SAMIS price analysis. This input for the 10 kW case is given in Figures 3-34, 3-35 and 3-36 which are the Format C, B and A forms, respectively. Format C defines the industry and the company which produces shingle solar cell modules at the rate of 10 kW per year. The module assembly process sequence is defined on Format B and each of these processes is described on the Format A forms.

Table 3-9 summarizes the results of this analysis using the SAMIS program to estimate the price of the shingle modules in 1980 $ per peak-watt. Each process is listed by the SAMIS process referent and the corresponding calculated price is given for the three production rates considered.

Table 3-7. Unit Cost of Fabricated Piece Parts (1980 $/Unit)

CATALOG NUMBER	DESCRIPTION	QUANTITY												
		300	600	1,000	2,000	3,000	6,000	10,000	20,000	30,000	60,000	100,000	200,000	1,400,000
ET1	SOLAR CELL						7.44 ←						→	7.44
ET2	COVERPLATE	15.60		15.00		14.43		13.82		13.25		12.65		
ET3	REAR COVER	0.375		0.225		0.165		0.135		0.110		0.100		
ET4	SUBSTRATE SKIN	4.70		4.20		4.00		3.90		3.75		3.65		
ET5	SUBSTRATE CORE	3.60		2.40		2.00		1.80		1.65		1.50		
ET6	NEGATIVE BUS STRIP	0.90		0.87		0.83		0.80		0.77		0.72		
ET7	POSITIVE BUS STRIP	0.45		0.44		0.42		0.40		0.39		0.36		
ET8	POSITIVE BOSS		1.60		1.21		1.17		1.14		1.11		1.10	
ET9	INSULATOR	0.10		0.089		0.080		0.070		0.060		0.050		
ET10	POSITIVE TERMINAL NUT		0.30		0.23		0.17		0.11		0.06		0.05	
ET15	INTERCONNECTOR		0.15		0.12		0.08		0.06		0.03		0.03	

Table 3-8. Unit Cost of Raw Materials

Catalog Number	Description	Unit Cost (1980 $/kg)
ET 11	M6338 Silaprene	3.30
ET 12	Silglaze SCS 2402	6.60
ET 13	534-044	10.00

Table 3-9. Summary of SAMICS/SAMIS Price Estimate by Process (1980 $/peak-Watt)

No.	Process Referent	Industry Size (peak-kW/year)		
		10	100	1000
1	CELBOND	17.230	14.328	13.652
2	CUREBOND	0.559	0.339	0.122
3	BACKSOLDR	0.382	0.189	0.057
4	INPROCINS	0.486	0.217	0.102
5	BOSSSOLDR	0.591	0.315	0.246
6	LAMINATE	1.861	0.968	0.783
7	CLEANSEAL	0.198	0.065	----
8	FINALTEST	3.351	0.641	0.271
9	CRATE	0.168	0.032	0.150
	Total Price	24.82	17.09	15.38

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT C

INDUSTRY DESCRIPTION

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr / Pasadena, Calif 91103

C1 Industry Referent BLOCK IV

C2 Description (Optional) ______

INDUSTRY OBJECTIVE

C3 Industry Result Packaged Shingle Solar Cell Modules

C4 Quantity Produced 10,000 peak-watts/year

DESCRIPTION OF THE FINAL PRODUCT OF THE INDUSTRY

C5 Reference PSHINGLE Name Packaged Shingle Solar Cell Modules

C6 Production is Measured in Packaged Modules

C7 Hardware Performance 367.5 peak watts/package (C4 per C6)

C8 Product Design Description (Optional) ______

MAKERS OF THE FINAL PRODUCT OF THE INDUSTRY

C9 Company Reference ROOFPWR Market Share 100%

Company Reference ______ Market Share ______

Company Reference ______ Market Share ______

Prepared by ______ Date ______

Figure 3-34. SAMICS Format C for the 10 kW Annual Production Case

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT B — COMPANY DESCRIPTION

Page 1 of 1

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr., Pasadena, Calif. 91103

Company Referent: ROOFPWR

DESCRIPTIVE NAME: A COMPANY WHICH MANUFACTURES BLOCK IV SHINGLE SOLAR CELL MODULES

0.	(b)	(Final) Product(s) Produced	PSHINGLE	
	(a)	(Final) Process(es)	CRATE	
1.	(c)	Ideal Ratio(s) with units	0.04 CRATE/MODULE	
	(b)	Intermediate Product(s)	AMODULE	
	(a)	Process(es)	FINAL TEST	
2.	(c)	Ideal Ratio(s) with units	1.0 MODULE/MODULE	
	(b)	Intermediate Product(s)	CMODULE	
	(a)	Process(es)	CLEANSEAL	
3.	(c)	Ideal Ratio(s) with units	1.0 MODULE/MODULE	
	(b)	Intermediate Product(s)	EMODULE	
	(a)	Process(es)	LAMINATE	
4.	(c)	Ideal Ratio(s) with units		
	(b)	Intermediate Product(s)		
	(a)	Process(es)		
5.	(c)	Ideal Ratio(s) with units	1.0 MODULE/COVERPLATE	1.0 MODULE/BUS STRIP
	(b)	Intermediate Product(s)	CELSAGLAS	PLUSSTRIP
	(a)	Process(es)	INPROCINS	BOSSSOLDR
6.	(c)	Ideal Ratio(s) with units	1.0 COVERPLATE/COVERPLATE	
	(b)	Intermediate Product(s)	CELSWGLAS	
	(a)	Process(es)	BACKSOLDR	
7.	(c)	Ideal Ratio(s) with units	1.0 COVERPLATE/COVERPLATE	
	(b)	Intermediate Product(s)	GLASACELS	
	(a)	Process(es)	CUREBOND	
8.	(c)	Ideal Ratio(s) with units	1.0 COVERPLATE/COVERPLATE	
	(b)	Intermediate Product(s)	GLASWCELS	
	(a)	Process(es)	CELBOND	
9.	(c)	Ideal Ratio(s) with units		
	(b)	Intermediate Product(s)		
	(a)	Process(es)		
	(c)	Ideal Ratio(s) with units		
		Purchased Product(s)		
		Supplier and Percentage		
		Supplier and Percentage		

PREPARED BY | DATE

JPL 3038-5 R 11/79

Figure 3-35. SAMICS Format B for the 10 kW Annual Production Case

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

PROCESS DESCRIPTION

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr. / Pasadena, Calif. 91103

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMIS III computer program.

A1 Process [Referent] CELBOND

A2 [Descriptive Name] Bond nineteen solar cells to the glass cover-plate with GE 534-044 pottant

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] GLASWCELS

A4 Descriptive Name [Product Name] Nineteen solar cells bonded to glass cover-plate

A5 Unit Of Measure [Product Units] Coverplate

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 0.0667 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] 17 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] 0.98 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	BONDFIXT	POTDISP	
A9a	Component [Descriptive Name] (Optional)	Cell Bonding Fixture	Pottant Dispensing Equipment	
A10	Base Year For Equipment Prices [Price Year]	1980	1980	
A11	Purchase Price ($ Per Component) [Purchase Cost]	4000	2000	
A12	Anticipated Useful Life (Years) [Useful Life]	4	4	
A13	[Salvage Value] ($ Per Component)	200	200	
A14	[Removal and Installation Cost] ($/Component)	0	0	

Note: The SAMIS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 6.0), DDB, and SL.

(a) Process CELBOND (front)

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) CELBOND

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A20640	97	Sq. Ft.	Floor Space
330480	1.0	PRSN/Shift	Encapsulator (electronics)

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
ET13	0.00424	kg/min	GE534-044 Pottant
ET2	0.0667	units/min	Glass Coverplate
ET1	1.28	units/min	Solar Cell with integral inter-connector

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A28 [Yield]* (%)	A26 [Ideal Ratio]** Of Units Out/Units In	A27 Units Of A25***	A25 Product Name
			/	
			/	
			/	

Prepared by ________ Date ________

* 100% minus percentage of required product lost
** Assume 100% yield here.
*** Examples: Modules/Cell or Cells/Wafer.

REVERSE SIDE JPL 3037-8 R 10/78

(b) Process CELBOND (back)

Figure 3-36. SAMICS Format A Form for the 10 kW Annual Production Case

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr., Pasadena, Calif. 91103

PROCESS DESCRIPTION

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMIS III computer program

A1 Process [Referent] CUREBOND

A2 [Descriptive Name] Cure bond between cells and glass coverplate

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] GLASACELL

A4 Descriptive Name [Product Name]

A5 Unit Of Measure [Product Units] Coverplate

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 0.004167 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] [illegible] Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] [illegible] Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	BONDFIXT		
A9a	Component Descriptive Name] (Optional)	Cell Bonding Fixture		
A10	Base Year For Equipment Prices [Price Year]	1980		
A11	Purchase Price ($ Per Component) [Purchase Cost]	4000.		
A12	Anticipated Useful Life (Years) [Useful Life]	4		
A13	[Salvage Value] ($ Per Component)	[illegible]		
A14	[Removal and Installation Cost] ($/Component)	[illegible]		

Note: The SAMIS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 6.0), DDB, and SL.

JPL 3037-S R10/78

(c) Process CUREBOND (front)

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) CUREBOND

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) **OR PER MACHINE PER SHIFT** (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
300640	30	Sq. Ft.	Floor Space (Type 1)
[illegible]	0.05	Pers. Shift	Encapsulator (electronic)

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs and Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description

PART 6 – INTRA INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Referent]	A28 "Yield"* (%)	A26 [Ideal Ratio]** Of Units Out/Units In	A27 Units Of A25***	A25 Product Name
GLASWCELL	100	1.1	Cover-plates/Coverplate	

Prepared by ______ Date ______

* 100% minus percentage of required product lost.
** Assume 100% yield here
*** Examples: Modules/Cell or Cells/Wafer.

REVERSE SIDE JPL 3037-S R10/78

(d) Process CUREBOND (back)

Figure 3-36. SAMICS Format A Form for the 10 kW Annual Production Case (Cont)

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

PROCESS DESCRIPTION

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr. / Pasadena, Calif. 91103

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMIS III computer program.

A1 Process [Referent] BACKSOLDR

A2 [Descriptive Name] Solder P contacts of nineteen solar cells on glass coverplate

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] CELSWGLAS

A4 Descriptive Name [Product Name] Nineteen interconnected solar cells bonded to glass coverplate

A5 Unit Of Measure [Product Units] Coverplate

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 0.1 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] 12 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] 0.99 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	PSOLDR		
A9a	Component [Descriptive Name] (Optional)	Soldering Equipment		
A10	Base Year For Equipment Prices [Price Year]	1980		
A11	Purchase Price ($ Per Component) [Purchase Cost]	700		
A12	Anticipated Useful Life (Years) [Useful Life]	1		
A13	[Salvage Value] ($ Per Component)	200		
A14	[Removal and Installation Cost] ($/Component)	0		

Note: The SAMIS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 6.0), DDB, and SL.

JPL 3037-S R10/

(e) Process BACKSOLDR (front)

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) BACKSOLDR

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) **OR PER MACHINE PER SHIFT** (Personnel) [Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A2064D	32	Sq. Ft.	Floor Space (Type A)
B3080D	1.0	PPSN/Shift	Module Assembler

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE [Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
EG1701D	0.0010	kg/min	Solder
FT15	0.2	Units/min	Interconnector Strip

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A28 [Yield]* (%)	A26 [Ideal Ratio]** Of Units Out/Units In	A27 Units Of A26***	A25 Product Name
GLASACELS	99.9	1/1	Cover-plates / Cover-plate	Nineteen solar cells bonded to glass coverplate

Prepared by ______ Date ______

* 100% minus percentage of required product lost.
** Assume 100% yield here.
*** Examples: Modules/Cell or Cells/Wafer.

REVERSE SIDE JPL 3037-S R10/78

(f) Process BACKSOLDR (back)

Figure 3-36. SAMICS Format A Form for the 10 kW Annual Production Case (Cont)

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

PROCESS DESCRIPTION

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Drive, Pasadena, Calif. 91103

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMIS III computer program

A1 Process [Referent] INPROCINS

A2 [Descriptive Name] In-process inspection of assembly of nineteen solar cells on glass coverplate

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] CELSAGLAS

A4 Descriptive Name [Product Name] Nineteen interconnected solar cells bonded to glass coverplate

A5 Unit Of Measure [Product Units] Coverplate

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 0.0667 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] 16 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] 0.93 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9 Component [Referent] SCOPE

A9a Component Descriptive Name (Optional) Microscope

A10 Base Year For Equipment Prices [Price Year] 1980

A11 Purchase Price ($ Per Component) [Purchase Cost] 1500

A12 Anticipated Useful Life (Years) [Useful Life] 10

A13 [Salvage Value] ($ Per Component) 150

A14 [Removal and Installation Cost] ($/Component) 0

Note: The SAMIS III computer program also provides for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 6.0), DDB, and SL.

JPL 3037-S R10/78

(g) Process INPROCINS (front)

Format A Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) INPROCINS

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) **OR PER MACHINE PER SHIFT** (Personnel) [Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A20640	32	Sq. Ft.	Floor Space Type 2
[illegible]	1.0	Full Shift	System Inspector

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE [Byproduct Outputs, and Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Referance]	A28 [Yield]* %	A26 [Ideal Ratio]** Of Units Out/Units In	A27 Units Of A26***	A25 Product Name
CELSAGLAS	95	1.0	Cover-plates/Cover-plates	

Prepared by ______ Date ______

* 100% minus percentage of required product lost
** Assume 100% yield here
*** Examples: Modules/Cell or Cells/Wafer

REVERSE SIDE JPL 3037-S R10/78

(h) Process INPROCINS (back)

Figure 3-36. SAMICS Format A Form for the 10 kW Annual Production Case (Cont)

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

PROCESS DESCRIPTION

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr., Pasadena, Calif. 91103

Note. Names given in brackets [ ] are the names of process attributes requested by the SAMIS III computer program

A1 Process [Referent] BOSSSOLDR

A2 [Descriptive Name] Solder positive contact bosses onto positive conductor strip

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] PLUSSTRIP

A4 Descriptive Name [Product Name] Positive bus strip with copper bosses

A5 Unit Of Measure [Product Units] Strips

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 0.2 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] 5 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] 0.38 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	BOSSFIXT	RESIST	
A9a	Component [Descriptive Name] (Optional)	Boss Locating Fixture	Solder Equipment	
A10	Base Year For Equipment Prices [Price Year]	1980	1980	
A11	Purchase Price ($ Per Component) [Purchase Cost]	1000	700	
A12	Anticipated Useful Life (Years) [Useful Life]	4	4	
A13	[Salvage Value] ($ Per Component)	100	100	
A14	[Removal and Installation Cost] ($/Component)	0	0	

Note: The SAMIS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 6.0), DDB, and SL.

