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AN INVESTIGATION OF THE ADHESIVE BONDING OF TEFLON SOLAR CELL COVERS

by

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FOREWORD

The author wishes to acknowledge the assistance received from James Sovey, NASA Lewis Research Center, in the production of ion-beam texturized Teflon that was successfully used in this program of investigation. The cooperation of the Silicone Products Department, General Electric Company, with consultation and material services supplied by Dr. H. A. Vaughn, Jr., is also gratefully aknowledged.

SUMMARY

A five-month experimental program was conducted to find materials that not only would be compatible with Teflon film polymers also would make practical the use of these polymers as covers for the ultra-thin 50-micrometer thick solar cell in the space environment. The initial thrust was to screen materials that could be used as adhesives at the cell/cover interface. Based on a limited amount of test and evaluation of several materials, it was concluded that the widely-used DC93-500 was as good as any commercially available product known at this time, as long as it was protected from ultraviolet (UV) radiation by a suitable UV-screening agent.

Attention was then turned to techniques that might be incorporated into a polymeric cell cover system that would make it fully competitive with the universally-used glass cover system. An extensive examination of ultraviolet (UV) screening agents showed that there were several chemical systems that were effective UV-blocking agents with good visual band transmittance in optically-clear silicone resin solutions. Based on the work done in this program, a silicone hard coat resin incorporating a UV screening agent was selected as a suitable coating material for PFA Teflon solar cell covers. Further test and evaluation of this material will be required before space qualification of this polymeric cell cover system is assured.

SECTION 1.0

1.1 INTRODUCTION

The desirability of replacing glass solar cell covers with polymeric sheet has been recognized for some years (references 1 and 2). The fluorocarbon resins (at least the FEP and PFA systems) provide a nearly absorption free, optically-clean medium with good thermal properties and good resistance to ionizing radiation. The early attempts to use FEP Teflon as a cell cover were based on heat sealing the polymer to the cell surface directly, thus eliminating the problems associated with darkening and embrittlement of the adhesive with ultraviolet irradiation. This heat-sealed cover process proved to be impractical with ultra-lightweight, flexible blanket solar array designs because of the elevated temperature (~250°C) required in the heat sealing process (Reference 3). This high-bonding temperature created a correspondingly high-thermally induced stress. This stress together with UV-induced stress was sufficient to cause cover darkening and embrittlement (Reference 4).

The program was initiated with the understanding of these prior attempts to use sheet polymeric covers in lieu of the common glass-adhesive cover system. The initial thrust of work on this program was an attempt to find a commercially-available adhesive that would exhibit a higher resistence to degradation under the thermally-induced and radiation-induced stresses found in the space environment.

The program plan called for the definition of a solar array based on the newly-introduced 50-micrometer thick silicon solar cell (reference 3). The array design, developed earlier at GE Co. for JPL Pasadena, CA, that led to the development of a flexible blanket solar array with a specific power of 200 w/kg (ref. 4) was taken as the baseline design. This design calls for a 25-micrometer thick Kapton-H substrate, 50-micrometer thick cells

joined by 50-micrometer thick cell interconnects and a 75-micrometer thick polymeric cell cover.

A limited amount of qualification testing was conducted in this program namely, temperature shock and temperature-humidity. A mechanical stress test was included. Exposure to ultraviolet and ionizing radiation was not scheduled in this program.

Twenty 2-cell test samples were fabricated to support the above noted tests at G.E. Thirty single-cell samples were fabricated for subsequent testing at Lewis Research Center.

A change in work scope was proposed by G E Co., and approved by the NASA Program Manager at about the half-way point in the program. This change was instigated based on some related experimental work at GE that offered a new approach to the solution of the central problem; i.e., prevention of optical darkening and embrittlement of the polymeric cover system by UV radiation. A new concept was proposed for this solution; namely, coat the photon incident surface with a silicon hard coat that contains a UV-screening agent. This approach offers protection to both the cover polymer and the underlying adhesive. This solution appears to be new technology, as applied to solar cell covers, and has been documented as such for reporting purposes.

THE EXPERIMENTAL PROGRAM

2.1 SCREENING OF ADHESIVE

The intital screening of candidate adhesives was performed based on the following criteria:

1) Optical clarity and high "silicon-band" (400 nm to 1100 nm) transmittance.

2) Good adhesion to low-energy surfaces.

3) Retention of these physical and chemical properties over a wide range of temperatures (-185°C to 100°C) experienced in a thermal cycle and under conditions of high humidity and elevated temperature (90% RH & 65°C).

4) Low absorptance in the ultraviolet band between 200 nm and 400 nm.

From our own experience and other work in the field (reference 5), there is ample evidence that silicone systems rank at the top of polymeric systems for the purpose intended here. For this reason, the scope of our investigation was limited to the silicone resins listed in Table 2-1.

While all of these silicones are essentially optically clear, the relative resistance to embrittlement and darkening through exposure to ultraviolet was a major concern. The screening criterian used here is the total hemispherical transmittance in the spectral interval of 200 nm to 400 nm. Thin coatings of these materials were cast on 50-micro meter thick PFA - CLP.

The total hemispherical transmittance was measured using a Beckman Model UV-5240 spectrophotometer.

SILICONE ADHESIVE

TABLE 2 - 1

ADHESIVE (Manufacture)	TYPE	USEABLE TEMPERATURE RANGE (°C)	VISCOSITY (CPS)	HARDNESS (Shore A)	APPLICATION NOTE	COMMENTS
DC93-500 (Dow Corning)	Two Part Methyl Silicone Encapsulant	-65 to 200	8000	46	Crosslinks from solution @ room temperature.	Space Qualified TML* 0.35% VCM* 0.1%
RTV - 615 (GE Co.)	Two Part Methyl Silicone Encapsulant (Addition Cure)	-65 to 200	4000	45	Crosslinks from solution @ room temperature	Very similar to DC93-500
DCR-6103 (Dow Corning)	Two-part Methyl Silicone Junction Coating	-65 to 200	4000 to 6500	40	Crosslinks from solution @ 150°C	Low Permeability to water vapor
RTV - 567 (GE Co.)	Two Part Methyl-Phenyl Silicone Encapsulant (Condensation Cure)	-115 to 150	4600	24	Crosslinks from solution @ room temperature	Space Qualified TML 0.29% VCM 0.04%
SR-574 (GE Co.)	Single Component High Tack 13% Phenyl Adhesive	-160 to 260	15000 to 40000	NA	Remove solvent first, then Crosslink @ 160°C	Pressure Sensitive Adhesive
SR-573 (GE. Co.)	Single Component Tack Free 6% Phenyl Adhesive	-160 to 260	20000 to 50000	NA	Remove solvent first, then Crosslink @ 160°C	Pressure Sensitive Adhesive

*TML - Total Mass Loss

*VCM - Volatile Condenseable Mass

The screening for solar cell cover adhesives was terminated at this point to address the basic problem of polymer stability under UV irradiance more directly.

2.2 ULTRAVIOLET SCREENING AGENTS

The objective of this program is to find an adhesive that may be used to bond a polymer film, like PFA Teflon, to an AR-coated solar cell at a moderate temperature. It occurred to us that undue emphasis had been placed on the adhesive, since the aging property of the polymer sheet appears to be at least as important to the development of a successful replacement for the glass-adhesive system that is in wide use today, as the adhesive itself. Both fused silica and ceria-doped glass covers are inherently stable in the presence of UV radiation. The intrinsic high absorbtion for UV seen with the ceria glass protects the underlying adhesive from degradation by the UV. On the other hand, since fused silica does not absorb in the 230- to 400-mm region of the spectrum, fused silica covers must be coated with a UV rejection (reflection) filter. In either case, it is the UV blocking properties of the inorganic cell cover that accounts for the success that the glass adhesive system has enjoyed.

All the adhesives available to this program fall into one of the following categories of experience:

1) Appropriate for terrestrial UV exposure,
2) Not appropriate as optically-clear media
3) Good life under space UV conditions as long as they are protected by UV reflection or absorption filter media; eg., ceria glass.

All of the silicones, acrylics, and fluorinated polymers and co-polymers, with few exceptions, fall into the first category. The di-methyl silicone resins are to be preferred over the methyl-phenyl resins from the UV absorption point of view. Unless these materials can be protected by UV screens, however, as in the case of the glass covers, they will break down under space UV conditions.

The Wacher Chemie S-191 RTV silicone falls into the second category in that it is red in color and only appropriate as a substrate adhesive.

This narrows the selection of appropriate adhesive down to cases where UV screening has been effective in protecting the adhesive from degradation in optical transmittance and elasticity. A review of UV screening agents was deemed necessary so that a strategy could be formulated for the attainment of a UV-proof polymeric cover-adhesive system.

2.3 SOLAR CELL TEST SAMPLES

The program plan called for the fabrication of twenty 2-cell test samples for test and evaluation at GE in addition to thirty single-cell samples to be delivered to Lewis Research Center. The construction of these samples closely followed the array design shown in Figure 2-1, developed earlier for the JPL 200-Watt/Kilogram Solar Array Program (Reference 4). Key to this design is the ultra-thin 50-micrometer thick silicon solar cell, the welded silver-plated Invar cell interconnects, the flexible Kapton-H substrate, and the FEP (or PFA) Teflon-cover material. The configuration for the 2-cell sample is shown in Figure 2-2.

