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REAL-TIME AND ACCELERATED OUTDOOR ENDURANCE TESTING OF SOLAR CELLS

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16. Abstract

Real-time and accelerated outdoor endurance testing was performed on a variety of samples of interest to the Energy Research and Development Administration, National Photovoltaic Conversion Program. The real-time tests were performed at seven different sites and the accelerated tests were performed at one of those sites in southwestern United States. The purpose of the tests were to help evaluate the lifetime of photovoltaic systems. Three types of samples were tested; transmission samples of possible cover materials, sub-modules constructed using these materials attached to solar cells, and solar cell modules produced by the manufacturers for the ERDA program. Results indicate that suitable cover materials are glass, FEP-A and PFA. Dirt accumulation and cleanability are important factors in the selection of solar cell module covers and encapsulants.

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Summary

Real-time and accelerated outdoor endurance testing was performed on a variety of samples of interest to the Energy Research and Development Administration (ERDA) National Photovoltaic Conversion Program. The real-time tests were performed at seven different sites and the accelerated tests were performed at one of those sites in southwestern United States. The purpose of the tests was to assist in the evaluation of the lifetime of photovoltaic applications and photovoltaic systems.

The samples tested were of three different types. Transmission samples were made from the encapsulant or cover materials under test and the optical transmission was measured before and after exposure to determine changes in transmission. Solar cell/test material samples were prepared by attaching the materials (encapsulant or cover) under test to solar cells. Solar cell characteristics before and after exposure were used to determine any effect on the test material and any effect of the test material or attachment process on the solar cells. Finally, solar cell modules, as produced by the manufacturers for the ERDA program, were also exposed. Fourteen materials, selected as possible solar cell covers, and one adhesive were tested. Four possible substrate materials were also tested. A total of almost 500 samples were tested.

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The results indicate that several materials such as glass, fluorinated ethylene propylene and perfluoroalkoxy are good candidates for covering or encapsulating solar cell modules. The results from two test sites in the Cleveland, Ohio area show the effect of dirt on the commercial solar cell modules. The results indicate that dirt accumulation and cleanability are important factors in the selection of solar cell module covers and encapsulants.

1. INTRODUCTION

One of the major factors in determining whether or not electrical energy from photovoltaic systems will be a viable source of energy in the future is the lifetime of the systems. The Energy Research and Development Administration (ERDA) has established, as one goal of the National Photovoltaic Conversion Program, that low cost solar cell arrays be developed with a lifetime of 20 years or more. To assist the Jet Propulsion Laboratory (JPL) in the evaluation of the lifetime of the systems, outdoor endurance testing was performed on solar cell modules which make up the systems and, other components, such as encapsulants and covers. This testing was a continuation of work begun by the Lewis Research Center (LeRC) under NASA sponsorship (1) This paper presents test results acquired since reference 1 was published.

A variety of samples were exposed at several test sites with different environments and under different conditions. Real-time outdoor exposure testing was performed to obtain the most exact determination of exposure effects on samples. However, since these tests may require years to obtain meaningful data, accelerated outdoor exposure testing was performed simultaneously to provide a more rapid determination of exposure effects.

The effects of the local environment on solar cell modules installed in a particular photovoltaic system were also determined. These modules were subjected to electrical stress by being utilized in arrays whose voltage output could exceed 200 volts dc.

This report presents the results of the test described above.

2. SAMPLE DESCRIPTION

A variety of samples including modules, sub-modules and plastic transmission samples were exposed. Modules were tested only under real-time conditions to determine their endurance and the effects of the environment at sites representative of sites for their intended use in applications. Submodules were used primarily for screening tests of new solar cell module packages. They were tested under both real-time and accelerated conditions. The plastic transmission samples were tested to screen new covers and encapsulants. They were also used to separately determine the effects of dirt and/or darkening of the proposed cover material.

Modules - The modules were obtained from four manufacturers. These modules were manufactured in 1976 for the 46-kW purchase of the ERDA/JPL Low Cost Silicon Solar Array Project (2) The manufacturers are Spectrolab, Sensor Technology, Solarex and Solar Power. The construction of these modules is described in Table I.

