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PRELIMINARY RESULTS OF ACCELERATED EXPOSURE TESTING OF SOLAR CELL SYSTEM COMPONENTS

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16. Abstract
Plastic samples and solar cell sub-modules have been exposed to an accelerated outdoor environment in Arizona and an accelerated simulated environment in a cyclic ultraviolet exposure tester which included humidity exposure. These tests were for preliminary screening of materials suitable for use in the manufacture of solar cell modules which are to have a 20-year lifetime. The samples were exposed for various times up to six months, equivalent to a real time exposure of four years. Suitable materials were found to be FEP-A, FEP-C, PFA, acrylic, silicone compounds and adhesives and possibly parylene. The method of packaging the sub-modules was also found to be important to their performance.

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PRELIMINARY RESULTS OF ACCELERATED EXPOSURE TESTING

OF SOLAR CELL SYSTEM COMPONENTS

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INTRODUCTION

More and more interest is being shown in solar energy as one of the possible energy sources for the near and distant future. Solar energy is inexhaustible and clean and free and many different programs are planned by the Energy Research and Development Administration (ERDA) to make use of this energy source. Part of the solar energy program is the development of solar photovoltaics.

A goal of a 20-year lifetime has been set for solar photovoltaic panels. These panels will have to endure a variety of environmental conditions. The most exact determination of exposure effects on panels would be real time testing at the site where they would be used, but such tests obviously require years to carry out. It is necessary, however, to screen materials and modules in some way to determine quickly which would have the best chance to survive. For this purpose, accelerated testing, both outdoor and indoor, can be used. As part of the ERDA National Photovoltaic Program, NASA-Lewis has conducted and monitored accelerated exposure testing of candidate solar cell module component materials. This report will describe the results of that testing.

DESCRIPTION OF SAMPLES AND TEST CONDITIONS

Plastic samples and sub-modules were exposed at Desert Sunshine Exposure Tests, Inc. (DSET), Phoenix, Arizona using their patented EMMAQUA machine which has been described earlier (ref. 1). Plastic samples were provided by various plastic manufacturers. Sub-modules were fabricated at NASA-Lewis Research Center by Jacob D. Broder and for this test consisted of five, 2 cm x 2 cm silicon solar cells connected in series, attached to a substrate and covered with the material of interest. For the plastic samples, the transmission from 0.35 μm to 1.2 μm was measured before and after testing to determine the effects of exposure. For the sub-modules, the current-voltage (IV) curve was determined and the short circuit current (I_{sc}) and maximum power (P_{max}) were used as criteria for degradation. If the sub-module is affected because of darkening of the cover, 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.

Other samples fabricated at Lewis were exposed in an apparatus manufactured by the Q-Panel Co. called a QUV Cyclic Ultraviolet Weathering Tester. The samples are exposed to 16 hours of ultraviolet light followed by 8 hours of humidity exposure. Two different types of sub-modules were exposed in this test; the first consisted of two 2 cm x 2 cm cells connected in series and constructed as those used in DSET tests, and the second consisted of single 2 cm x 2 cm cells encapsulated with the plastic parylene in vacuum. A third type of sample exposed in the tester consisted of single 5.34 cm round cells, not electrically connected, sprayed with a variety of coatings as part of a preliminary screening program. For the sub-modules, electrical measurements could be made and I_{sc} and P_{max} were used for evaluation as described earlier. The results for the sprayed sample tests are reported only as qualitative visual observations.

As a continuation of testing begun by NASA-Lewis (ref. 1), five-cell sub-modules, constructed as described earlier, were sent to DSET for exposure. Six of the earliest samples were made using cells with front and back contacts. Test results (ref. 1) indicated that there were problems of the cutting through of covers by the interconnects. For this reason, succeeding samples were made using wraparound contact cells. The interconnects were spot welded. The construction of the various kinds of sub-modules is described in Table I: the covers are FEP-A and FEP-C, perfluoroalkoxy (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, and all of the other covers were attached with adhesive.

Current-voltage (IV) curves for the sub-modules were recorded before and after exposure. Some of the current-voltage curves were measured at air mass zero (AM 0), 25° C using either the X-25 solar simulator or a flash simulator and others at air mass 1 (AM 1), 28° C using the flash simulator. This occurred because the AM 1 condition was decided on as a standard for terristrial measurements (ref. 2) after the tests had begun and the flash simulator was not operational until mid 1976.