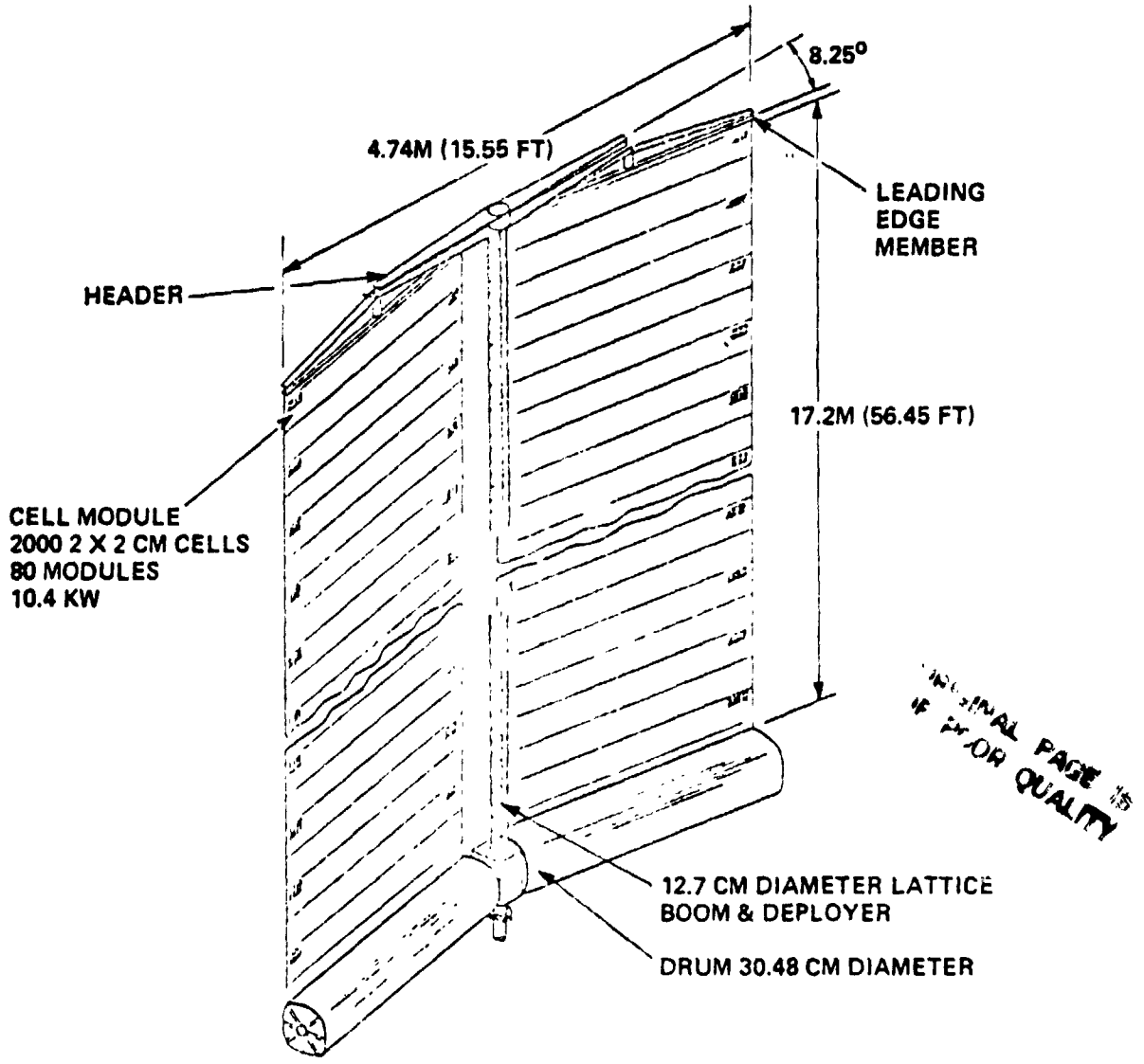


Figure 2-1a. Generic Solar Array Design, 10KW Capacity

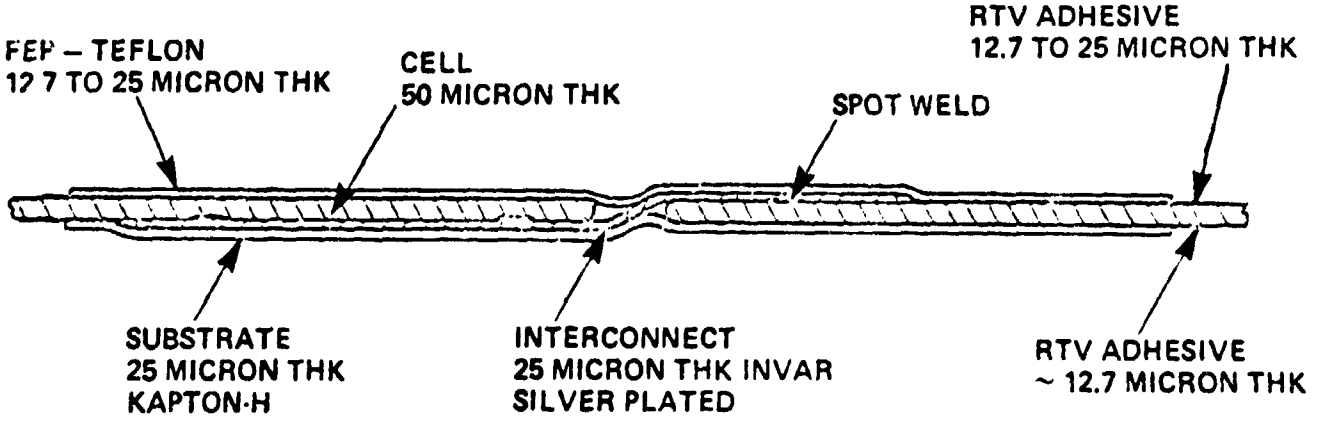


Figure 2-1b. Blanket Cross-Section

TEST SAMPLE CONFIGURATION

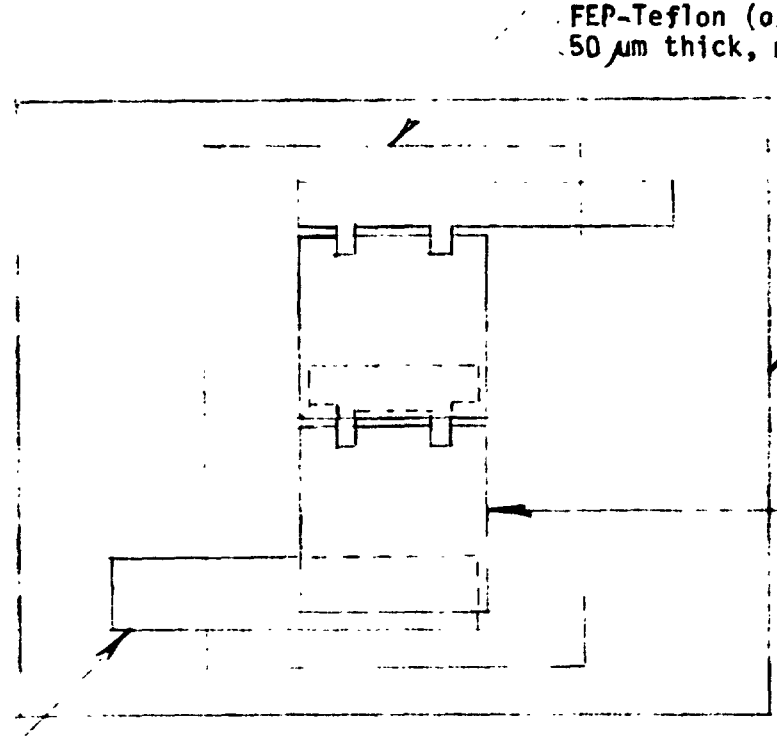


FIGURE 2 - 2

2.4 TEST AND EVALUATION OF SAMPLES

Two sets of tests were conducted on the 2-cell samples. Electrical performance was measured after weld bonding, cover bonding to the cell, and before and after each new stress was applied to the samples.

The flexibility and temperature humidity test sequence went as follows:

Flexibility Test - wrap cells over 25-cm diameter drum

Electrical Performance Measurement

Temperature - Humidity Test - 65^{o}C and 100% R. H. for 10 days

Electrical Performance Measurement

The thermal shock test sequence consisted of rapid temperature cycling of the cell from 100^{o}C to -185^{o}C fifteen times with a 5-minute soak at each end. Electrical performance was measured afterwards.

Optical transmittance measurements were taken throughout the fabrication phase and in one case after the temperature shock test when one of the cell covers was peeled off. Similarly optical transmittance data was taken on four different silicone primers as a means of selecting the preferred one.