JPL 3037-S R10/78

(i) Process BOSSSOLDR (front)

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) BOSSSOLDR

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel) [Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A20640	32	Sq. Ft.	Floor Space (Type A)
B30800	1.0	PRSN/Shift	Module Assembler

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE [Byproduct Outputs] and Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Descriptor
ET8	0.40	Units/min	Positive boss
ET7	0.20	Units/min	Positive boss strip
FS17010	0.003	kg/min	Solder

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A28 [Yield]* (%)	A26 [Ideal Ratio]** Of Units Out/Units In	A27 Units Of A26***	A25 Product Name
			/	
			/	
			/	

Prepared by ______ Date ______

* 100% minus percentage of required product lost
** Assume 100% yield here
*** Examples: Modules/Cell or Cells/Wafer.

REVERSE SIDE JPL 3037-S R10/78

(j) Process BOSSSOLDR (back)

Figure 3-36. SAMICS Format A Form for the 10 kW Annual Production Case (Cont)

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

PROCESS DESCRIPTION

JET PROPULSION LABORATORY

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMIS III computer program.

A1 Process [Referent] LAMINATE

A2 [Descriptive Name] Laminate and encapsulate module

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] EMODULE

A4 Descriptive Name [Product Name] Laminated and encapsulated module

A5 Unit Of Measure [Product Units] Module

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 0.0667 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] [illegible] Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] [illegible] Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	LAMFIXT	SILIDISP	SILADISP
A9a	Component Descriptive Name] (Optional)	Laminating Fixture	Silicone Dispensing Equipment	Silaprene Dispensing Equipment
A10	Base Year For Equipment Prices [Price Year]	1980	1980	1980
A11	Purchase Price ($ Per Component) [Purchase Cost]	[illegible]	[illegible]	[illegible]
A12	Anticipated Useful Life (Years) [Useful Life]	4	4	[illegible]
A13	[Salvage Value] ($ Per Component)	200	[illegible]	[illegible]
A14	[Removal and Installation Cost] ($/Component)	0	0	0

Note: The SAMIS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 6.0), DDB, and SL.

JPL 3037-S R10/78

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) LAMINATE

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel) [Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
[illegible]	108	Sq. Ft.	Floor Space Type A
[illegible]	[illegible]	[illegible]/Shift	Module Assembler

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE [Byproduct Outputs, and Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
ET12	0.01193	kg/min	DC 2402
ET11	0.01707	kg/min	Silaprene #6338
ET8	0.06667	units/min	Foam Core
ET4	0.06667	units/min	Substrate skin
ET3	0.06667	units/min	Rear Cover
ET9	0.06667	units/min	Kapton Insulator
ET6	0.06667	units/min	Negative Conductor

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A28 [Yield]* (%)	A26 [Ideal Ratio]** Of Units Out/Units In	A27 Units Of A26***	A25 Product Name
[illegible]	[illegible]	[illegible]	modules/coverplate	
[illegible]	[illegible]	[illegible]	modules/[illegible]	

Prepared by ______ Date ______

* 100% minus percentage of required product lost

** Assume 100% yield here

*** Examples: Modules/Cell or Cells/Wafer.

REVERSE SIDE JPL 3037-S R10/78

(k) Process LAMINATE (front)

(l) Process LAMINATE (back)

Figure 3-36. SAMICS Format A Form for the 10 kW Annual Production Case (Cont)

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SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

PROCESS DESCRIPTION

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr. / Pasadena, Calif. 91103

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMIS III computer program

A1 Process [Referent] CLEANSEAL

A2 [Descriptive Name] Clean, seal and install positive terminal nut on completed module.

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] EMODULE

A4 Descriptive Name [Product Name] Completed module

A5 Unit Of Measure [Product Units] module

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 0.25 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] 5 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] 0.98 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9 Component [Referent]

A9a Component [Descriptive Name] (Optional)

A10 Base Year For Equipment Prices [Price Year]

A11 Purchase Price ($ Per Component) [Purchase Cost]

A12 Anticipated Useful Life (Years) [Useful Life]

A13 [Salvage Value] ($ Per Component)

A14 [Removal and Installation Cost] ($/Component)

Note: The SAMIS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 6.0), DDB, and SL.

JPL 3837-S R 10/78

(m) Process CLEANSEAL (front)

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) CLEANSEAL

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel) [Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A2064D	22	Sq. Ft.	Floor Space (Type A)
B3080D	1.0	PPSN/Shift	Module Assembler

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE [Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
ET12	0.0005	kg/min	SCS 2402
ET10	0.5	units/min	Positive Terminal Nut

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A28 [Yield]* (%)	A26 [Ideal Ratio]** Of Units Out/Units In	A27 Units Of A26***	A25 Product Name
EMODULE	100	1/1	Modules /Module	

Prepared by ______ Date ______

* 100% minus percentage of required product lost
** Assume 100% yield here
*** Examples: Modules/Cell or Cells/Wafer.

REVERSE SIDE JPL 3837-S R 10/78

(n) Process CLEANSEAL (back)

Figure 3-36. SAMICS Format A Form for the 10 kW Annual Production Case (Cont)

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

PROCESS DESCRIPTION

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Drive, Pasadena, Calif. 91103

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMIS III computer program.

A1 Process [Referent] FINALTEST

A2 [Descriptive Name] Final inspection and illumination test of completed module

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] SMODULE

A4 Descriptive Name [Product Name] Accepted module

A5 Unit Of Measure [Product Units] Module

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) [illegible] Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] [illegible] Calendar Minutes (Used only to compute in process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] [illegible] Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	[illegible]	[illegible]	
A9a	Component Descriptive Name (Optional)	Module illuminator	Module illuminator fixture	
A10	Base Year For Equipment Prices [Price Year]	[illegible]	[illegible]	
A11	Purchase Price ($ Per Component) [Purchase Cost]	[illegible]	[illegible]	
A12	Anticipated Useful Life (Years) [Useful Life]	[illegible]	[illegible]	
A13	[Salvage Value] ($ Per Component)	[illegible]	500	
A14	[Removal and Installation Cost] ($/Component)	[illegible]	[illegible]	

Note: The SAMIS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 6.0), DDB, and SL.

JPL 3837-S R 12/78

Format A Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) FINALTEST

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel) [Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
[illegible]	[illegible]	Sq. Ft.	Floor Space, Type A
[illegible]	[illegible]	[illegible]	System Technician

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE [Byproduct Outputs, and Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
[illegible]328	[illegible]	kWh-min	Electricity

PART 6 – INTRA INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A28 [Yield]* (%)	A26 [Ideal Ratio]** Of Units Out/Units In	A27 Units Of A26***	A25 Product Name
SMODULE	99.5	[illegible]	Modules/Module	Modules

Prepared by ______ Date ______

* 100% minus percentage of required product lost
** Assume 100% yield here
*** Examples: Modules/Cell or Cells/Wafer

REVERSE SIDE JPL 3837-S R 10/78

(o) Process FINALTEST (front)

(p) Process FINALTEST (back)

Figure 3-36. SAMICS Format A Form for the 10 kW Annual Production Case (Cont)

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

PROCESS DESCRIPTION

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr / Pasadena, Calif 91103

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMIS III computer program.

A1 Process [Referent] CRATE

A2 [Descriptive Name] Crate modules

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] PSHINGLE

A4 Descriptive Name [Product Name] Packaged shingle solar cell modules

A5 Unit Of Measure [Product Units] Packaged Modules

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 0.1 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] 12 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] 1.00 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9 Component [Referent]

A9a Component [Descriptive Name] (Optional)

A10 Base Year For Equipment Prices [Price Year]

A11 Purchase Price ($ Per Component) [Purchase Cost]

A12 Anticipated Useful Life (Years) [Useful Life]

A13 [Salvage Value] ($ Per Component)

A14 [Removal and Installation Cost] ($/Component)

Note: The SAMIS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 6.0), DDB, and SL.

JPL 3837-S R 10/78

(q) Process CRATE (front)

Format A Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) CRATE

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel) [Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A20640	32	Sq. Ft.	Floor Space (Type A)
B36400	1.0	PPSN/Shift	Packager

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE [Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
E11800	0.90	Cu. Ft/min	Crates, wooden

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A28 [Yield]* (%)	A26 [Ideal Ratio]** Of Units Out/Units In	A27 Units Of A26***	A25 Product Name
AMODULE	100	1/25	Crate/Module	Crated modules

Prepared by ________ Date ________

* 100% minus percentage of required product lost.
** Assume 100% yield here
*** Examples: Modules/Cell or Cells/Wafer.

REVERSE SIDE JPL 3837-S R 10/78

(r) Process CRATE (back)

Figure 3-36. SAMICS Format A Form for the 10 kW Annual Production Case (Cont)

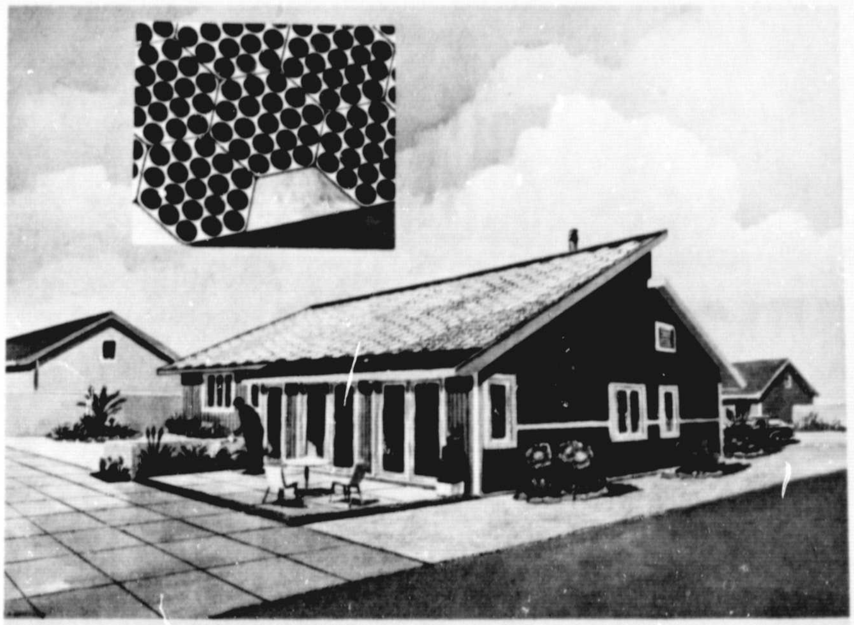
SECTION 4

CONCLUSIONS

SECTION 4
CONCLUSIONS

The shingle module developed under this contract offers many advantages for applications which require the mounting of photovoltaic modules on the sloping roofs of new or existing residential buildings since no changes in conventional roof construction are imposed by the photovoltaic installation and no ancillary module interconnecting wiring or connectors are required. Since the shingle module installation functions as a weathertight roof covering, the use of a conventional roofing surface under the photovoltaic modules can be eliminated, thereby affecting additional savings in installation costs.

A residential application of these shingle modules should be aesthetically acceptable as shown in Figure 4-1 which is an artist's rendering of a typical installation.



- 475 SHINGLE MODULES
- SUPPLIES 19.8 MWh OF ANNUAL SOLAR ARRAY OUTPUT IN PHOENIX

Figure 4-1. Typical Shingle Module Installation on a Residence

The "third-generation" modules developed under this contract have satisfactorily survived the JPL-defined qualification testing program.

The price of these modules, as predicted by the SAMICS/SAMIS methodology, ranges from \$24.82 to \$15.38 per peak watt (1980 dollars) as the annual production rate is increased from 10 to 1,000 kW.

SECTION 5

RECOMMENDATIONS

SECTION 5
RECOMMENDATIONS

The installation of a representative sample of these modules on a prototype residence seems appropriate as the next step in the development of this module concept. Such an experimental installation is the only practical way to address certain basic concerns such as:

1. Ease of installation and module-to-module electrical interconnection
2. Electrical safety issues
3. Ease of module replacement
4. Methods for detection of failed modules
5. Aesthetic acceptance
6. Long-term performance as a watertight roofing surface

