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INVESTIGATION OF TEST METHODS, MATERIAL PROPERTIES, AND PROCESSES FOR SOLAR CELL ENCAPSULANTS

Twenty-Fifth
Quarterly Progress Report

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For

JET PROPULSION LABORATORY
4800 Oak Grove Drive
Pasadena, California 91103

ENCAPSULATION TASK OF THE FLAT-PLATE
SOLAR ARRAY PROJECT

The JPL flat-Plate Solar Array Project is sponsored by the U.S. Department of Energy and forms part of the Solar Photovoltaic Conversion Program to initiate a major effort toward the development of low-cost solar arrays. This work was performed for the Jet Propulsion Laboratory, California Institute of Technology, by agreement between NASA and DOE

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TECHNICAL CONTENT STATMENT

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I. SUMMARY

Springborn Laboratories, Inc. is engaged in a study of potentially usefull low cost encapsulation materials for the Flat-Plate Solar Array Program (FSA) funded by the Department of Energy and administered by the Jet Propulsion Laboratory. The goal of the program is to identify, test, evaluate and recommend encapsulation materials and processes for the fabrication of cost-effective and long life solar modules. During the past quarter these investigations have included continued investigations of accelerated aging techniques for module component lifetime studies, an investigation of candidate outer cover films and continued evaluation of soil-repellant coatings.

A program of accelerated aging is being conducted for the purpose of (a) generating empirical and practical data relating to longevity, (b) rating and ranking of the stability of candidate formulations, and (c) generating data that may be used in mathematical model for the prediction of service life. In this report the results of RS/4 sunlamp are compared for dry conditions versus that incorporating a water spray cycle. The results of 10,000 hours of this type of accelerated aging show that the water spray (simulating rain extraction) imposed no additional stress on almost all of the specimens tested. Only one material , Acrylar acrylic film,was effected by the water spray and appeared to lose its physical properties more rapidly than its dry counterpart. Additionally, the water spray resulted in loss of UV screening agent from this material with a consequent decrease in its ultraviolet protective quality. More data was obtained from the Outdoor Photothermal aging racks (OPTs). These are devices that age polymers in natural sunlight while accelerating the degradation reactions with heat. They are on only during the sunlight hours and are operated at 70°, 90° and 105°C. The first set of (pottant) specimens has been completed under these exposures. At the lowest temperature, most of the formulations are still under test after 4,000 hours, however one formulated without the hindered amine stabilizer (Tinuvin 770) failed (zero

tensile strength) with 2,000 hours. The 90^{o}C condition appears to be more severe and no material survives past 3,000 hours. The EMA formulations appear to be somewhat better than the EVA compounds under these conditions and the formulation without the HALS stabilizer degraded well within the 1,000 point. The high temperature unit (105^{o}C) is the most severe of the three and results in large decreases in most properties within 1,500 hours. The results obtained with the OPTs are very encouraging in that it is now possible to degrade candidate polymer formulations under conditions similar to the intended application and within periods of time short enough to reformulate for the optimum stability. In addition, the OPTs have clearly shown the need for the HALS type stabilizer, and new formulations have been deployed to test the effectiveness of a number of commercially available compounds. In addition, whole modules have been put under test to examine the longevity and mode of failure for a complete system of components. In this type of exposure, the pottants now also have the benefit of the protective glass superstrate or outer cover film that extends their life.

Outer cover films are required for the protection of substrate designed modules in which the cells are supported from the underside. The outer cover must be highly transparent and weatherable. Initially, it was thought that UV screening was also a necessity, however most of the candidate pottants are sufficiently stable that the additional protection may not be required. This now increases the number of materials that might be suitable for this application. Some of the more expensive fluoropolymers may still be cost effective due to their low refractive indices. The improvement in optical coupling may result in an increase in module efficiency of several percent. Some of these newer candidates will be evaluated further in future work.

An experimental program continued to determine the usefulness of soil resistant coatings. These coatings are intended to be surface treatments applied to the sunlight side of solar modules and function to prevent the persistent adhesion of soil to the surface, aid in its removal, and consequently keep the power output high. These treatments have been applied to "Sunadex" glass, Tedlar and oriented acrylic film. After twenty four months of outdoor exposure a fluorosilane treatment designated E-3820, was found to be the best coating for all three outer surfaces and result in significantly better soil resistance than the controls.

II. INTRODUCTION

The goal of this program is to identify and evaluate encapsulation materials and processes for the protection of silicon solar cells for service in a terrestrial environment.

Encapsulation systems are being investigated consistent with the DOE objectives of achieving a photovoltaic flat-plate module or concentrator array at a manufactured cost of \$0.70 per peak watt (\$70/m^2) (1980 dollars). The project is aimed at establishing the industrial capability to produce solar modules within the required cost goals by the year 1986.

To insure high reliability and long-term performance, the functional components of the solar cell module must be adequately protected from the environment by some encapsulation technique. The potentially harmful elements to module functioning include moisture, ultraviolet radiation, heat build-up, thermal excursions, dust, hail, and atmospheric pollutants. Additionally, the encapsulation system must provide mechanical support for the cells and corrosion protection for the electrical components.

Module design must be based on the use of appropriate construction materials and design parameters necessary to meet the field operating requirement, and to maximize cost/performance.

Assuming a module efficiency of ten percent, which is equivalent to a power output of 100 watts per m^2 in midday sunlight, the capital cost of the modules may be calculated to be \$70.00 per m^2. Out of this cost goal, only 20 percent is available for encapsulation due to the high cost of the cells, interconnects, and other related components. The encapsulation cost allocation[a] may then be stated as \$14.00 per m^2 which included all coatings,

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a. JPL Document 5101-68

The former cost allocation for encapsulation materials, was \$2.50/m^2 (0.25/ft^2) in 1975 dollars, or \$3.50/m^2 (\$0.35/ft^2) in 1980 dollars. The current cost allocation of \$14/m^2 is an aggregate allocation for all encapsulation materials including an edge seal and gasket.

pottants, and mechanical supports for the solar cells.

