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AUTOMATED SOLAR PANEL ASSEMBLY LINE

LSA TASK: PRODUCTION PROCESSES & EQUIPMENT

Quarterly Report No. 1

JPL Contract No. 955278

Prepared For:

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, California 91103

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April 8, 1979

Submitted By:

ARCO SOLAR INC.
20554 Plummer Street
Chatsworth, California 91311

AUTOMATED SOLAR PANEL ASSEMBLY LINE

QUARTERLY REPORT NO. 1

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PREPARED BY: H. Somberg

REPORT DATE: April 8, 1979

The JPL Low-Cost Silicon 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.

Submitted By:

ARCO SOLAR, INC.
20554 Plummer Street, Chatsworth, California 91311

ABSTRACT

The objective of this program is to design, fabricate and demonstrate an automated solar cell module production line with the ultimate goal of reducing module assembly costs.

During this reporting period the automated module design was completed. The design of the solar cell assembly prototype (SCAP) was about 75% completed and the solar panel lamination prototype (SPLP) was built and tested.

TABLE OF CONTENTS

1.0 SUMMARY

1.1 Introduction

The objective of this program is to design, fabricate and demonstrate an automated solar panel production line with the ultimate goal of reducing module assembly costs.

The principal tasks in this program are 1) the generation of a module design compatible with automated assembly methods, 2) the design and fabrication of automatic soldering equipment capable of interconnecting 12 solar cells/minute, 3) the design and construction of automatic laminating equipment capable of producing 12 modules/hour and 4) operation of an automated pilot line.

The approach used in the design of the solar cell module was to adapt a field-proven encapsulation system to a circuit design compatible with automated assembly.

The major differences between the conventional and automated module are larger cells (100mm vs. 75mm), module size increase to .3m x 1.2m (1 x 4 feet), halving of the encapsulant thickness to 2-.38mm (.015 inch) thick layers of PVB and extruded aluminum side and end channels instead of an enclosed box. The peak power of the module is 33 watts and its NOCT is 47°C.

The approach to solar cell interconnection was to design equipment capable of making series strings from individual cells. The design includes automatic cassett unloading and wafer alignment, ribbon feed and deployment, simultaneous soldering of top and bottom interconnects, in-line removal of soldering flux and attachment of a Mylar* strip to each string for dimensional stability and handling.

ARCO Solar uses a superstrate module design to which the circuit is laminated using PVB. Lamination of PVB is accomplished using a "vacuum bag" approach which is intgrated with infrared heating into a single system. Multiple lamination stations are part of a rotating carousel so that all work can be directed from one area.

1.2 Module Design

The basis for the ASI module design is a glass superstrate to which the solar cell circuit is laminated using PVB and Tedlar* as a back cover. Circuit terminations are installed through the back cover and fitted with an ABS junction box. Extruded aluminum side and end channels complete the module and provide for structural support. Figures 1 and 2 are laminate and module assembly drawings respectively.

