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on the

DESIGN, ANALYSIS, AND TEST VERIFICATION OF ADVANCED ENCAPSULATION SYSTEM

For Period Ending

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1.0 SUMMARY STATEMENT

Procurement of 4" x 4" polycrystalline solar cells has proceeded with some delays. A total of 1200 cells have been procured for use in both the verification testing and qualification testing.

Additional thermal structural analyses have been run and the data are presented. An outline of the verification testing is included with information on test specimen construction.

2.0 INTRODUCTION

The objective of this program is to develop analytical methodology for advanced encapsulation systems which will aid in the determination of optimum systems for meeting the Low Cost Solar Array Project goals. The program consists of three phases. In Phase I, analytical models were developed to perform optical, thermal, electrical, and structural analyses on candidate encapsulation systems. From these analyses a candidate system will be selected for qualification testing during Phase II.

Additionally, during Phase II, test specimens of various types will be constructed and tested to determine the validity of the analysis methodology developed in Phase I.

In Phase III, a finalized optimum design based on knowledge gained in Phases I and II will be developed and delivered to JPL.

3.0 TECHNICAL DISCUSSION

3.1 CELL PROCUREMENT

An agreement has been worked out with Solec International, Inc. where the 4" x 4" cells for Phase II testing are being procured. Initially, Solec was to make 2000 cell starts with 1600 meeting Spectrolab requirements. One of these requirements was that the front contact survive a tape pull test after 36 hours at 65°C and 95% RH. Solec had been unable to meet this requirement using their $POCl_2$ diffusion technique. A small number of cells were then prepared by first etching and diffusing the cells at Spectrolab and then cleaning and printing the cells at Solec. These cells are considerably less efficient because they are not texture etched as was proposed in the original Solec process, but meet the Spectrolab adhesion requirements.

Spectrolab has reissued a P.O. which will allow Solec to produce 500 cells with no humidity requirements. An additional 1500 cells will be etched and diffused at Spectrolab and then sent to Solec for final processing.

The 500 cells will be used in the Phase II verification testing where humidity sensitivity is not required. The 1500 cells will be used in qualification modules. The lower efficiency of the cells is not a problem since the goal of these tests is not to prove an absolute module efficiency but predict and verify module design performance.

To date, 500 cells have been made without the humidity requirement and 700 with the humidity requirement.

3.2 THERMAL STRUCTURAL ANALYSIS

An additional thermal/structural analysis for wood substrate modules was done. The purpose of this analysis was to investigate the effect of water absorption in the wood substrate on cell stress. To simplify the analysis, the increased expansion due to water absorption was taken into account by assuming that the combined effect of thermal expansion and water absorption results in an "effective" thermal expansion coefficient about 10 times greater than that for dry wood. The thermal expansion coefficient for dry wood is 7.2×10^{-6} in. (in °C)$^{-1}$, and the assumed thermal/moisture expansion coefficient for wood was taken as 7×10^{-5} in. (in °C)$^{-1}$. Values for all other parameters of this analysis were the same as those used previously; these parameters are listed below:

1) Uniform temperature excursion (all layers) = 100°C

2) Thickness
   a) Wood: .125 inch
   b) Front cover (Korad): .005 inch
   c) Pottant: .001, .005, .015 and .030 inch

3) Modulus of elasticity
   a) Wood: 8×10^5 psi
   b) Front cover (Korad): 2.7×10^5
   c) Pottant: 10^3, 5×10^4, 2.5×10^5 psi

4) Expansion coefficient
   a) Wood: 7×10^{-5} in (in °C)$^{-1}$
   b) Korad: 10^{-4} in (in °C)$^{-1}$

Results of the analysis are listed in Table 1 and shown in Figure 1. As seen in Figure 1, the increased expansion coefficient of the wood leads to much higher cell stresses than predicted previously. The slopes of the curves for each pottant modulus are less (in a relative sense) for $\alpha = 7 \times 10^{-5}$ than those for $\alpha = 7.2 \times 10^{-6}$. For a pottant modulus of 1000 psi, increasing the pottant thickness leads to a decrease in cell stress for $\alpha = 7.2 \times 10^{-6}$.

3.3 VERIFICATION TESTING

Verification testing will consist of five tasks:

a) Optical Testing
b) Electrical Testing
c) Structural (Thermal) Testing
d) Structural (Deflection) Testing
e) Thermal Testing

3.3.1 Optical Testing

The specimens used in the optical verification are listed in Table 2. A typical coupon is shown in Figure 2. The optical test coupon is constructed with a bare back and exposed front contact so that cell response can be measured with the same test fixture before and after encapsulation. Areas of the cell which will not be encapsulated are covered with an opaque masking tape to assure that all differences are caused by encapsulation effects. Thicknesses of encapsulation shown in Table 2 are nominal and the exact thicknesses of each coupon will be measured individually.