APPENDIX A

MODULE DRAWINGS

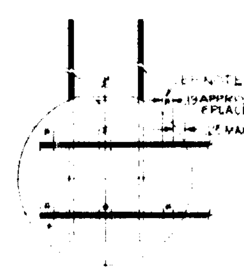
12 11 10

D

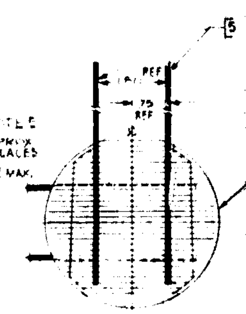
C

B

A



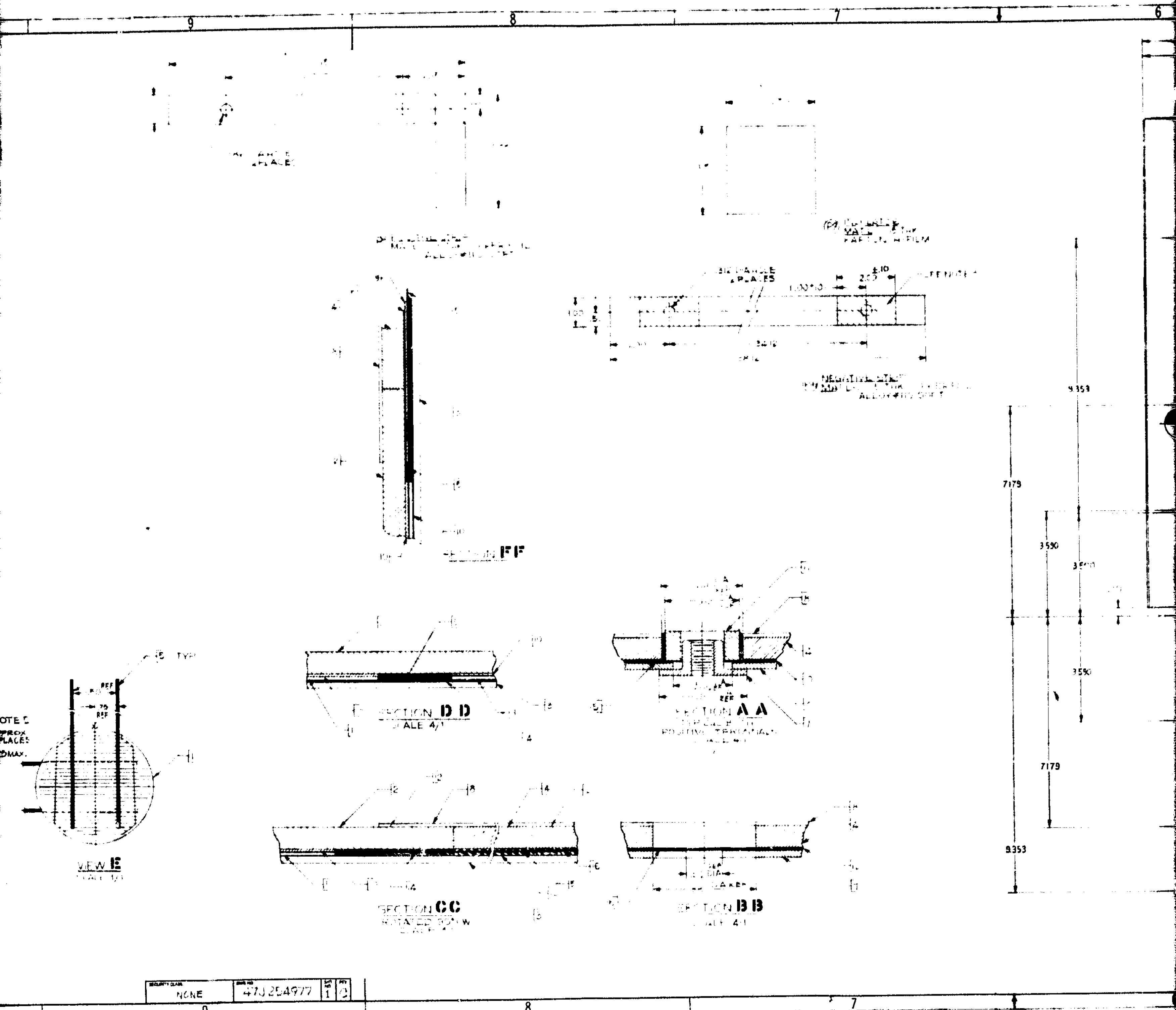
VIEW E



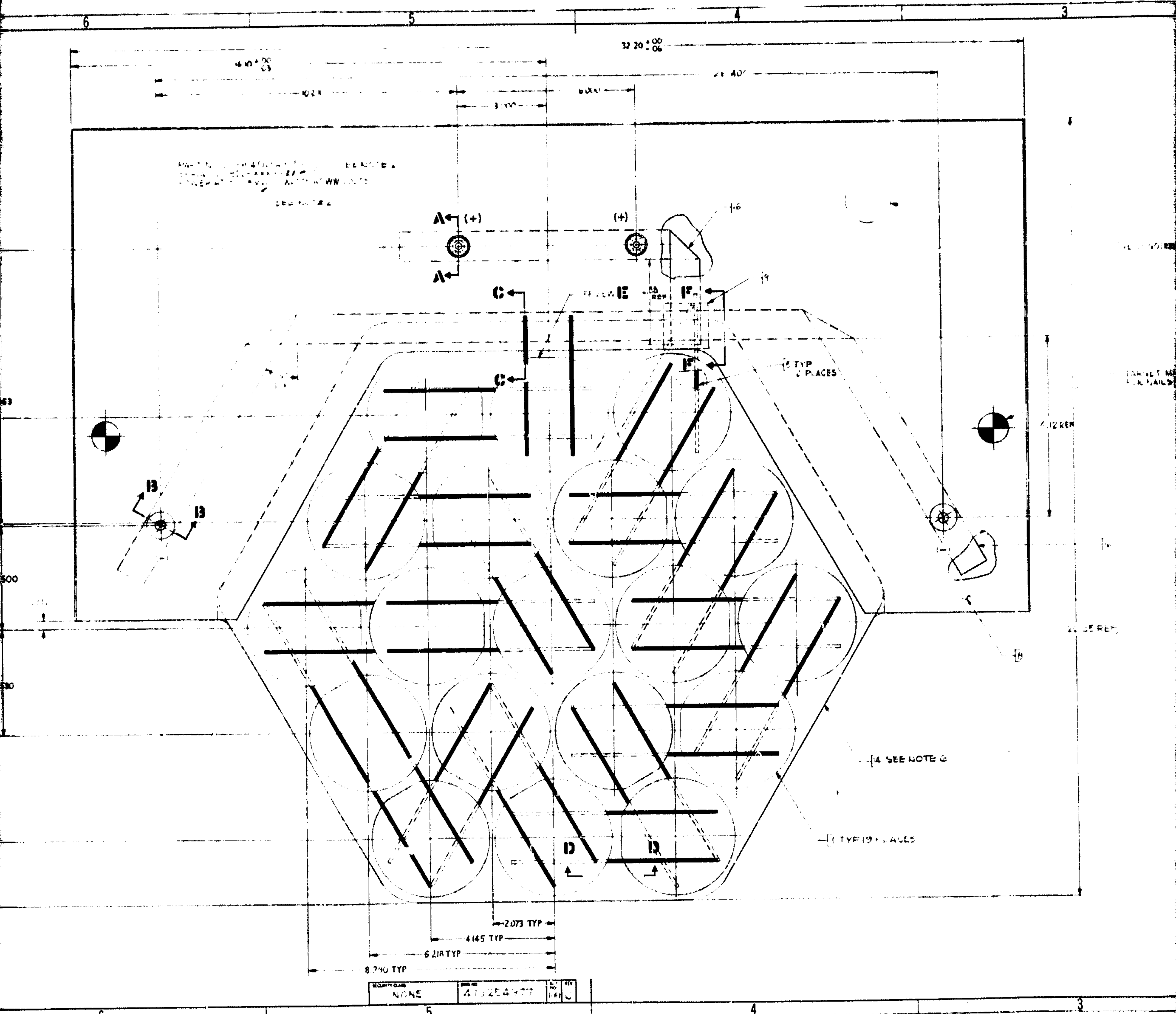
VIEW E

12 11 10

FOLDOUT FRAME



FOLDOUT FRAME 2



3

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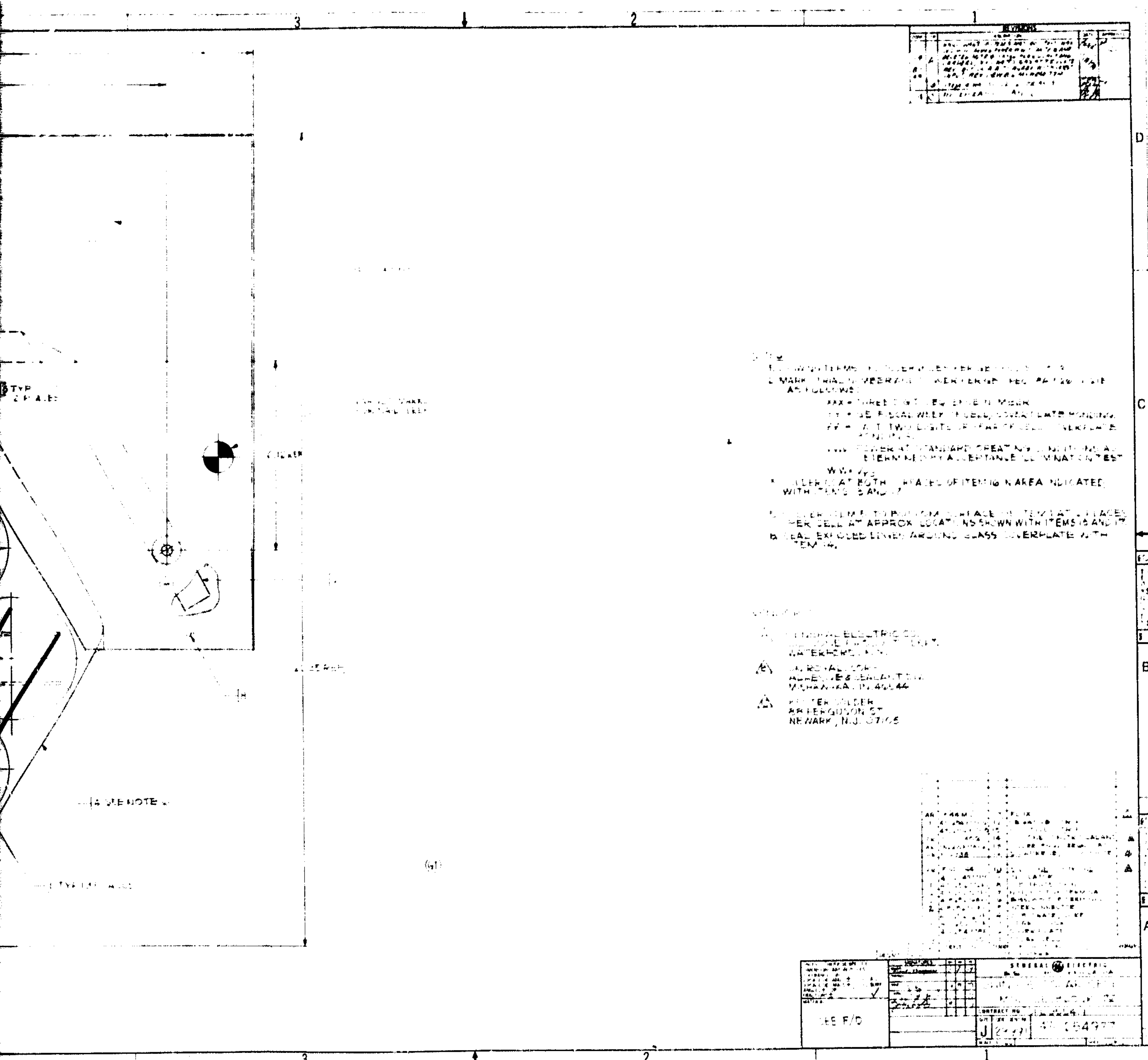
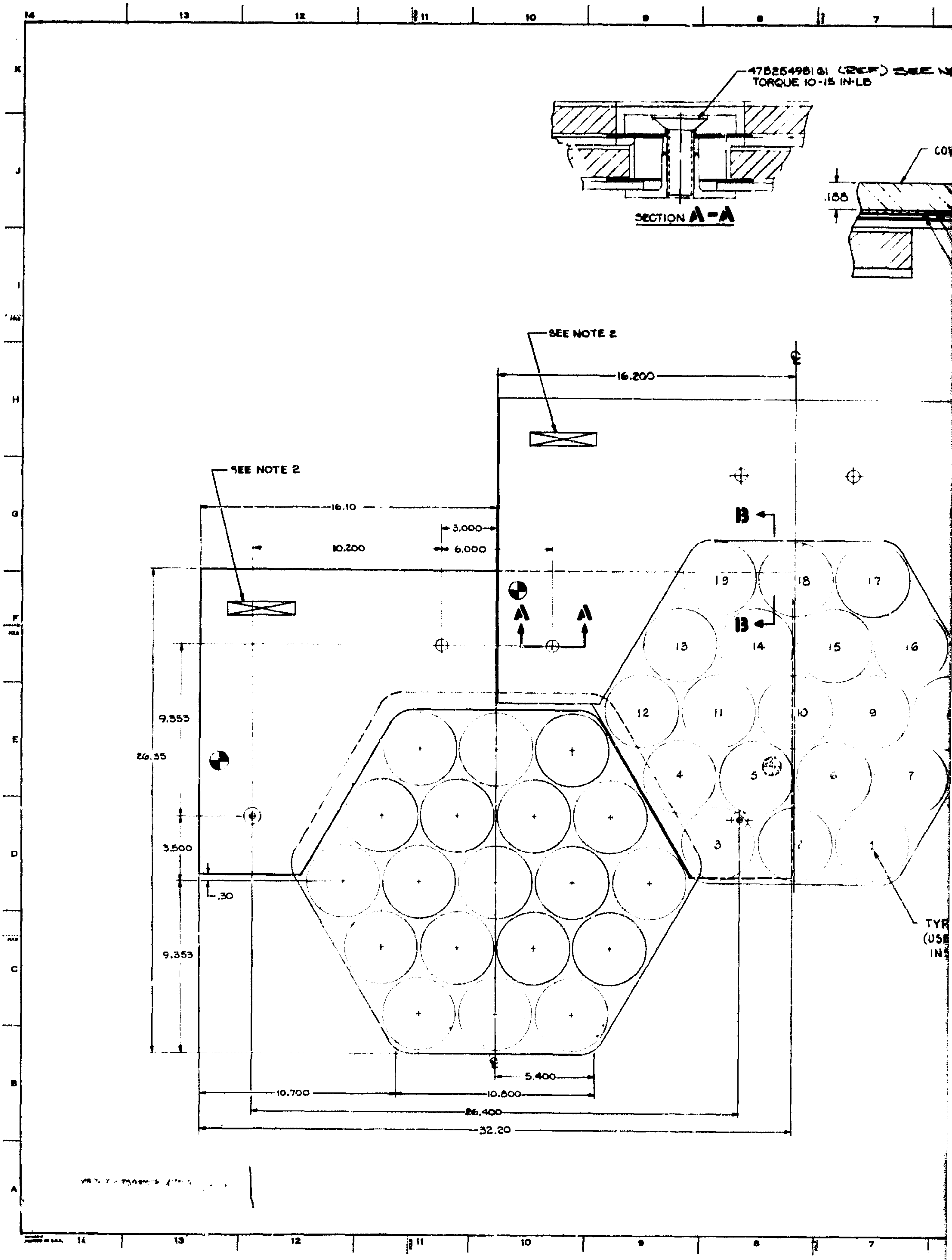

WITH ITEMS 15 AND 17
PER CELL AT APPROX. LOCATIONS SHOWN WITH ITEMS 15 AND 17
NEWARK, N.J. 07105
SEE F/D
GENERAL ELECTRIC