SECTION 3.0

TEST EQUIPMENT AND PROCEDURES

3.1 DIAGNOSTIC TESTING

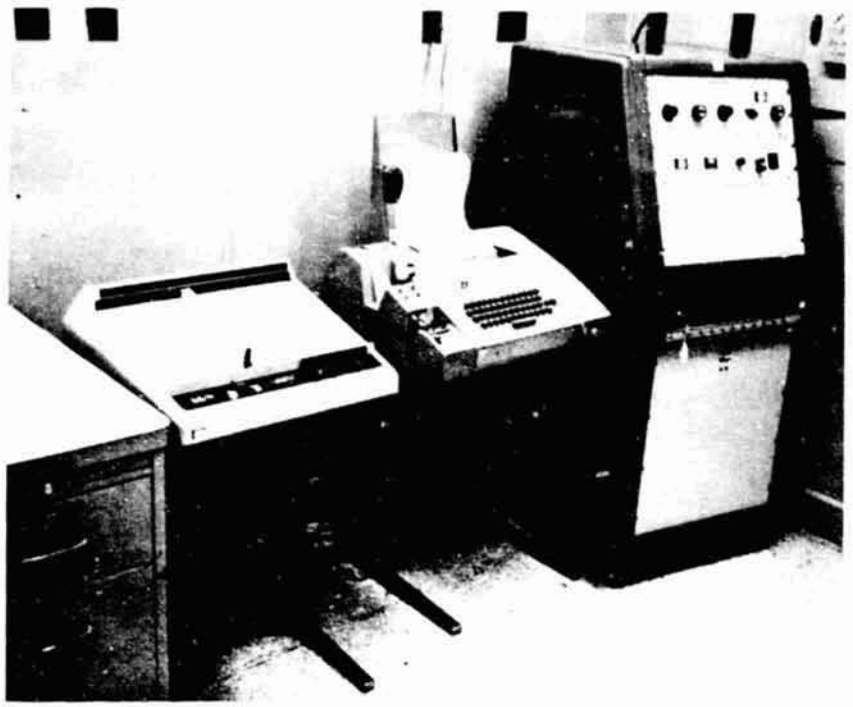
The Beckman Model UV-5240 spectrophotometer was used with the integrating sphere attachment to obtain total hemispherical transmittance as a function of wavelength between 200-nm and 800-nm on cell cover material, adhesive and coatings. Silicone films were cast on type CLP 200 PFA Teflon. A one cm quartz cell was used in the case of fluids, like the silicone primers. In every case, a 100% curve was taken to normalize the transmission data.

The electrical performance of the solar cell samples was recorded using the Spectrolab Large Area Pulsed Solar SImulator (LAPSS) Figure 3-1, and a 1 X 2 cm^2-shallow junction, Hybrid A type, reference cell , also from Spectrolab. The cells were measured under AM0 conditions with the data base adjusted for laboratory temperature. Current-voltage curves were taken after welding, after cover attachment and after each step in the testing process.

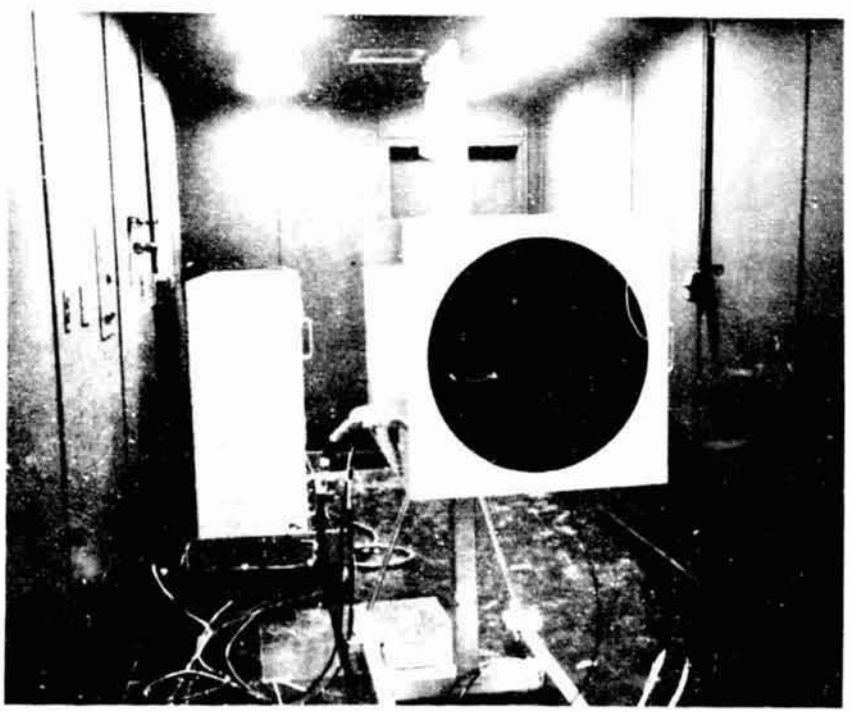
3.2 THERMAL SHOCK TESTING

An 18" vacuum belljar facility,

thermal shock test. An exploded view of the thermal platens and the sample under test is shown in Figure 3-3. Two thermocouples, one for Figure 3-2, was used to conduct the control, the other for recording, are soldered to one of the cell interconnects. A half-cycle timer is adjusted for the optimum cold and hot-half-cycle periods. The operation is such that on the hot-half-cycle, the electrical heater is on. During the cold cycle the electrically-controlled solenoid valve is open allowing LN_2 to flow to the platens. In this manner, a hot-half-cycle of 20 minutes and a cold-