Results of these measurements will be compared with those predicted to verify the optical model.

Table 1

RESULTS OF THERMAL/STRUCTURAL ANALYSIS
FOR WATER ABSORPTION IN WOOD SUBSTRATE MODULE

Pottant Modulus, psi	Pottant Thickness inch	Normal Stress, psi*			
		Pottant	Substrate	Cell	Korad
10^3	.001	512	-3000	16800	-2500
	.005	219	-2780	15150	-2575
	.015	150	-2200	11930	-2720
	.030	100	-1670	9030	-2830
5×10^4	.001	-	-	-	-
	.005	-1350	-2880	16040	-2575
	.015	-863	-2600	15250	-2730
	.030	-665	-2200	14120	-2915
25×10^5	.001	-4100	-3000	17170	-2525
	.005	-2930	-2825	17720	-2550
	.015	-	-	-	-
	.030	-2040	-2025	23110	-2715

*Negative sign indicates compressive stress

Figure 1

Cell Stress vs Pottant Thickness for "Dry" and "Water Infiltrated" Wood Substrate Modules

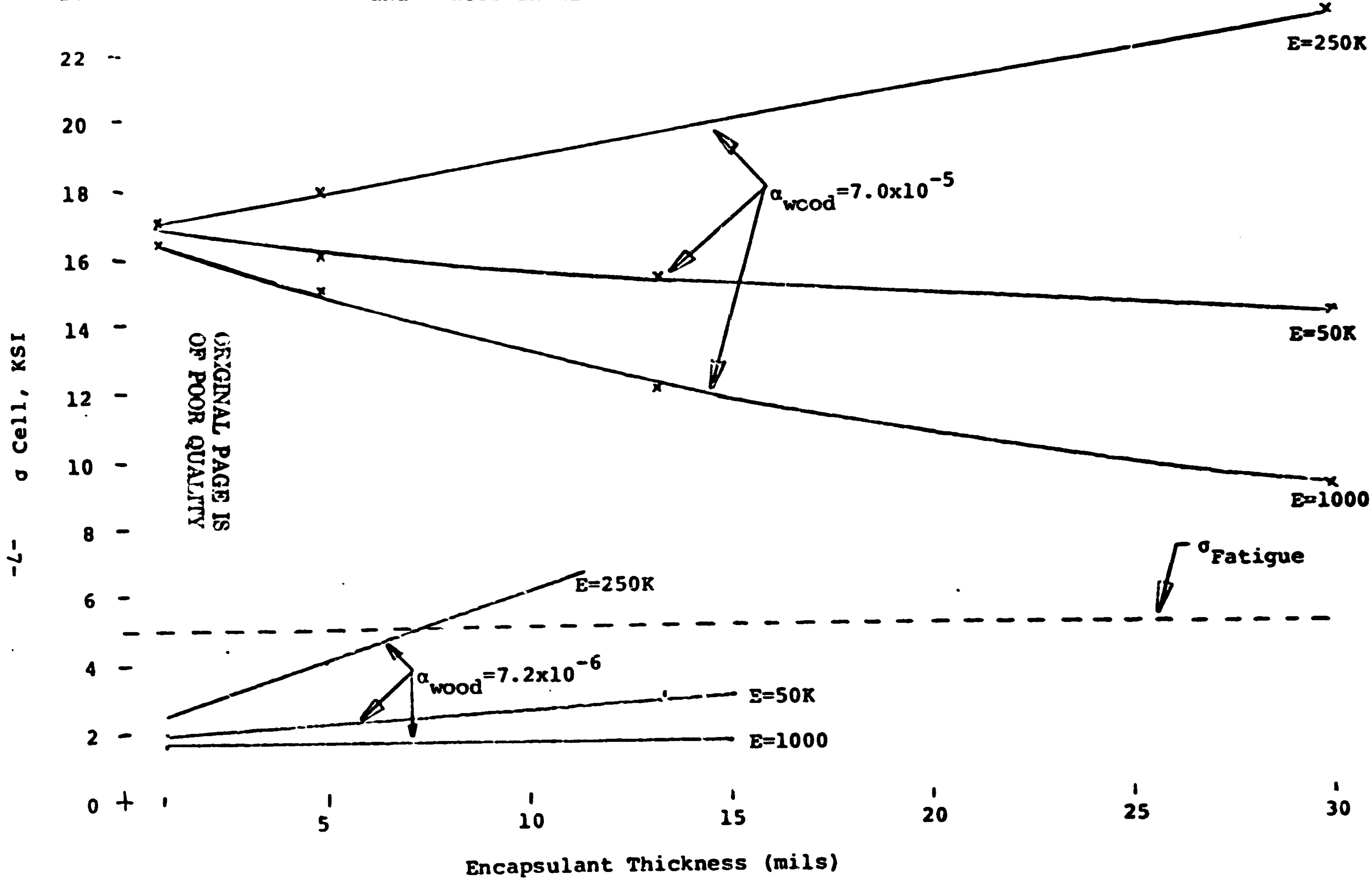