Assuming the flat-plate collector to be the most efficient design, photovoltaic modules are composed of seven basic construction elements. These elements are (a) outer covers; (b) structural and transparent superstrate materials; (c) pottants; (d) substrates; (3) back covers; (f) edge seals and gasket compounds; and, (g) primers. Current investigations are concerned with identifying and utilizing materials or combinations of materials for use as each of these elements.

Throughout this program, extensive surveys have been conducted into many classes of materials in order to identify a compound or class of compounds optimum for use as each construction element.

The results of these surveys have also been useful in generating first-cut cost allocations for each construction element, which are estimated to be as follows (1980 dollars):

Construction Elements	Approximate Cost Allocation* ($/m^2)
Substrate/Superstrate (Load Bearing Component)	7.00
Pottant	1.75
Primer	0.50
Outer Cover	1.50
Back Cover	1.50
Edge Seal & Gasket	1.85

*Allocation for combination of construction elements: $14/m^2.

From the previous work, it became possible to identify a small number of materials which had the highest potential as candidate low cost encapsulation materials. The first page of Appendix A (Table I' gives the status of candidate encapsulation materials identified to date. These materials are thought to be the most satisfactory for use as the construction element indicated.

In addition to materials, two encapsulation processes are being investigated:

1) Vacuum bag lamination
2) Liquid Casting

The suitability of these processes for automation is also being investigated. However, the selection of a process is almost exclusively dependent on the processing properties of the pottant. This interrelationship may have a significant influence on the eventual selection of pottant materials.

Recent efforts have emphasized the identification and development of potting compounds. Pottants are materials which provide a number of functions, but primarily serve as a buffer between the cell and the surrounding environment. The pottant must provide a mechanical or impact barrier around the cell to prevent breakage, must provide a barrier to water which would degrade the electrical output, must serve as a barrier to conditions that cause corrosion of the cell metallization and interconnect structure, and must serve as an optical coupling medium to provide a maximum light transmission to the cell surface and optimize power output.

This report presents the results of the past year which has been directed at the continuing development and testing of pottants and other components.

The topics covered in this report are as follows:

(a) the comparison of two closely related aging techniques, RS/4 and RS/4 with water spray,

(b) the results of pottant exposure on the Outdoor Photothermal aging racks (OPTs),

(c) a survey of new candidate outer cover materials, and

(c) continuation of the study of anti-soiling coatings for the surfaces of PV modules.

III. AGING AND DEGRADATION STUDIES

The candidate encapsulation materials being investigated in this project are intended for the construction of solar cell modules for terrestrial deployment and consequently must be capable of enduring the operating temperatures, insolation, precipitation and other elements of the outdoor exposure in the geographical region selected. Although the severity of these conditions may be fairly accurately gauged (climatic atlas, weather records, etc.) the lifetime and performance of individual materials or combinations of materials is not as easily assessed. The chemical pathways and rates at which materials age in outdoor exposures are very complex and predictive techniques often turn out to be inacurrate.

The degradation of polymeric materials in outdoor weathering is caused primarily by sunlight, especially the ultraviolet component. In actuality, the deteriorating effect of light is usually enhanced by the presence of oxygen, moisture, heat, abrasion, etc. and in most cases may be referred to as photo-oxidation, resulting from the combined effects of oxygen and sunlight.

Sunlight reaching the earth is filtered through the atmosphere, removing shorter wavelengths up to 290 nm before it reaches the surface of the earth. Thus, ultraviolet effects on plastic result primarily from wavelengths of approximately 290-400 nm, which constitute less than 4 percent of the total solar radiation reaching the earth.

The shorter the wavelength of light the greater is its potential to produce a chemical change in material. This energy must first be absorbed in order for damage to occur.

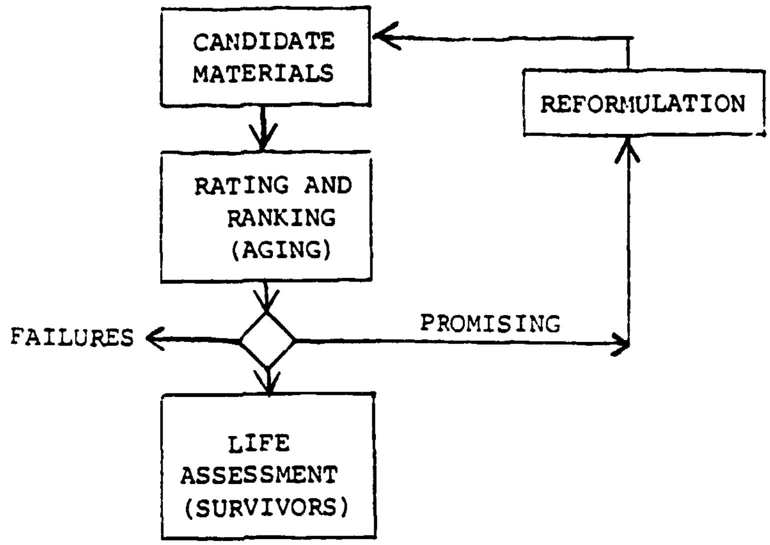
The degradative effects of these environmental stresses may be effectively inhibited by the incorporation of specially formulated additives to the polymer. Compounds that serve as ultraviolet light absorbers, antioxidants, hydroperoxide decomposers, metal deactivators, etc. may result in dramatic improvements in the service life of polymeric systems. Regardless of the inherent sensitivity of the polymer or the effectiveness of the additives and formulation, the question of lifetime under service conditions remains an important question.

Accelerated tests are frequently used to assess long term aging effects and compare the effectiveness of stabilizers in providing improved protection against environmental deterioration. Typically, properties such as tensile strength, elongation at break, apparent modulus, resistance ot flex cracking and other properties are measured on samples aged for known periods of time under specified conditions. These tests are useful for determining the relative stability of polymers and formulations, but correlation with actual service is not always accurate.

This is especially true for outdoor aging where the conditions of weathering cannot be precisely simulated or accelerated in the laboratory. Changes in the ratio of crosslinking to chain scission, temperature variations, differing oxygen concentrations, ultraviolet flux, dark cycle reactions, etc. add to the difficulty of correlation and performance prediction. Accelerated tests are useful, however, for the relative ranking and rating of materials and can provide approximate acceleration factors that are useable over a certain range.