4



47825498161 (REF) SEE N
TORQUE 10-15 IN-LB
SECTION A-A
.188
SEE NOTE 2
16.200
SEE NOTE 2
16.10
3.000
10.200
6.000
B
B
A
A
9.353
26.35
3.500
.30
9.353
5.400
10.700
10.800
26.400
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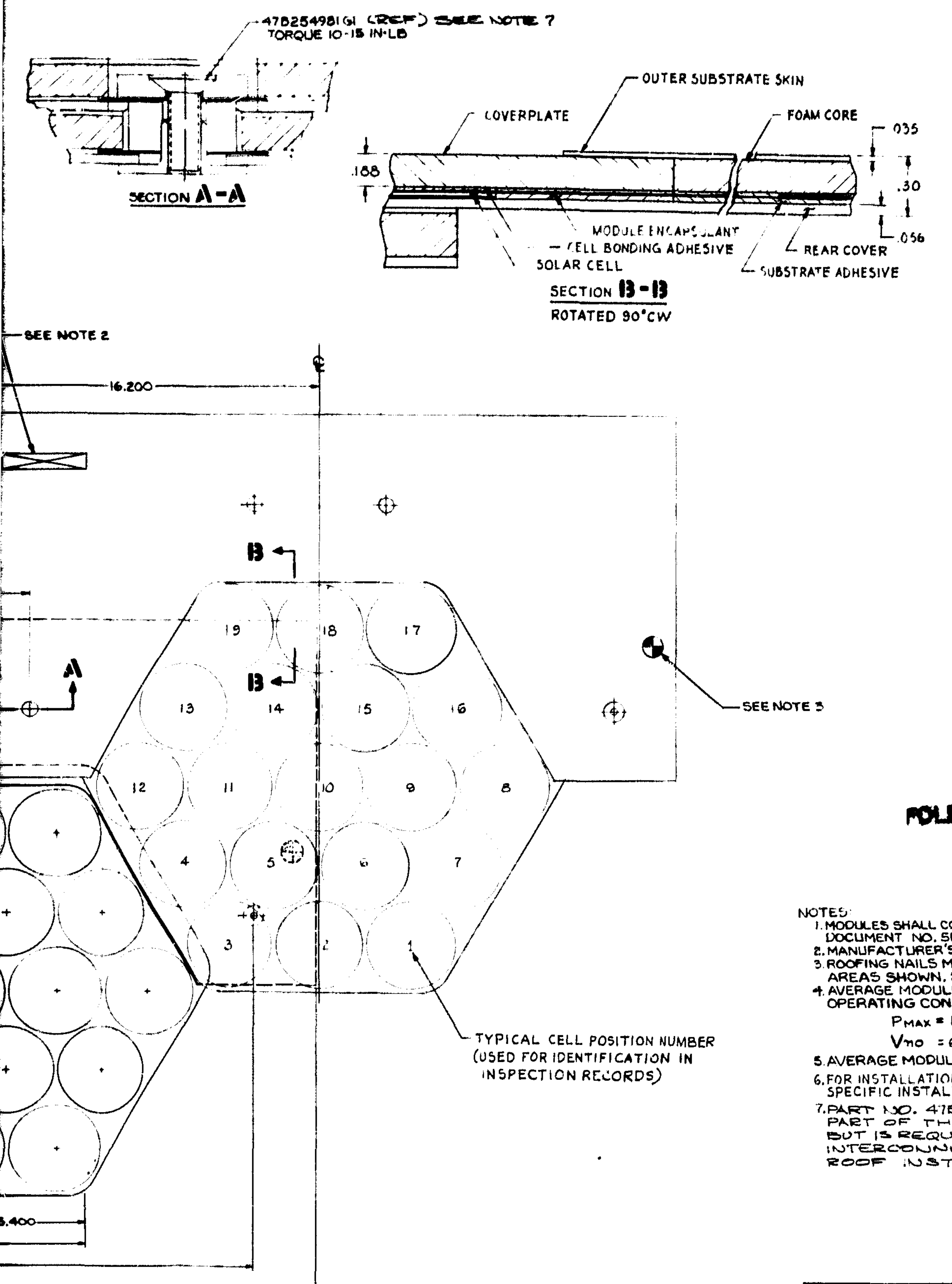

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FOLDOUT FRAME 2

NOTES:
1. MODULES SHALL CONFORM TO THE REQUIREMENTS OF JPL DOCUMENT NO. 5101-83.
2. MANUFACTURER'S PART NO. & SERIAL NO. IN AREA INDICATED.
3. ROOFING NAILS MUST BE WITHIN OUTLINE OF TARGET AREAS SHOWN. 2 PER MODULE.
4. AVERAGE MODULE ELECTRICAL PERFORMANCE AT STANDARD OPERATING CONDITIONS.

P_{MAX} = 14.7 WATTS

V_{no} = 6.6 VOLTS

5. AVERAGE MODULE WEIGHT = 3.9 kg.
6. FOR INSTALLATION DETAILS REFER TO APPLICABLE SITE-SPECIFIC INSTALLATION DRAWINGS
7. PART NO. 47B254981G1 IS NOT INCLUDED AS PART OF THE BLOCK IV SHINGLE MODULE BUT IS REQUIRED TO ELECTRICALLY INTERCONNECT ADJACENT MODULES IN A ROOF INSTALLATION.

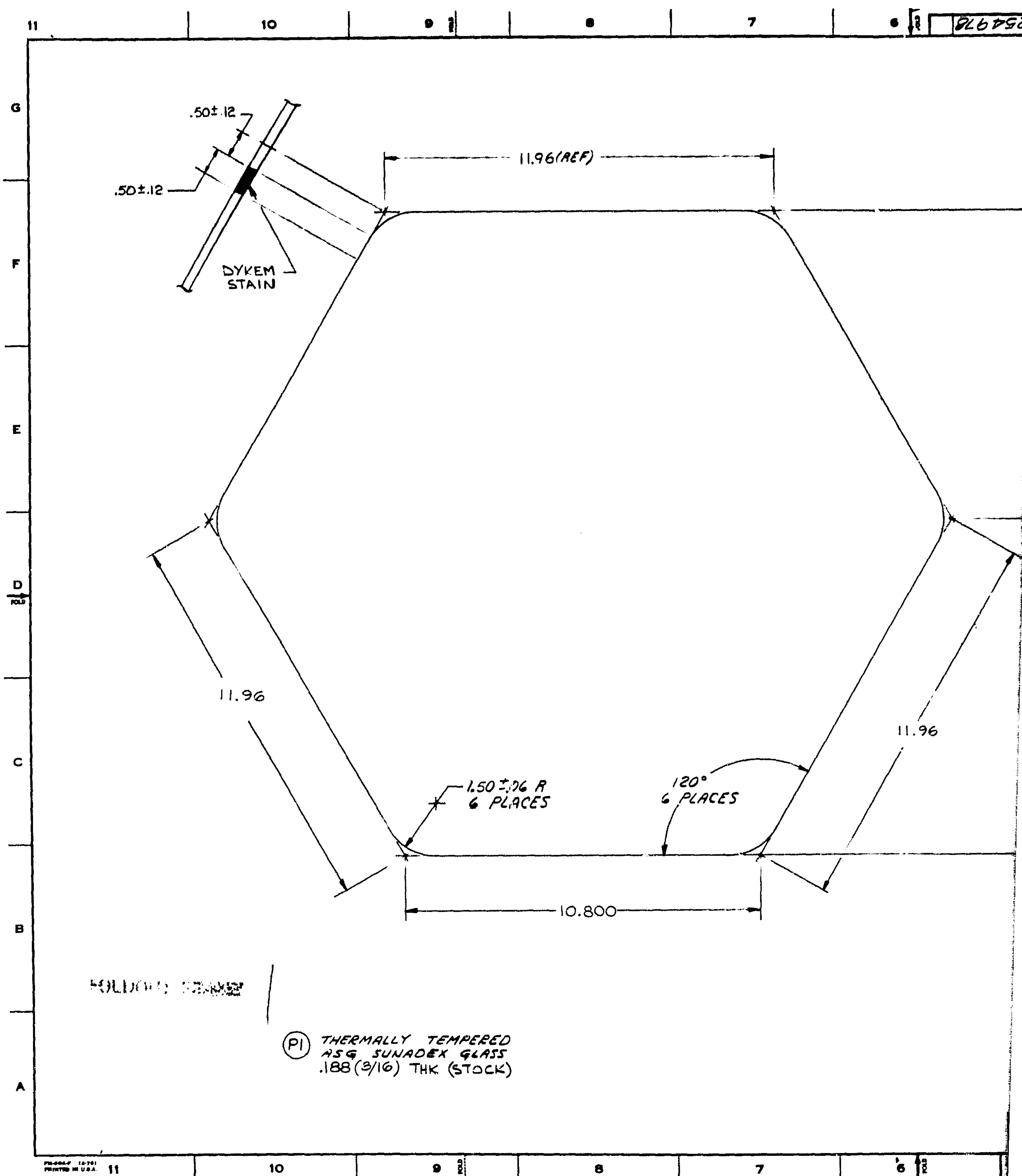
GENERAL ELECTRIC
SPACE SYSTEMS PHILA PA

INTERFACE CONTROL DWG,
BLOCK IV SHINGLE MODULE

JPL 955401

SIZE	CODE IDENT NO	DWG NO
E	23991	47F254979

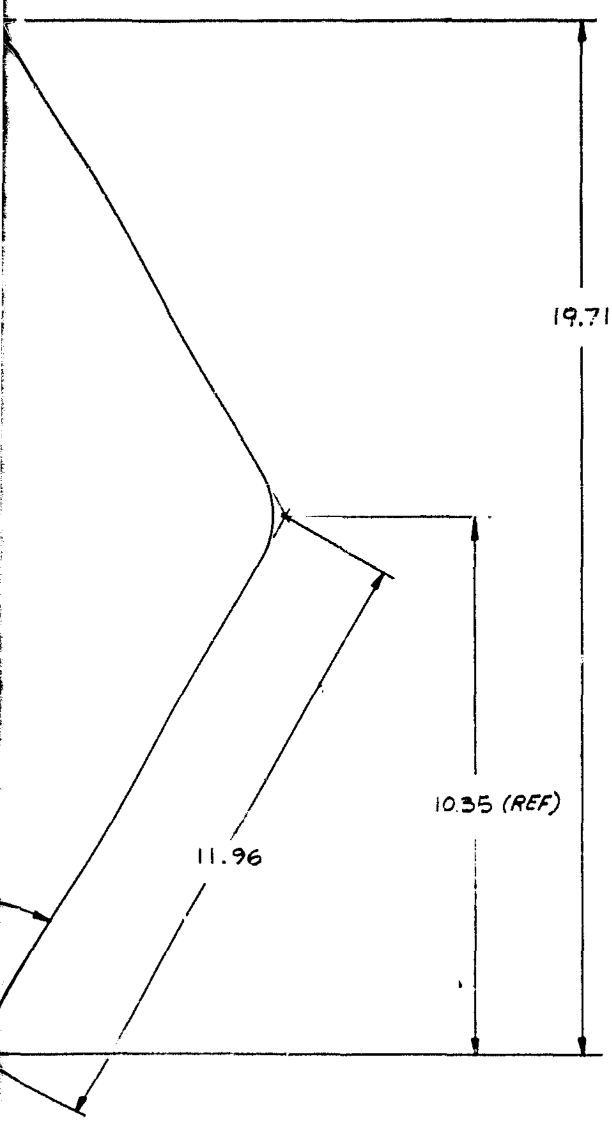
SCALE NONE SHEET 1 OF 1


.50±.12
.50±.12
DYKEM STAIN
11.96(REF)
11.96
11.96
1.50±.06 R
6 PLACES
120°
6 PLACES
10.800
(P1) THERMALLY TEMPERED
ASG SUNADEX GLASS
.188(3/16) THK (STOCK)

47D254978

REVISIONS

ZONE	LTR	DESCRIPTION	DATE	APPROVED



NOTES:

1- DRAWING TERMS AND TOLERANCES PER S30009.

2- THE MEAN MODULUS OF RUPTURE IN BENDING SHALL EXCEED 20,000 PSI WHEN TESTED IN ACCORDANCE WITH METHOD "A" OF ASTM C158-72 "FLEXURE TESTING OF GLASS".

2

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES— TOLERANCES ON: 2-PLACE DECIMALS ±.06 3-PLACE DECIMALS ±.020 ANGLES ± 0° 30' FRACTIONS ± ALL SURF. ✓