Table 2

OPTICAL VERIFICATION TEST SPECIMENS

COUPON NO.	OC-1	OC-2	OC-3	OC-4	OC-5	OC-6	OC-7	OC-8	OC-9	OC-10	OC-11	OC-12	OC-13
Load Bearing Member	Low-Iron Glass Stipple-In	Low-Iron Glass Stipple-In	High-Iron Glass	Low-Iron Glass Stipple-In	Low Iron Glass Stipple-Out	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Top Cover	--	--	--	--	--	Korad	Tedlar	Tedlar	Tedlar	Tedlar	Tedlar	Tedlar	Tedlar
Encapsulant	EVA	EVA	EVA	EVA/CG	EVA/CG	EVA	EVA	EVA/CG	EVA/CG	EVA/CG	EVA	EVA	EVA/CG
Encapsulant Thickness	10 mil	10 mil	10 mil	10 mil	10 mil	10 mil	10 mil	10 mil	10 mil	10 mil	54 mil	10 mil	10-mil
Cell Type*	SC-2"Sq	PC-2"x4"	SC-2"Sq	SC-2"Sq	SC-2"Sq	SC-2"Sq	SC-2"Sq	SC-2"Sq	SC-2"Sq (AR)	SC-2"D (Text)	SC-2"Sq	SC-2"Sq (AR)	SC-2"D (AR-Text)
No. Cells	2	2	2	2	2	2	2	2	2	2	2	2	2