a. Data Console, Printer and Plotter



b. Pulsed Arc Lamp

Figure 3-1. Large Area Pulsed Solar Simulator

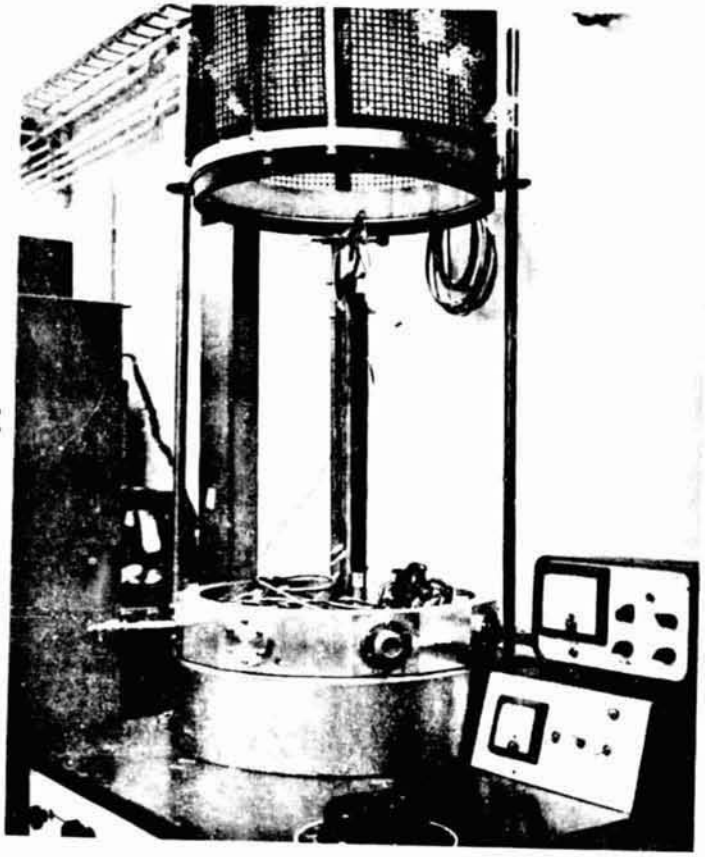


Figure 3-2.
Vacuum Belljar
Test Station

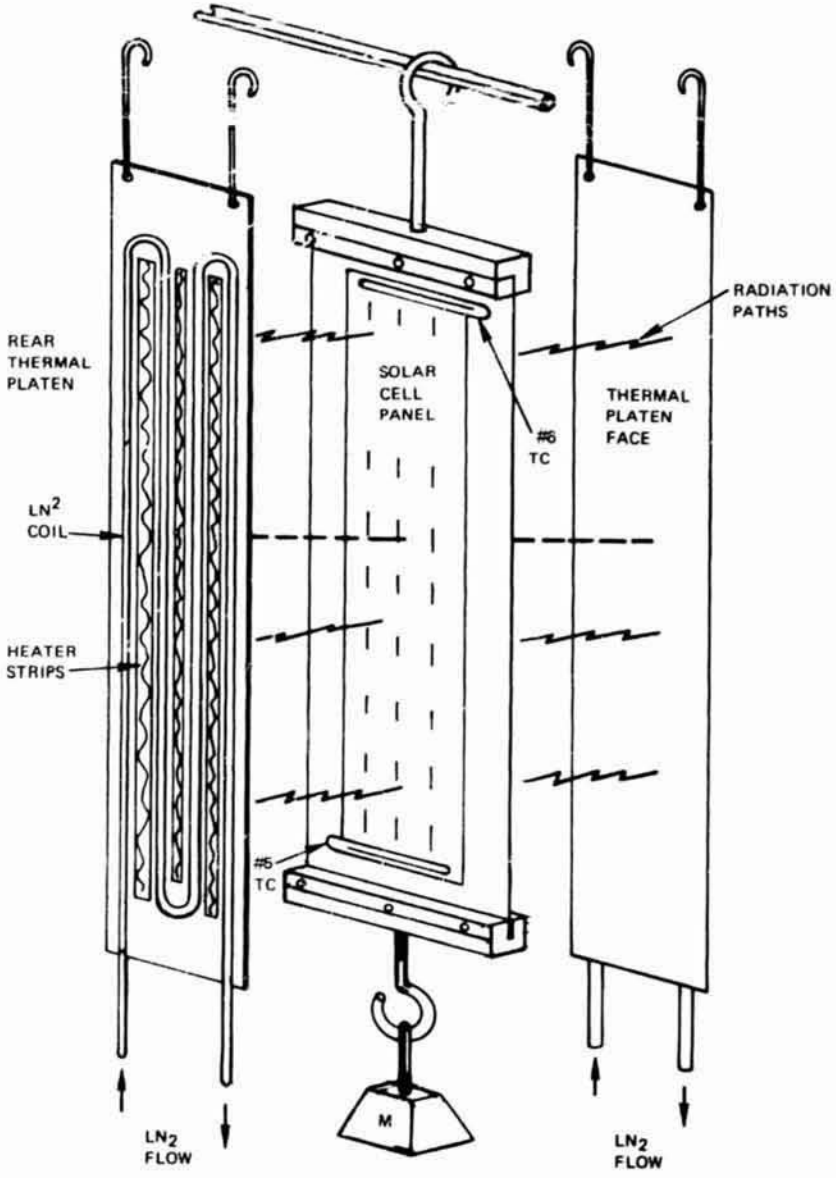


Figure 3-3.
Thermal Vacuum Test Setup
Exploded View

half-cycle of 21 minutes was achieved with a 5-minute soak at both ends.

3.3 TEMPERATURE - HUMIDITY TEST

This test was conducted by suspending the samples over water of a 4-liter beaker. The beaker and samples were then completely encased in a large polyethylene bag and placed in a 65°C oven. The top of the bag was adjusted so that condensed water vapor would drain back to the liquid in the bottom of the beaker.

3.4 FLEXURE TEST

Four single-cell samples were wrapped around a 25-cm diameter cylinder and taped in place, see Figure 3-4. This procedure was repeated five times. The electrical performance of the cells was measured after the last flexure cycle.

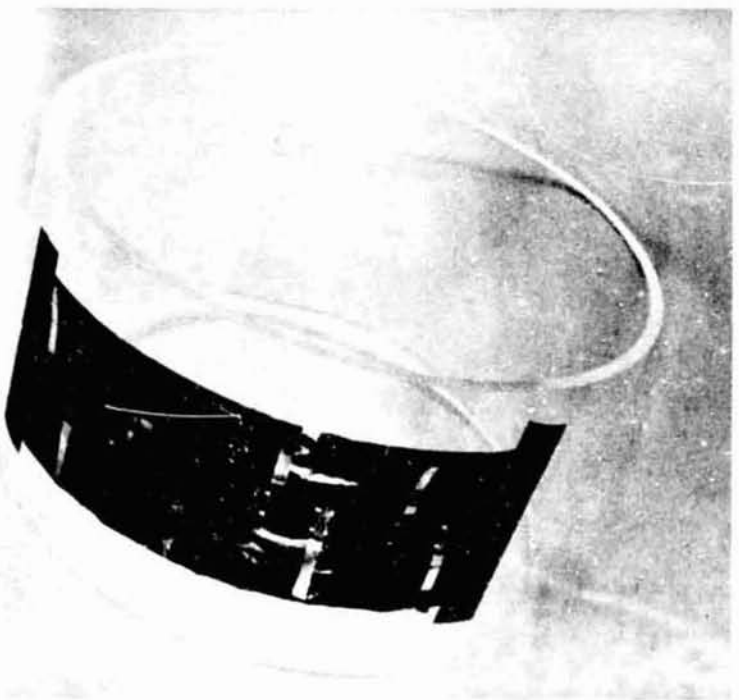


Figure 3-4. Flexure Test Fixture

SECTION 4.0

TEST RESULTS

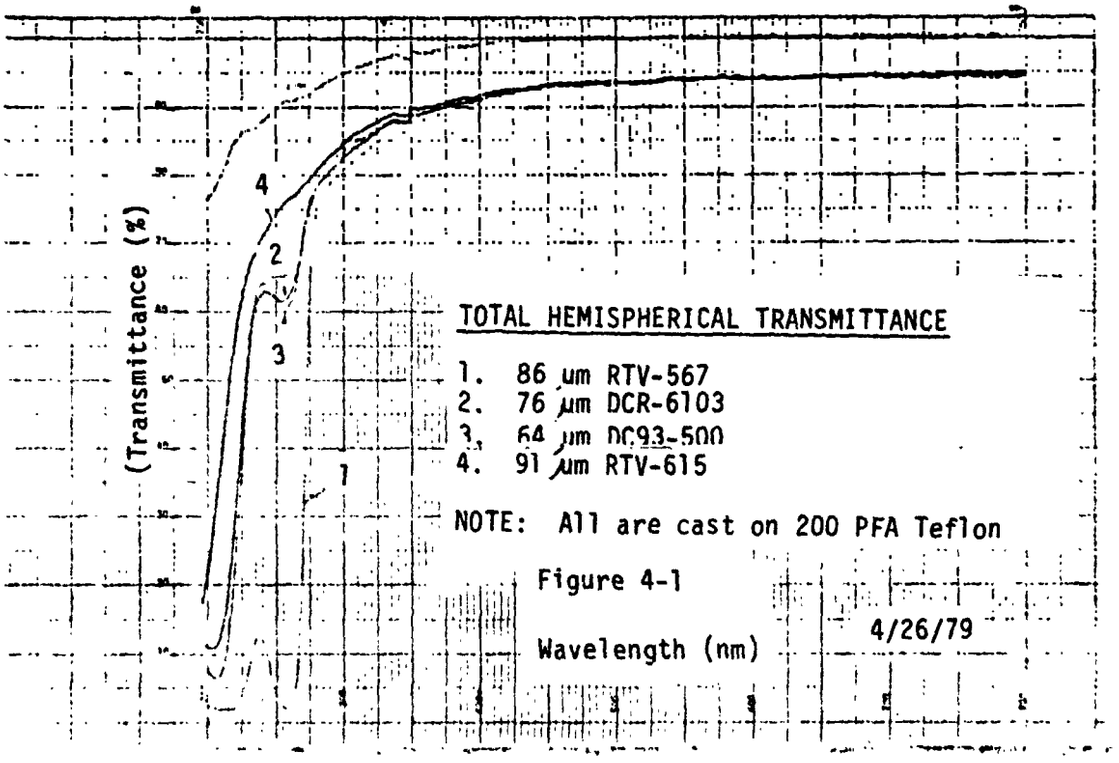
4.1 EXPLORATION OF MATERIALS AND TECHNIQUES

4.1.1 ADHESIVES

The spectral transmittance of the leading candidate silicone adhesives is shown in Figure 4-1 and 4-2. The corrected transmittance at selected wavelengths is given in Table 4-1. Since all these silicones were cast on the same transparent substrate (PFA Teflon), and the index of refraction of each is approximately the same ($1.41 < n < 1.44$), the absorption coefficients for each may be calculated based on the thickness of each cast film, see Table 4-2. Finally, a ranking of these silicones may be made based on these calculated absorption coefficients, see Table 4-3. Based on this data, the RTV-615 silicone would be the least affected by ultraviolet and SR574 the most affected. This correlates with the fact that RTV-615 is a di-methyl silicone, whereas the SR 574 is a 13% phenylsilicone. This propensity of the methyl-phenyl silicones to absorb more in the ultraviolet has been observed on earlier occasions (Reference 4). On an equal exposure basis, then, RTV-615 should darken and embrittle the least and, therefore, would be the adhesive of choice.