Use of the different simulators can account for value differences of approximately $\pm 3\%$. Day-to-day variations in data are of the order of $\pm 2\%$, so that differences less than this are considered non-significant.

The exposures 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.

Plastic transmission samples were also exposed on the EMMAQUA. These are listed in Table II. The transmission of the samples was measured before and after exposure using a Cary 14 spectrophotometer. The wavelength range used was 0.35 to 1.2 μm.

Several varieties of samples were exposed on the cyclic exposure tester. A schematic cross section of the tester is shown in Fig. I. The tester has sample holders placed against an otherwise enclosed chamber with a water pool on the bottom, heated if necessary, and a bank of four fluorescent sun lamps on each side. The temperature is adjusted, so that, the samples are at 62° C during the UV cycle and 48° C during the humidity cycle. A plot of the relative energy versus wavelength for a representative lamp of the type used is shown in Fig. II. Figure III shows the percentage of the lamp's radiation below a particular wavelength, again for a representative lamp. Actual lamps have been calibrated at zero time, 415 hours and 836 hours and the number of UV equivalent suns (wavelengths less than 0.36 μm) at the sample plane has been calculated. New lamps give a factor of three times solar ultraviolet intensity for wavelengths below 0.36 μm at the sample plane. After 415 hours, the lamp output has dropped 26% and at 836 hours, the output has dropped an additional 1%. This is typical behavior for ultraviolet lamps in that the largest decrease in output occurs early in the lamp's life and thereafter the decrease is much more gradual. An overall acceleration factor of 2.25 is estimated herein.

Three groups of samples have been exposed in the cyclic tester. The first group of twenty samples consisted of 5.34 cm diameter silicon cells attached to embossed aluminum and coated. A description of the coatings applied to the samples is given in Table III. These samples were exposed for 415 hours to ultraviolet light and then examined. Since the samples were not electrically connected, results of this test are limited to visual observations. Two samples, numbers 7 and 314, were continued on test to 836 hours.

The second group of samples consisted of eleven single 2 cm x 2 cm cells coated with either 37.5 or 56.3 μm of parylene. Parylene is polyparoxylylene (or a derivative thereof) which has been suggested as a candidate cover material. Adherent, conformal, pinhole-free films are formed readily in vacuum. IV curves were recorded before and after testing and I_{sc} and P_{max} values were noted. The samples were exposed for 415 hours.

The third group of samples consisted of twenty-one, two cell submodules covered with PFA, FEP-A or FEP-C attached to the cells and Kapton backing with GE 574 adhesive. Thicknesses of 50 μm and 125 μm of each material were used. The IV curves were recorded at AM 1, 28° C before exposure and after 415 and 836 hours. All of the 50 μm covered sub-modules were made using front and back contact cells and all of the 125 μm covered sub-modules were made using wraparound contact cells.

RESULTS AND DISCUSSION

Table I presents the data on the sub-modules exposed at DSET, Inc. Included in the table are the details of construction of the sub-modules, the test time and exposure, I_{sc} and P_{max} for the initial and final condition, ΔP_{max}, the percentage change in this parameter from the beginning to the end of the test and observations on the physical condition of the samples at the end of the test. Because of the large number of samples listed in Table I, the data on loss of maximum power in the sub-modules are summarized in Table VI. Many of the samples had some degree of power loss, some quite large. However, comparison of the short circuit current data in Table I with Table VI shows that even when a sub-module had a power loss, the I_{sc} value often times was within experimental error. This performance indicates that the degradation is not due to a loss in transmission of the cover material.

Table II gives the effect of accelerated exposure at DSET, Inc. 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 II 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 current data from Table I with the transmission data of Table II 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.

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 GE 585 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 III lists the samples exposed in the ultraviolet cyclic exposure tester, and the effect of the exposure on these samples. The data are self-explanatory from the remarks under the heading of final appearance. Since electrical measurements could not be made, it is not possible to determine whether poor appearance also meant poor performance. The appearance of the Vacseal indicates that it should be a subject of further testing. On the FEP sample, the GE 574 had formed a hard coating which remained on the cell surface even after the film was peeled away. It is possible that the conditions in the QUV tester transformed the adhesive to a material which might be suitable as a cover.