*SC - Single Crystal Silicon
PC - Polycrystalline Silicon

N/A - Not applicable for this test

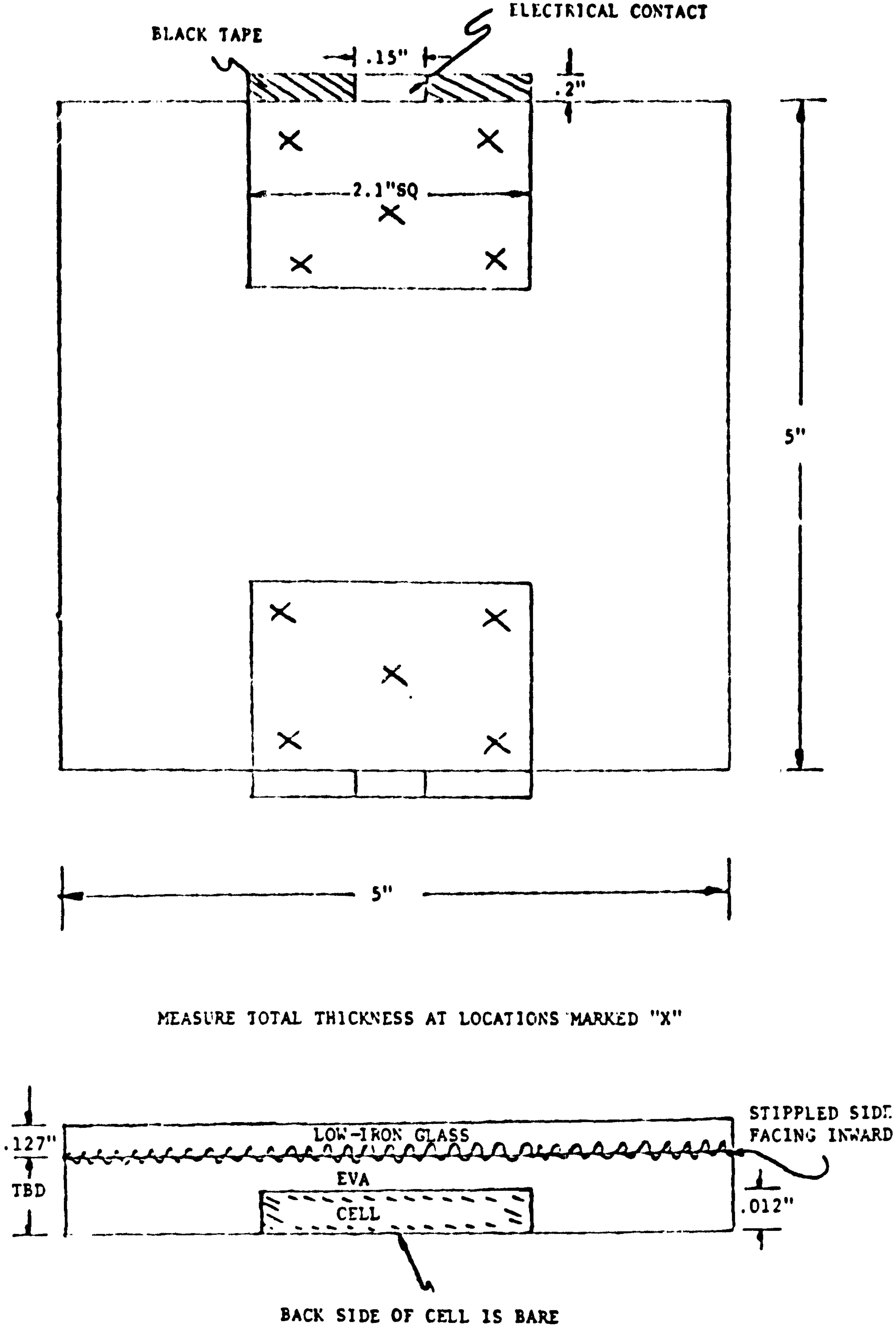

Figure 2. TYPICAL OPTICAL TEST COUPON

3.3.2 Electrical Testing

Verification of the electrical model will be accomplished by measuring dielectric breakdown strength of four types of samples shown in Table 3. Twenty-five of each type of sample will be made and breakdown tested from the center copper sheet to both the back and the front of the sample. A typical construction is shown in Figure 3.

3.3.3 Structural (Thermal) Testing

Twelve, one-cell coupons, as designated in Table 4, will be used as test specimens for the thermal/structural tests. In addition, a bare polycrystalline silicon cell (3.93 inches square), a piece of low-iron glass (7.5 inches square), and a piece of mild steel (7.5 inches square) will be instrumented to provide calibration for the strain gauges mounted on the coupons. The geometric layouts of a typical coupon is illustrated in Figure 4. The coupons will then be put through a thermal excursion and the strain measured compared to that predicted by the model.

3.3.4 Structural (Deflection) Testing

Structural deflection test specimens will consist of 46" x 46" structural members of various materials as listed in Table 5. Figure 5 shows a typical construction. Three 3.93" x 3.93" wafers of silicon will be attached to the structures with varying glue line thicknesses. Strain gauges will be attached to the silicon and strain monitored as the structure is deflected. Strain measurements will be compared to those calculated from the structural deflection model.

Table 3

SPECIMENS FOR ELECTRICAL VERIFICATION TESTS

Type	Front Side		Back Side	
A	.004 Tedlar	.018" EVA/CG	.018" EVA/CG	.001 Al/Polyester
B	.001 Tedlar	.018" EVA/CG	.036" EVA/CG	.001 Al/Polyester
C	.001 Tedlar	.018" EVA	.018" EVA/CG	Wood*
D	.001 Tedlar	.036" EVA/CG	.036" EVA/CG	Wood*

*Duron (U. S. Gypsum Co.)