In order to assess the relative stability of individual polymers and to determine the effectiveness of varying formulations, Springborn Laboratories is conducting a program of accelerated aging and life predictive strategies that should be useful for: (a) rating, ranking and reformulating candidate encapsulation materials, (b) generating practical data that relate to material performance under use conditions, and (c) generating data that may be useful in some type of predictive manner for life assessment.

These goals are being met by using the scheme presented in the following diagram:



This method is intended to serve as a multipurpose data source.

A variety of accelerated aging conditions have been set up at Springborn Laboratories and are continually generating a data for the purposes previously mentioned. The aging conditions all employ either single stresses or combinations of the following:

(a) thermal stress (heat aging)
- in inert atmosphere
- in air ,

(b) ultraviolet stress (UV exposure),

(c) hydrolytic stress (water exposure),

(d) catalytic stress (metal catalyzed oxidation),

(e) combined stresses (any of the above together).

The effects of these stresses on the candidate encapsulation materials is determined by measuring specific properties as a function of time. These properties were selected for their relevance to module service life and were chosen from four categories considered to be potentially life-limiting, as follows:

- Mechanical: tensile strength, elongation, gel content, modulus
- Optical: yellowing, haze, optical transmission from 0.4 to 1.1 microns
- Chemical: loss of stabilizers, degradation, corrosion of interconnect metalization, metal catalyzed reactions, outgassing
- Dielectric: field stress degradation, decay of breakdown strength, leak current, loss of electrical isolation

A number of approaches to data modeling may be considered, the simplest being first order behavior in which the log of the property being measured in linear over log time. This relationship may be used easily for life prediction, especially when the reaction rate is proportional to the temperature (Arrhenius relationship). Polymer degradation is frequently a complex relationship of many competing chemical reactions, however, and may shift dramatically with subtle changes in temperature, light intensity, additives, etc. The behavior most frequently observed is the "induction period" type in which the degradation rate suddently changes and the property vs. time curve shows a sharp downward trend.

In this report the results of two selected accelerated aging conditions are given. The first is a comparison of RS/4 sunlamp exposure with and without water spray and the second concerns data obtained from Outdoor Photo-Thermal aging reactors (OPTs).

A. RS/4 Exposures

The RS/4 Sunlamp exposure condition consists of a rotating table carrying the test specimens beneath a General Electric RS type sunlamp. This lamp consists of a medium pressure mercury arc lamp in a quartz tube balasted by a tungsten filament. The assembly is mounted in an inert gas filled bulb with a reflective coating and a transmission cutoff near 290 nm. The bulb is additionally filtered with a piece of Pyrex (cutoff 300 nm) to insure the absence of spectra below the terrestrial limit. This condition is one of the most easily monitored and is widely used throughout the plastics industry for the purpose of comparative aging. This device is a modification of the test procedure ASTM D-1501, "Exposure of Plastics to Fluorescent Sunlamp: and is operated at a temperature of $50^{o}C$.

Photometric measurements of the RS/4 light source indicate that its output in the terrestrial ultraviolet range is approximately 1.4 suns in intensity. Because the lamp operates 24 hours a day, an additional acceleration factor is included to give an overall calculated acceleration factor of approximately 6.7. Equivalently, one year of outdoor exposure (in terms of ultraviolet) is accomplished in about 1,300 hours of RS/4 exposure.[a] Under these conditions, unstabilized polypropylene degrades in approximately 160 hours and polyethylene in about 450 hours(at 50^{o}C).

The RS/4 conditions are operated at a temperature of 50^{o}C (except for the temperature condition, not discussed in this report) and have two variations, wet and dry. In the wet condition, the specimens are sprayed with distilled water for ten minutes once every two hours. The purpose of this modification is to simulate the effects of rainwater that may occur in an outdoor environment and assess the fugitive nature of compounding ingredients incorporated in the polymeric materials.

Tables 2 thru 6 in the appendix give the results for a number of dry RS/4 exposures; tables 7 thru 11 give the results for the equivalent wet condition. The materials compared to this evaluation are (a) EVA 9918 candidate pottant (ethylene/vinyl acetate), (b) EMA 13439 pottant (ethylene/methyl acrylate, (c) PUZ-2591, an aliphatic polyurethane pottant, (d) Tedlar 100 BG30UT, a candidate outer cover film, and (e) Acrylar X22417, a candidate outer cover film based on acrylic chemistry. A comparison of the performance of these materials is given as follows:

a. Willis, P., et al., Investigations of Test Methods, Material Properties, and Processes for Solar-Cell Encapsulants, Annual Report, ERDA/JPL-954527, Springborn Laboratories, Inc., Enfield, Connecticut, July 1980.

RS/4 Exposures; Dry versus Water Cycle

Tables: Dry/Wet	Material	Exposure Time	Property	Performance Dry	Performance Wet
2/7	EVA 9918	10,000	Tensile	1,520	2,810
			Elongation	570	675
			Gel Content	69.8	69.8
			UV Cutoff	357	360
3/8	EMA 13439	10,000	Tensile	2,280	2,217
			Elongation	657	600
			Gel Content	34.4	63.5
			UV Cutoff	358	363
4/9	PU Z-2591	10,000	Tensile	137	241
			Elongation	102	220
			Gel Content	93.1	96.1
			UV Cutoff	366	367
5/10	Tedlar 100BG30UT	15,000/ 10,000	Tensile	14,500	13,000
			Elongation	72	55
			Gel Content	n/a	n/a
			UV Cutoff	355	358
6/11	Acrylar X-22417	12,000/ 10,000	Tensile	14,500	9,200
			Elongation	7	1
			Gel Content	n/a	n/a
			UV Cutoff	381	321

As may be seen in the preceding chart, the values obtained for wet and dry RS/4 conditions vary very little within the range of experimental error. There are no major differences observed for values of ultimate tensile strength, ultimate elongation, gel content (crosslink density) or ultraviolet cutoff (retention of UV stabilizer) for most of the materials tested.