Sub-Modules - Since some modules were not available for testing or were too large for the test equipment, sub-modules were used. These were fabricated at the LeRC by Jacob D. Broder and were of two sizes. Some were 2.5 cm by 12.7 cm and consisted of five 2 cm by 2 cm silicon solar cells connected in series, attached to a substrate and covered with the material of interest. The other size of sub-module was 6.5 cm by 12.7 cm and consisted of two 5.3 cm round cells connected in series and packaged as above.

Transmission Samples - All transmission samples were plastic and were tested to determine environmental effects on candidate covers and encapsulants. The samples tested were 2.5 cm by 12.7 cm in size and supported on a metal or cardboard frame. The plastics were provided by various manufacturers and were also used to prepare the sub-modules described above.

3. EXPERIMENTAL PROCEDURE

To determine the effect of the environment on the modules and sub-modules current-voltage (I-V) curves were measured at LeRC before and after exposure. From these curves the short-circuit current (I_{sc}), open-circuit voltage (V_{oc}), maximum power (P_{max}), fill factor and efficiency were determined and were used as criteria to evaluate degradation. If the cover of the module or sub-module darkens, both the I_{sc} and P_{max} should decrease. If the degradation occurs through other means, possibly an increase in series resistance, the I_{sc} can remain constant even though the P_{max} decreases.

I-V curves were obtained at air mass zero (AMO) conditions and 25° C for the first sub-modules tested in this program. On the more recent samples measurements were made at air mass one (AMI) and 28° C using a xenon flash simulator. These latter conditions were also used for all of the module measurements. For voltage, current and power measurements, the reproducibility is ± 2%. Differences less than this are not considered significant.

For the plastic samples, the transmission was measured over the wavelength range 0.35 to 1.20 μM before and after exposure using a Cary 14 spectrophotometer.

Real-Time Testing - Real-time testing is discussed in detail in reference 3. Table II lists the sites where real-time outdoor exposure tests were conducted. The first five sites are commercial testing companies and were chosen because of the environment in their location and also because they could supply some weather data for their location. The two sites in Cleveland were chosen primarily for convenience in making frequent measurements and because they allowed comparison of results under heavy and light air pollution conditions under almost identical weather conditions.

Tables III, IV and V give a complete listing and description of the samples tested at the commercial test sites. Although initial data was recorded for all samples, only comments of a qualitative nature will be made for the Florida and Puerto Rico sites since the samples are still being tested and have not been returned for measurements.

At the two sites in Cleveland, Ohio, modules from the four manufacturers (Table II) were exposed for approximately two months. For these modules, I-V curves were obtained before and after exposure but before the modules were cleaned, and then again after they were cleaned with detergent and water.

Accelerated Testing - Accelerated testing (4) of plastic samples and sub-modules was performed only at site 1 in Phoenix, Arizona using a patented EMMAQUA machine which has been described earlier (1). The plastic samples are identical to those used in the real-time tests at that site. The five cell sub-modules were also described earlier. The cover materials tested on these sub-modules included FEP-A, FEP-C, perfluoro-alkoxy (PFA), polyethersulfone, acrylic sheet, UV stabilized Lexan (polycarbonate) and clear silicone potting compound. Some of the FEP-A-covered and PFA-covered sub-modules were heat-bonded. The silicone was cast in place. All of the other covers were attached with adhesive. The exposure of the sub-modules were made in time groups of two months with various times between subsequent exposures. It was assumed that the deterioration of samples was a function of the accumulated test exposure time and the periods between exposures had no effect.

Photovoltaic System Testing - The effect of outdoor exposure on modules from three of the four manufacturers (Table I) was investigated (5). The modules were installed in the ERDA/NASA Photovoltaic Systems Test Facility (STF) located at the LeRC in Cleveland, Ohio (6). One type of module was not used in the STF. The STF modules were the only modules subjected to electrical stress (~200V) during the endurance test period. Prior to installation of the modules in the STF, I-V curves of a random sampling of the modules were obtained.