In Table IV, the effect of the exposure in the cyclic exposure tester on parylene coated cells is presented. The meaning of the data is not easy to ascertain. About half of the cells showed no change in current ($\pm$2%). The fact that some of the control cells lost almost as much in I_{sc} as cells which were exposed indicates that the test conditions were not the cause of this loss. The coating on the cells appeared very dull and vigorous rubbing resulted in the removal of some brownish stain without any improvement in the appearance. The maximum power data shows even greater inconsistency although some cells performed very well. For this last reason, a new group of sub-modules is being fabricated to repeat the exposure both on the QUV and at DSET.

The data presented in Table V are the effects of exposure in the QUV tester on the sub-modules covered with FEP-A, FEP-C and PFA. The I_{sc} and P_{max} at zero, 415 and 836 hours are given. These data have to be prefaced with comments on the construction of the samples and visual inspection of them after exposure. The samples covered with 50 μm material all were made with front and back contact cells. Most of these degraded in both I_{sc} and P_{max} over the duration of the test. Inspection of the samples showed severe bubbling at the interconnects on these cells. The samples with 125 μm covers were all made with wraparound contact cells. Only one of these showed bubbling. All of the wraparound-cell sub-modules retained their initial short circuit current. These results would tend to indicate that the cover materials withstand the UV-humidity regimen well. Sometime after 415 hours of exposure to ultraviolet light, however, the maximum power started to degrade and by the end of the test, all but one sample had lost from 3 to 10% in P_{max}. Some of the samples showed corrosion at the silver plated Invar interconnects where the plating was broken through. There were some fairly large deposits of what appeared to be rust, indicating that water had entered this area. Again, more work appears in order for the packaging of the cells.

CONCLUSIONS

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, silicone compounds and adhesives and possibly parylene. 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, can sort out unlikely candidates and possibly point out problem areas that might turn up in real time testing after a number of years.

REFERENCES

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TABLE I. - EFFECT OF ACCELERATED EXPOSURE ON SOLAR CELL SUB-MODULES EXPOSED ON THE EMMAQUA AT DESERT SUNSHINE EXPOSURE TESTS, INC., PHOENIX, ARIZONA.