The only real change between wet and dry conditions is found for Acrylar. This material is an outer cover film candidate consisting of a biaxially oriented acrylic film containing an ultraviolet screening compound. In the exposure that included the water spray, the Acrylar film showed much greater losses of tensile strength and its elongation decreased to the point of not being testable in many specimens. Most conspicuously, the ultraviolet cutoff wavelength dropped from 382 nm,in the control and dry conditions,to 321 nm, indicating loss of UV screening stabilizer. These results suggest that Acrylar may loose its protective screening property with outdoor exposure.

In general, the RS/4 incorporating the water cycle does not appear to add much of an additional stress component to the aging condition and does not result in increased degradation rates.

B. Outdoor Photothermal Reactors

The predominant cause of outdoor deterioration is photothermal aging; the combination of heat and ultraviolet light. In all the laboratory techniques devised to date, it is mainly the light that is increased (photoacceleration) through the use of arcs and discharge lamps. In the OPT reactors, natural sunlight is used as the light source and the specimen temperature is increased. The OPT reactors consist of heated aluminum blocks surfaced with stainless steel and mounting hardware to hold the test specimens flush with the surface. The reactors are tilted at 45° south and the device turns on at sunrise and off at sunset. Three temperatures have initially been selected: 70°C, 90°C, 105 $^{\circ}$C. This approach eliminates the difficulties associated with the irregular spectrum of artificial light sources, exposes the specimens to other environmental conditions such as rain and pollution, and additionally incorporates a dark cycle. The only acceleration, therefore, is in the temperature, all other environmental conditions being present in their natural occurrence and intensity. This *condition is therefore considered to be a closer approximation meaning*ful acceleration of modules and module components than the other types also being used. The results for specimens depolyed to date are given in tables 12 through 17 (70°C), tables 18 through 23 (90°C) and tables 24 through 29 (105°C). A general comparison of the performance of these materials is presented in the following table in which the percent of original tensile is given as a function of exposure time. The presence of several zeros in a row indicate that the specimen remained in sufficiently good condition to continue under exposure but that the mechanical properties did not permit physical testing. Conditions shown as a single zero indicate that the polymer was too degraded to provide further information.

Outdoor Photothermal Aging Reactors

Percent Tensile Strength Retained

OPT 70°C		Exposure Time, Hours				
Table #	Compound	1000	1,500	2,000	3,000	4,000
12	EVA 9918	152%	-	106%	124%	140%
13	EMA 152257	82%	-	89%	91%	89%
14	PU Z2591	123%	-	158%	156%	154%
15	EMA 16717	92%	-	89%	84%	-
16	EVA 16718A	97%	-	93%	101%	-
17	EVA 16718B	53%	-	4.9%	-	-
OPT 90°C						
18	EVA 9918	133%	-	-	-	-
19	EMA 15257	61%	-	25%	-	-
20	PU Z-2591	101%	-	-	-	-
21	EMA 16717	76%	64%	20%	-	-
22	EVA 16718A	-	-	-	-	-
23	EVA 16718B	-	-	-	-	-
OPT 105°C						
24	EVA 9918	98%	-	12%	-	-
25	EMA 15257	50%	-	11%	-	-
26	PU Z-2591	137%	-	-	-	-
27	EMA 16717	53%	15%	-	-	-
28	EVA 16718A	68%	8%	-	-	-
29	EVA 16718B	-	-	-	-	-

As may be seen in the preceding chart, the 70°C condition is the least severe of the three and most of the candidate pottants under exposure have survived 3,000 to 4,000 hours without much decrease in tensile strength. The one exception is an experimental formulation of EVA designated 16718B that is essentially destroyed at the 2,000 hour point. This compound contains the co-polymerized ultraviolet screener (UV-2098, American Cyanamide) but no hindered amine type stabilizer (Tinuvin-770, Ciba-Geigy) which appears to be essential for its stability. The 90°C condition is seen to be much more severe with all candidates terminating within 3,000 hours. The most stable of the candidate resins appear to be those based on EMA, which last 2,000 hours but become untestable at the 3,000 hour point. The EVA formulations do not perform quite as well and degrade to the point of being untestable for mechanical properties with 2,000 hours of exposure. The least stable formulation (EVA 16718B) was again the one without the hindered amine type light stabilizer. The 105°C OPT conditions were the most severe and no candidate pottant survived much beyond 1,500 hours without considerable decay in properties. The EMA resins showed no particular improvement over the EVA specimens in this condition. Under this test, the EVA formulation A9918 appears to out perform the new EVA formulation 16718A, which contains TBEC, Tinuvin-770 and co-reacted UV-2098. None of the OPT specimens appear to be losing UV screener and the cutoff wavelengths are unchanged.

The early failure of formulations without the Tinuvin-770 stabilizer again point out the importance of HALS stabilizers on the usccessful protection of polyolefins.

The OPT data gathered so far is considered to be a "calibration" run in order to assess the relative acceleration rates of these devices. This data also demonstrate the fact that they are an effective method for the rapid aging and and ranking of module materials under conditions similar to those of the intended application. In the future, the evaluation periods will be more closely spaced in order to examine the changes in polymer properties with greater precision and guide the development of further formulations. In addition to individual materials, whole modules may be exposed on the OPTs and the interactions of complete systems observed. Sets of two-cell trial modules have already been deployed for this purpose and will be evaluated in subsequent reports.

IV. OUTER COVER MATERIALS

Due to the relatively high cost of glass (appx. $0.90/ft^2) and the low cost of structural materials such as steel ($0.25/ft^2) and wood products ($0.15/ft^2), substrate designs offer a potential cost advantage in the construction of PV modules. With the use of wood or mild steel and additional cost component will be required for environmental protection, however the composite cost is still imagined to be considerably lower than that of a glass surfaced superstrate module. In substrate designs, the cell string is supported from the underside, leaving the cell string and pottant exposed on the outer sunlit side.

Soft elastomeric materials must be used for pottants in order to prevent cracking of the silicon cells due to stresses resulting from thermal expansion differences. Soft materials are prone to soiling and dust retention, however, which reduces the light transmission and impairs the module efficiency. Hard coatings are, therefore, desirable to avoid this problem. Additionally, the function of UV screening is required for the outer cover in order to reduce the effects of photolytic degradation and provide the maximum useful lifetime for the pottant and other components.