The installation date of the modules varied because of variation in delivery time and priority considerations for module applications. Therefore, the duration of outdoor exposure for the modules reported here was as follows: brand Z-41 days, brand X-48 days, and brand Y-153 days and 245 days.

After exposure to the environment, selected modules were removed from the STF and I-V curves were again obtained under the same standard conditions. I-V curves were obtained after exposure. The modules were cleaned, using a detergent solution, and I-V curves obtained again. The effect of the dirt and cleaning of the modules was determined by comparing data from the three sets of I-V curves, initial, after exposure and after cleaning. Additional modules that did not have an initial I-V curve were removed from the STF after exposure to obtain additional data on the effects of dirt removal on module performance.

4. RESULTS AND DISCUSSION

Real Time Testing - The data for the sub-modules exposed at Site 1 (Phoenix) are shown in Table III. The first three columns identify and describe each sample. Next is given the exposure time in months and the solar flux in langleys. I_{sc} and P_{max} are given at the initial and final time of the test as is the percentage change in P_{max} (ΔP_{max}) over the course of the test. Finally, the visual observations on the condition of the sub-modules are shown under "Remarks."

Of the 31 sub-modules exposed at Site 1, three showed loss of current after testing, and five had no output at the end of the test. Those with no output had either a broken cell or problems with bubbling of the adhesive around the interconnects which may have caused poor contact. These results point out that, for these limited exposures, darkening of the cover plastic is not a problem.

In general, little change was observed under visual examination for these sub-modules. For a large proportion of the samples the change in maximum power, the parameter of most interest, was less than the experimental error.

The sub-modules that degraded the least had covers of heat-bonded FEP-A or FEP-A attached with either GE574 or GE585 adhesive. One acrylic-covered sub-module also did not degrade. Of the six sub-modules whose maximum power decreased, two were covered with UV-stabilized Lexan, one was a potted silicone (XR-63489) sample and one each was covered with heat-bonded FEP-C, heat-bonded PFA and polyethersulfone attached with GE585. Part of the poor performance of these latter samples may be attributed to technique problems in making the sub-modules and the limited sampling.

The results for the plastics exposed at Site 1 are shown in Table IV. There was very little transmission loss for any of the samples except Mylar. The losses that did occur were higher in the blue end of the spectrum which could be observed by noting tanning of the samples.

The results from Sites 2 (Puerto Rico) and, 3, 4 and 5 (Florida) will be discussed together since the samples at all sites were similar. The results are presented in Table V.

The general types of observations which were made were for cracking, tearing, darkening, delamination and physical deterioration of the samples. All of the samples have been exposed for six months but because of different angles of exposure and a different latitude for Puerto Rico, the flux density received by the samples was not the same. This accounts for the occurrence of a particular effect at different times. Also, different observers may judge the same effect differently. For these reasons, the observations from these sites cannot be interpreted more precisely until the first phase of exposure (12 months) is over and transmission is remeasured.

In general, the following comments can be made about these samples. Several formulations of polyvinylidene performed less well than the rest. Information from the manufacturer indicated that these formulations were slightly changed relatively frequently and further characterization was not possible. The material might be a good cover material but sub-modules constructed using a specific formulation would have to be exposed to assure quality.

For some materials, effects appeared at some sites but not at others. Included in this group are PFA, acrylic, TVP, FEP-A, FEP-C, UV-stabilized Lexan and the silicone. Other materials were affected at all sites. These were three of the polyvinylidene formulations, polyester and Kapton which all disintegrated to some degree. The free fiberglas samples had a tendency to ravel but were unaffected otherwise. The polyurethane-covered sub-modules darkened at all sites and in some cases eroded away.