*Dupont trademark

FIGURE 1

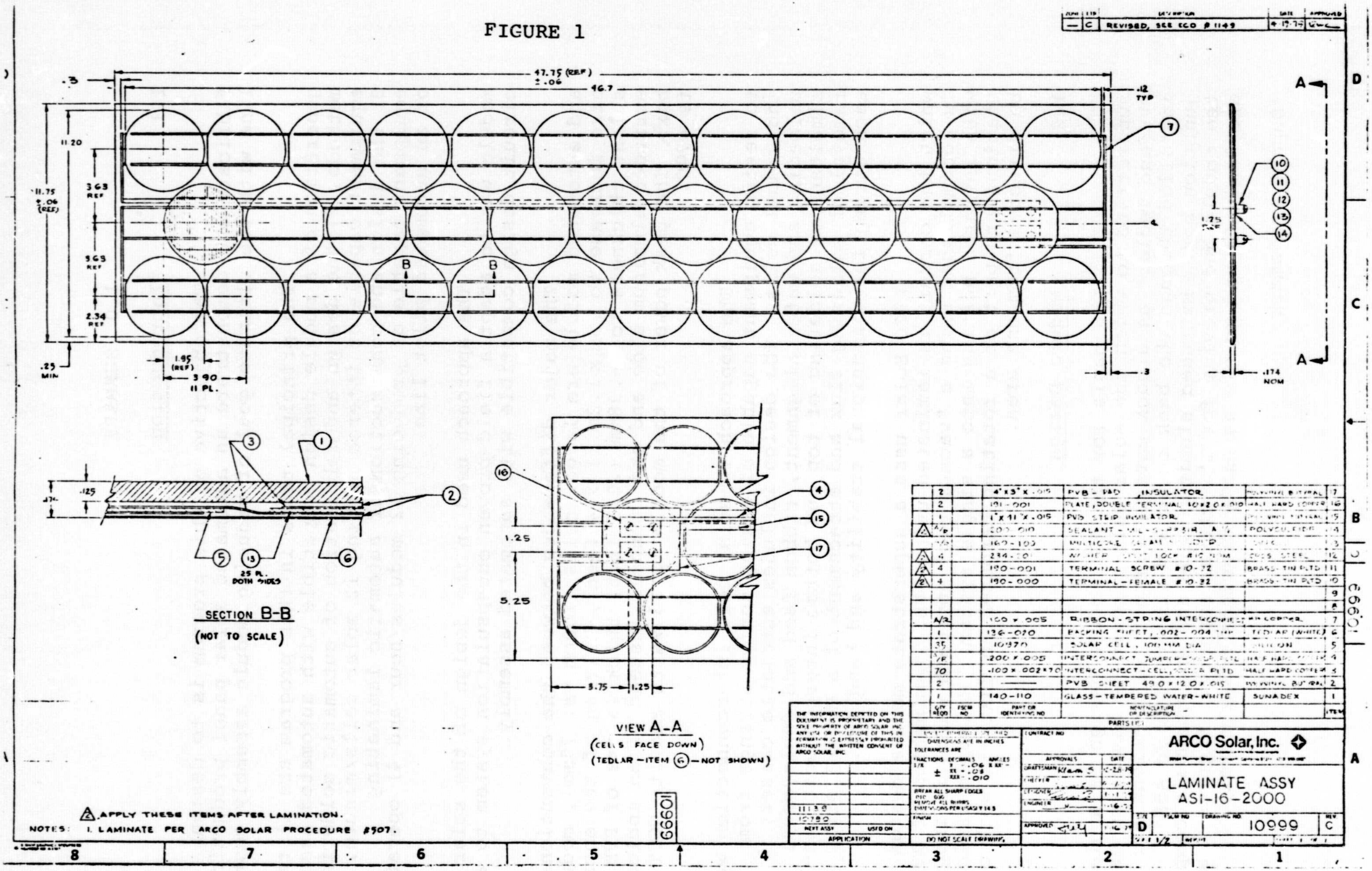
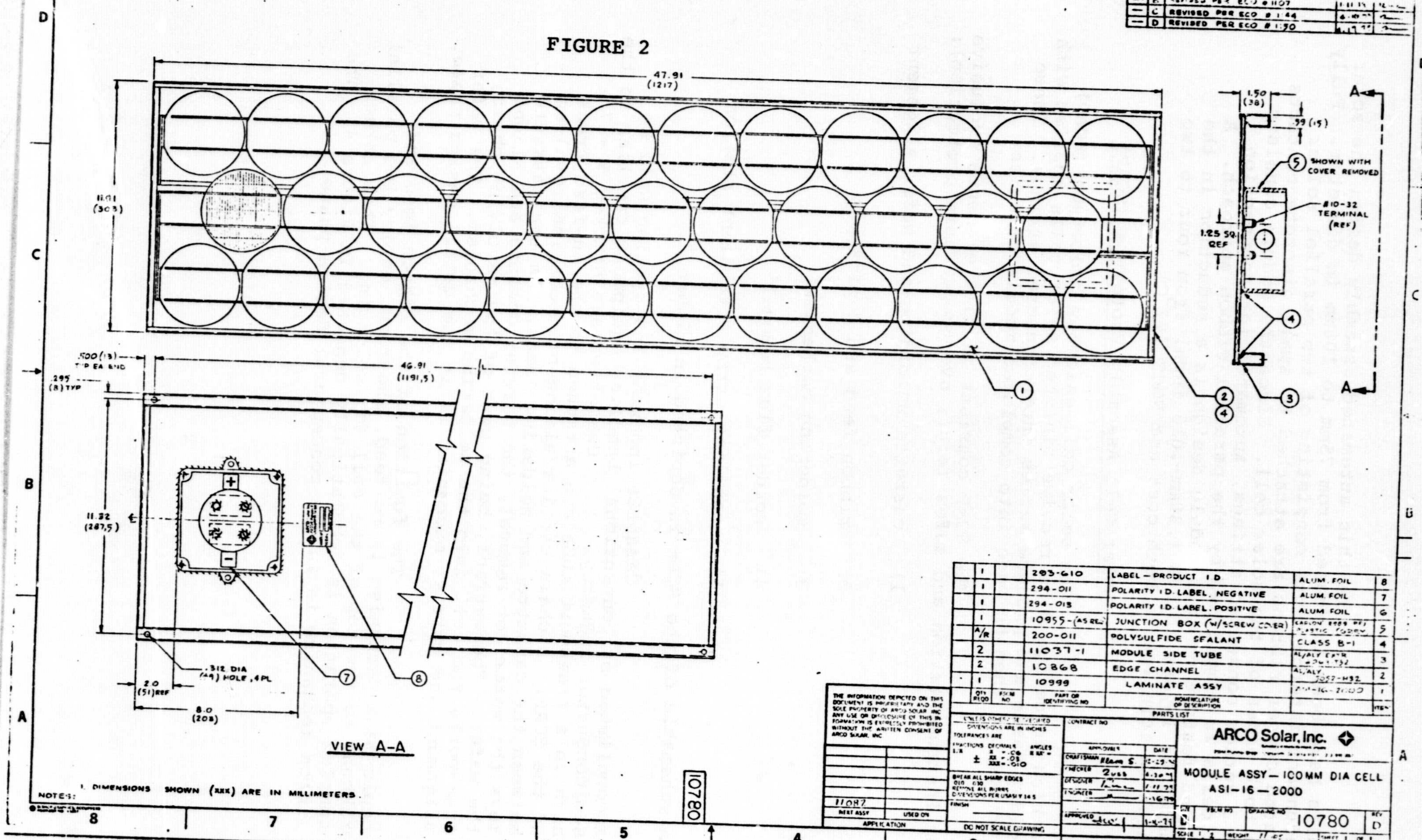