Sub-Module Identification Number	Sub-Module Construction		Test Time and Exposure	Short Circuit Current, I_{sc}, amps		Maximum Power, P_{max}, watts		ΔP_{max}, percent	Observations
	Cover	Substrate		Initial	Final	Initial	Final		
81	FEP-A, heat bonded[a]	Aluminum	6 months; 775,890 langleys	[b]0.127	[b]0.119	[b]0.274	[b]0.254	-7.3	Delaminated
83				.131	.126	.266	.240	-9.8	Delaminated at end contacts
99		Fiberglas		.127	.122	.272	.267	-1.8	Delaminated area
112		Aluminum		.132	.134	.268	.251	-6.3	Delaminated area
123		Fiberglas		.136	.134	.277	.263	-5.0	Delaminated area
127				.135	.136	.277	.277	0	Delaminated area
148		Aluminum	4 months; 487,020 langleys	.141	.144	.270	.219	-19	Cracked cover, delaminated
149				.140	.146	.263	.268	+1.9	Some bubbling at cell edges
153		Fiberglas		.141	.144	.259	.239	-7.7	Good appearance
154				.144	.146	.268	[illegible]	+2.2	Good appearance
180	0.762 cm acrylic		2 months; 256,360 langleys	.133	----	[illegible]	----	-----	Interconnects came apart, corroded
193	.159 cm acrylic sealed at edges			.135	.133	[illegible]	.172	-31	Bubbling at cell edges - cement yellowed
194				.136	----	.246	----	-----	Bubbling at cell edges - cement yellowed
196	Cast XR-63489 (silicone)			.139	.138	.265	.248	-6.4	Translucent
197				.140	.144	.257	.210	-18	Translucent
199	UV stabilized Lexan	Polystyrene		.129	----	.255	----	-----	Translucent with yellowed areas
200				.125	.114	.251	.128	-49	Translucent with yellowed areas
203	FEP-A, heat bonded, no primer	Aluminum		.137	.146	.258	.207	-20	Some delamination at interconnects
204				.136	.144	.272	.247	-9.2	Delaminated
205	FEP-C, attached with Mystik tape			[c].120	[c].116	[c].214	[c].200	-6.5	Cover pulled away; dirty, discolored
207				.120	.118	.222	.122	-45	Cover pulled away; dirty, discolored
209	FEP-C, with GE 585 adhesive			.120	.124	.230	.234	+1.7	Many bubbles
210				.124	.126	.217	.216	-0.5	Many bubbles
212	PFA with GE 585 adhesive			.125	.104	.159	.096	-52	Many bubbles
213				.122	.122	.221	.207	-6.3	Many bubbles
215	UV stablized Lexan with GE 585 adhesive			.126	.112	.246	.222	-9.8	Looks "burned" on one edge; dulled across module
216				.119	.117	.232	.208	-10	Many bubbles; dulled; browned edge
218	Polyether sulfone with GE 585 adhesive			.124	.096	.239	.187	-22	Cover disintegrated; pieces left are translucent
219				.122	.098	.240	.193	-20	Cover disintegrated; pieces left are translucent
220	PFA, heat bonded	Fiberglas		.131	.130	.244	.231	-5.3	Delaminated at interconnects
221				.132	.130	.220	.205	-6.8	Delaminated at interconnects
224	FEP-A with GE 585 adhesive	Aluminum		.128	.122	.242	.232	-4.1	Many large bubbles
225				.126	----	.210	----	-----	Many large bubbles
227		Formica		.131	.126	.244	.236	-3.3	Many large bubbles, browned edge
228				.131	.125	.249	.247	-0.8	Many large bubbles
230	PFA with GE 585 adhesive			.132	.086	.244	.183	-25	Many large bubbles, large brown-stained area
231				.134	.126	.234	.226	-3.4	Many large bubbles
232	FEP-A with GE 585 adhesive	Aluminum		.132	.128	.250	.247	-1.2	Bubbles at edges and across cells
233				.132	.131	.245	.243	-0.8	Bubbles at edges and across cells
235		Kapton		.128	.128	.230	.221	-3.9	Bubbles
236				.129	.130	.245	.242	-1.2	Bubbles
238	FEP-C and XR-63489			.130	.128	.241	.239	-0.8	Discoloration on cells
240	PFA with GE 585 adhesive			.130	.125	.256	.236	-7.8	Bubbles
241				.128	.120	.250	.238	4.8	Bubbles
242		Aluminum siding		----	----	----	----	-----	Broken cell, bubbles
243	FEP-C with densil adhesive			----	----	----	----	-----	Broken cell, large delamination
244				.121	.099	.218	.182	-16	Some discoloration
245				.124	.128	.222	[illegible]	-6.3	Good appearance
246	FEP-A with GE 574 adhesive	Aluminum		.126	.126	.235	.224	-4.7	Edge delamination
247				.121	.126	.208	.213	+2.4	Slight delamination
248		Kapton		.125	.127	.224	.142	-37	Edge delamination through module sides
249		Aluminum		.128	.130	.248	.245	-1.2	Slight delamination
251		Kapton		.122	.124	.246	.237	-3.6	Good appearance
254	FEP-C with GE 574 adhesive			.124	.125	.240	.210	-12	Very slight delamination
255				.132	.132	.239	.167	-30	Delamination on back
257	FEP-A with GE 574 adhesive	Fiberglas		.126	----	.231	----	-----	Good appearance
258				.129	.131	.244	.246	+0.8	Good appearance
261	FEP-C with GE 574 adhesive			.130	.130	.238	.232	-2.5	Good appearance
262				.128	.132	.249	.248	-0.4	Good appearance
266	FEP-A with GE 574 adhesive	Fiberglas and Kapton		.126	.130	.246	.245	-0.4	Good appearance
268				.128	.132	.249	.241	-3.2	Good appearance
272	PFA with GE 574 adhesive	Kapton		.125	----	.242	----	-----	Delamination across interconnects in back
273				.128	.131	.242	.222	-8.3	Delamination across interconnects in back
274		Fiberglas		.130	.131	.242	.242	0	Good general appearance, but stained
275				.127	.131	.191	.188	-1.6	Good general appearance, but stained

[a]These cells were made using front and back contact cells. All others had wraparound contact cells.

[b]These parameters, for sample numbers 81-204 were measured at AM 0, 25° C.

[c]These parameters for sample numbers 205-241 and 244-275 were measured at AM 1, 28° C.