The results from the modules exposed at Sites 6 and 7 (Cleveland, Ohio) are presented in Table VI. Listed are I_{sc} and P_{max}. ΔI_{sc} and ΔP_{max} are also shown. Three values are listed for each module; the initial data, the data measured on the modules after exposure and prior to cleaning, and that measured after cleaning with detergent and water. Comparing the data for similar modules, one can immediately see the effect of heavy industrial pollution. Most of this was solid material which can be removed by washing. However, the surface of the module is very important. Note that Spectrolab modules, which are glass-covered, are much less affected by outdoor dirt. This probably occurs because rain or snow can carry off some of this material which apparently does not adhere tightly to glass. The other three modules, whose surface is a softer silicone, tend to hold the dirt more tightly and, in fact, the dirt may actually imbed in the surface and not wash off easily. Differences in formulation of this silicone rubber layer may account for the higher losses in Solar Power modules after cleaning.

Accelerated Testing - Because of the large number of samples tested, Table VII presents only a summary of the loss of maximum power in the sub-modules. The complete data is available in reference 4. Many of the samples had some degree of power loss, some quite large. However, examination of the short-circuit current data indicates that the degradation is not due to a loss in transmission of the cover material.

The loss in maximum power, if not due to darkening of the sub-module cover, is likely due to problems resulting from the construction of the sub-module. Inspection of the samples constructed using GE585 and 574 indicated the presence of large bubbles, primarily in the interconnect areas. These bubbles probably began as minute ones in the freshly prepared samples but the heat and light which they see during exposure and the possible release of solvent might tend to increase their size. More refined methods of sample preparation are indicated.

Table VIII gives the effect of accelerated exposure in Phoenix on the transmission of plastic samples. The samples were exposed to 230,660 langleys during a period of two months, equivalent to 16 months of real time exposure at that location.

Table VIII shows that all of the plastic samples exposed on the EMMAQUA experienced some transmission loss. In every case except FEP-A, the samples lost more transmission at the blue end of the spectrum (0.35 μm) than at the red end (1.2 μm). Mylar and Aclar 22A also were very brittle after the test and required careful handling.

A comparison of short-circuit current data with the transmission data of Table VIII indicates that even when some free films lose transmission, sub-modules covered with these materials do not experience a short-circuit current loss. Several reasons are possible for the apparent discrepancy. First, most of the free films lose more transmission at the blue end of the spectrum, and the solar cells are not strongly responsive to this wavelength of light. Also, the free films can experience a decrease in apparent transmission because of scattering from scratches or "milkiness". The cells of the sub-modules, however, can still make use of this scattered light and thus the short-circuit current is not diminished.

Photovoltaic System Testing - The effect of outdoor-exposure and cleaning of modules where initial I-V curves were obtained is shown in Table IX. After 48 days of exposure in the STF the brand X modules visual examination revealed only an accumulation of dirt on the surface. The measurements indicate a loss in power or degradation that was not restored by the cleaning technique used. However, it is very likely that all of the dirt that accumulated on the modules was not removed. The surface of the modules is very soft and it is possible that dirt became imbedded in this soft surface and was not removed in the cleaning process.

The brand Y modules were exposed for the longest period of time, 153 days. These modules exhibited delamination of the encapsulant from the fiberglas backing in several areas but never directly over a solar cell. Again the measurements, as shown in Table IX, indicate a loss in power that was not restored by cleaning. Since the surface of the modules is identical to that discussed above the same remarks apply.

There was only one brand Z module available for examination in this test. Table IX shows the same general effect as was discussed above. Even though the surface of the brand Z module was the smoothest to the touch the data indicates it did not act any differently after outdoor exposure and cleaning.

From Table IX all three types of modules show approximately similar decreases in P_{max}, despite the fact that they had widely varying exposure times. It cannot be determined from these limited data whether the modules were affected by dirt accumulation and retention differently or that the loss in P_{max}, possibly due to not being able to clean the modules thoroughly, tends to saturate at the same level.