REVISED, SEE ECO # 1149
47.75 (REF) ±.06
46.7
.12 TYP
11.20
11.75 ±.06 (REF)
3.63 REF
3.63 REF
2.34 REF
1.95 (REF)
3.90 11 PL.
.25 MIN
1.75 TYP
.174 NOM
A
B
SECTION B-B
(NOT TO SCALE)
25 PL. BOTH SIDES
.125
1.25
5.25
3.75
VIEW A-A
(CELLS FACE DOWN)
(TEDLAR - ITEM 6 - NOT SHOWN)
PVB - PAD INSULATOR
PLATE, DOUBLE TERMINAL
PVB STRIP INSULATOR
SEALANT
TERMINAL SCREW #10-32
TERMINAL - FEMALE #10-32
RIBBON - STRING INTERCONNECT
BACKING SHEET
SOLAR CELL, 100 MM DIA
PVB SHEET 49.0 x 12.0 x .015
GLASS - TEMPERED WATER-WHITE
SUNADEX
PARTS LIST
ARCO Solar, Inc.
LAMINATE ASSY
ASI-16-2000
10999
DO NOT SCALE DRAWING
APPLY THESE ITEMS AFTER LAMINATION.
NOTES: 1. LAMINATE PER ARCO SOLAR PROCEDURE #507.

FIGURE 2



C REVISED PER ECO # 1144
D REVISED PER ECO # 1190
47.91 (1217)
11.01 (303)
1.50 (38)
.59 (15)
SHOWN WITH COVER REMOVED
#10-32 TERMINAL (REF)
1.25 SQ. REF
A
.500 (13) TYP EA END
.295 (8) TYP
46.91 (1191,5)
11.32 (287,5)
.312 DIA (44) HOLE, 4PL
2.0 (51) REF
8.0 (208)
VIEW A-A
NOTES:
1. DIMENSIONS SHOWN (XXX) ARE IN MILLIMETERS.
10780
1 293-610 LABEL – PRODUCT I D ALUM. FOIL 8
1 294-011 POLARITY I.D. LABEL, NEGATIVE ALUM. FOIL 7
1 294-013 POLARITY I.D. LABEL, POSITIVE ALUM. FOIL 6
1 10955-(AS REQ) JUNCTION BOX (W/SCREW COVER) 5
A/R 200-011 POLYSULFIDE SEALANT CLASS B-1 4
2 11037-1 MODULE SIDE TUBE 3
2 10868 EDGE CHANNEL 2
1 10999 LAMINATE ASSY 1
QTY REQD
PART OR IDENTIFYING NO
NOMENCLATURE OR DESCRIPTION
PARTS LIST
THE INFORMATION DEPICTED ON THIS DOCUMENT IS PROPRIETARY AND THE SOLE PROPERTY OF ARCO SOLAR, INC. ANY USE OR DISCLOSURE OF THIS INFORMATION IS EXPRESSLY PROHIBITED WITHOUT THE WRITTEN CONSENT OF ARCO SOLAR, INC.
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
BREAK ALL SHARP EDGES
DO NOT SCALE DRAWING
11087
NEXT ASSY
USED ON
APPLICATION
CONTRACT NO
ARCO Solar, Inc.
MODULE ASSY – 100MM DIA CELL
ASI-16 – 2000
10780
REV D