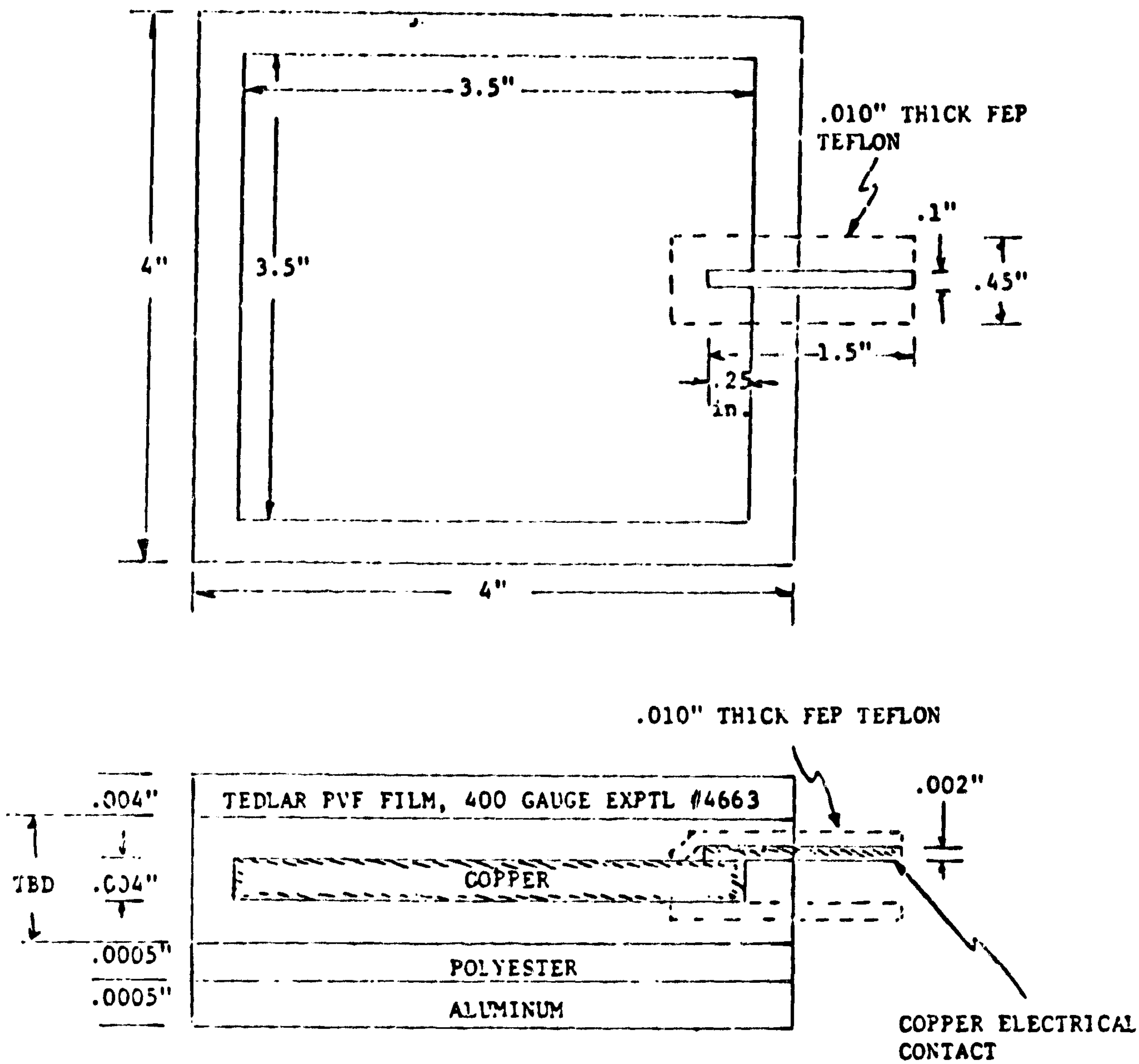

Figure 3. ELECTRICAL COUPON, TYPE A

Table 4

THERMAL/STRUCTURAL VERIFICATION TEST SPECIMENS

COUPON NO.	TSC-1	TSC-2	TSC-3	TSC-4	TSC-5	TSC-6	TSC-7	TDC-8	TSC-9	TSC-10	TSC-11	TSC-12
Load Bearing Member	Low Iron Glass	Low Iron Glass	Low Iron Glass	Low Iron Glass	Low Iron Glass	Al	Al	Mil Stl	Mil Stl	Mil Stl	Mil Stl	Mil Stl
Top Cover	-	-	-	-	-	Tedlar	Tedlar	Tedlar	Tedlar	Tedlar	Tedlar	Tedlar
Encapsulant	EVA	Sili-cone	Sili-cone	RTC Epoxy	RTC Epoxy	EVA	Sili-cone	EVA	Sili-cone	Sili-cone	RTC Epoxy	RTC Epoxy
Encapsulant Thickness, mil	18	10	20	10	20	18	10	18	20	20	10	20
Cell Type	PC-4" Sq	PC-4" Sq	PC-4" Sq	PC-4" Sq	PC-4" Sq	PC-4" Sq	PC-4" Sq	PC-4" Sq	PC-4" Sq	PC-4" Sq	PC-4" Sq	PC-4" Sq
No. Cells*	1	1	1	1	1	1	1	1	1	1	1	1

*Etched silicon wafers will be used in place of finished cells.

