237
7-18-77
mines NTIS

UC-63

ERDA/NASA/1022-77/10
NASA TM X-73655
pr 1229

REAL TIME OUTDOOR EXPOSURE TESTING OF SOLAR CELL MODULES AND COMPONENT MATERIALS

Evelyn Anagnostou and Americo F. Forestieri
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

April 1977

MASTER

Prepared for
ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
Office of the Assistant Administrator for
Solar, Geothermal, and Advanced Energy Systems
Division of Solar Energy
Under Interagency Agreement E(49-26)-1022

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM X-73655		
4. Title and Subtitle REAL TIME OUTDOOR EXPOSURE TESTING OF SOLAR CELL MODULES AND COMPONENT MATERIALS		5. Report Date April 1977 6. Performing Organization Code
7. Author(s) Evelyn Anagnostou and Americo F. Forestieri		8. Performing Organization Report No. E-9127 10. Work Unit No.
9. Performing Organization Name and Address National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio 44135		11. Contract or Grant No. 13. Type of Report and Period Covered Technical Memorandum
12. Sponsoring Agency Name and Address Energy Research and Development Administration Division of Solar Energy Washington, D.C. 20545		14. Sponsoring Agency ~~Code~~ Report No. ERDA/NASA 1022/77/10

15. Supplementary Notes

Project report. Prepared under Interagency Agreement E(49-26)-1022.

16. Abstract

Plastic samples, solar cell modules and sub-modules have been exposed at test sites in Florida, Arizona, Puerto Rico and Cleveland, Ohio, in order to determine materials suitable for use in solar cell modules with a proposed 20-year lifetime. Various environments have been encountered including sub-tropical, sub-tropical with a sea air atmosphere, desert, rain forest, normal urban, and urban-polluted. The samples have been exposed for periods up to six months. Materials found not suitable were polyurethane, polyester, Kapton, Mylar and UV-stabilized Lexan. Suitable materials were acrylic, FEP-A and glass. The results of exposure of polyvinylidene fluoride were dependent on the specific formulation but several types appear suitable. RTV silicone rubber (clear) appears to pick up and hold dirt both as a free film and as a potting medium for modules. The results indicate that dirt accumulation and cleanability are important factors in the selection of solar cell module covers and encapsulants.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Weather tests Solar cell modules	Unclassified - unlimited STAR category 44 ERDA category UC-63

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified		

* For sale by the National Technical Information Service, Springfield, Virginia 22161

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

REAL TIME OUTDOOR EXPOSURE TESTING OF SOLAR

CELL MODULES AND COMPONENT MATERIALS

by Evelyn Anagnostou and Americo F. Forestieri

Lewis Research Center
National Aeronautics and Space Administration
Cleveland, Ohio

E-9127

INTRODUCTION

Increasing emphasis is being placed on solar energy programs, including solar photovoltaics. With this emphasis, solar cell modules are being produced by different manufacturers for the Energy Research and Development Agency (ERDA) Photovoltaic Program. Since the modules which will eventually be in general use must withstand a variety of environmental conditions, the modules and their components must be tested to determine the effects of outdoor exposure.

In a continuation of real-time testing begun under NASA sponsorship (ref. 1), plastic samples, solar cell modules and sub-modules have been exposed at several test sites with different environments under real-time conditions. The modules were manufactured in 1976 as part of the 46-kW ERDA/Jet Propulsion Laboratory (JPL) Low Cost Silicon Solar Array Project. Plastic samples were provided by manufacturers and the sub-modules were made at NASA-LeRC by Jacob D. Broder. This report covers the recent results of these tests. In some cases, quantitative data is available. For others, only qualitative observations can be reported.

TEST SITES AND CONDITIONS

Modules, sub-modules and plastic samples have been exposed at the following sites at the given panel inclination angle and under the conditions listed.

1. Desert Sunshine Exposure Tests, Inc., Phoenix, Arizona. South-facing 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^o and 45^o. Sub-tropical conditions.

5. South Florida Testing Service, Miami, Florida. South-facing panels inclined at 5^o and 45^o. Sub-tropical, sea air atmosphere.

6. Air Pollution Control Center, Cleveland, Ohio. South-facing panels inclined at 40^o. A very heavy industrial environment.

7. NASA-Lewis Research Center, Cleveland, Ohio. South-facing panels inclined at 40^o. Ordinary urban environment (commercial business/residential areas in prevailing upwind direction).

A variety of samples was exposed at each site. The optical transmission samples were 2.54-cm-by-12.7-cm in size supported on a metal or cardboard frame. The sub-modules were two sizes. Some were 2.54-cm by 12.7-cm and consisted of five 2-by-2-cm solar cells connected in series. The rest were 6.50-cm-by-12.7-cm and consisted of two 5.30-cm round cells connected in series.