In this automated assembly design the solar cells have been increased from 75mm to 100mm in diameter. Fully redundant interconnects consisting of two parallel solder plated copper ribbons are attached to small discrete contacts on both sides of the solar cell. Since the module consists of 3 series connected strings, automated interconnection of cells is simplified by the parallel ribbon approach. A second feature of this module design is a reduction in the number of layers of PVB (.38mm-.015 inch) from four to two which in turn lowers both cost and NOCT (47°C).

1.3 Solar Cell Assembly Prototype (SCAP)

The solar cell assembly prototype (SCAP) machine is designed to receive finished solar cells applied with solder paste and produce series interconnected strings. These strings can then be made into completed module circuits.

The SCAP consists of five elements exclusive of instrumentation and safes (e.g., overtemperature protection):

1) cassette unloading and wafer alignment

2) ribbon feed and deployment

3) soldering mechanism

4) solder flux removal

5) handling strip attachment station

A schematic of the SCAP is depicted in Figure 3.

Cassette indexing and cycling will be accomplished by conventional handling equipment familiar to the semiconductor industry. Cassettes are stacked 5 - 7 high in a transport tube and attached to the in-feed track of the SCAP. A chain carrier/alignment mechanism revolves between the cassette and soldering leads. As the cassette keys the wafer for removal, the carrier accepts and aligns the wafer. The carrier, being part of the revolving chain, transports the cell into the soldering mechanism. The wafer alignment and carrier mechanism is in the detail design phase.

The function of the ribbon feed and deployment mechanism is to feed, shear and deploy two parallel ribbons to the top of the cell for soldering. This rather complex operation is schematically depicted in Figure 4. The ribbon mechanism is in the conceptual design phase.