The properties of an idealized outer cover may be stated as follows:

(1) high optical transparency;

(2) compatible refractive index properties to the pottant that favor optical coupling;

(3) chemical compatibility with either the pottant or a suitable primer or adhesive to insure a high reliability bond that will not delaminate during the useful lifetime of the module;

(4) inherent weatherability;

(5) ultraviolet light screening properties to protect the underlying pottant;

(6) anti-reflective properties to increase the total light transmission (if used on the sunlit side);

(7) resistance to thermal cycling without melting, cracking, or deforming;

(8) surface hardness sufficient to retard soiling and to withstand cleaning processes in routine maintenance;

(9) abrasion resistance to prevent loss of material or sufficient haze to impair the transmission characteristics.

In accordance with these requirements, Springborn Laboratories has continued to evaluate transparent weatherable organic films and coatings that have the ability to screen out UV light. Many of the candidate pottant compounds do not appear to need this UV protection however, and seem to be remarkably stable to photodegradation. The RS/4 sunlamp exposure, normally regarded as severe in the polymer industry, results in failure of EVA 9918 candidate pottant only after 40,000 hours. This is a remarkably long time and indicates a high resistance to photodegradation. If the photolytic effect is not considered to be a problem then the investigation of suitable outer covers may now be expanded to include films and coatings that do not have screening properties. The following table is a survey of commercially available outer cover films, both screening and non-screening.

The two most important factors are cost ($\$/ft^2/mil$) and the power transmission. The best overall combination is found for Acrylar X22417. This is a three mil oriented acrylic film containing a screener,and although it has low cost and high transmission it is very difficult to handle(notch sensitivity) and shows evidence of outdoor degradation. The next most promising film is oriented Kynar (Pennwalt Corporation, Philadelphia, PA). This material is now being marketed as a transparent, weather resistant film designed for solar energy application. This strong, tough, fatigue resistant film is particularly useful for solar collectors, solar stills, and greenhouse glazing. Kynar PVDF is exceptionally stable to ultraviolet radiation, its mechanical properties are maintained throughout many years of outdoor exposure. The manufacturer claims that oriented Kynar film on accelerated weathering to an equivalent of 16 to 28 years exposure, lost 2-5% of its original specular transmittance and showed only insignificant change in mechanical properties. Additionally, its lower refractive index than acrylics or Tedlar films should be an advantage in optical coupling to increase the transmitted light. The idea of optical coupling to improve the throughput of power is also a consideration. Light entering any combination of materials in which there is a discontinuity in the index of refraction will result in a partial reflection at the interface and consequent loss of transmitted energy. The degree of this reflection is the reflection coefficient, R.

For a given interface with index n_1 on one side and n_2 on the other, the reflection coefficient, R, can be expressed as:

$$R = \frac{(n_1 - n_2)^2}{(n_1 + n_2)^2}$$

R is reflection coefficient

n_1 is refractive index of medium 1

n_2 is refractive index of medium 2

For example, if medium 1 is glass (Index 1.5) and medium 2 is air (1.0), the reflection coefficient R =

$$R = \frac{(0.5)^2}{(2.5)^2} = 0.04 \text{ or } 4\%$$

For passage of light through a pane of glass, there will be a loss of about 4% on entering and another 4% on leaving. This value agrees well with experimental data and gives a glass/air interface a maximum transmission of 92%. Repeating the calculation for FEP (Fluorinated ethyylene/propylene copolymer, DuPont) with a refractive index of 1.345 gives a reflection coefficient of 2.16% per reflection. This indicates that the maximum transmitted power of an FEP/air interface is 95.7%, a difference of 3.7%. This improvement in the use of available sunlight may well justify the use of a more expensive film.

Due to the potential for improved weatherability and power output with these films, these are being incorporated into the evaluation program as candidate outer cover materials and will be assessed for suitability in module applications. A table of some of the more promising commercial candidates and their relevant properties is given on the following page.

CANDIDATE SCREENING AND NON SCREENING OUTER COVERS

Material	Chemistry	Thickness (inches)	Non-Screening Screening	n_D	Tear Strgth ASTMD1004 (gm/mil)	Tensile Strenth (psi)	Ultimate Elongation (%)	Optical Transmission[e,b] %T	Optical Transmission[e,b] %Pcell	Cost[c] ($/lb)	Denisty (gm/cc)	Cost $ (as shown $/ft²/mil)	Cost ($/ft²/mil)
Tefzel 200	ETFE	.005	N	1.403	634	6,500	200	85.6	89.2	14.50	1.7	0.64	0.128
Kynar-Oriented	PVF_2	.0035	N	1.42	575	23,000	125	88.8	90.3	6.05	1.75	0.192	0.055
Tedlar 100BG30UT	PVF	.001	S	1.46	530	17,700	71	76.2	84.1	13.80	1.5	0.098	0.098
Tedlar 400BG20SE	PVF	.004	S	1.46	530	13,000	250	63.9	70.3	16.25	1.5	0.464	0.116
Halar	ECTFE	.002	N	1.4	500	7,000	200	85.3	87.4	11.00	1.68	0.192	0.096
Acrylar 22417	PMMA	.003	S	1.493	746	24,000	1	80.7	90.9	3.65	1.18	0.0675	0.0225
PFA 9705	PFA	.005	N	1.3	289	4,300	300	88.4	90.2	11.00[a]	2.15	0.615	0.123
FEP 100	FEP	.002	N	1.345	289	3,500	300	93.6	94.8	9.75	2.15	0.218	0.109
Tedlar 100SG30TR	PVF	.001	N	1.46	530	17,700	100	-	-	11.90	1.5	0.085	0.085

a. estimated cost
b. power transmission, standard single crystal silicon cell
c. 1983 prices
d. composite cost
e. range: 350-900 nm

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VI. SOILING EXPERIMENTS

The performance of photovoltaic modules is adversely affected by surface soiling, and generally, the loss of performance increases with the quantity of soil retained on their surfaces. To minimize performance losses caused by soiling, photovoltaic modules not only should be deployed in low-soiling geographical areas, but also should have surfaces or surfacing materials with low affinity for soil retention, maximum susceptibility to natural removal by winds, rain, and snow; and should be readily cleanable by simple and inexpensive maintenance cleaning techniques.