MATERIAL— SEE F/D

SIGNATURES	DAY	MO	YR
DRAWN	24	7	79
CHECKED			
ISSUED	6	8	79
ENGRG	9	8	79
	9	8	79

GENERAL ELECTRIC

SS DEPT LOC. PHILA PA

COVER PLATE, SHINGLE SOLAR CELL MODULE

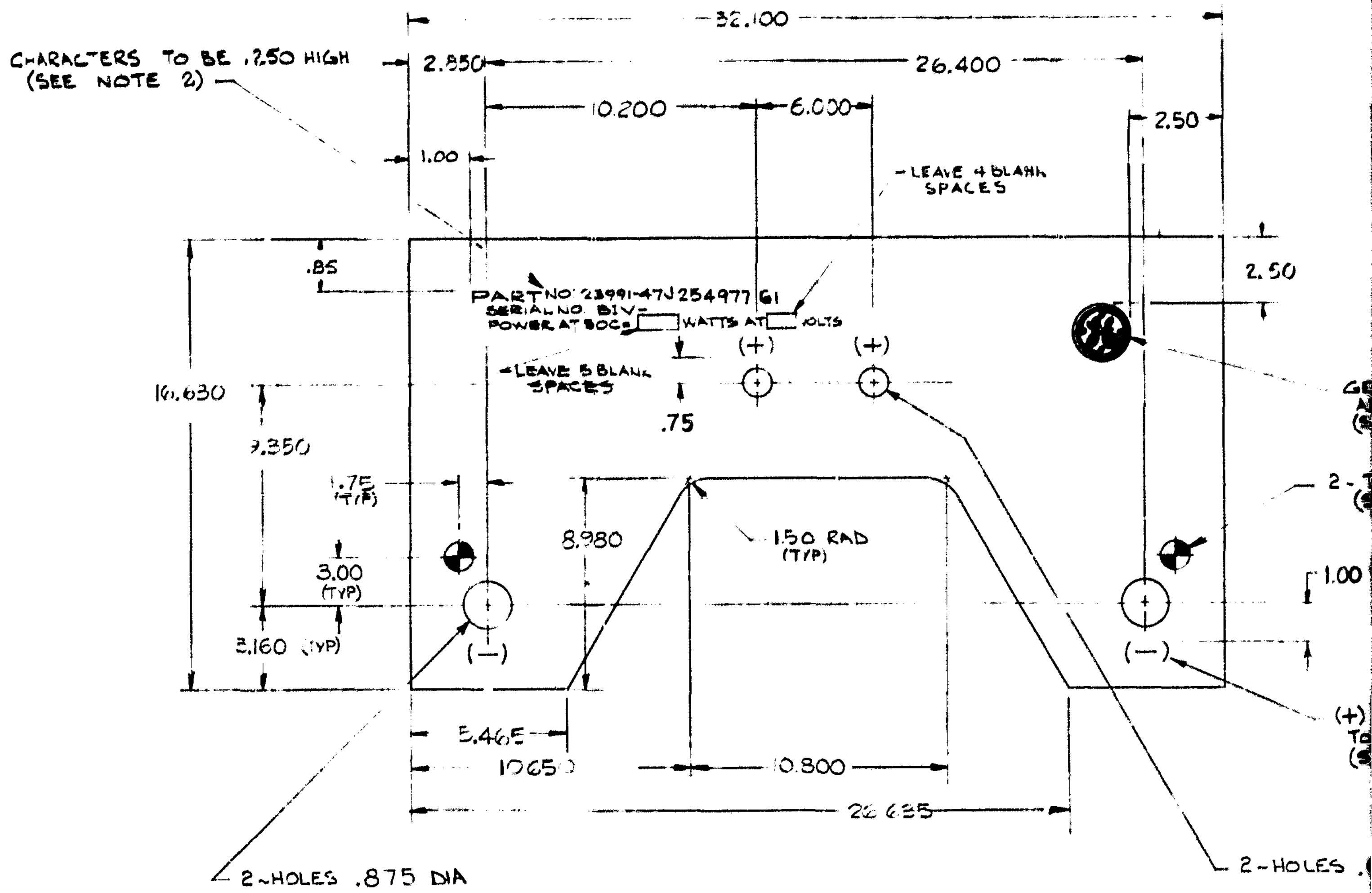
CONTRACT NO JPL 955401

SIZE	CODE IDENT NO.	
D	23991	47D254978

SCALE NONE SHEET 1 OF 1

P1	Later	SHINGLE MOD
SUFFIX	NEXT ASSY	USED ON
	APPLICATION	

D 47D254978

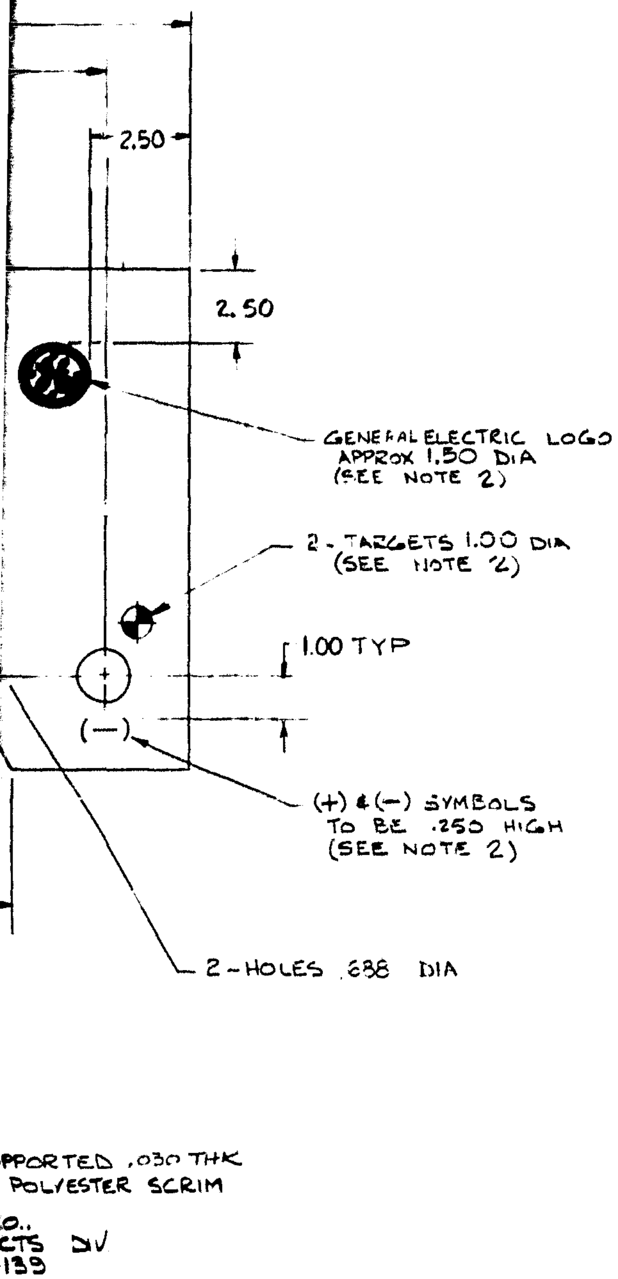


(P1) MATL: FLEXSEAL WHITE SUPPORTED .030 THK
HYPALON WITH 6X6 POLYESTER SCRIM

VENDOR: B.F. GOODRICH CO.
GENERAL PRODUCTS DIV
SOLON, OH. 44139

FOLDOUT FRAME

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED
F6	A	7.5 VOLTS WAS 7.3 VOLTS	[illegible]	[illegible]
F6	B	ADDED LOCATION DIM FOR LOGO	[illegible]	[illegible]

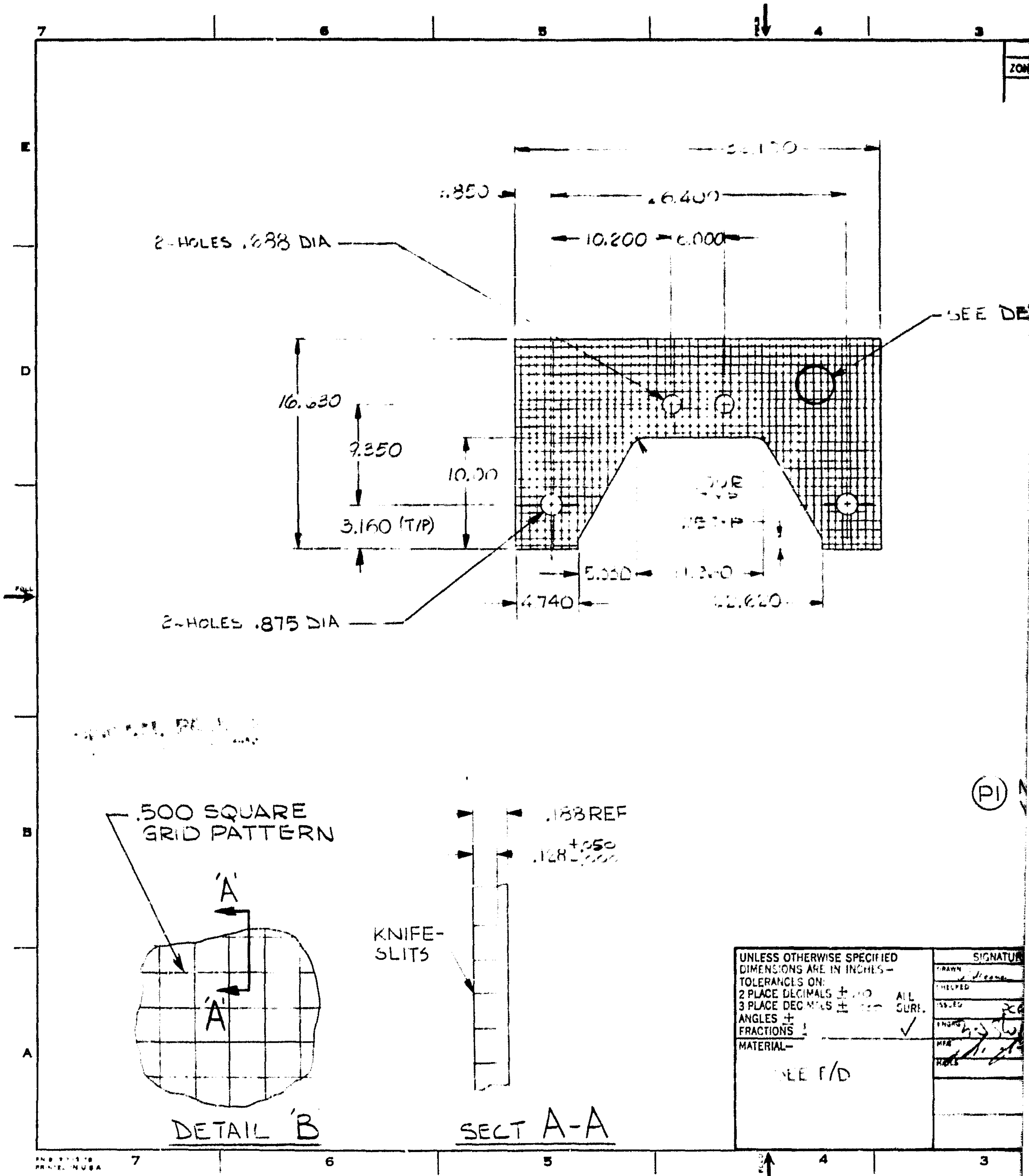


NOTES :-

1. DWG TERMS & TOL PER GE SPEC S30009
2. MARKINGS PER G.E. SPEC. 118A1526 CL 21E.

FOLDOUT FRAME 2

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES— TOLERANCES ON: 2 PLACE DECIMALS ±.10 3 PLACE DECIMALS ±.030 ANGLES ± FRACTIONS ± ALL SURF. ✓	SIGNATURES	GENERAL ELECTRIC SS DEPT LOC. PHILA, PA
MATERIAL— SEE F/D		SUBSTRATE SKIN SOLAR CELL MODULE
		CONTRACT No. JPL 955401
		SIZE D CODE IDENT NO. [illegible] 47D252772
		SCALE NONE SHEET 1 OF 1

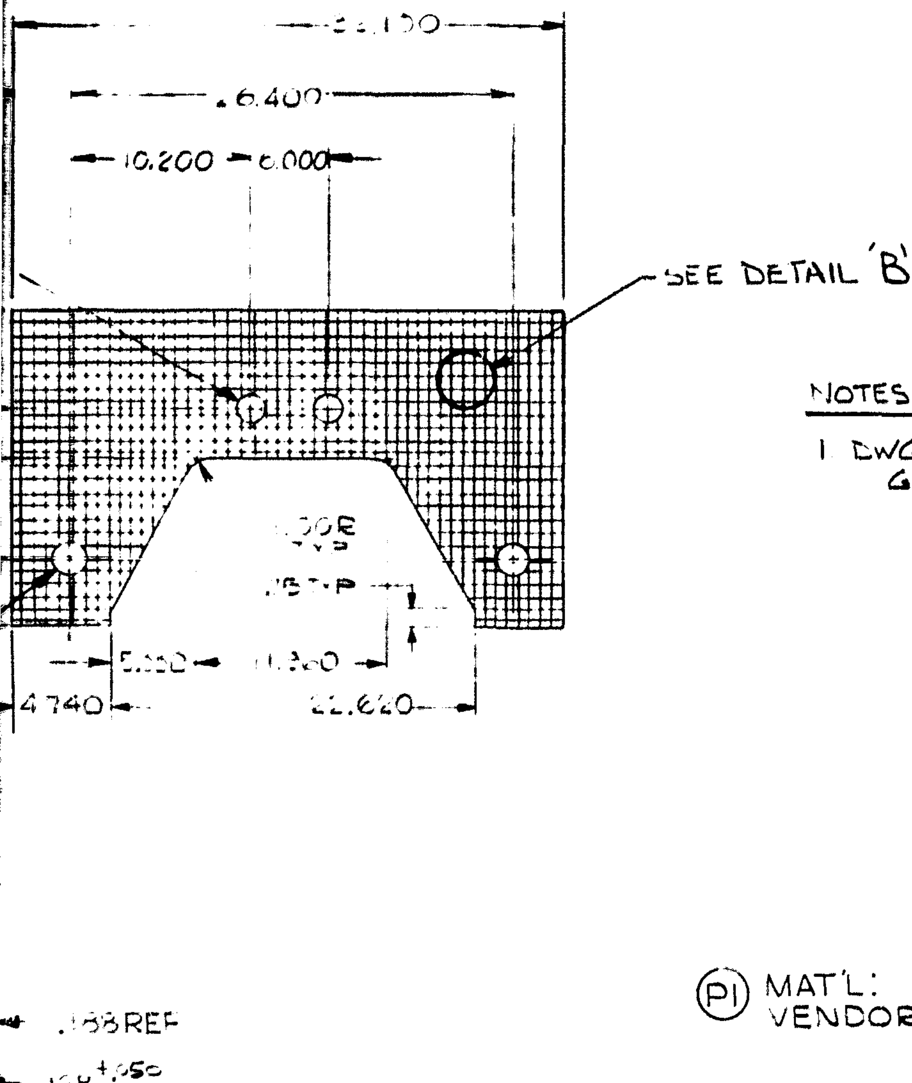


2-HOLES .688 DIA
.850
16.400
10.200
6.000
SEE DE
16.630
9.350
10.00
3.160 (TYP)
5.550
4.740
2-HOLES .875 DIA
.500 SQUARE GRID PATTERN
'A'
'A'
DETAIL 'B'
.188 REF
KNIFE-SLITS
SECT A-A
(P1)
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES –
TOLERANCES ON:
2 PLACE DECIMALS ±
3 PLACE DECIMALS ±
ANGLES ±
FRACTIONS ±
ALL SURF.
MATERIAL–
SEE F/D
SIGNATURE
DRAWN
CHECKED
ISSUED
ENGRG
MFG