4.1.2 COVERS

A spectral analysis of polymeric cover materials was made in a similar manner to see which material had the least absorption in the ultraviolet. These data are shown in Table 4-4. The fluorocarbons absorb the least while Tedlar-UT and Tedlar XRB absorb the most. The latter was puzzling, at first, because the manufacturer (DuPont) has developed the XRB type for solar collector glazing. Note that the transmission falls abruptly from 86% at 500 nm to 9% at 350 nm. Note the similarity to the type UT Tedlar. In a we thering test conducted in Florida, the XRB material retained 95% of its original transmission after 5 years



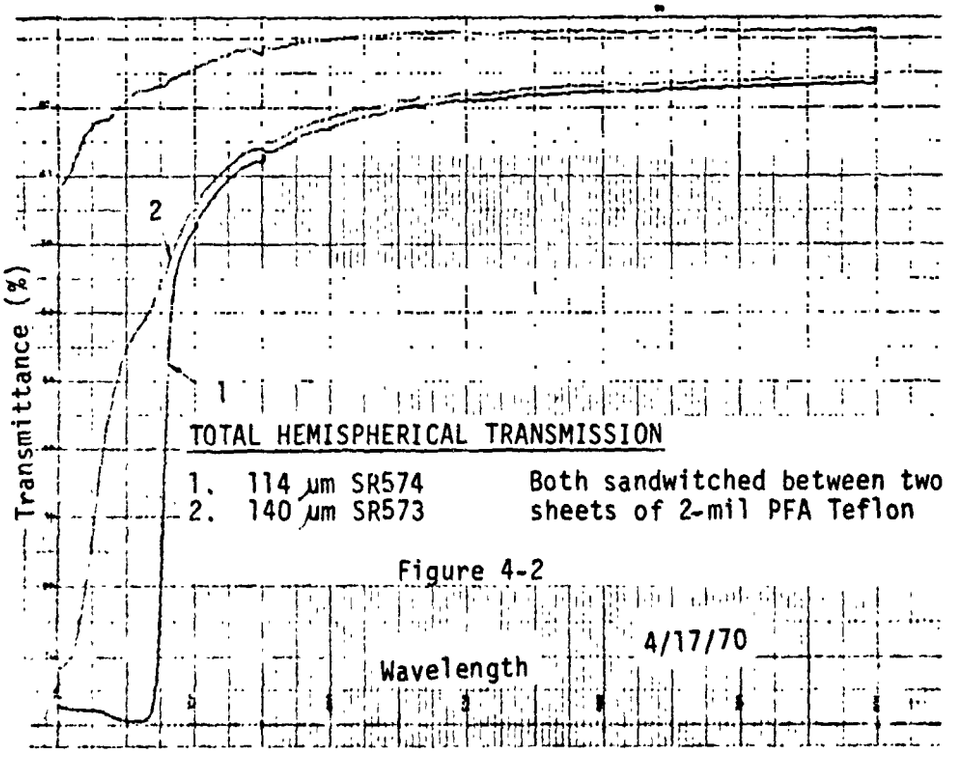


Table 4-1. Total Hemispherical Transmittance at Selected Wavelengths

MATERIAL*	WAVELENGTH (NM)						SAMPLE THICKNESS (NM)
	200	250	300	350	400	800	
DC93-500	0.10	0.69	0.88	0.91	0.92	0.94	64
RTV-615	0.29	0.82	0.89	0.92	0.93	0.94	91
DCR-6103	0.14	0.69	0.87	0.91	0.92	0.94	76
RTV-567	0.03	0.04	0.85	0.90	0.91	0.94	86
SR-574	0.03	0.01	0.75	0.84	0.86	0.92	114
SR-573	0.11	0.60	0.78	0.86	0.88	0.93	140

*All were cast on 50-micrometer thick PFA Teflon

Table 4-2. Optical Absorption Coefficients @ Selected Wavelengths

MATERIAL	CALCULATED ABSORPTION COEFFICIENTS (μm^{-1})					
	200 nm	250 nm	300 nm	350 nm	400 nm	800 nm
DC93-500	3.6 (10^{-2})	5.8 (10^{-3})	2.0 (10^{-3})	1.47 (10^{-3})	1.3 (10^{-3})	9.7 (10^{-4})
RTV-615	1.4 (10^{-2})	2.2 (10^{-3})	1.3 (10^{-3})	9.2 (10^{-4})	8.0 (10^{-4})	6.8 (10^{-4})
DCR-6103	2.6 (10^{-2})	4.9 (10^{-3})	1.8 (10^{-3})	1.24 (10^{-3})	1.1 (10^{-3})	8.1 (10^{-4})
RTV-567	4.1 (10^{-2})	3.7 (10^{-2})	1.9 (10^{-3})	1.22 (10^{-3})	1.1 (10^{-3})	7.2 (10^{-4})
SR-574	3.1 (10^{-2})	4.0 (10^{-2})	2.5 (10^{-3})	1.53 (10^{-3})	1.3 (10^{-3})	7.3 (10^{-4})
SR-573	1.6 (10^{-2})	3.6 (10^{-3})	1.77(10^{-3})	1.1 (10^{-3})	9.1 (10^{-4})	5.2 (10^{-4})

where absorptance = $-\frac{\ln \tau}{x}$

and τ = total hemispherical transmittance

x = sample thickness in μm

Table 4-3. Ranking of Silicones by Absorption Coefficient

MATERIAL	WAVELENGTH (NM)					TOTAL SCORE
	200	250	300	350	400	
DC93-500	5	4	5	5	4	23
RTV-615	1	1	1	1	1	5
DCR-6103	3	3	3	4	3	16
RTV-567	6	5	4	3	3	21
SR-574	4	6	6	6	4	26
SR-573	2	2	2	2	2	10

TABLE 4-4

OPTICAL TRANSMITTANCE OF SHEET POLYMERS

MATERIAL (Thickness)	TYPE	TOTAL HEMISPHERICAL TRANSMITTANCE 200 nm	300 nm	350 nm	400 nm	800 nm	1100 nm
FEP-A (50 μm)	Fluorinated Co-polymer	0.89	0.91	0.92	0.93	0.95	0.95
FEP-C (50 μm)	Same as A type	0.92	0.91	0.92	0.93	0.95	0.95
PFA-CLP (50 μm)	Perfluoro-alkoxy fluorocarbon	0.83	0.92	0.93	0.94	0.95	0.95
PFA-CP (50 μm)	Same as LP Type but cementable	0.81	0.91	0.93	0.94	0.95	0.96
TEFZEL (50 μm)	Copolymer of ethylene and TFE	0.80	0.92	0.93	0.94	0.95	0.95
Tedlar-TR (25 μm)	Polyvinyl	0.32	0.85	0.89	0.91	0.92	0.92
TFE (125 μm)	Fluorinated	0.22	0.42	0.50	0.55	0.83	0.90
PES (50 μm)	Polyether-sulfone	0.13	0.02	0.76	0.84	0.89	0.89
HALAR (50 μm)	Copolymer of ethylene & chlorinated TFE	0.16	0.91	0.90	0.91	0.93	0.94
UDEL (100 μm)	Polysulfone	0.04	0.00	0.66	0.84	0.89	0.90
ARDEL (50 μm)	Polyarylon	0.00	0.00	0.33	0.85	0.91	0.90
Tedlar-UT (25 μm)	Polyvinyl	0.00	0.00	0.01	0.86	0.92	0.92
Tedlar - XRB (100 μm)	Polyvinyl fluoride	0.00	0.00	0.09	0.86	0.92	0.92

in the Florida sun. The conclusion to be drawn from this data is that UV hardening has been imparted to the Tedlars by blocking out or screening the UV. Tedlar XRB and Tedlar UT must have a small percentage of a screening agent incorporated into the resin itself, or applied to the surface, or both. This UV protection, achieved in Tedlar, pointed the way to what we desired in this program; i.e., a UV screen effective down to 200 nm. The question of whether this same type of modification could be applied to the Teflons led to an investigation of UV screening agents.

4.1.3 ULTRAVIOLET SCREENING AGENTS

Both RTV-615 silicone and the proprietary GE experimental SHC-1000 silicone hard-coat resin were used as host materials. These materials are free of the phenyl group and, therefore, show a minimal amount of UV absorption. The silicone hard coat has the added feature of a hard, low-tack surface. It goes on as a thin film, typically 25 to 35 micrometers thick, while the RTV silicone is most conveniently cast as a 50- to 75-micrometer thick coating. Teflon, PFA or FEP, 50 micrometers thick was used as the substrate in both cases. Ultraviolet screening agents are available commercially from the following companies:

- American Cynamid Co., Bound Brook, NJ — Cyasorb 5411, Cyasorb UV24
- Argus Chemical Corp. Brooklyn, NY — Mark 1413, Mark 1535, Mark 446
- Ciba-Geigy Corp. Ardsley, NY — Tinuvin 327, Tinuvin P, Tinuvin 328, Tinuvin 770
- Sandoz Colors & Chemicals E. Hanover, NJ — Sanduvor N-PU, Sanduvor E-PU