The action of soiling is considered to include accumulation, natural removal by wind, rain, and snow; and activation of mechanisms that result in surface soiling that resists natural removal, thus requiring maintenance methods.

The theoretical aspects of soiling have been addressed recently in documents by the Jet Propulsion Laboratory.[a., b.] The basic findings of these studies show that the rate of soil accumulation in the same geographical area is material independent and that rainfall functions as a natural cleaning agent. The effectiveness of the cleaning effect of the rain is material dependent, however.

Based on the postulated mechanisms for soil retention on surfaces, certain characteristics of low-soiling surfaces may be assumed. These are: (a) hard, (b) smooth, (c) low in surface energy, (d) chemically clean of water soluble salts, and (e) chemically clean of sticky materials. It is possible that cost effective coatings having these required porperties may exist and be applied to solar module surfaces and result in low maintenance costs and preserve the effective generation of power from these devices.

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a. Cuddihy, E. F., "Encapsulation Materials Status to December 1979" LSA Project Task Report 5101-144, Jet Propulsion Laboratory, Pasadena, CA January 15, 1980.

b. Hoffman, A. R., and Maag, C. R., "Airborne Particulate Soiling of Terrestrial Photovoltaic Modules and Cover Materials", Proceedings of the Institute of Environmental Sciences, May 11-14, 1980; Philadelphia, PA.

The candidate materials for the outer surface of solar modules currently consist of low-iron glass, Tedlar fluorocarbon film (DuPont) and biaxially oriented acrylic film, Acrylar (3M Corporation; product X-22417). These materials are all relatively hard, smooth and free of water soluble residues, consequently experiments were conducted to determine if an improvement in soiling resistance could be obtained by the application of low surface energy treatments.

Of the initial seven coatings of treatments initially explored in this program, four were continued for evaluation of anti-soiling effectiveness out to twenty-eight months of outdoor exposure. These four treatments are:

1. L-1668, an experimental fluorochemical silane produced by 3M Corporation that is used to impart water and oil repellencey to glass surfaces. This material is not yet commercial.

2. L-1668 following treatment of the surface with ozone activation (for the organic films only).

3. Dow Corning E-3820-103B, an experimental treatment consisting of perfluorodecanoic acid coupled to a silane (Z-6020). This compound is not commercially available.

4. The E-3820-103B following surface treatment with ozone to create active sites on the organic polymer films.

Ozone treatments are not used with the glass because no surface activation occurs in this case.

These coatings/treatments were applied to each of the three candidate outer surfaces using the recommended application technique. The organic film materials, Tedlar and Acrylar, were supported by a piece of glass on the underside, and attached with a colorless and ultraviolet stable pressure sensitive adhesive. The completed test coupons were then mounted in outdoor racks on the roof of Springborn Laboratories' facilities in Enfield, Connecticut. Evaluation was performed monthly and a record of rainfall was kept in order to corelate soiling effects with precipitation.

The degree of soiling on the completed specimens was measured by power transmission using a specially designed standard cell device. This instrument measures the drop in short circuit current, I_{sc}, with the use of a laboratory grade volt-ohm meter. This method was found to be better than spectroscopic measurement, due to difficulties in mounting the test specimens at the spectrometer port. Additionally, the use of a silicon cell as a detector gives a more meaningful reading due to the response to scattered light he direct measurement of the variation in cell power.

The results of months of outdoor exposure are give in Tables 30 through 32. and Figures 1 through 3 . The tables give the values for the percent variation in short circuit current for Sunadex glass, Tedlar film and Acrylar film, for each month and each coating. In the figures, the values for control and the best performing treatments are graphed for clarity.

The data for Sunadex low-iron glass is given in Table 30 and Figure 1 . Sunadex glass, and the treatments applied to it, gave specimens with the best overall inherent soil resistance. The control and most of the coated specimens followed the same pattern of rising and falling simultaneously throughout the exposure period and the rainy months showed a dramatic decrease in power in all cases. A constant differential was found between the control measurements and the most effective coating, E-3820, which was consistently in the order of 0.5 to 1.0 percent better than the untreated control.

This has been the case throughout the exposure period except for the twenty-fourth month, in which the control gave slightly better performance.

The treated specimens have shown a significant improvement in the transmission of usable power and have "self-cleaned" effectively during periods of sufficient rain. The E-3280 treatment has been found to be somewhat better than the L-1668, and the enhancement of power from a module with this coating is estamiated to be about 1% over a two year period.

Data for the second candidate outer surface, Tedlar (100BG30UT) fluorocarbon film is given in Table 29 and Figure 2 . The overall performance and inherent soiling resistance of this material is much worse than for the Sunadex glass. Untreated control specimens degraded steadily in power throughout to a maximum loss of 8.8% in the tenth month, recovering to about 3% in the subsequent months. All the coatings applied to Tedlar improved its resistance to soil accumulation, however, the fluorosilane treatments were conspicuously better than the other.

Of all the treatments used with Tedlar 100BG30OUT, only one appears to retain its usefulness at the 28 month point. Again, E-3820 is found to be the most effective coating and shows significant improvement over the control values. Treatments with E-3820 result in I_{sc} measurements that run consistently 3-5% better than the control or other treatments. The usefulness of this coating on Tedlar is clearly shown in the Figure (2) and the estimated improvement in produced power over a two year period of time is about 3.8%.

Data for the last candidate film, Acrylar X-22417, is given in Table 30 and Figure 3.

The Acrylar acrylic film formulations soiled much more severely than the Sunadex glass and Tedlar specimens. All the specimens steadily lost power throughout the exposure period, however, almost all of the treatments had a beneficial effect. The uncoated control specimens soiled very badly and at one point (10th month) dropped to a low -10.8% power loss. Following this point, the control fluctuated at about 7-8% decrease in I_{sc}, while the treated specimens varied widely in value.