To assess the effects of dirt accumulation due to outdoor exposure, twenty-five additional modules, without initial I-V curves, were removed from the STF and I-V curves were obtained both before and after cleaning. During the last three months of the exposure period, excavation, bulldozing and field construction for expansion of the STF from 10 kW to 40 kW, took place. Therefore, the environment was considerably different as a function of time and it can be assumed that the dirt accumulation was not linear with time.

Table X lists the percent change in average maximum power of the twenty-five modules. It can be seen that the change in P_{max} is greater for those modules exposed for a longer time in the field. However, the percentage change is not directly proportional to time.

5. CONCLUSIONS

Limited real-time outdoor exposure has shown that some materials are not suitable for solar cell module construction. These are polyurethane, polyester, Kapton, Mylar and UV-stabilized Lexan. Polyvinylidene fluoride may be suitable, but because different formulations are available, each must be evaluated. Acrylic, FEP-A and glass appear to be good candidates for module covers. RTV silicone rubber (clear) appears to pick up and hold dirt both as a free film and as a potting medium for modules. These results indicate that dirt accumulation and cleanability are important factors in the selection of solar cell modules covers and encapsulants.

Testing of solar cell sub-modules under accelerated conditions indicates that some of the presently available materials look very promising for use as cover materials, notably FEP-A and FEP-C, PFA, acrylic, and silicone compounds and adhesives. However, the technique of packaging solar cells using these materials requires further development. There are other properties of these materials that require investigation. Some of these are dirt retention, mildew growth, smoothness and ease of application in large sizes and/or quantities. Preliminary studies, such as this one, help sort out unlikely candidates and possibly point out problem areas that might turn up in real time testing after a number of years. Because of the limited test time in this report period, there has been no overlap in exposure yet between the real-time tests and the accelerated tests. To correlate these two types of tests will require more test time and more frequent measurements. Thus far there has been no disagreement in the results of the two types of tests.

Installation of solar cell modules in a working photovoltaic system did not seem to have any adverse effect on the modules. Cleaning the modules after outdoor exposure revealed a non-recoverable loss in maximum power output for those modules encapsulated with silicone. It appears that the modules could not be thoroughly cleaned by the technique used and some dirt remained imbedded in the soft module surface.

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TABLE I - DESCRIPTION OF MODULES SUPPLIED TO THE ERDA/JPL LOW COST SILICON SOLAR ARRAY PROJECT

(46 kW PURCHASE, 1976)

Spectrolab	Aluminum backed; 52mm diameter cells completely encapsulated in silicone (RTV 615); covered with glass sheet 1/8" thick.
Sensor Tech	Aluminum backed; 52mm diameter cells completely encapsulated in silicone (RTV 615).
Solarex	Fiberglas-epoxy composite backed; 76mm diameter cells completely encapsulated in silicone (Silgard 184).
Solar Power	Fiberglas-epoxy composite backed; 88mm diameter cells completely encapsulated in silicone (Silgard 184) covered with Dow QR-4-3117.

TABLE II - REAL-TIME EXPOSURE TEST SITES

1. Desert Sunshine Exposure Tests, Inc., Phoenix, Arizona. Southfacing panels, inclined at 45°. Desert conditions.
2. Caribbean Testing, Inc., Caguas, Puerto Rico. South-facing panels inclined at 5°, 18° and 45°. A fourth panel has its inclination angle changed by 5° approximately every two weeks to follow the sun. The maximum angle is 40° and the minimum is 0°. Tropical, rain forest conditions.
3. Solar Testing Service, Inc., Pompano Beach, Florida. South-facing panels inclined at 5° and 45°. Sub-tropical conditions.
4. Sub-Tropical Testing Service, Miami, Florida. South-facing panels inclined at 5° and 45°. Sub-tropical conditions.
5. South Florida Testing Service, Miami, Florida. South-facing panels inclined at 5° and 45°. Sub-tropical, sea air atmosphere.
6. Air Pollution Control Center, Cleveland, Ohio. South-facing panels inclined at 40°. A heavy industrial environment.
7. NASA-Lewis Research Center, Cleveland, Ohio. South-facing panels inclined at 40°. An urban environment (commercial business/residential areas in prevailing upwind direction).