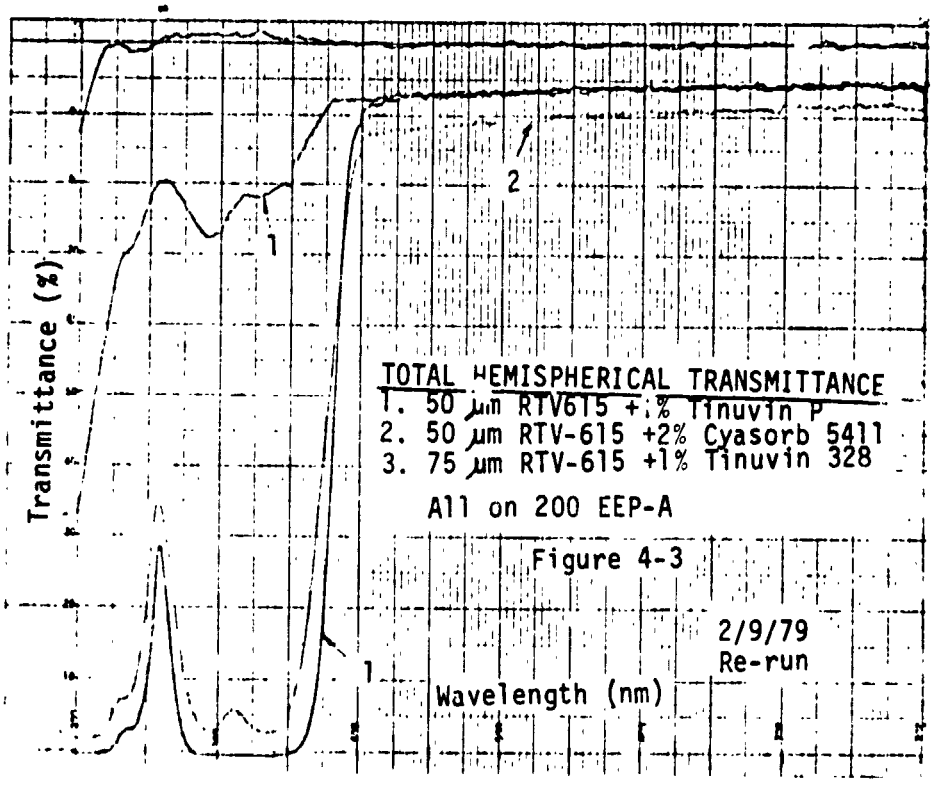
Small quantities of the screening agents were added to the host material as a means of filtering out the UV by absorption and dissipation as heat. In principle, then, the UV screening agent acts as a filter to prevent bond scission and color center formation. The results using a UV-screening agent in thin films of RTV-615

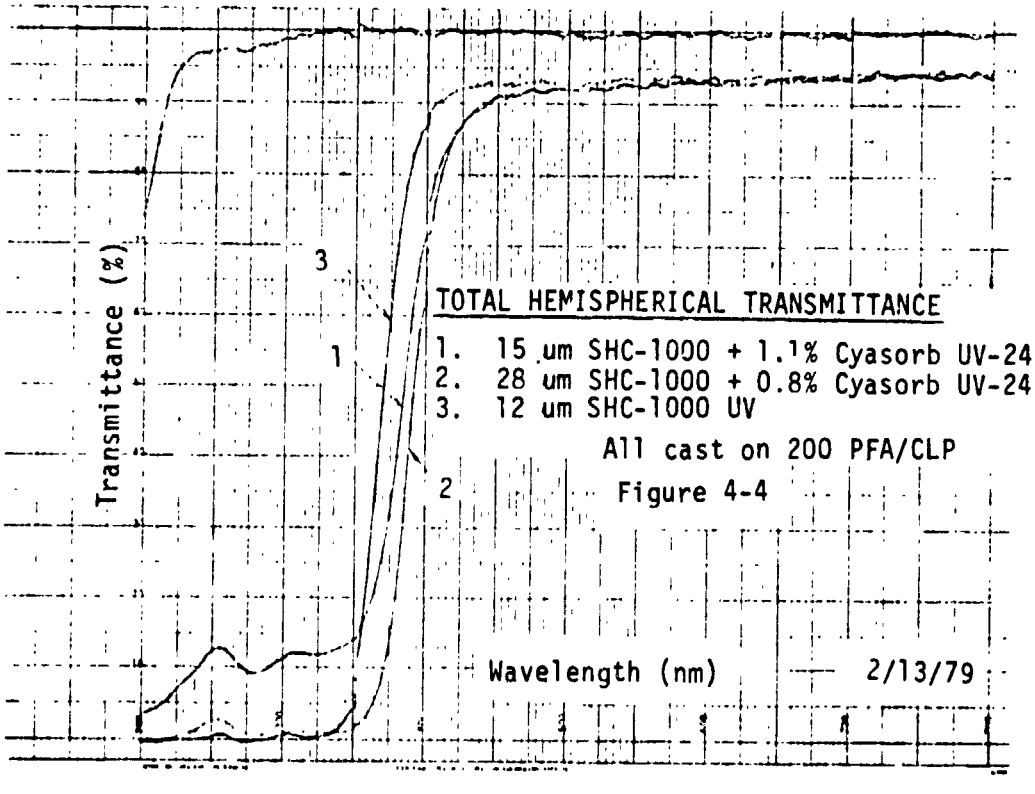
are shown in Figure 4-3 and in Table 4-5, The Cyasorb 5411 and Tinuvin 328 appeared to be the most effective in blocking the UV. Note the comment about re-crystallization in the case of a 1% solution (by weight) of Tinuvin 327. Re-crystallization occurs at room temperature when the solubility limit given by the manufacturer is approached. Another solvent may be indicated here. The transmittance peak at 256 nm is not desired in the case of extra-terrestrial usage of these coatings since there is appreciable UV below 300 nm outside of the earth's atmosphere.

The results using GE SHC-1000 as a host material are shown in Table 4- . Again, the objective of total blockage of the UV radiation below 400 nm was not achieved. Only the Cyasorb UV-24 gave almost complete rejection of the UV below 400 nm as shown in Figure 4-4, Curve #2. A new proprietary GE Co. material known as SHC-1000 UV became available. This is the same basic material as the SHC-1000 with a UV-screening agent added. The almost complete blockage achieved with 12 micrometers of this material is seen in Figure 4-4, Curve #3. A 25-micrometer thick coating does provide complete blockage in the UV, see Figure 4-5. These data (Figure 4-5) was taken after 15 cycles of thermal shock (-185°C to 100°C). There was no deterioration in the filter properties or its adherence to the PFA Teflon substrate. With the arrival of the SHC-1000 UV material, further search for a better UV-screening agent was dropped.

4.1.4 PRIMERS

A screening of four silicone primers was made on the basis of UV and visible transmittance. Since these materials are available as fluids, a one-cm quartz cell was