In the first year of exposure, the L-1168 treatment was marginally better than the Ozone/E-3820 fluorosilane, both running 2% to 3% ahead of the control. In the second year, however, the effectiveness of the L-1668 appears to decline and the Ozone/E-3820 performs conspicuously better, returning to 0% loss in in the twenty-first month, following heavy rainfall. This treatment was found to run several percent better than the other surface chemistries and about 6% better than the control. Over a two year period of time, the estimated improvement in short circuit current is estimated to be about 3.9%.

Observations of the data trends in soiling show that the low points, in the tenth and twentieth months, correspond to periods of little rainfall. These are the winter months in Enfield where there is almost no rain and the precipitation occurs as snow, which is not thought to have much of a cleaning action on the specimen surface. All the specimens begin to regain their transmission and I_{sc} values as the Spring rains occur in the months of April through June. The rainfall data, which correlates well with the fluctuations of soiling data.

In summary, low surface energy treatments, based on fluorosilane chemistry, appear to be effective in retarding the accumulation of soil on candidate outer surfaces of interest in module construction. The most successful treatments identified to date are: for Sunadex and Tedlar, E-3820, for Acrylar, ozone pretreatment followed by E-3820. This surface coating is based on expensive fluorochemicals, however, it should prove to be cost-effective due to the extremely small amount that is applied to the surface. This coating appears to be effective where there are weather conditions that result in "natural cleaning" of the surface, and it seems that a certain amount of rain is required to keep the light transmission high.

APPENDIX A

Tables 1 through 32

TABLE I

Status of Candidate Encapsulation Materials
(Identified in Springborn Labs Program)

1.	Surface materials & modification	Under development (Springborn)
2.	Top Covers (with UV screening property)	
	a. Glass	Available, many commercial sources
	b. Tedlar X00 BG 30 UT	Available (DuPont)
	c. Acrylar Acrylic film (X-2241-6, -7)	Available (3M Corp.)
3.	Pottants	
	a. Ethylene Vinyl Acetate (A9918)	Available (Springborn, Rolland)
	b. Ethylene Methyl Acrylate (13439)	Available (Springborn)
	c. Aliphatic Polyether Urethane (Z-2591)	Available (Development Associates)
	d. Poly Butyl Acrylate (13870)	Available (Springborn)
4.	Electrical and mechanical spacer	
	a. Non-woven glass mats	Available (Crane Co.)
5.	Substrate panels	
	a. Hardboards	Available (Masonite, "Super-Dorlux", Laurel 200, Ukiah Standard Hardboard)
	b. Strandboard	Under development (Potlatch Corp.)
	c. Glass-reinforced concrete	Under development (MB Associates)
	d. Mild steel (including galvanized & enameled)	Available, many commercial sources
6.	Back Covers	
	a. Aluminum foils & polymer laminates	Available
	b. Tedlar, Mylar, Korad (polymer films)	Available (DuPont, Excell, 3M)
7.	Gaskets	
	a. EPDM (standard or custom profiles)	Available (Pawling Rubber Co., others)
8.	Sealants	
	a. "Tape" sealants	Available (Tremco, Pecora, 3M)
	b. Gunnable sealants	Available (Tremco, 3M, others)

Project No. 6072.1 **POLYMER AGING STUDIES** Table 2

Exposure Condition : RS/4 DRY

Material : EVA A9918 **Notebook No: A12504-3**

Atmosphere : Air **Temperature : 50 °C**

Description : Candidate pottant : standard commercial grade EVA

Specimen	Exposure, Hrs.	0 (control)	2,880	5,760	8,640	15,120	End
	Date :						
	Unit No. :	3	5	5	3	3	
	No. of Specimens	10	5	5	5	5	end
Physical	Tensile strength, psi	1,890	1,930	1,340	1,460	1,520	
	Ult. elongation, %	510	631	550	590	570	
	Modulus , psi	890	780	820	850	875	
	Swell Ratio	32.2	a.	a.	a.	28.5	
	Gel content , %	74%	a.	a.	a.	69.8%	
	Appearance	Transparent film	1	1	1	1	
Optical	Total optical , %T						
	UV cutoff , nm	355	355	356	357	357	
	Color * %T-400 n m	76.0	32.7	45.5	28.7	29.5	
Elect.	Dielct. Stgth., V/mil		b.	b.	b.	b.	
	Leak current , ma		b.	b.	b.	b.	
Corrosion *	Copper dust, %T	n/a	n/a	n/a	n/a	n/a	
	Copper metal	—					
	Aluminum	—					
	60/40 Solder	—					
	Nickel	—					
	Titanium	—					
	Silver	—					

Notes : a. not measured
b. insufficient material

1 = no change
2 = faint color
3 = moderate color
4 = strong color
5 = degraded
6 = extreme degradation
7 = melted
8 = broken
9 = surface cracks

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Project No. 6072.1 **POLYMER AGING STUDIES** Table 3

Exposure Condition : RS/4 Dry

Material : EMA 13439 Notebook No: 13872-1

Atmosphere : Air Temperature : 50 °C

Description : Candidate pottant

Specimen	Exposure, Hrs.	0 (control)	2,880	5,760	7,608	10,000	15,000
	Date :						
	Unit No.:	4	4	4	1	1	
	No. of Specimens	10	5	5	3	3	End
Physical	Tensile strength, psi	2,000	2,690	2,420	2,400	2,280	
	Ult. elongation, %	570%	623%	647%	680%	657%	
	Modulus, psi	3,240	a.	a.	2,000	3,200	
	Swell Ratio	11.2	a.	24.3	28.4	25.5	
	Gel content, %	62%	a.	20%	59%	34.4%	
	Appearance	Clear	1	1	1	1	
Optical	Total optical, %T						
	UV cutoff, nm	354	a.	a.	360	358	
	Color %T 400 nm	73.0	16.8	15.6	20.4	25.2	
Elect.	Dielct. Stgth., V/mil		b.	b.	b.	b.	
	Leak current, ma		b.	b.	b.	b.	
Corrosion*	Copper dust, %T	n/a	n/a	n/a	n/a	n/a	
	Copper metal	—					
	Aluminum	—					
	60/40 Solder	—					
	Nickel	—					
	Titanium	—					
	Silver	—					