TABLE II. - 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 III. - EFFECT OF EXPOSURE TO ULTRAVIOLET LIGHT AND HUMIDITY ON VARIOUSLY COATED SILICON CELLS

ULTRAVIOLET LIGHT EXPOSURE TIME, 415 HOURS

Sample Number	Composition of Coating	Final Appearance
1	Methyl Methacrylate (MMA) with acetate, applied hot	Melted, dulled with bubbles
2	Polyester casting resin	Light tan, but otherwise of good appearance
3	Polyester casting resin, brush applied	Tanned, dull
4	Polymethyl Methacrylate (PMMA), with inhibitor	Embrittled, cracked, translucent
5	Polyester casting resin plus MMA with inhibitor	Tanned, bubbled, delaminated, translucent
6	Polyvinyl acetate	Small blisters, dull
7	Vacseal (a silicone spray coating)	(a) Slightly yellow, some bubbles over cell. (b) Unchanged from (a).
8	PMMA plus acetate	Dulled, blistery
9	PMMA plus acetate with accelerator	Dulled, blistery
10	Acrylic, sprayed	Tan, cracks, bubbles
11	Acrylic, sprayed	Tan, bubbly, peeled from edges
12	PFA, powder application	Bubbly, whitened, delaminated

TABLE III. - Concluded.

Sample Number	Composition of Coating	Final Appearance
13	PFA, powder application	Very pitted, bubbly delaminated from edges
14	Urethane, sprayed	Tanned, translucent, brittle, curled and peeled
15	Urethane, sprayed	Tanned, translucent, brittle, curled and peeled
16	FEP, sprayed	Translucent, peeled from cell edges
17	FEP, sprayed	Translucent, peeled from cell edges
18	Nylon 11, powder application	Tanned, "swiss cheese" appearance, peeled from cell, stiff, translucent
19	Nylon 11, powder application	Tanned, "swiss cheese" appearance, peeled from cell, stiff, translucent
314	FEP film attached with GE 574 adhesive	(a) Good appearance. (b) Film cracked and delaminated, GE 574 coating intact.

(a) 415 hours exposure.

(b) 836 hours exposure.

TABLE IV. - EFFECT OF ULTRAVIOLET EXPOSURE ON

PARYLENE COATED SILICON CELLS

TOTAL EXPOSURE TIME, 415 HOURS

Sample Number	Short Circuit Current, I_{sc}, amps		ΔI_{sc}, %	Maximum Power, P_{max}, watts		ΔP_{max}, %
	Initial	Final		Initial	Final	
1	0.111	0.110	-1.0	0.0463	0.0310	-33
2	.116	.112	-3.4	.0487	.0479	-1.6
3	.114	.112	-1.7	.0477	.0269	-44
4	.114	.114	0	.0484	.0492	+1.6
5	.116	.109	-6.0	.0487	.0458	-5.9
6	.116	.115	-0.9	.0477	.0474	-0.6
7*	.116	.112	-3.4	.0475	.0465	-2.1
8*	.116	.110	-5.2	.0472	.0438	-7.2
9	.114	.112	-1.7	.0490	.0489	-0.2
10	.116	.113	-2.6	.0493	.0466	-5.5
11	.115	.111	-3.5	.0487	.0488	+0.2
12	.114	.112	-1.7	.0490	.0467	-4.7
13	.114	.112	-1.7	.0478	.0494	+3.3
14*	.116	.115	-0.9	.0486	.0405	-16.7
15*	.115	.112	-2.6	.0460	.0442	-3.9
16*	.116	.116	0	.0307	.0308	0

*Control cells.

TABLE V. - EFFECT OF EXPOSURE IN THE QUV TESTER ON FEP-A, FEP-C AND PFA COVERED SUB-MODULES

Exposure Time / Sample Code	I_{sc}, amps			P_{max}		
	0 hrs	415 hrs	836 hrs	0 hrs	415 hrs	836 hrs
*2A7	0.120	0.138	0.070	0.0921	0.0864	0.0235
8	.122	.122	.102	.0927	.0593	.0365
9	.120	.118	.108	.0984	.0608	.0501
10	.122	.123	.120	.0964	.0742	.0542
*2C7	.120	.122	.118	.0978	.0895	.0652
8	.121	.124	.115	.1003	.0653	.0506
9	.121	.119	----	.0894	.0608	-----
10	.120	.122	.114	.0956	.0665	.0500
*2P10	.122	.122	.106	.0899	.0662	.0427
11	.120	.122	.118	.0983	.0697	.0533
12	.122	.098	.076	.0805	.0339	.0252
13	.120	.120	.093	.0962	.0580	.0382
*5A9	.130	.134	.130	.0994	.1048	.0953
10	.132	.136	.132	.1010	.1056	.0929
11	.130	.136	.131	.1022	.1064	.0965
*5P7	.134	.136	.132	.1042	.1058	.0900
8	.136	.137	.134	.1015	.1002	.0912
9	.134	.096	.135	.0968	.0356	.0763
*5C7	.132	.136	.134	.1008	.1030	.0968
8	.132	.136	.132	.1031	.1013	.0958
9	.134	.136	.134	.1015	.1010	.0950