FIGURE 3

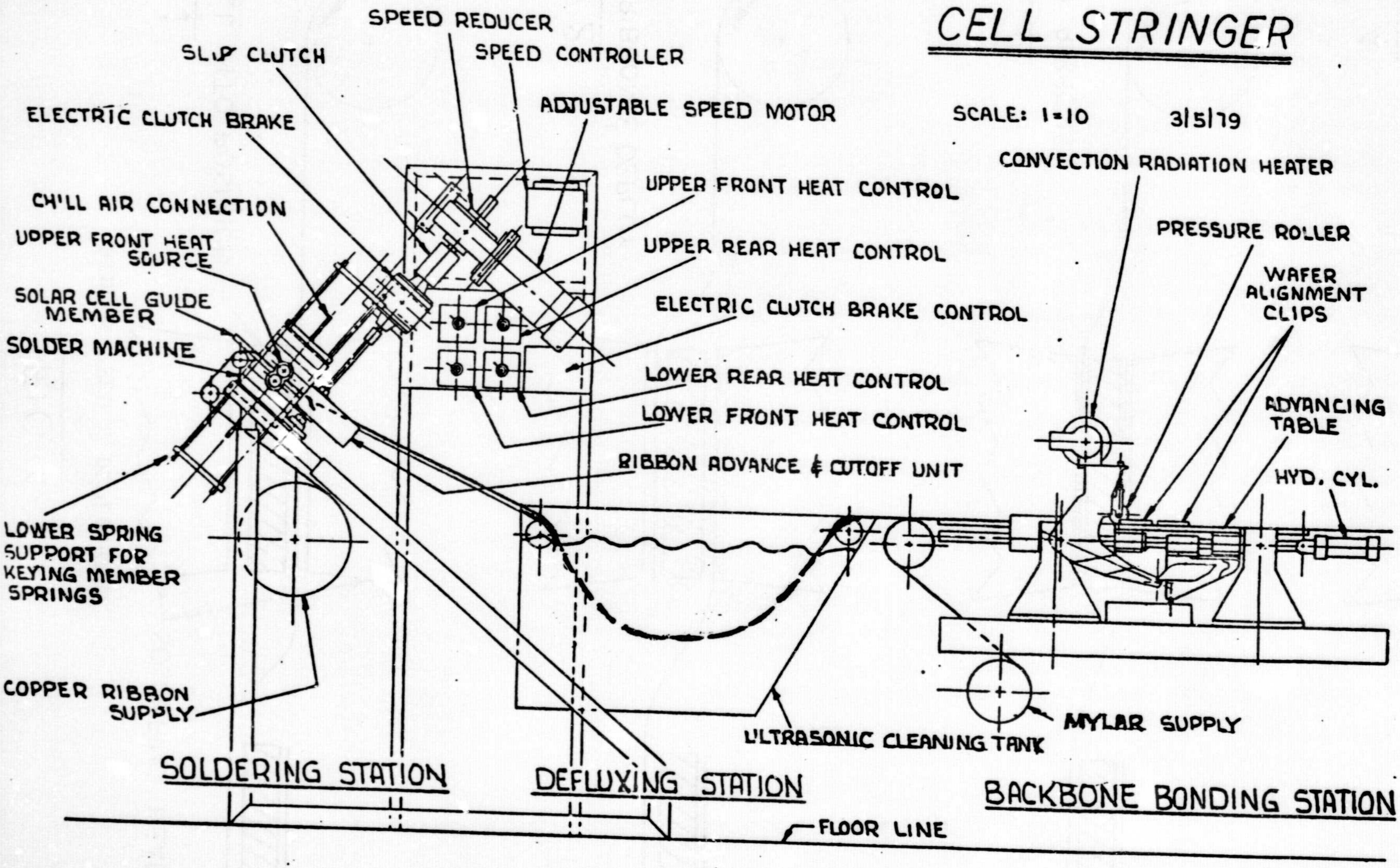
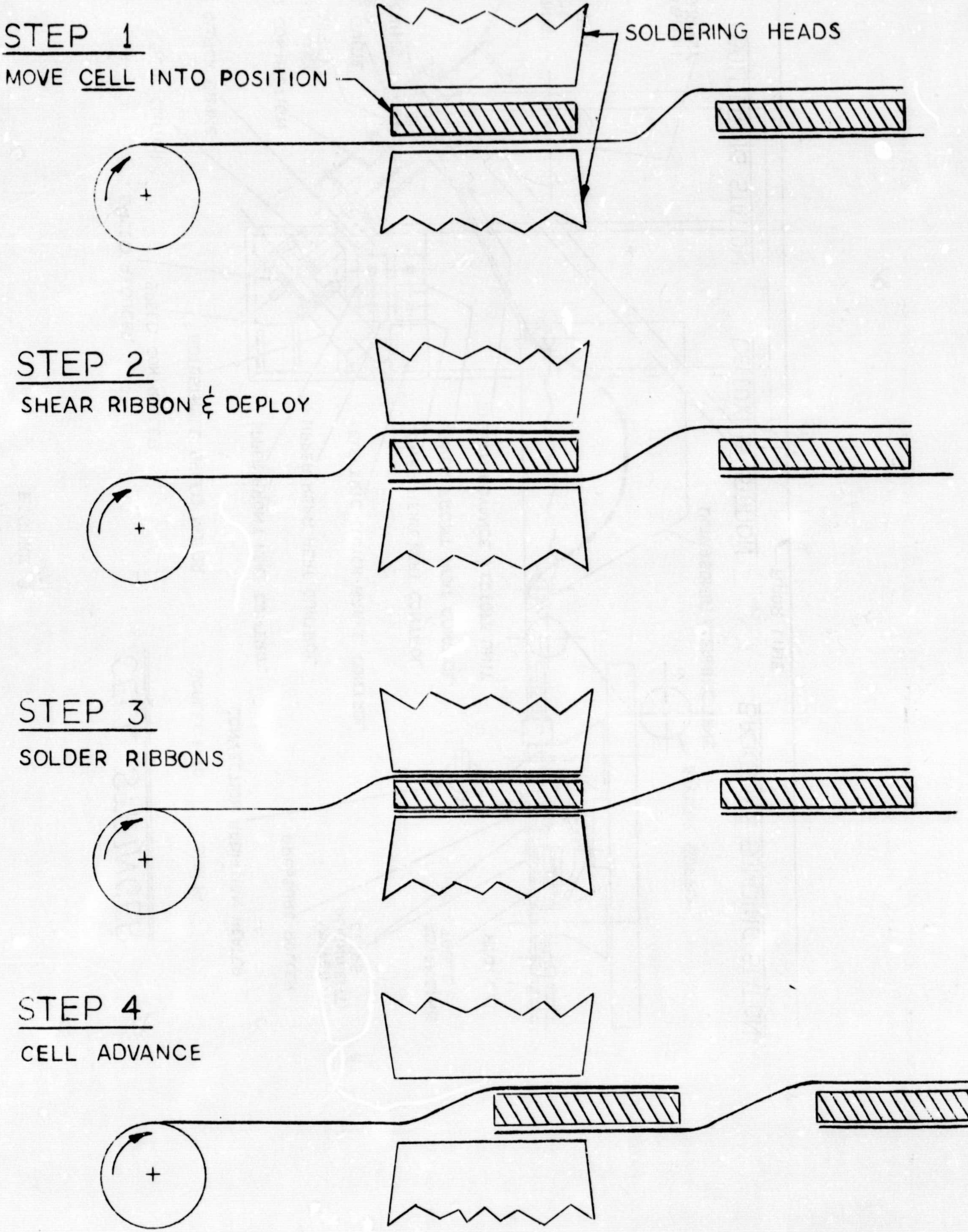