TABLE III

EFFECT OF REAL TIME EXPOSURE ON SOLAR CELL SUB-MODULES EXPOSED AT DESERT SUNSHINE EXPOSURE TESTS, INC., PHOENIX, ARIZONA. PANELS FACING SOUTH AT 45° INCLINATION

SUB-MODULE ID NO.	SUB-MODULE COVER	CONSTRUCTION SUBSTRATE	TEST TIME & EXPOSURE	SHORT CIRCUIT CURRENT Isc, AMPS		MAXIMUM POWER Pmax, WATTS		ΔPmax,%	OBSERVATIONS
				INITIAL	FINAL	INITIAL	FINAL		
84	FEP-A, heat bonded[a]	aluminum	6 months;	.128[b]	.130[b]	.266[b]	.268[b]	+ .7	slight delamination at end interconnect
85			97,652 langleys	.131	.134	.277	.282	+1.8	some edge delamination
105				.128	.127	.276	.280	+1.4	discolorated
114				.128	.131	.270	.274	+1.5	edge delamination
117				.131	.136	.276	.278	+ .7	some edge delamination
126		fiberglas		.136	.138	.280	.279	- .4	good appearance
116[c]		aluminum	2 months;	.128	.134	.227	.234	+3.1	edge delamination
121[c]		fiberglas	34,612 langleys	.130	.128	.253	.266	+5.1	interconnects cut through
195	.159 cm acrylic sealed at the edges			.136	.134	.231	.232	+ .4	good appearance; some milkiness at edge
198	cast XR-63489 (clear silicone)			.143	.140	.251	.225	-10	dulled surface
201	UV stabilized Lexan	polystyrene		.127	.106	.220	.099	-55	good appearance
202	FEP-A, heat bonded, no primer attached with Mystak tape	aluminum		.139	.144	.255	.170	-33	one cell delaminated
206	FEP-C, att. w/Mystik tape	aluminum		.121[d]	.122[d]	.201[d]	.183[d]	-8.9	delaminated
211	FEP-C, GE 585 adhesive	aluminum		.123	.124	.223	.225	+ .9	bubbling at cell edges
214	UV stabilized Lexon with GE 585 adhesive	aluminum		---	---	---	---	---	broken cell; delamination, bubbles
217	Polyether sulfone with GE 585 adhesive	aluminum		.123	.110	.235	.192	-18	yellow, brittle, pulling off at edges
222	PFA, heat bonded	fiberglas		.120	.075	.243	.142	-42	some delamination where bubbled; interconnects are white
223	FEP-A with GE 585 adhesive	aluminum		.126	.128	.240	.234	-2.5	delamination at edges and interconnects
226	FEP-A with GE 585 adhesive	Formica		.124	.127	.243	.245	+ .8	bubbled at cell edges
229	PFA with GE 585 adhesive	Formica		.134	.13[illegible]	.237	.234	-1.3	bubbled at cell edges and on one cell
234	FEP-A with GE 585 adhesive	aluminum		.132	.128	.241	.234	-2.9	unstuck at cell edges
237	FEP-A with GE 585 adhesive	Kapton		.127	.128	.251	.251	0	slight bubbling at several cell corners
250	FEP-A with GE 574 adhesive	aluminum		.124	.130	.247	.249	+ .8	edges unstuck
252	FEP-A with GE 574 adhesive	Kapton		.121	.124	.201	.204	+1.5	cracked cell; bubbles at cell edge
253	FEP-C with GE 574 adhesive	Kapton		.128	---	.239	---	---	bubbling at interconnects
259	FEP-A with GE 574 adhesive	fiberglas		.122	.124	.224	.224	0	some discoloration on cell back
260	FEP-C with GE 574 adhesive	fiberglas		.129	---	.191	---	---	good appearance
267	FEP-A with GE 574 adhesive	" & Kapton		.129	.132	.207	.207	0	good appearance; some discoloration on cell back
271	PFA with GE 574 adhesive	Kapton		.127	---	.191	---	---	good appearance; some discoloration on cell back
276	PFA with GE 574 adhesive	fiberglas		.125	.132	.187	.183	-2.1	good appearance; some discoloration on cell back
PFA-X	PFA with GE 585 adhesive	aluminum		.126	---	.222	---	---	delamination at several areas; lead tab off

(a) These sub-modules were made using front and back contact cells. All others had wraparound contact cells.