*2A and 5A are 50 and 125 μm FEP-A, respectively.
2C and 5C are 50 and 125 μm FEP-C, respectively.
2P and 5P are 50 and 125 μm PFA, respectively.
(All covers are attached with GE 574.)

TABLE VI. - LOSS IN MAXIMUM POWER IN SUB-MODULES

UNDER ACCELERATED TESTING AT DSET

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

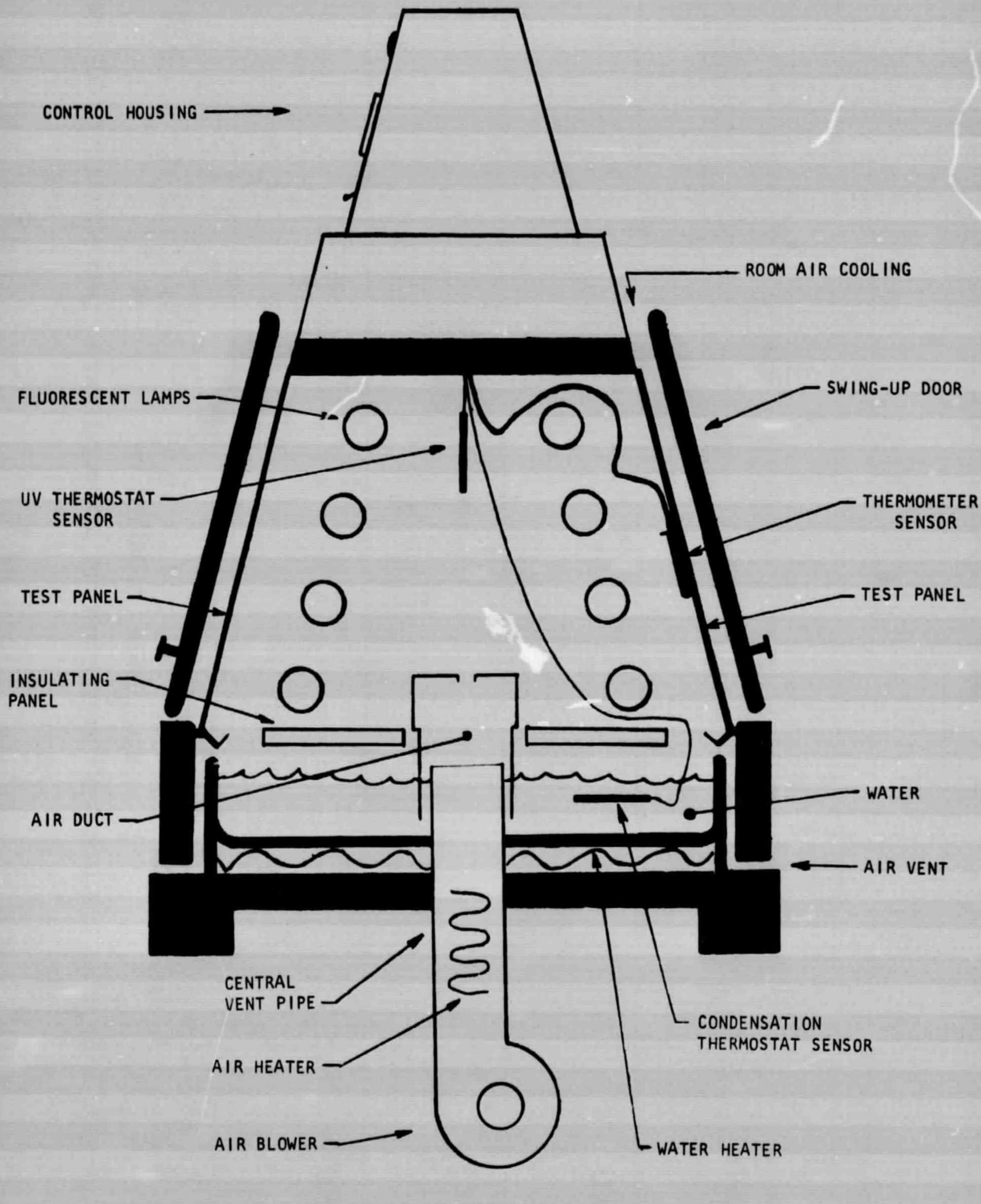

FIGURE 1. - QUV TESTER SCHEMATIC CROSS SECTION

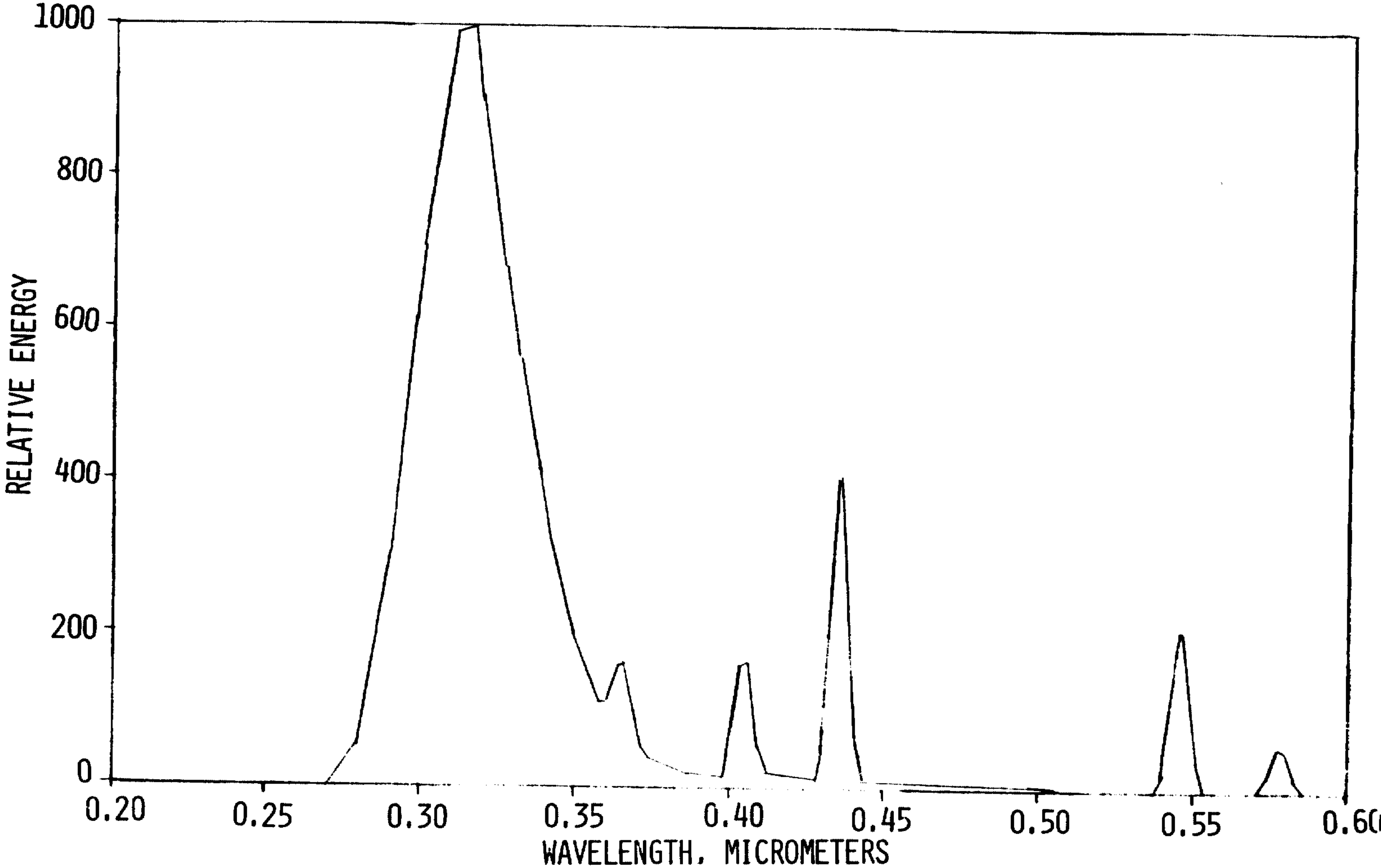