C | 47C252769

REVISIONS

ZONE	LTR	DESCRIPTION	DATE	APPROVED



NOTES.-

1. DWG. TERMS & TOL. PER GE SPEC S30009

(P1) MAT'L: L-200 MINICEL .188THK.
VENDOR: RODGER FOAM CORP
SOMERVILLE, MA 02145

T A-A

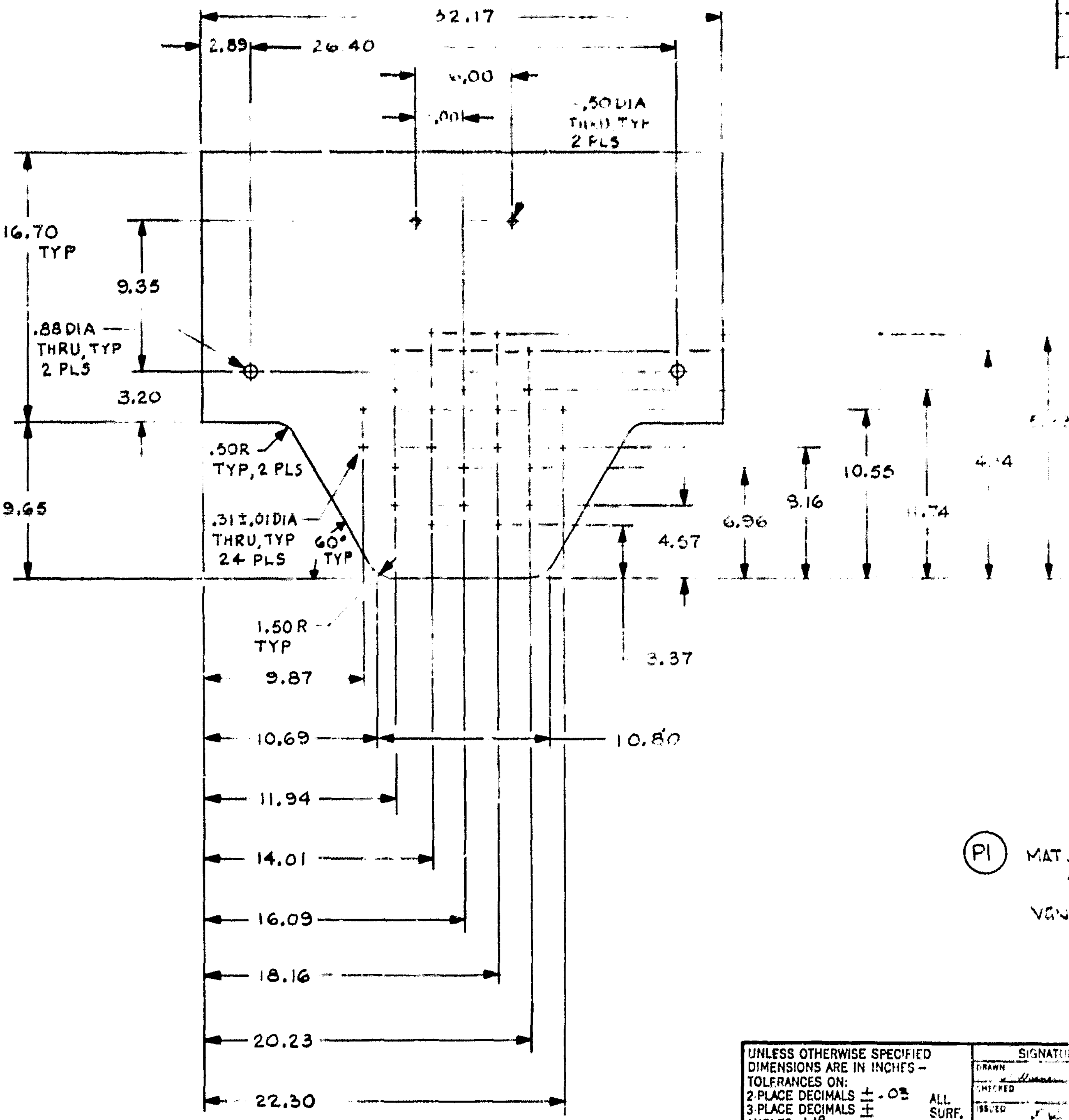
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES— TOLERANCES ON:	SIGNATURES	DAY	MO	YR
2 PLACE DECIMALS ± .10	DRAWN			
3 PLACE DECIMALS ± .030 ALL SURF. ✓	CHECKED			
ANGLES ±	ISSUED			
FRACTIONS ±	ENGRG	7	8	79
MATERIAL— SEE F/D	MFG	9	8	79

GENERAL ELECTRIC
SS DEPT LOC. PHILA.PA.

SUBSTRATE CORE
SOLAR CELL MODULE

CONTRACT No. JPL 955401

SIZE	CODE IDENT NO.	
C	23991	47C252769
SCALE NONE		SHEET 1 OF 1



(P1) MAT'L: PAN-L-
GRADE .O
VENDOR: ME
LY

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES –
TOLERANCES ON:
2-PLACE DECIMALS ± .03
3-PLACE DECIMALS ±
ANGLES ±1°
FRACTIONS ±
ALL SURF. ✓

MATERIAL–
SEE F/D

SIGNATURES
DRAWN
CHECKED
ISSUED
ENGRG
MFG
MA

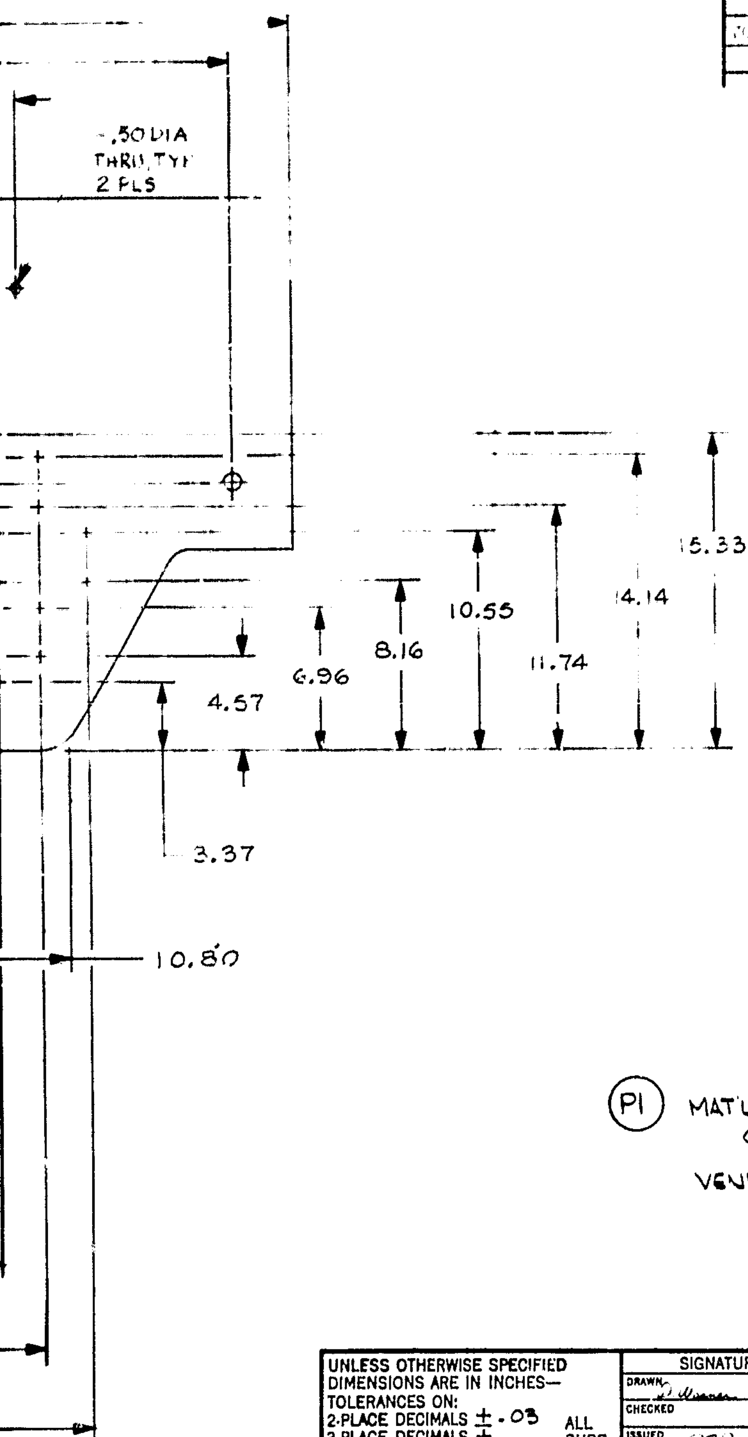
A REDR

FN 805-P13-781
PRINTED IN U.S.A.

C 47C252770 REV A

REVISIONS

ZONE	LTR	DESCRIPTION	DATE	APPROVED
	A	REDRAWN IN ENTIRETY PER AN-1		



NOTES:
1. DRAWING TERMS & TOLERANCES PER GE SPEC 530009

(P1) MAT'L: PAN-L-BOARD DIELECTRIC GRADE, .056 THK.

VENDOR: MEAD PAPERBOARD PRODUCTS INC LYNCHBURG, VA.

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES— TOLERANCES ON:	SIGNATURES	DAY	MO	YR
2-PLACE DECIMALS ± .03	DRAWN	13	7	79
3-PLACE DECIMALS ±	CHECKED			
ANGLES ±1°	ISSUED	10	8	79
FRACTIONS ±	ENGRG	9	8	79
ALL SURF.	MFG	9	8	79
MATERIAL— SEE F/D	MATL			

GENERAL ELECTRIC

SS DEPT LOC. PHILA PA

REAR COVER, SHINGLE SOLAR CELL MODULE

CONTRACT NO. JPL 955401

SIZE	CODE IDENT NO.	
C	23991	47C252770

SCALE: 1/20=1" SHEET 1 OF 1

REV A 47C252770 C

3169-7

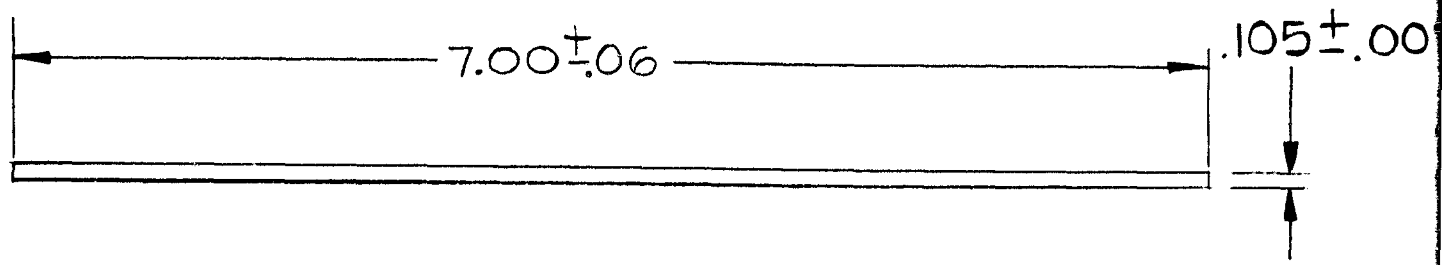
DIST TO

C-2

4

D

C



B

P1 MAT'L .002 THICK COP
FOIL, ALLOY

UNLESS OTHE
DIMENSIONS
TOLERANCES
FRACTIONS
±
ALL SURFAC
MATL-
SEE

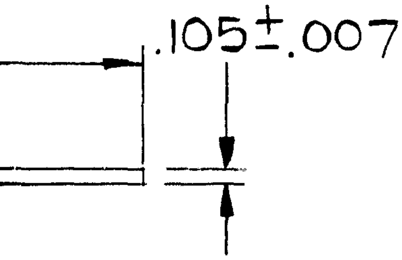
FOLDOUT FRAME

5 4 3

SIZE		SHEET	REV
B	47B252771	1	A

REVISIONS

ZONE	LTR	DESCRIPTION	DATE	APPROVED
	A	CHG PER AN-1 CHANGED NOTE 2 & 3	1/18/80	[illegible]



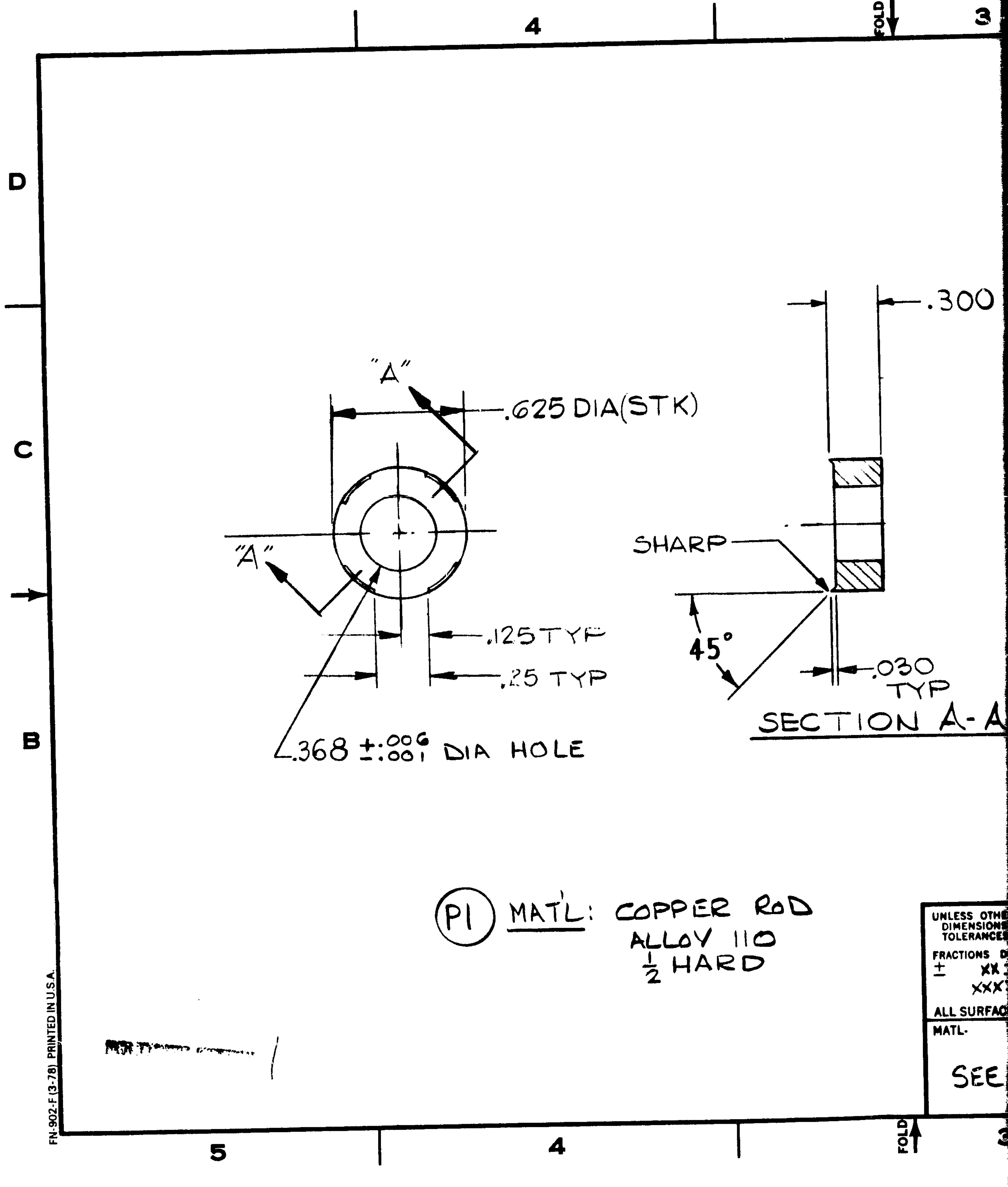
NOTES

1. DWG TERMS AND TOLERANCES PER G.E. SPEC S30009.
2. TIN PLATE PER ASTM STD B545-72 CLASSIFICATION NO. Cu/Sn 5.
3. BURRS GREATER THAN .001 ARE UNACCEPTABLE

.002 THICK COPPER FOIL, ALLOY NO 110 (SOFT)

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES. TOLERANCES ON:	SIGNATURES	DAY	MO	YR	
FRACTIONS ± ~ DECIMALS ± AS NOTED ANGLES ± ~	DRAWN D. Weaver	10	7	79	GENERAL ELECTRIC SS DEPT LOC PHILA PA
ALL SURFACES ✓	CHECKED				INTERCONNECTOR CELL TO CELL
MATL- SEE F/D	ISSUED	16	8	79	CONTRACT NO. JPL 955401
	ENGRG	9	8	79	SIZE B; CODE IDENT NO. 23991; 47B252771
	MFG	9	8	79	SCALE 5/1; SHEET 1 OF FIN

A-13/14

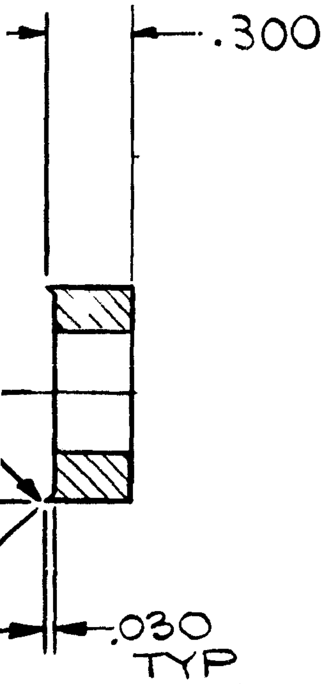


4
FOLD
3
D
C
B
5
4
FOLD
.300
"A"
.625 DIA(STK)
"A"
SHARP
.125 TYP
.25 TYP
45°
.030
TYP
SECTION A-A
.368 ±.006 / -.001 DIA HOLE
P1 MAT'L: COPPER ROD
ALLOY 110
1/2 HARD
UNLESS OTHE
DIMENSIONS
TOLERANCES
FRACTIONS D
±
XX
XXX
ALL SURFAC
MATL-
SEE
FN-902-F (3-78) PRINTED IN U.S.A.