(b) These parameters through sample number 202 were measured at AM0, 25° C.

(c) Samples were placed on real time test after four months of accelerated exposure. Initial parameters are those measured prior to real time test.

(d) These parameters for this and all subsequent samples measured at AM1, 28° C.

TABLE IV - TRANSMISSION EFFECTS ON PLASTIC SAMPLES EXPOSED UNDER REAL TIME EXPOSURE AT DESERT SUNSHINE EXPOSURE TESTS, INC., PHOENIX, ARIZONA ON SOUTH-FACING PANELS INCLINED AT 45° TOTAL EXPOSURE, 30161 LANGLEYS

Sample	Number of Samples	Original Transmittance		Transmission Loss	
		0.35µm	1.2µm	0.35µm	1.2µm
FEP-A, 2 layers, heat bonded	2	0.48	0.92	3%	3%
Acrylic	1	0.20	0.87	1	0.5
Perfluoroalkoxy (PFA)	2	0.83	0.95	9	1
Mylar	2	0.69	0.92	25	4
Polyester (Scotchpar)	1	0.04	0.95	4	1
Aclar 22A	1	0.93	0.94	3	0
Tefzel	2	0.86	0.94	4	2

TABLE V - QUALITATIVE EFFECTS OF REAL TIME EXPOSURE IN FLORIDA AND PUERTO RICO TOTAL TIME, 6 MONTHS

Sample Group Identification Number	Sample Description	Number of Samples	Observations
1	Eight formulations of polyvinylidene fluoride (Pennwalt)	64	Three formulations showed darkening or disintegration after 3 months; others showed no effects.
2	Perfluoroalkoxy (PFA), (DuPont)	10	One sample showed some darkening.
3	Two quartz cover slips cemented with GE585	10	Unaffected.
4	Acrylic (Lucite)	10	Showed some buckling in Puerto Rico. Others Unaffected.
5	TVP - a laminate of UV stabilized Tedlar, plastic grid (Vexar) and UV inhibited polyethylene	6	" " "
6	Polyester (Scotchpar, 3M), 2 thicknesses	33	Samples disintegrated after 2 months in all cases.
7	RTV, XR 63489 cast at Lewis Research Center	10	Appeared to be picking up dirt or possibly mildew.

TABLE V - QUALITATIVE EFFECTS OF REAL TIME EXPOSURE IN FLORIDA AND PUERTO RICO
(continued)
TOTAL TIME, 6 MONTHS

Sample Group Identification Number	Sample Description	Number of Samples	Observations
8	Fiberglas	15	Ravelling
9	Kapton (DuPont)	14	Buckles and tears and eventually breaks up.
10	FEP-A and fiberglas heat-bonded together	20	Unaffected
11	FEP-A	32	Some samples in Puerto Rico curling and slightly yellow.
12	FEP-C	24	" " "
13	UV stabilized Lexan	17	Buckling and cracking of several samples.
14	Polyurethane covered sub-modules	33	Darkening and some flaking of coating (also noted in earlier DSET tests).