Figure 4. THERMAL/STRUCTURAL TEST COUPON NO. TSC-2

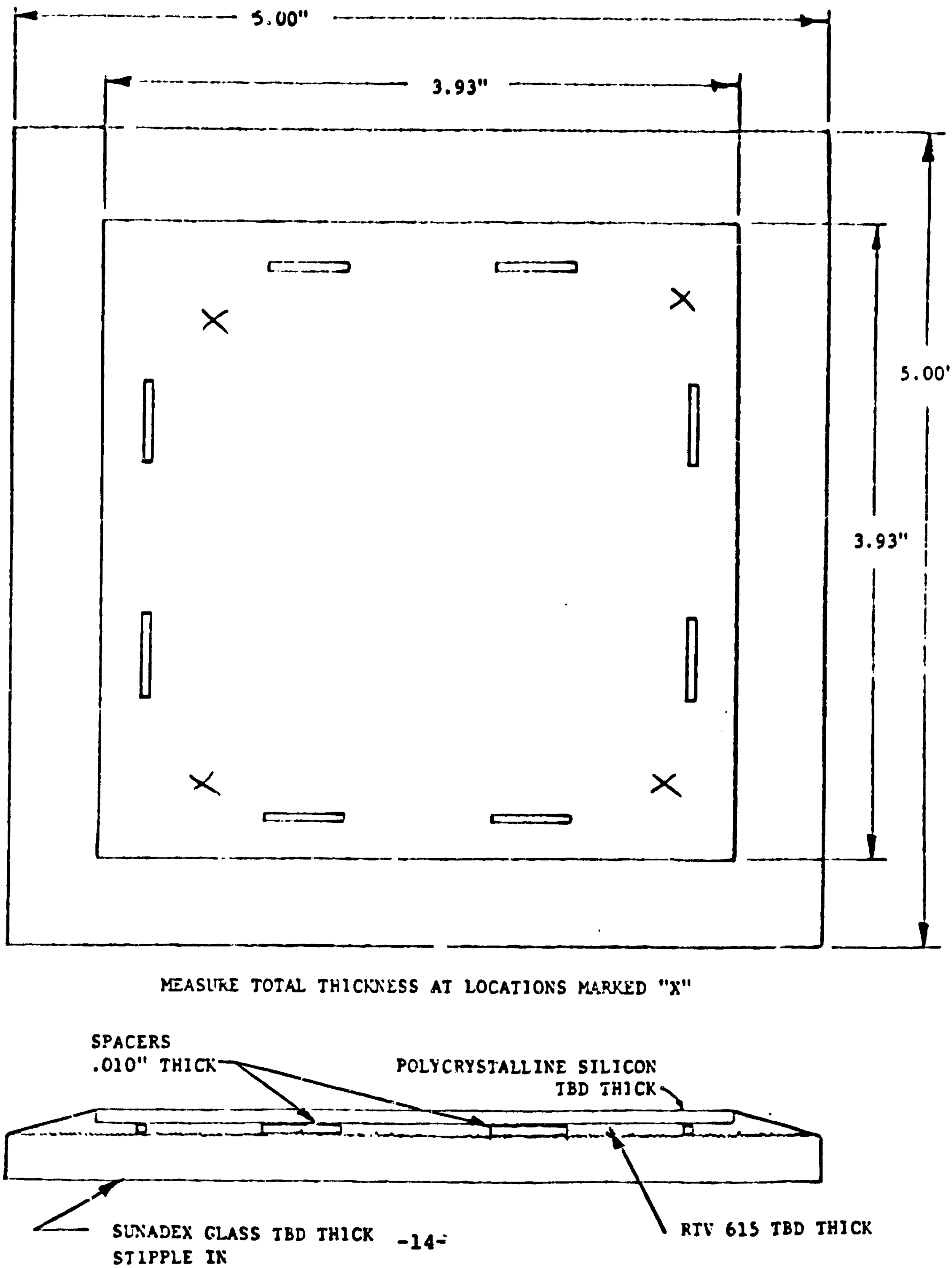

Table 5

STRUCTURAL/DEFLECTION VERIFICATION TEST SPECIMENS

MODULE NO.	SOM-1	SOM-2	SOM-3	SOM-4	SOM-5	SOM-6	SOM-7	SOM-8	SOM-9
Load Bearing Member	LI Glass	LI Glass	LI Glass	LI Glass	Plain Wood P	Plain Wood P	Ribbed Wood P	Mild Steel	Ribbed Wood P
Top Cover	-	-	-	-	-	-	-	-	-
Encapsulant	Silicone	Silicone	Epoxy	Epoxy	Silicone	Silicone	Silicone	Silicone	Silicone
Encapsulant Thickness, mil	10	20	10	20	10	20	10	20	30
Cell Type*	PC-4"Sq	PC-4"Sq	PC-4"Sq	PC-4"Sq	PC-4"Sq	PC-4"Sq	PC-4"Sq	PC-4"Sq	PC-4"Sq
No. Cells	3	3	3	3	3	3	3	3	3
Module Size	46" x 46"	46" x 46"	46" x 46"	46" x 46"	46" x 46"	46" x 46"	46" x 46"	46" x 46"	46" x 46"