SIZE	DWG NO.	SHEET	REV
B	47B252768	1 OF 1	A

REVISIONS

ZONE	LTR	DESCRIPTION	DATE	APPROVED
	A	REMOVED SLOT & HOLE DIA WAS .250 +.001 -.001	[illegible]	[illegible]



CTION A-A

NOTES:-

1. DWG TERMS & TOL PER GE. SPEC S30009
2. SOLDER PLATE ALL SURFACES WITH SN60 PER QQ-S-571 .0007-.0010 THK.

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UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES. TOLERANCES ON:

FRACTIONS	DECIMALS	ANGLES
±	XX ± .020	± 1°
	XXX ± .005	

ALL SURFACES 125

MATL. SEE F/D

SIGNATURES		DAY	MO	YR
DRAWN	D. Wenn	12	7	77
CHECKED				
ISSUED	PCR	16	8	79
ENGRG	[illegible]	9	8	79
MFG	J. Wright	9	8	79
MATLS				

GENERAL ELECTRIC

SS DEPT LOC PHILA, PA.

BOSS, POSITIVE TERMINAL SOLAR CELL MODULE

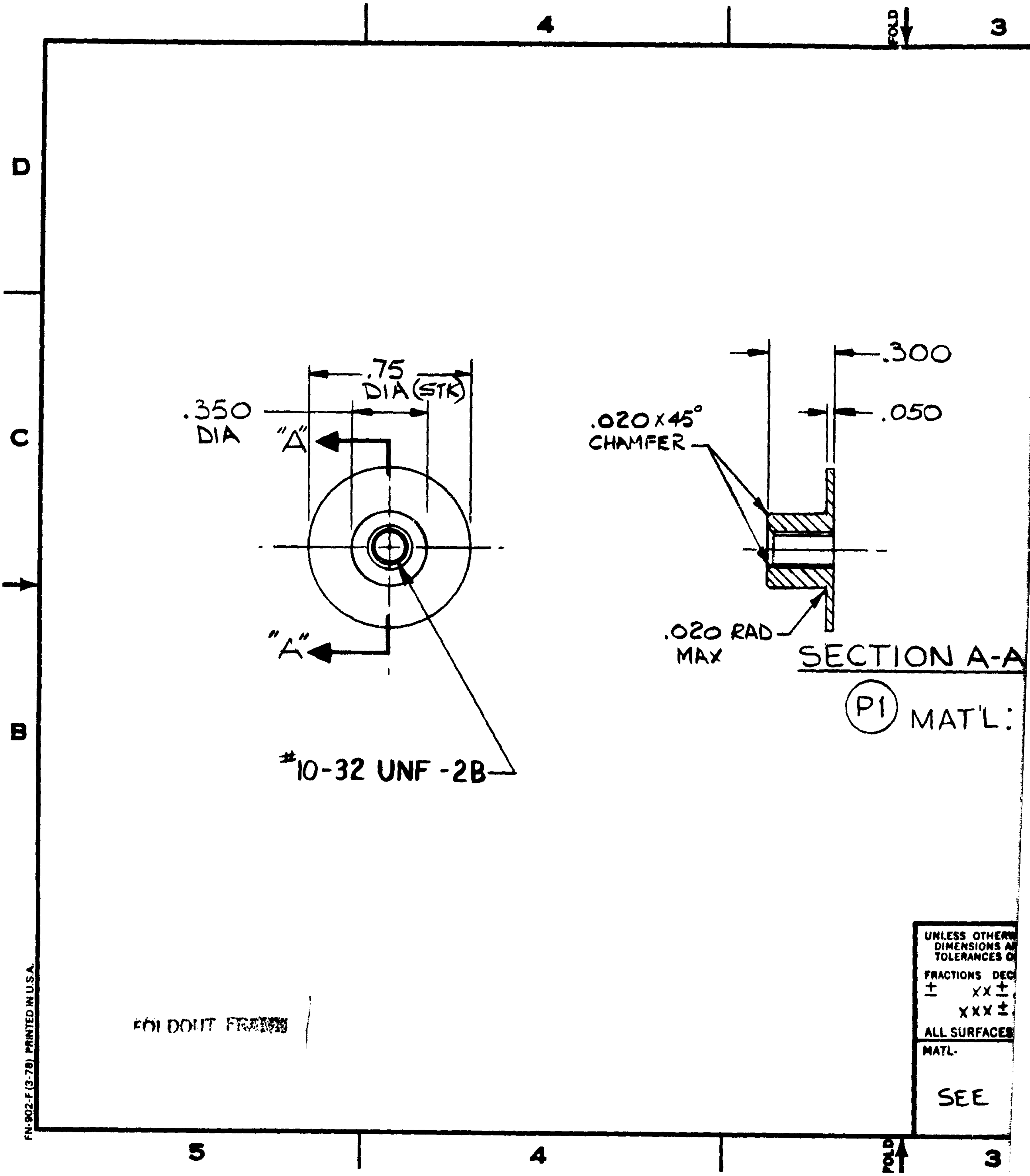
CONTRACT NO. JPL 955401

SIZE	CODE IDENT NO.	
B	23991	47B252768

SCALE 2/1 SHEET 1 OF 1

3/dg-7

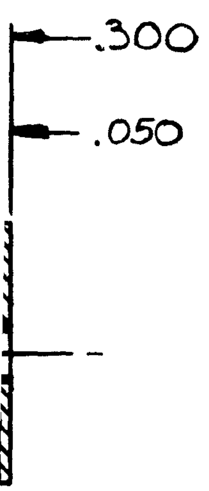
DIST TO


4
3
FOLD
D
C
B
.75
DIA (STK)
.350
DIA
"A"
"A"
#10-32 UNF -2B
.300
.050
.020 x 45°
CHAMFER
.020 RAD
MAX
SECTION A-A
P1 MAT'L:
UNLESS OTHERW
DIMENSIONS AR
TOLERANCES O
FRACTIONS DECI
±
XX ±
XXX ±
ALL SURFACES
MATL-
SEE
FOLDOUT FRAME
FN-902-F (3-78) PRINTED IN U.S.A.
5
4
3

SIZE B 47B252767 SHEET 1 OF 1 REV A

REVISIONS

ZONE	LTR	DESCRIPTION	DATE	APPROVED
	A	REMOVED FLATS FROM .350 DIA	[illegible]	[illegible]



NOTES:-

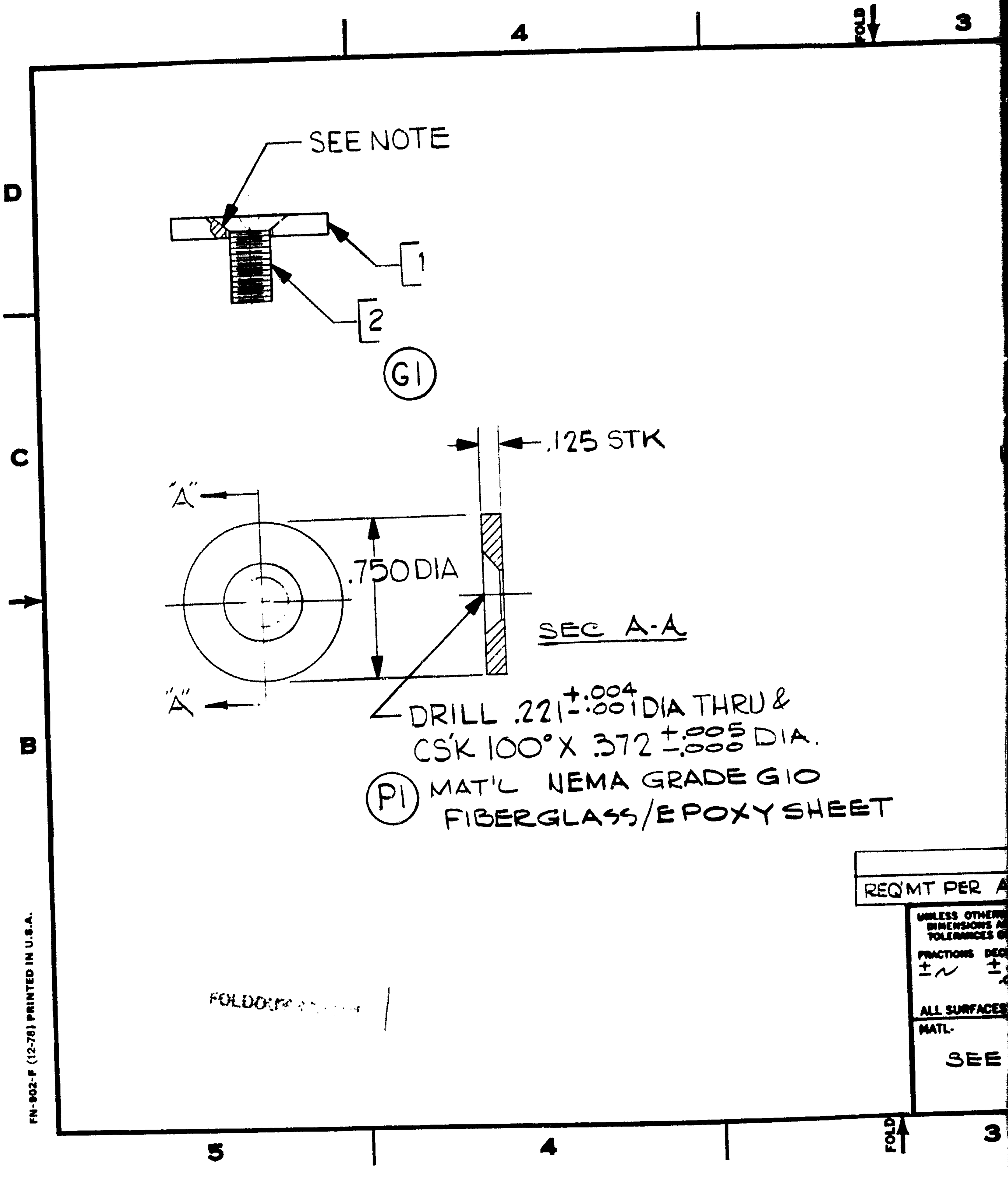
1. DWG TERMS & TOL PER GE. SPEC. S30009

ECTION A-A

P1 MAT'L: ANNEALED NYLON ROD TYPE 6 OR 6/6

FOLDOUT FRAME 2

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES. TOLERANCES ON:	SIGNATURES	DAY	MO	YR	GENERAL ELECTRIC SS DEPT LOC PHILA, PA
FRACTIONS ± DECIMALS XX ±.02 XXX ±.005 ANGLES ±	DRAWN D. Wawa	11	7	79	NUT, POSITIVE TERMINAL SOLAR CELL MODULE
ALL SURFACES 125	CHECKED				
	ISSUED	10	8	79	
	ENGRG	9	8	79	
	MFG	9	8	79	CONTRACT No JPL 955401
MATL- SEE F/D	MATLS				SIZE B CODE IDENT NO. 23991 47B252767
					SCALE 2/1 SHEET 1 OF 1



4
3
FOLD
D
SEE NOTE
1
2
G1
C
.125 STK
"A"
.750 DIA
SEC A-A
"A"
B
DRILL .221 +.004 -.001 DIA THRU &
CS'K 100° X .372 +.005 -.000 DIA.
P1 MAT'L NEMA GRADE G10
FIBERGLASS/EPOXY SHEET
REQ'MT PER
UNLESS OTHERWISE
DIMENSIONS A
TOLERANCES O
FRACTIONS
ALL SURFACES
MATL-
SEE
FOLDOUT
5
4
FOLD
3

3 | 2

47B254981

REVISIONS

ZONE	LTR	DESCRIPTION	DATE	APPROVED

D

ORIGINAL PAGE IS OF POOR QUALITY

C

NOTES

1. BOND ITEMS 1 AND 2 WITH ITEM 3.

(A) SHELL CHEMICAL CO BAYSIDE NY

AR	OR EQUIV EPON 812	3	ADHESIVE	(A)
1	47B254981P2	2	FL.HD,SCR-100°-#10-32 x 1/2 LG S/STL	
1	47B254981P1	1	COUNTERSUNK WASHER	
G1	IDENT. NO.	ITEM NO	DESCRIPTION	REMARKS
REQ'MT PER ASSY	LIST OF MATERIALS			

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES. TOLERANCES ON:
FRACTIONS ± ~ DECIMALS ±.03 .010 ANGLES ± ~
ALL SURFACES ✓
MATL- SEE F/D

SIGNATURES	DAY	MO	YR
DRAWN	8	8	79
CHECKED			
ISSUED	10	8	79
ENGRG	9	8	79
MFG	9	8	79
MATL			

GENERAL ELECTRIC
S.S. DEPT LOC PHILA PA

SCREW, TERMINAL

CONTRACT NO JPL 955401

SIZE	CODE IDENT NO.	
B	23991	47B254981

SCALE 2/1 SHEET 1 OF 1

Bldg 7

DIST TO

3 | 2

APPENDIX B

SHINGLE MODULE TESTING AT JPL

(SUPPLIED BY JPL)

1.0 QUALIFICATION TESTING

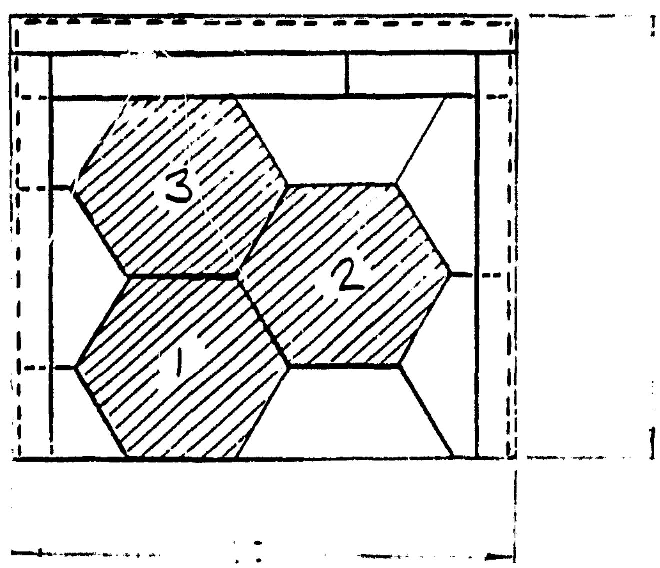
1.1 Introduction

As provided by the Contract, Article 1., Statement of Work, Paragraph (a)(D)(ii), three pre-production shingle modules were mounted on a simulated roof section approximately 1.26 by 1.16 meters by the contractor and delivered to JPL for qualification testing.