TABLE VI - EFFECT OF DIRT ON MODULE PERFORMANCE

ΔI_{sc}, amps

I_{sc}, %

ΔP_{max}, watts

P_{max}, %

		Start	Removed from Site		Cleaned		Start	Removed from Site		Cleaned	
		I_{sc}	I_{sc}	ΔI_{sc}	I_{sc}	ΔI_{sc}	P_{max}	P_{max}	ΔP_{max}	P_{max}	ΔP_{max}
Spectrolab	A*	0.625	0.640	+2.4	0.638	+2.1	5.08	5.17	+1.8	5.08	0
	B*	0.596	0.570	-4.4	0.615	+3.2	5.07	4.78	-5.7	5.16	+1.8
Sensor Technology	A	0.525	0.484	-7.8	0.521	-0.8	5.65	5.17	-8.5	5.60	-0.9
	B	0.540	0.355	-34.3	0.526	-2.6	5.61	3.65	-34.9	5.39	-3.9
Solarex	A	1.470	1.362	-7.4	1.478	+0.5	9.54	8.60	-9.8	9.34	-2.1
	B	1.473	1.075	-27.0	1.460	-0.9	9.73	7.02	-27.8	9.43	-3.1
Solar Power	A	1.528	1.375	-10.0	1.475	-3.5	13.85	12.64	-8.7	13.41	-3.2
	B	1.450	0.980	-32.4	1.362	-6.1	13.52	9.27	-31.4	12.35	-8.6

* Site A - NASA-Lewis, 74 days exposure. (Average daily total suspended particulates, 45)

* Site B - Air Pollution Control Center, 81 days exposure. (Average daily total suspended particulates, 135)

TABLE VII - LOSS IN MAXIMUM POWER IN SUB-MODULES UNDER ACCELERATED TESTING AT DSET

Test Sample	Test Time and Exposure	No. of Samples	Power Loss
FEP-A, laminated	(1)	6	0-10%, all delaminated
FEP-A, laminated	(2)	4	0-20%, 2 delaminated
FEP-A, laminated	(3)	2	10-20%, 2 delaminated
FEP-A, with GE 585 adhesive	↓	8	1-4%
FEP-A, with GE 574 adhesive	↓	11	<5%, except one sample with 37%
FEP-C, with GE 585 adhesive	↓	2	0
FEP-C, with GE 574 adhesive	↓	4	0-30%
PFA, laminated	↓	2	6%
PFA, with GE 585 adhesive	↓	7	3-50%
PFA, with GE 574 adhesive	↓	4	0-10%
Acrylic	↓	3	>25%
Silicone, XR 63489-cast	↓	2	6%, 18%
UV stabilized Lexan	↓	4	>10%
Polyether sulfone, with GE 585 adhesive	↓	2	>20%

(1) 6 months; 775,890 langleys

(2) 4 months, 487,020 langleys

(3) 2 months; 256,360 langleys

TABLE VIII - EFFECT ON THE TRANSMISSION OF PLASTIC SAMPLES OF ACCELERATED EXPOSURE USING THE EMMAQUA, DESERT SUNSHINE EXPOSURE TESTS, INC.
Total Exposure, 230660 Langleys

Sample	Number of Samples	Transmission Loss	
		0.35 μm	1.2 μm
Teflon FEP-A, 2 layers heat bonded together	6	6%	6%
Acrylic	2	9	2
Perfluoroalkoxy (PFA)	2	10	2
Mylar	1	60	53 very brittle
Polyester (Scotchpar)	2	13	1
Aclar 22 A	2	30	25 very brittle
Tefzel	2	11	3

TABLE IX - PERCENT CHANGE IN MAXIMUM POWER, FROM THE AS-RECEIVED UNEXPOSED CONDITION TO AFTER OUTDOOR EXPOSURE AND CLEANING OF MODULES IN THE ERDA/LeRC PHOTOVOLTAICS SYSTEMS TEST FACILITY

Module		Outdoor exposure, days	Change in average maximum power, percent
Brand	Number		
X	3	48	-5.7
Y	3	153	-5.2
Z	1	41	-6.1

TABLE X - PERCENT INCREASE IN MAXIMUM POWER DUE TO CLEANING OF MODULES EXPOSED IN THE ERDA/LeRC PHOTOVOLTAIC SYSTEMS TEST FACILITY

Module		Outdoor exposure, days	Increase in average maximum power, percent
Brand	Number		
X	3	48	5.9
Y	16	245	11.0
Z	6	41	4.6