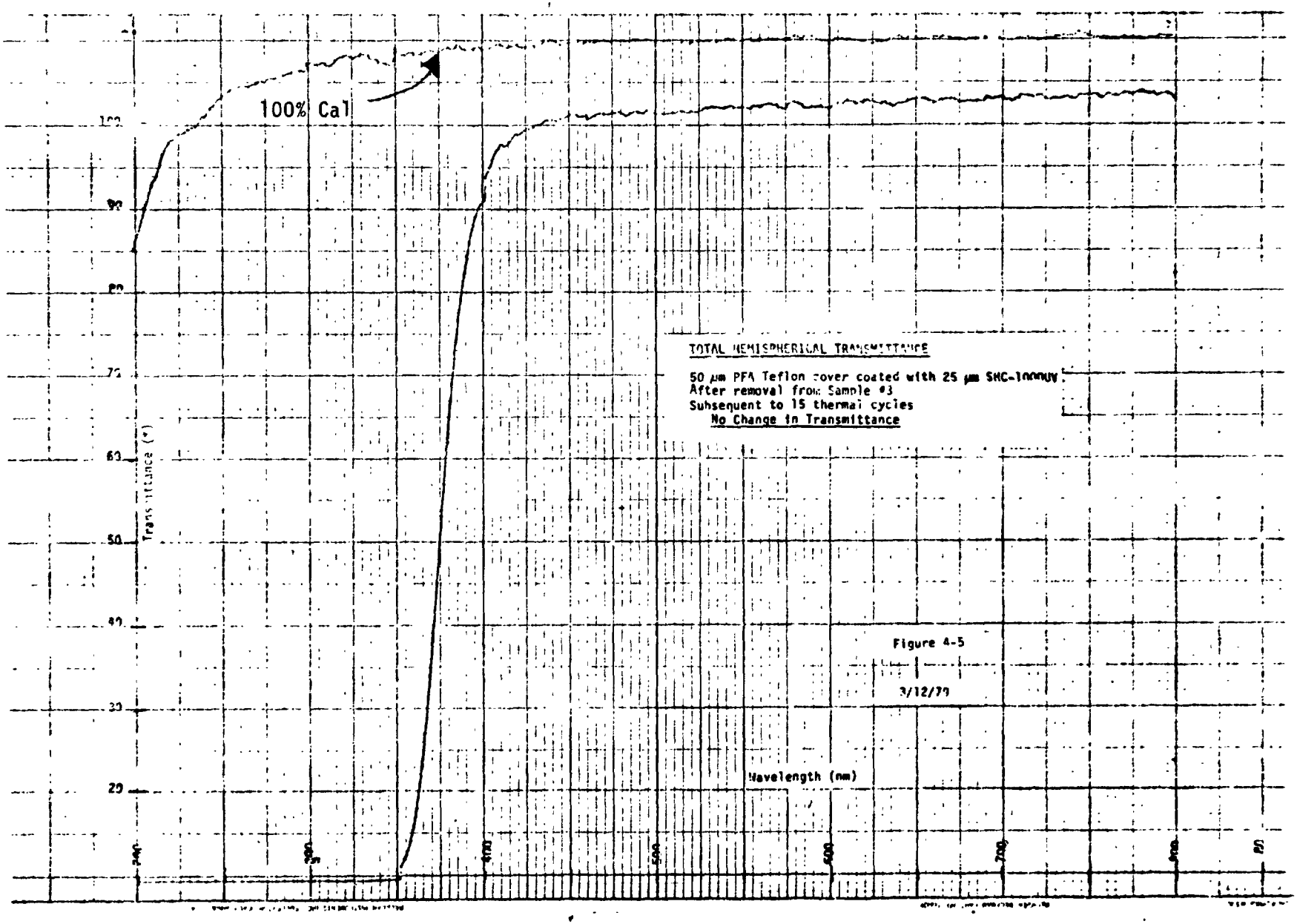


TABLE 4-5

UV SCREENING AGENTS IN

RTV SILICONE

MATERIAL (Thickness)	TOTAL HEMISPHERICAL TRANSMITTANCE					
	200nm	250nm	300nm	350nm	400nm	500-800nm
RTV-615 (100 μm)	0.16	0.80	0.88	0.92	0.93	0.94
PFA-CLP (50 μm)	0.69	0.85	0.90	0.92	0.93	0.95
RTV-615 Plus 1% Tinuvin-P (50 μm)	0.38	0.78	0.72	0.81	0.92	0.94
RTV-615 Plus 2% Cyasorb 5411 (50 μm)	0.02	0.18	0.00	0.00	0.92	0.94
RTV-615 Plus 1% Tinuvin 328 (75 μm)	0.00	0.10	0.00	0.00	0.90	0.94
RTV-615 Plus 1.8% Tinuvin 770 (75 μm)	0.03	0.78	0.85	0.89	0.92	0.94
RTV-615 Plus 0.5% Sanduvor N-PU (75 μm)	0.08	0.58	0.78	0.87	0.92	0.94
RTV-615 Plus 1% Tinuvin 327 (75 μm) (Re-crystallized)	0.00	0.14	0.02	0.02	0.84	0.94

NOTES: All films cast on 200 PFA-CLP Teflon

Table 4-6

UV SCREENING AGENTS IN

SILICONE HARD COAT RESIN

MATERIAL (Thickness)	TOTAL HEMISPHERICAL TRANSMITTANCE					
	200nm	250nm	300nm	350nm	400nm	500-800nm
SHC-1000 (5 μm)	0.62	0.85	0.90	0.92	0.93	0.94
SHC-1000 Plus 0.26% EPU (5 μm)	0.18	0.61	0.57	0.86	0.92	0.94
SHC-1000 Plus 0.23% NPU (5 μm)	0.35	0.57	0.75	0.87	0.92	0.94
SHC-1000 Plus 0.44% Tinuvin 770 (12 μm)	0.46	0.83	0.87	0.90	0.92	0.94
SHC-1000 Plus 0.5% Cyasorb 5411 (5 μm)	0.04	0.54	0.20	0.25	0.92	0.94
SHC-1000 Plus 0.5% Tinuvin 328 (5 μm)	0.05	0.57	0.29	0.32	0.91	0.94
SHC-1000 Plus 0.23% Tinuvin P (5 μm)	0.34	0.76	0.65	0.71	0.92	0.94

NOTE: All samples cost on 200 PFA-CLP Teflon

used. A comparison of the total hemispherical transmittance is shown in Table 4-7. The material commonly known as HMDS* (hexamethyldisilazane) shows the best overall transmittance. This material was used exclusively in priming the cell and cover surfaces.

Table 4-7. A Comparison of Silicone Primers

	TOTAL HEMISPHERICAL TRANSMITTANCE (RELATIVE) (1 cm path length)					
	200 nm	250 nm	300 nm	350 nm	400 nm	500-800 nm
SS-4044	0.00	0.00	0.00	0.00	0.30	>0.95
SS-4120	0.00	0.00	0.40	0.85	0.95	>0.95
SS-4155	0.00	0.00	0.00	0.15	0.35	~0.45
HMDS	0.00	0.07	0.80	0.96	0.97	0.97

4.2 FABRICATION, TEST AND EVALUATION FABRICATION

Thirty single-cell samples were fabricated for delivery to NASA Lewis Research Lab. using the following materials from the substrate up:

- Substrate - 25-micrometer Kapton-H
- Adhesive - 25-micrometer DC93-500
- Solar Cell - 50-micrometer Silicon
- Adhesive - 25-micrometer DC93-500
- Cover - 50-micrometer PFA Teflon
- Coating - 25-micrometer SHC-1000 UV Silicone

An additional twenty 2-cell test samples were fabricated using the same materials for test and evaluation at GE Co.

*PCR Research Chemicals, Inc.
Gainesville, FL 32602

4.2.1 PERFORMANCE TESTING

An electrical output measurement was made after each major step in the fabrication cycle as well as after each stress test. A printed record of current voltage and a plot of these parameters as the cell load is changed (see Figure 4-6) serves to document the health of the cell throughout the fabrication, test and evaluation cycle. Short-circuit current and maximum powers have been tabulated together with the deltas at each step, so that the trend and magnitude of the change in these parameters may be noted. A sampling of this data for the single-cell samples is shown in Table 4-8. It should be noted that because of incidental production problems, 17 of these samples were not good examples of optically clear and intact coatings. That the loss in short-circuit current and maximum power shown for these 17 samples is not what can be achieved may be seen by examination of the same parameters for the last four samples listed. There should be little (1%) or no loss in I_{sc} and P_{mp} with a good UV screen-coated cover.

4.2.2 TEMPERATURE-HUMIDITY TESTING

Two separate temperature-humidity tests were conducted with three 2-cell samples under test in each case. The samples were exposed to 65°C and 100% relative humidity. The first test lasted 10 days and the second 13 days. Test samples #6 and #7 showed signs of delamination at the coating/cover interface, This was analyzed as an adhesion problem because of inadequate etch of the PFA Teflon.

The second test lasting 13 days was run on samples covered with PFA that had been severely modified by ion beam etching of both surfaces by J. Sovey, Lewis Research Center. In addition, the manufacturing process was changed at this point; i.e., the silicone hard coat was applied after the cells were bonded to the Kapton-H substrate. Also, an accidental embossing of the cell covers resulted as a consequence of using a woven parting cloth in the cover bonding. While the ion beam modification of