*PC - polycrystalline silicon

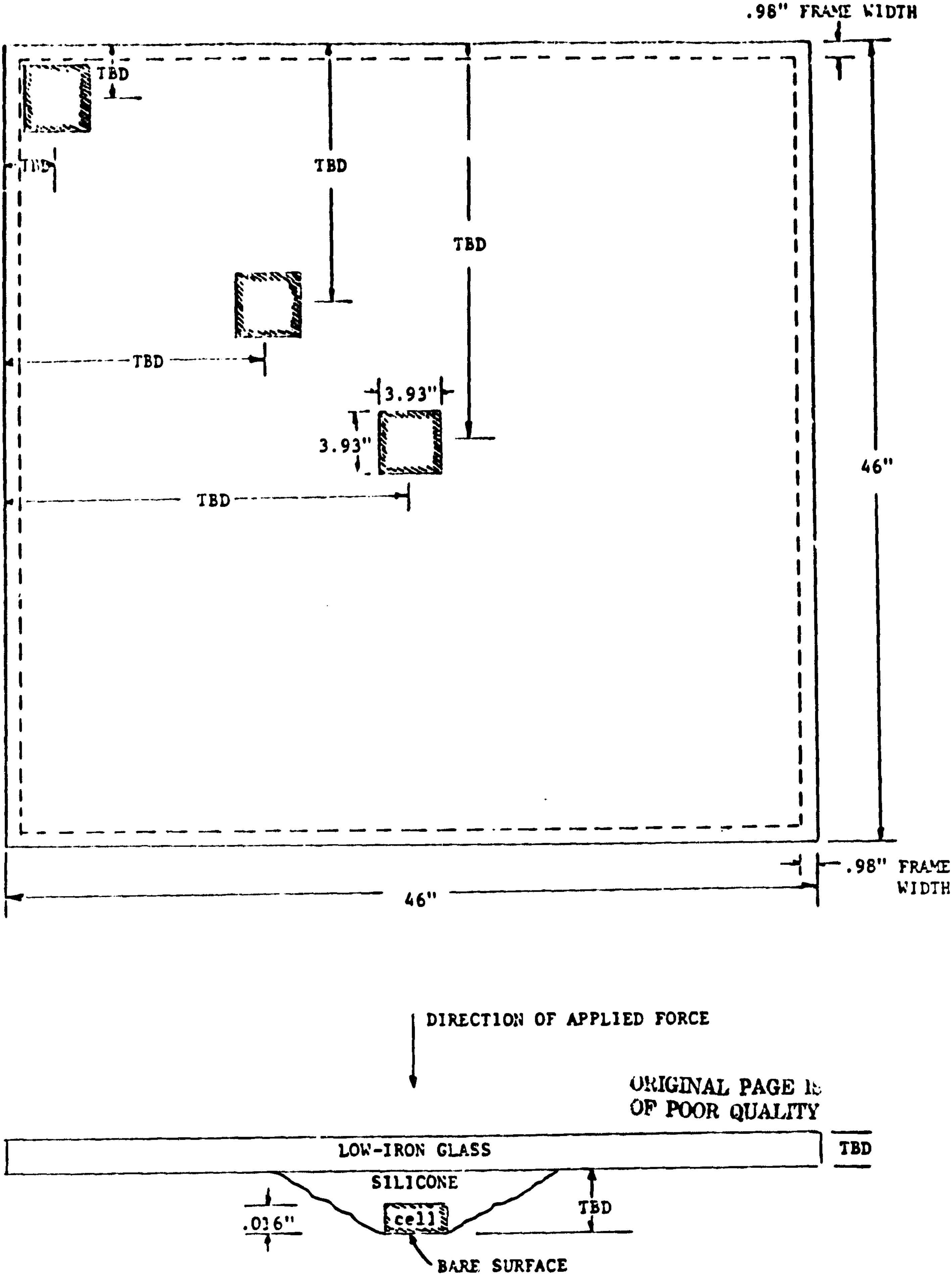

Figure 5. MODULE SOM-1, STRUCTURAL DEFLECTION TEST

3.3.5 Thermal Testing

Four minimodules, as designated in Table 6, will be used as test specimens for the thermal tests. Each minimodule will use nine single crystalline silicon cells, as shown in Figure 6. The back side emissivity of these modules will be changed during the test. Testing will be done in a controlled chamber.