CELL STRINGER
SCALE: 1=10
3/5/79
SPEED REDUCER
SPEED CONTROLLER
SLIP CLUTCH
ADJUSTABLE SPEED MOTOR
ELECTRIC CLUTCH BRAKE
CHILL AIR CONNECTION
UPPER FRONT HEAT SOURCE
SOLAR CELL GUIDE MEMBER
SOLDER MACHINE
LOWER SPRING SUPPORT FOR KEYING MEMBER SPRINGS
COPPER RIBBON SUPPLY
UPPER FRONT HEAT CONTROL
UPPER REAR HEAT CONTROL
ELECTRIC CLUTCH BRAKE CONTROL
LOWER REAR HEAT CONTROL
LOWER FRONT HEAT CONTROL
RIBBON ADVANCE & CUTOFF UNIT
CONVECTION RADIATION HEATER
PRESSURE ROLLER
WAFER ALIGNMENT CLIPS
ADVANCING TABLE
HYD. CYL.
MYLAR SUPPLY
ULTRASONIC CLEANING TANK
SOLDERING STATION
DEFLUXING STATION
BACKBONE BONDING STATION
FLOOR LINE

FIG. 4

RIBBON FEED & DEPLOYMENT



The soldering mechanism consists of two precisely machined and opposing heads that match the solar cell metallization pattern. The heads move vertically to and away from the cell during each machine cycle and heat input is through conduction. Between the relieved pads on each soldering head are holes that provide for adiabatic cooling of the solder connections.

The soldering heads are each attached to a sequencer whose role is to act as a cam in coordinating the vertical head movement, and to provide both heating and cooling during each soldering cycle. The soldering head/sequencer arrangement have compliance to the solar cell by means of the spring load in a wave washer.

As the sequencer rotates through its cycle, heat input is provided by contact with copper heat sources that are resistively heated.

The soldering mechanism has been designed, fabricated and mechanically operated at room temperature. The copper heat sources have been fabricated, and the control and instrumentation package is near completion.

The defluxing station is an in-line ultrasonic cleaning tank which is replenished with clean distilled solvent by an off-line solvent reclamation unit. The sizing of the ultrasonic tank was based on the machine cycle of 12 cells/minute and the residence time necessary in the U.S. tank for thorough residual flux removal. Both 1-1-1 trichloroethane and a freon-alcohol azeotrope (Blacotron TMS Plus, Baron-Blakeslee) were assessed for cleaning efficiency. Each solvent was heated to its optimum cavitation temperature, 57°C (135°F) and 30°C (86°F) respectively. The optimum cavitation temperature is a threshold level at which solution degassing is complete and maximum cavitation efficiency is achieved. Below this temperature dissolved gases absorb the generated ultrasonic energy and cleaning efficiency is poor.

Both solvents were found to remove residual flux (rosin) within 20 - 30 seconds. Absence of rosin was verified using both microscopic and colorimetric methods.[1] The U.S. tank was subsequently sized to permit residence time in the tank of 40 seconds minimum/cell. A refrigeration coil will be incorporated at the top of the tank to minimize solvent evaporation and a spray of hot clean solvent distillate will remove any rosin dragout from the tank as cells emerge from the solution. The ultrasonic system has been sized and ordered.

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[1] See appendix A

The handling strip attachment station will apply a thin .080mm (.003 inch) strip of Mylar to the back of each cell in order to provide a dimentionally stable and manageable circuit string. This mechanism will also count and shear each series string at the appropriate length. The Mylar has a thin .025-.050mm (.001 - .002 in.) layer of thermoplastic polyester adhesive which is heat-applied to the back of each cell. This machine element is 90% designed and is being assembled.