Figure 4-6 a

SAMPLE #8B
Single 2-mil cell after folding

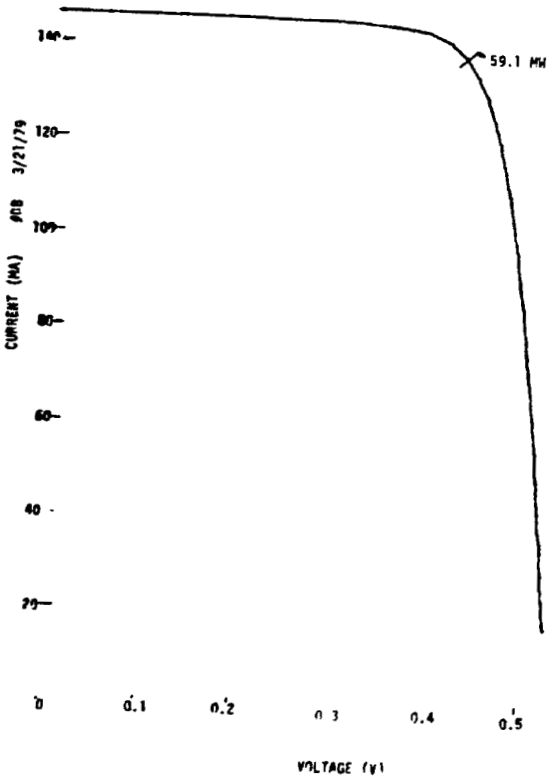


Figure 4-6 b

SAMPLE #8B
SINGLE 2-MIL CELL AFTER PFA/SHC-1000 UV COVER

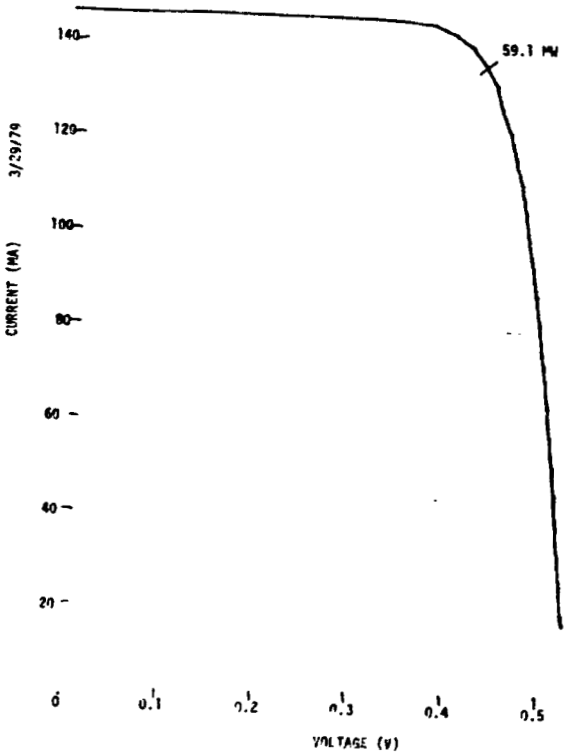


Table 4-8. Electrical Performance Before & After Coated PFA Teflon Covers

CELL #	AFTER WELDING ISC (MA)	AFTER WELDING PUMP (MW)	AFTER COVER ΔISC (MA)	AFTER COVER ΔPUMP (MW)	COMMENTS
D'	146	59.3	-5	-2.8	
E'	139	53.9	-4	-2.5	
F'	143	56.5	-5	-2.6	Samples D' through V' were not optically clear coatings. Almost all showed signs of poor adhesion of the SHC-1000 to the PFA cover.
H'	140	55.3	-5	-2.9	
I'	142	56.9	-5	-2.3	
J'	145	58.0	-4	-2.0	
K'	144	56.3	-4	-2.5	
L'	139	54.9	-5	-2.9	
M'	145	59.2	-4	-3.5	
N'	145	57.8	-1	-1.3	
O'	146	60.8	-2	-2.5	
P'	145	58.6	-4	-2.5	
Q'	140	56.6	-4	-2.0	
R'	138	55.0	-5	-3.4	
S'	148	61.2	-4	-3.1	
U'	133	53.4	-1	-0.7	
V'	141	57.1	-3	-2.6	
Ave. Value	142	57.1	-4	-2.5	
X'	143	58.0	+1	-0.1	These 4 samples were optically clear without any separations.
Y'	140	59.1	±0	-0.3	
Z'	142	58.0	+2	+0.5	
BB	146	59.1	±0	+0.0	
Ave. Value	145	58.6	+0.75	+0.0	

the PFA Teflon proved to be a major step forward, the application of the silicone hard coat to an embossed surface proved to be a retrogression. As a consequence of these procedures, the second set of test samples showed generalized flaking of the silicone hard coat after the conclusion of the 13-day test. The lessons learned through this testing are:

1. Good adhesion of both silicone hard coat and silicone adhesive may be had with PFA Teflon if it is first modified by an ion beam etch.
2. A smooth parting sheet; i.e., Kapton-H should be used during the cover bonding step, and
3. The silicone should be at least 25 micrometers thick to resist the invasion of water vapor.

The electrical performance history of both sets of test samples is shown in Table 4-9.

4.2.3 THERMAL SHOCK TEST

Two thermal shock tests were run using three 2-cell test samples in each case. The first test went 17 cycles and the second was 10 cycles in length. In each case, the samples were cycled between -185°C and 100°C with a 5-minute soak at each end. The rate of change during cooldown was about 11°/minute, while on warmup was approximately 15°/minute. Again, the first test was run with PFA covers with an inadequate surface etch, while the covers in the second test were those PFA covers modified at Lewis Research Center. These tests uncovered no new problems. None of the cells were cracked during the second temperature shock tests, nor was there any delamination or checking of the silicone hard coat. The electrical performance of these test samples is listed in Table 4-10. The optical properties ...e SHC-1000 remained unchanged, see Figure 4-5.

4.2.4 FLEXURE TEST

Four single-cell samples were individually wrapped and unwrapped around a 25-cm diameter cylinder a total of five times. One cell was electrically inactive. The

Table 4-9. Electrical Performance of 2-Cell Samples Through Temperature-Humidity Test

CELL #	AFTER WELDING		AFTER COVER		AFTER T-H TEST		COMMENTS
	I_{sc} (MA)	P_{mp} (MW)	ΔI_{sc} (MA)	ΔP_{mp} (MW)	ΔI_{sc} (MA)	ΔP_{mp} (MW)	
5	148	128	-1	-2	-4	-2	Slight checking of hard coat after T-H test
6	143	126	-2	-4	-4	-3	"
7	142	123	-1	-2	-4	-3	General checking & delamination after T-H test
11	146	128	NA	NA	NA	NA	1 cell shorted after bonding of cover
13	147	59.4	-2	-1.0	-4	-1.5	1 cell shorted during welding. Flakey appearance of silicone hard coat
15	137	122	+2	-1	-7	-5	Flakey appearance of silicone hard coat after T-H test

Table 4-10. Electrical Performance Through Temperature Shock Test

CELL NO.	AFTER WELDING		AFTER COVER BONDING		AFTER TEMP. SHOCK		COMMENTS
	I_{sc} (MA)	P_{mp} (MW)	ΔI_{sc} (MA)	ΔP_{mp} (MW)	ΔI_{sc} (MA)	ΔP_{mp} (MW)	
1	145	127	-2	-3	-4	-7	5% Change in P_{mp}
3	147	127	-3	-3	-2	-6	4.1% Change in P_{mp}
8	145	125	-1	-1	-2	-4	2.7% Change in P_{mp}
12	144	126	+2	$\pm$0	-2	$\pm$0	No Change in P_{mp}
14	140	122	$\pm$0	-16	-2	+12	8.6% Change in P_{mp}
16	144	124	-3	-5	-1	+1	$\angle$1% Change in P_{mp}

electrical performance of the remaining three is given in Table 4-11. There were no obvious signs of cell fracture or cover/coating delaminations. The approximate 5% loss in I_{sc} and P_{mp} may be the result of micro-cracks or resistive welds or both.

Table 4-11. Electrical Performance Before & After Flexure Test

CELL #	AFTER WELDING		AFTER COVER (NO COATING)		AFTER FLEX. TEST		COMMENTS
	I_{sc} (MA)	P_{mn} (MW)	ΔI_{sc} (MA)	ΔP_{mn} (MW)	ΔI_{sc} (MA)	ΔP_{mn} (MW)	
B'	148	61.5	+5 (+3.4%)	+2.1 (+3.4%)	-8 (-5.2%)	-3.8 (-6.0%)	No cracks or delaminations
C'	143	57.4	+3 (+2.1%)	+1.3 (+2.3%)	-7 (-4.8%)	-2.7 (-4.6%)	"
Y	148	59.8	+2 (+1.4%)	+0.0 (0%)	-6 (-4%)	-4.1 (-6.8%)	"
Average	146	59.6	+2.3%	+2.8%	-4.7%	-5.8%	Approximately 5% loss

SECTION 5.0

CONCLUSIONS

A brief, five-month program was conducted towards finding an adhesive and/or coatings for PFA and FEP Teflon that would permit these co-polymers to be used successfully as a solar cell cover material in a space environment. A new concept has been identified ; namely, coat the Teflon with a thin (25 micrometer thick) silicone hard coat resin containing an ultraviolet-screening agent. This coating, on the photon-incident surface, has the potential of protecting both the Teflon and the adhesive at the cover/cell interface from degradation by ultraviolet radiation. A preliminary screening of materials was accomplished. There are UV-screening agents other than those tried; antioxidents and thermal stabilizers that should be examined for their potential in thwarting degradation of these polymeric covers by ultraviolet radiation and elevated temperatures. Some preliminary environmental tests were conducted; namely, thermal shock and temperature humidity, but the most critical test of all, ultraviolet exposure, was not within the work scope.

Much of the effort on this program was devoted, of necessity, to working out fabrication procedures and techniques for introduction of the UV-screening agents into silicone resins, on the one hand, and application of these UV-inhibited coatings to the Teflons, on the other. Much was accomplished in this regard. Aside from incorporating a few refinements from time to time, we can say that a workable process for fabrication of these coated covers has been achieved.

REFERENCES

1. A. F. Forestieri and J. D. Broder
LEWIS RESEARCH CENTER, Cleveland, OH
"Improvement in Silicon Solar Cell Coverglass Assembly and Packaging Using FEP Teflon"
July, 1970
Report No. NASA TMX - 52875

2. S. A. Greenberg, M. McCargo and W. L. Palmer
LOCKHEED RESEARCH LAB, Palo Alto, California
"Investigation of FEP Teflon as a Cover for Silicon Solar Cells"
Final Report, August, 1971
Report No. LMSC - D - 243070

3. G. J. Rayl
GENERAL ELECTRIC CO., Valley Forge, PA
"200 Watt/Kilogram Solar Array Conceptual Design Study"
JPL Contract 954328
Assessment Report No. 200 w/kg 7.77-048
8 July 1977

4. G. J. Rayl
GENERAL ELECTRIC CO., Valley Forge, PA
"200 Watt/Kilogram Solar Array Conceptual Design Study"
JPL Contract No. 954393
Final Report, Phase III
30 October 1978

5. Joseph Lindmayer, et al
SOLAREX CORPORATION, Rockville, MD
"Development of a High Efficiency Thin Silicon Solar Cell"
JPL Contract 954290
Report No. SX/105/6Q
March 1977

6. D. C. Carmichael, et al
BATTELLE COLUMBUS LABORATORIES, Columbus, OH
"Review of World Experience & Properties of Materials for Encapsulation of Terrestrial Photovoltaic Arrays"
JPL Contract 954328
Report No. ERDA/JPL-954328-76/4
21 July 1976