Table 6

THERMAL VERIFICATION TEST SPECIMENS

MODULE NO.	TM-1	TM-2	TM-3	TM-4
Load Bearing Member	Low-Iron Glass	Mild Steel	Wood P	Wood P
Top Cover	-	Tedlar	Tedlar	Tedlar
Encapsulant	EVA/CG	EVA/CG	EVA/CG	EVA/CG
Encapsulant Thickness	18 mil	18 mil	18 mil	36 mil
Cell Type*	SC-2"Sq	SC-2"Sq	SC-2"Sq	SC-2"Sq
No. of Cells	9	9	9	9

*PC - polycrystalline silicon, AR-coated

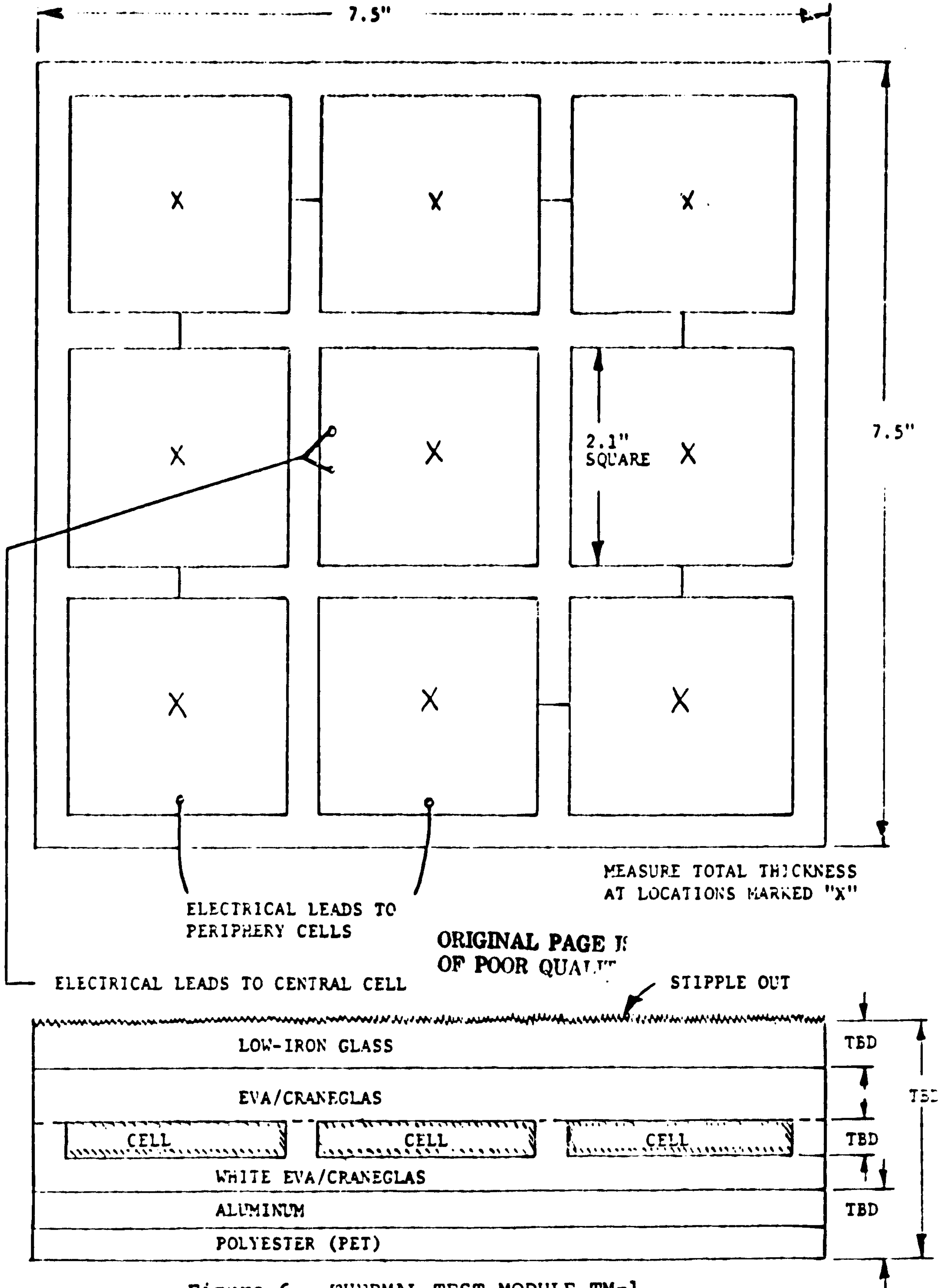

Figure 6. THERMAL TEST MODULE TM-1

4.0 CONCLUSIONS AND RECOMMENDATIONS

There are no conclusions and recommendations for this period.

5.0 PLANNED ACTIVITIES

The final Interim Report which describes Phase I results will be delivered to JPL. A Test Plan for Phase II will be delivered. Verification testing will continue with the completion of the optical, electrical, thermal structural, structural deflection, and thermal verification testing. Work will begin on the construction of the full size qualification module pending JPL okay of the module design.