FIGURE 2. - RELATIVE ENERGY VERSUS WAVELENGTH FOR A REPRESENTATIVE LAMP USED IN THE QUV TESTER

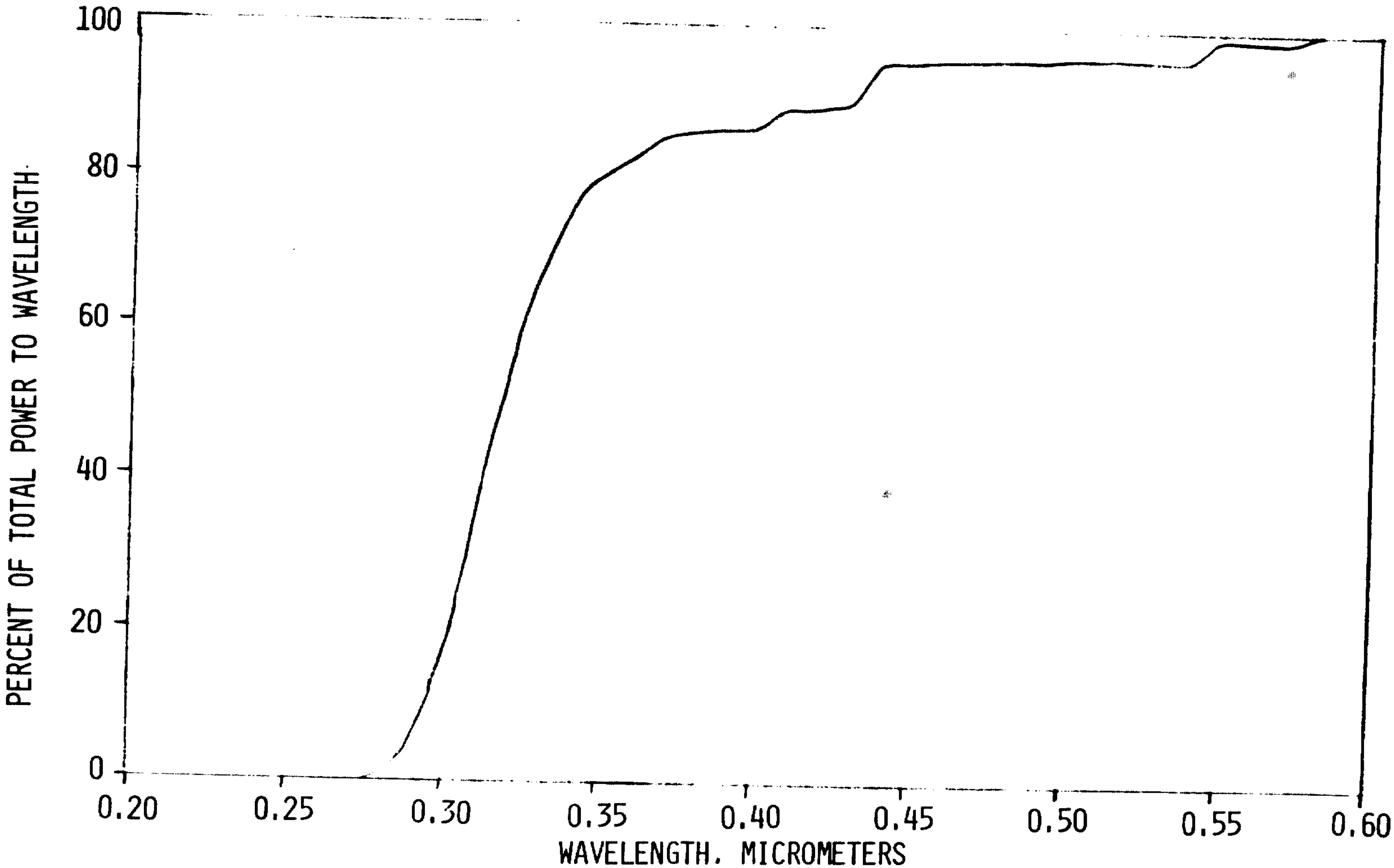

FIGURE 3. - DISTRIBUTION OF ENERGY BELOW A GIVEN WAVELENGTH FOR A REPRESENTATIVE LAMP USED IN THE QUV TESTER