At Site 1, 7 different plastics and 31 five-cell sub-modules were tested. The plastics were FEP-A, acrylic, perfluoroalkoxy (PFA), Mylar, polyester, Aclar 22A and Tefzel. The sub-modules were covered with FEP-A (heat bonded or glued), FEP-C (heat bonded or glued), acrylic, clear silicons rubber, UV-stabilized Lexan, polyether-sulfone and PFA (heat bonded or glued). A more detailed listing of these samples is given in Tables I and II.

For the plastic samples, the transmission was measured over the wavelength range 0.35 to 1.20μm before and after testing using a Cary 14 spectrophotometer. For the modules, current-voltage (I-V) traces were made before and after testing and from these, the short-circuit current (I_{sc}), open-circuit voltage (V_{oc}), maximum power (P_{max}), fill factor and efficiency were determined. All of these measurements were made at LeRC. On earlier samples I-V measurements were made using the X-25 solar simulator at air mass zero (AMO) conditions and 25^o C. On the more recent samples measurements were made at air mass one (AM1) and 28^o C using a flash simulator since these conditions have been standardized for terrestrial testing.

At Site 2, 97 samples of types described in Table III, numbers 1 through 13, are being exposed along with 9 sub-modules of type number 14. The sub-modules are made using two round cells as described earlier. Initial transmission data (except for the fiberglas samples, numbers 8 and 10) and I-V measurements for the sub-modules have been recorded but since these samples are still on-site, only comments of a qualitative nature will be made.

At Site 3, 54 samples of types 1 - 13 in Table III are being exposed. Again, only qualitative comments can be made for these samples.

At Site 4, 53 samples of types 1 - 13 and 11 sub-modules, type 14, as described in Table III are being exposed.

At Site 5, 61 samples of types 1 - 13 and 13 sub-modules, type 14, as described in Table III are being exposed.

At Sites 6 and 7, modules from four manufacturers have been exposed for approximately two months outdoors. These modules were manufactured in 1976 for the 46-kW purchase of the ERDA/JPL Low Cost Silicon Solar Array Project. The manufacturers are Spectrolab, Sensor Technology, Solar Power and Solarex. The construction of the modules is described in Table IV. For these modules, initial I-V curves were taken using a flash simulator (AM1, 28^{o} C). The curves were again recorded after exposure but before the modules were cleaned. After they were cleaned with detergent and water, another I-V curve was recorded. I_{sc}, V_{oc} and P_{max} were determined from the curves. For both power and current measurements, the reproducibility is ±2%.

RESULTS

The data for the sub-modules exposed at Site 1 are shown in Table I. 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."

The first eight sub-modules listed were made using 2x2-cm cells with front and back contacts. Previous accelerated outdoor exposure of similarly constructed samples (ref. 1) showed that stress-cracking at the interconnect areas occurred. Therefore subsequent samples were made using wraparound contact 2x2-cm solar cells.

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, 20 out of 31, the change in maximum power, the parameter of most interest, was less than the experimental error. Same-day and day-to-day variations in current and maximum power measurements of reference cells and modules shows the experimental error to be ±4%.

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 II. 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, 3, 4 and 5 will be discussed together since the samples at all sites were similar. The results are presented in Table III. 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 site 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 are presented in Table V. 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.

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.

REFERENCE

1. Americo F. Forestieri and Evelyn Anagnostou: The Effect of Sunshine Testing on Terrestrial Solar Cell System Components. NASA TM X-71722, May 1975.

TABLE I

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	.130	.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 AMO, 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 II. - 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	Transmission Loss	
		0.35μm	1.2μm
FEP-A, 2 layers, heat bonded	2	3%	3%
Acrylic	1	1	0.5
Perfluoroalkoxy (PFA)	2	9	1
Mylar	2	25	4
Polyester (Scotchpar)	1	4	1
Aclar 22A	1	3	0
Tefzel	2	4	2

TABLE III. - 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 (Pennevalt)	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 III (Continued)

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 IV. - DESCRIPTION OF MODULES SUPPLIED TO THE ERDA/JPL

LOW COST SILICON SOLAR ARRAY PROJECT

(46 kW PURCHASE, 1976)

Spectrolab	Aluminum backed; 2" diameter cells completely encapsulated in silicone; covered with glass sheet ~1/8" thick.
Sensor Tech	Aluminum backed; 2" diameter cells completely encapsulated in silicone.
Solarex	Fiberglas-epoxy composite backed; 3" diameter cells completely encapsulated in silicone.
Solar Power	Fiberglas-epoxy composite backed; 3" diameter cells completely encapsulated in silicone.

TABLE V. - EFFECT OF DIRT ON MODULE PERFORMANCE

		I_{sc}, ΔI_{sc} amps, %					P_{max}, ΔP_{max} watts, %				
		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)