1.4 Solar Panel Lamination Prototype (SPLP)

The encapsulation system utilizes a superstrate design and extruded layers of polyvinyl butyral (PVB) as the adhesive to form a thin profile laminate, 4.5mm (.180 inches) thick.

In order to effectively remove the interfacial air between the layers of PVB, the laminate stackup (glass, PVB, solar cell circuit and Tedlar* back cover) must be evacuated within a vacuum. The approach taken to accomplish both evacuation and heating was to combine them in a single chamber. The chamber design is shown in Figure 5. Each half of the chamber can be evacuated independantly of the other so that after the initial pumpdown period, the top half can be backfilled to atmospheric pressure.

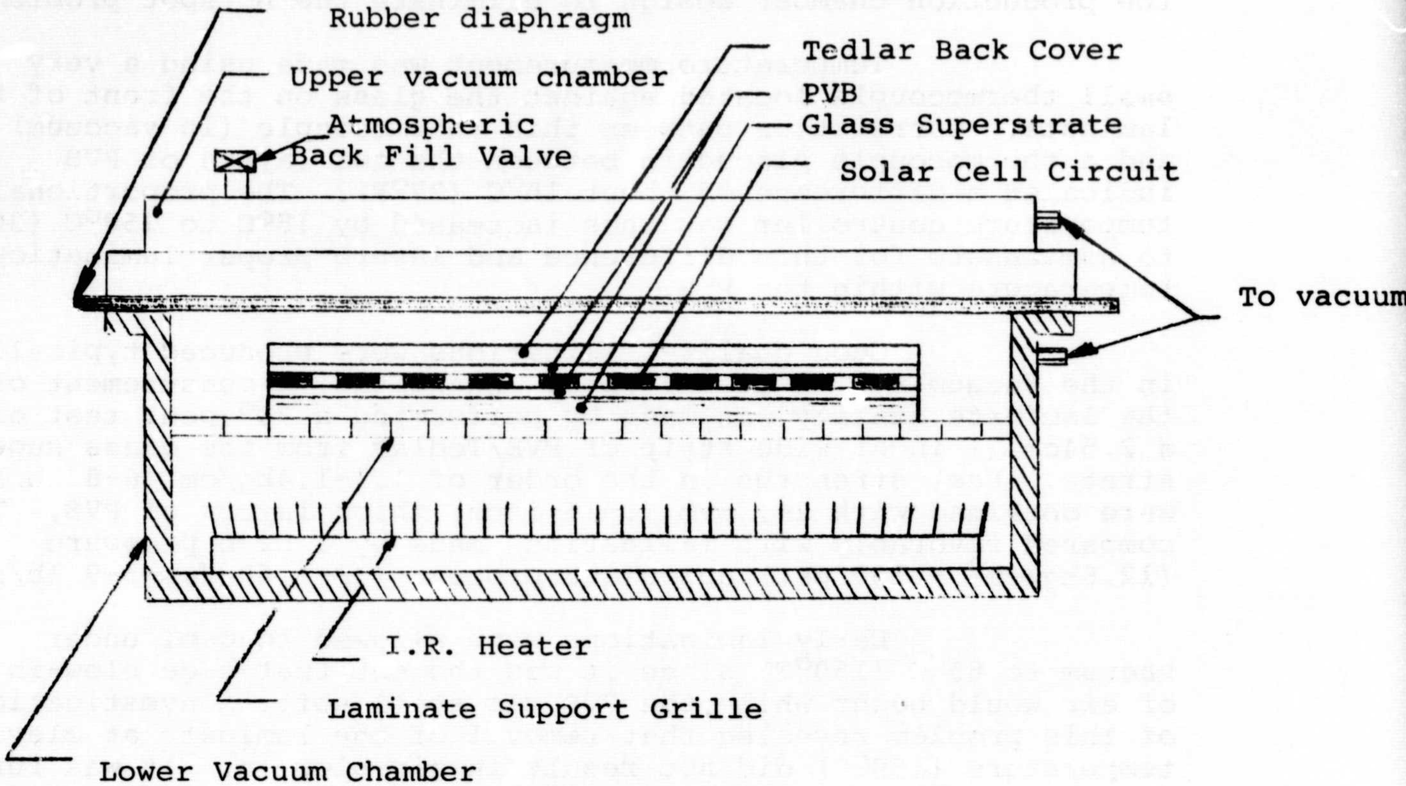
The first approach to sealing the two chambers from each other was to extend the flexible back cover (Tedlar) of the laminate over the gasket seal in the flange area. In this way a new diaphram (back cover) would be introduced for each new laminate. The reliability of this approach both for maintaining adequate sealing properties and providing a smooth uniform back cover was inadequate.