The roof section consisted of module serial numbers BIV-0054979, BIV-0064979 and BIV-0074979 electrically connected in series by the module-to-module interconnectors. This roof section is basically the same as the roof section assembled and tested by the contractor. (Figure 1).

Prior to and immediately following each environmental test, an electrical performance test was conducted and a detailed visual inspection was performed by JPL Quality Assurance. The electrical performance tests were conducted in the JPL Large Area Pulsed Solar Simulator (LAPSS) using reference cell No. GR-406.

The qualification tests were performed in accordance with Document 5101-83, entitled "Block IV Solar Cell Module Design and Test Specification for Residential Applications".



Position 1 Module S/N BIV-0064979

Position 2 Module S/N BIV-0054979

Position 3 Module S/N BIV-0074979

Two Thermocouples are mounted to the center cell of Module S/N BIV-0054979 (Position 2).

Figure 1. Diagram of Roof Section Showing Module Positions

1.2 Thermal Cycling Test

The roof section was subjected to the thermal cycling procedure consisting of 50 cycles with the cell temperature varying between -40° and +90°C at a rate not exceeding 100C°/hour. Two thermocouples mounted on the rear of the center cell of module S/N BIV-0054979 were used to determine the test article temperature.

1.3 Humidity Test

The roof section was subjected to the 7-day humidity cycling procedure. Cell temperature was determined by using the thermocouples described in Para. 1.2 above. Electrical testing was performed within 4 hours from the time the roof section completed the humidity test.

1.4 Wind Resistance Test

A wind resistance test was performed in accordance with the requirements of UL 997. The test was conducted at JPL using wind generating equipment modified to produce a 60 mph air stream. A roof slope of 9.5 degrees from the horizontal was maintained while the direction of the wind was varied from head-on to 30 degrees and then 60 degrees from head-on.

1.5 Twisted Mounting Surface Test

A twisted surface mounting test was performed in accordance with Para. F of Section V of 5101-83. The roof section was tested as a unit.

1.6 Hail Impact Test

The simulated roof section was subjected to normal hail impact loading in accordance with Para. F of Section V of 5101-83 with minor modifications.

The most sensitive points of the modules were not determined through destructive testing, but rather were selected using judgment and experience acquired from previous hail impact testing on solar cell modules.

Due to the tendency of the shingle modules to fall away from the roof structure when placed in an inverted position for hail testing, the modules were held in firm contact to the roof structure by encircling the roof structure with plastic bands and then inserting foam pieces between the bands and the glass surface of the modules at strategic locations.

Eleven different sensitive points were struck two or three times each for a total of 27 impacts by 20 mm (3/4 inch) diameter ice balls traveling at terminal velocity of 20.1 m/sec (45 mph).

2.0 QUALIFICATION TEST RESULTS

2.1 Thermal Cycling Test

Following the test the roof section was found to be open circuited when the electrical performance test was attempted. The roof section was then removed from the LAPSS area and a 1-ampere forward current was passed through the series string. At this point continuity was restored and the electrical performance test was completed satisfactorily. A Problem/Failure Analysis Report (PFR) No. 1789 (Figure 2) was written with analysis to be performed at the conclusion of the environmental test series.

Visual inspection performed following thermal cycling revealed some interconnector delamination. Corrosion or contamination of the cell interconnect strip was evident on modules S/Ns BIV-0054979, and BIV-0064979.

Table 1 summarizes the results of the electrical performance measurements made prior to and at the conclusion of each of the environmental tests.

2.2 Humidity Test

A photograph of the simulated roof section following humidity exposure is shown in Figure 3. Warpage of the dummy shingles is evident throughout the roof section. PFR No. 2207 (Figure 4) addresses the warpage problem.

Electrical performance as shown in Table 1 was satisfactory.

2.3 Wind Resistance Test

No damage or visible changes were noted following this test.

2.4 Twisted Mounting Surface Test

No damage or visible changes were noted following this test.

2.5 Hail Impact Test

No damage or visible changes were noted following this test.

Electrical performance as shown in Table 1 was satisfactory.

1789

LSA PROJECT/FIELD ORGANIZATION PROBLEM/FAILURE REPORT

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr / Pasadena, Calif 91103

Figure 2

1789

WRITTEN BY	REPORTING FACILITY	Bldg.	PROBLEM/FAILURE DATE	IR NO.
D. Hansen	JPL	248	2-7-80	46767

MODULE DESCRIPTION	MFR	S/N	TEST ACTIVITY
General Electric Roof Sample Block IV	GEZGFS	* See Below	Post Temp Cycling for 50 ∿

FAILURE SITE (BLDG/APPLICATION)
N/A

TIME IN FIELD/APPLICATION (YRS/MONTHS)
N/A

I. DESCRIPTION OF PROBLEM/FAILURE

(1) Three modules exhibit flux contamination on interconnects - green in color.
(2) Two modules - interlayer delamination adjacent to 7 cells.
(3) One module - delamination over all interconnects (38)
(4) Roof sample showed - 100% electrical degradation on post T-50 ∿ flash.

*Roof sample consisting of three modules: S/N 0054979, 0064979, 0074979

II. VERIFICATION AND ANALYSIS

(1) The tarnishing of the interconnects was caused by acetic acid cure by-products of the SCS 1202 encapsulant.
(2)(3) Module interlayer delamination and delamination over the interconnects was probably caused by entrapped air around the cells and cell interconnects or the material was not completely deairated prior to encapsulation, thus causing the delamination problems.
(4) The open circuit problem could not be verified after it was initially observed. Forward current of ≃2 amp was passed through the module with no difficulty. Inspection of the contact points at tear down of the roof assembly showed some variance in pressure applied in torqueing of terminal screws. No conclusive evidence was found to determine the cause of the open circuit. Reference DOE/JPL-955401-80-1 for problem analysis.

CAUSE OF PROBLEM/FAILURE

☐ DESIGN ☒ WORKMANSHIP ☐ PIECE PART FAILURE ☐ MANUFACTURING ☐ DAMAGE (MISHANDLING) ☐ ADJUSTMENT ☐ OTHER

PERSON COMPLETING SECTION II	SIGNATURE	DATE
	Steve Pollock	4-22-80

III. CORRECTIVE ACTION TAKEN

(1) The manufacturer has changed the encapsulant material to SCS 2402. Modules serial above BIV-0064979 use the new material.
(2)(3) The backside (mead board) was perforated to provide better curing of encapsulant on serial numbers beginning with BIV-0074979.
(4) During module installation it is important to assure proper torqueing of module interconnecting screws to the 10-15 in lbs. to assure electrical integrity.

ORIGINAL PAGE IS OF POOR QUALITY

DISPOSITION

☐ REWORKED ☐ REDESIGNED ☐ READJUSTED ☐ SCRAPPED ☐ RETESTED ☒ OTHER use as is

PERSON COMPLETING SECTION III	SIGNATURE	DATE	TASK MANAGER SIGNATURE	DATE
	Richard F. Greenwood	4-23-80	L. D. Runkle	4-23-80

JPL 2506 R 2/79

TABLE 1. Electrical Performance of the Simulated Roof Structure*

TEST	Pmax (WATTS)	DELTA, Pmax (%)	Flash Date
Pre-Test	56.92	--	01-25-80
Post Thermal Cycle	55.58	-2.4	02-08-80
Post Humidity	57.30	+0.7	02-22-80
Post Wind	57.18	+0.5	03-13-80
Post Twist	56.78	-0.2	03-14-80
Post Hail	55.92	-1.8	03-21-80

*At 100 mW/cm^2 and 28°C

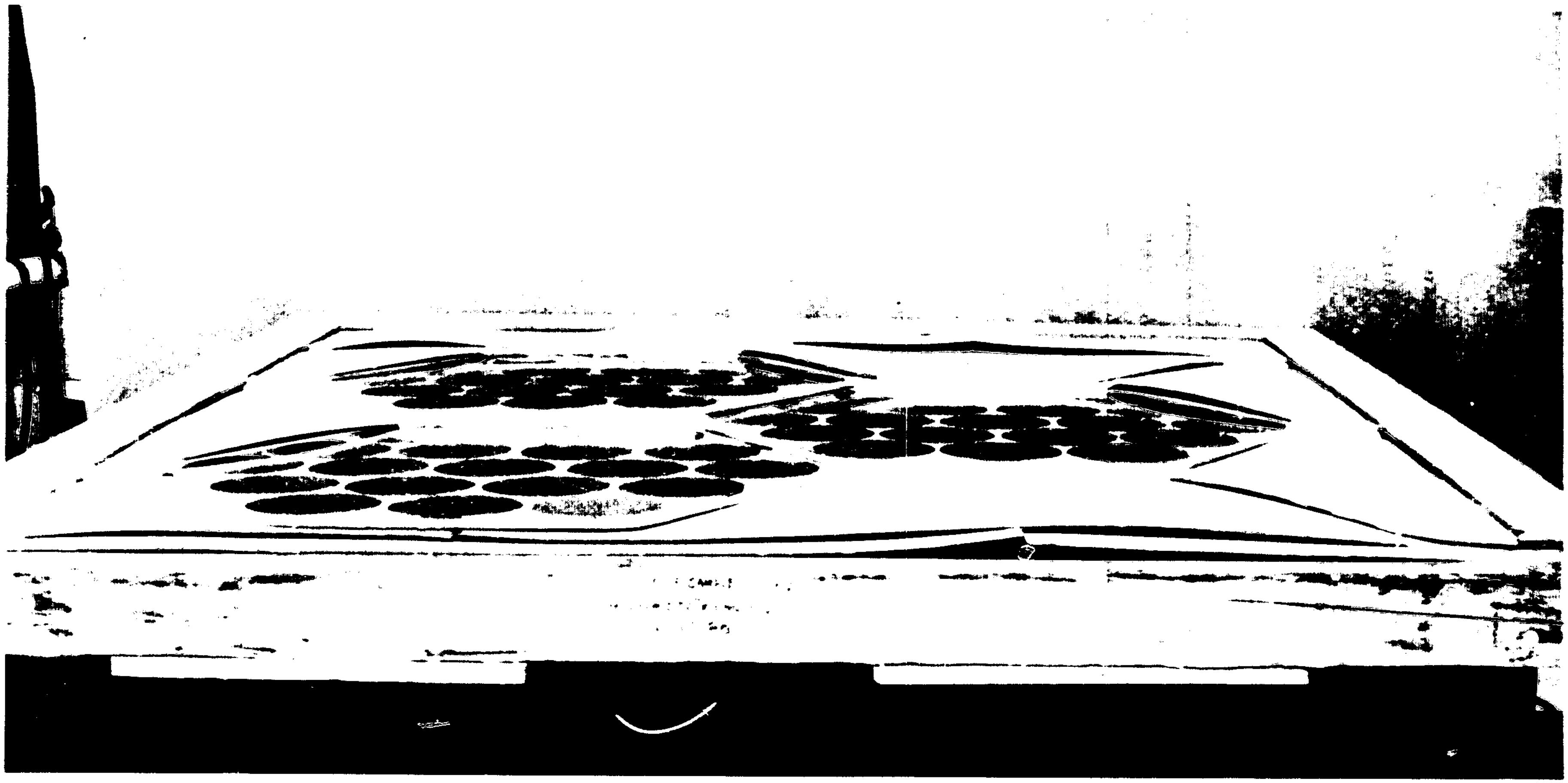


Figure 3. Simulated Roof Section After Humidity Test Showing Warpage of Dummy Shingles

LSA PROJECT/FIELD ORGANIZATION PROBLEM/FAILURE REPORT

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr / Pasadena Calif 91103

2207

Figure 4

WRITTEN BY	REPORTING FACILITY	Bldg.	PROBLEM/FAILURE DATE	IR NO
D. Hansen	JPL	248	2-25-80	46767

MODULE DESCRIPTION	MFR	S/N *	TEST ACTIVITY
General Electric Roof Sample Block IV	GEZGFS	See Below	Post Humidity Cycling for 5 ...

FAILURE SITE (BLDG/APPLICATION)

N/A

TIME IN FIELD/APPLICATION (YRS/MONTHS)

N/A

2207

I. DESCRIPTION OF PROBLEM/FAILURE

(1) Qty 9 - All blank shingles exhibi ... page on edges not bonded to roof.

*Roof sample consisting of three modules: S/N 0054979, 0064979, 0074979

II. VERIFICATION AND ANALYSIS

The manufacturer has attributed the warpage of the dummy shingles to the mead Pan-L board rear cover moisture absorption and expansion as a result of temperature humidity.

CAUSE OF PROBLEM/FAILURE

☒ DESIGN ☐ WORKMANSHIP ☐ PIECE PART FAILURE ☐ MANUFACTURING ☐ DAMAGE (MISHANDLING) ☐ ADJUSTMENT ☐ OTHER

PERSON COMPLETING SECTION II	SIGNATURE	DATE
	Steve Sollock	4-22-80

III. CORRECTIVE ACTION TAKEN

The manufacturer is investigating a new masonite material. The warpage was found to return to normal after a period of air drying

DISPOSITION

☐ REWORKED ☐ REDESIGNED ☐ READJUSTED ☐ SCRAPPED ☐ RETESTED ☒ OTHER use as is

PERSON COMPLETING SECTION III	SIGNATURE	DATE	TASK MANAGER SIGNATURE	DATE
	Richard T. Greenwood	4-23-80	[illegible]	4-23-80

JPL 2506 R 2/79