The second approach simplified sealing and also eliminated the need for a gasket or O-ring. In this approach a large rubber diaphragm was placed over the laminate stackup and the flange area. The weight of the top chamber initiated a seal around this flange perimeter and repeatable evacuations were achieved. The one prerequisite for using a rubber diaphragm is a breather-release material. The purpose of this material is to prevent the rubber diaphragm from applying non-uniform pressure to the Tedlar back cover when atmospheric pressure is applied. It also serves to permit better evacuation or "breathing" of air between the rubber and Tedlar. Presently two materials are used for this application; a teflon-coated textile serves as a non-stick or release material and thin felt is used as a breather.

In the prototype chamber inexpensive nichrome infrared lamps were used for heating the laminate. Initial temperature measurements indicated the presence of hot spots,

*Dupont Trademark

FIGURE 5
LAMINATION SYSTEM



SEQUENCE OF OPERATION

1. Evacuate lower chamber
2. Evacuate upper chamber
3. Backfill upper chamber to atmospheric pressure
4. Heat to 150°C (302°F) and hold for 15 minutes
5. Backfill lower chamber to atmosphere
6. Remove finished laminate

and narrow strips of aluminum foil were strategically placed to improve uniformity. Using 4-1kW lamps a temperature uniformity of 5°C (9°F) was achieved over the 1.2 meter (48 inch) length of the laminate. Tungsten filament lamps will be incorporated into the production chamber design to eliminate the hotspot problem.

Temperature measurement was made using a very small thermocouple located against the glass on the front of the laminate. Correlation between this thermocouple (in vaccuum) and a thermocouple placed in between the two layers of PVB indicated a difference of about 15°C (27°F). The proportional temperature controller was thus increased by 15°C to 150°C (302°F) to compensate for this difference and insure proper lamination temperature within the PVB.

Good quality laminations were produced typically in the vacuum region of 1-5 Torr. Quantitative measurement of the laminate quality was made by performing a 90° peel test of a 2.54cm (1 inch) wide strip of PVB/Tedlar from the glass superstrate. Peel strengths in the order of 1.1-1.4kg/cm (6-8 lb/in) were obtained with 2-.38mm (.015 inch) thick layers of PVB. This compared favorably with laminations made by a high pressure (12.6kg/cm^2 - 180 psi) autoclave process (.9-1.6kg/cm-5-9 lb/in).

Early laminations were allowed to cool under vacuum to 65°C (150°F) since it was thought that edge blow-in of air would occur while the PVB was still soft. Investigation of this problem revealed that removal of the laminate at elevated temperature (150°C) did not result in air blow-in. It was further determined that the grille on which the laminate is supported did not require cooling for the next lamination cycle. Since the glass in the laminate stackup is a relatively poor thermal conductor a new layup could be placed in the chamber and evacuated before the PVB softened. Premature heating of the PVB before complete air evacuation can result in sealed-in air pockets. The cycle time for the complete lamination process has thus been reduced from 45 minutes to about 30 minutes.

To demonstrate a pilot line capable of producing 12 laminates/hour, a moving carousel with nine lamination chambers is to be designed and constructed. The first phase design of a production lamination chamber has been completed and is in fabrication. The conceptual design of the carousel is complete.

2.0 RESULTS AND DISCUSSION

During this quarter the prototype lamination chamber was operated and a process was determined. The production laminator was designed. A module design was selected that is compatible both with automated interconnection and lamination. A major effort in the design/development of the soldering equipment resulted in significant progress on three of the machine elements.

3.0 FUTURE PLANS

During the next quarter physical and enviornmental tests will be performed on the 100mm solar cell/interconnect design. The design and fabrication of the SCAP and SPLP will be completed and performance testing will be initiated.

APPENDIX A

COLORIMETRIC DETECTION OF ROSIN

TYPE OF TEST: Rosin isolation and qualitative identification using sucrose/sulfuric acid test.

DESCRIPTION OF TEST: Extract rosin from assembly using methylene chloride (dichloromethane) or toluene. Concentrate extract by forced evaporation. Shake extract with small amount of concentrated sucrose solution. After addition of 2-3 drops of concentrated sulfuric acid, a scarlet red color will develop if rosin is present.

INTERPRETATION: Detection limit of rosin is ~1.0mg/liter using this test.