Notes : a. not measured
b. insufficient sample

1 = no change
2 = faint color
3 = moderate color
4 = strong color
5 = degraded
6 = extreme degradation
7 = melted
8 = broken
9 = surface cracks

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Project No. 6072.1 — POLYMER AGING STUDIES — Table 4

Exposure Condition : RS/4 DRY

Material : PU Z-2591 — Notebook No: 14600

Atmosphere : Air — Temperature : 50 °C

Description : Candidate pottant - casting system

Specimen	Exposure, Hrs.	0 (control)	2,160	4,125	6,000	8,000	10,000
	Date :						
	Unit No.:	6	6	6	6	6	6
	Remaining No. of Specimens	22	18	14	11	8	4
Physical	Tensile strength, psi	160	196	131	199	193	137
	Ult. elongation, %	115	143	105	143	232	102
	Modulus , psi	254	263	241	222	226	180
	Swell Ratio	2.7	a.	3.3	3.45	3.6	3.7
	Gel content , %	93.2%	a.	91.7%	93%	49.5	93.1
	Appearance	transparent sheet	1	1	2	2	
Optical	Total optical , %T						
	UV cutoff , nm	366	366	367	367	366	366
	Color *%T-400 nm	63.6%	32.2	52.4	17.5	15.3	
Elect.	Dielct. Stgth., V/mil		b.	b.	b.	b.	b.
	Leak current , ma		b.	b.	b.	b.	b.
Corrosion *	Copper dust, %T	n/a	n/a	n/a	n/a	n/a	n/a
	Copper metal	—					
	Aluminum	—					
	60/40 Solder	—					
	Nickel	—					
	Titanium	—					
	Silver	—					

Notes : a. not measured
b. insufficient sample

1 = no change
2 = faint color
3 = moderate color
4 = strong color
5 = degraded
6 = extreme degradation
7 = melted
8 = broken
9 = surface cracks

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Exposure Condition : RS/4 DRY

Material : Tedlar 100BG30UT Notebook No: A12811

Atmosphere : Air Temperature : 50 °C

Description : Outer cover candidate

Specimen	Exposure, Hrs.	0 (control)	2,880	5,760	9,744	15,120	20,000
	Date :						
	Unit No.:	6	6	3	3	3	3
	(Starting No.) No. of Specimens	10	20	13	8	5	4
Physical	Tensile strength, psi	17,700	16,819	16,200	16,400	14,500	13,300
	Ult. elongation, %	71%	70	78	69	65	72
	Modulus , psi	2.4×10^5	6×10^5	2.5×10^5	10×10^5	2×10^5	2×10^5
	Swell Ratio	na	na	na	na	n/a	n/a
	Gel content , %	na	na	na	na	n/a	n/a
	Appearance	hazy	1	1	1	1	1
Optical	Total optical , %T						
	UV cutoff , nm	356	355	356	354	354	355
	Color *	slight blue hazy	1	1	1	1	1
Elect.	Dielct. Stgth., V/mil		a.	a.	a.	a.	a.
	Leak current , ma		a.	a.	a.	a.	a.
Corrosion *	Copper dust, %T	-	na	na	na	na	na
	Copper metal	—					
	Aluminum	—					
	60/40 Solder	—					
	Nickel	—					
	Titanium	—					
	Silver	—					

Notes : a. insufficient sample

1 = no change
2 = faint color
3 = moderate color
4 = strong color
5 = degraded
6 = extreme degradation
7 = melted
8 = broken
9 = surface cracks

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Project No. 6072.1 — **POLYMER AGING STUDIES** — Table 6

Exposure Condition : RS/4 DRY

Material : Acrylar X22417 — Notebook No: A12528

Atmosphere : Air — Temperature : 50 °C

Description : Outer cover candidate ; biaxially oriented acrylic film

Specimen	Exposure, Hrs.	0 (control)	1,440	2,880	5,760	12,000	End
	Date :						
	Unit No. :	4	4	4	4	4	
	No. of Specimens	10	5	5	5	5	
Physical	Tensile strength, psi	24,000	24,000	13,200	15,000	14,500	
	Ult. elongation, %	1	1	1	6	7	
	Modulus , psi	4.4×10^5	4×10^5	a.	6×10^5	5×10^5	
	Swell Ratio	Soluble	n/a	n/a	n/a	n/a	
	Gel content , %	Soluble	n/a	n/a	n/a	n/a	
	Appearance	Transparent film	1	1	1	1	
Optical	Total optical , %T						
	UV cutoff , nm	382	381	382	382	381	
	Color *	Clear	1	1	1	1	
Elect.	Dielect. Stgth., V/mil		b.	b.	b.	b.	
	Leak current , ma		b.	b.	b.	b.	
Corrosion *	Copper dust, %T	n/a	n/a	n/a	n/a	n/a	
	Copper metal	—					
	Aluminum	—					
	60/40 Solder	—					
	Nickel	—					
	Titanium	—					
	Silver	—					
Notes :	$\overline{M}_v$ c.	116,000	100,000	a.	a.	94,800	

a. not measured
b. insufficient specimen
c. Viscosity average molecular weight

1 = no change
2 = faint color
3 = moderate color
4 = strong color
5 = degraded
6 = extreme degradation
7 = melted
8 = broken
9 = surface cracks

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Project No. 6072.1 **POLYMER AGING STUDIES** Table 7

Exposure Condition : RS/4-WET (15264)

Material : EVA Notebook No: A9918

Atmosphere : Air Temperature : 50 °C

Description :

Specimen	Exposure, Hrs.	0 (control)	2,000	4,000	6,000	8,000	10,000
	Date :						
	Unit No.:	# 9	9	9	9	9	End 9
	No. of Specimens	10	3	3	3	3	2
Physical	Tensile strength, psi	1,890	3.240	3,080	3.650	5.930	2.810
	Ult. elongation, %	510	690	610	680	755	675
	Modulus , psi	890	740	674	362	950	774
	Swell ratio	32.2	20.6	20.1	21.3	22.3	18.1
	Gel content , %	74 %	70.5%	75.0%	67.5%	66.4%	69.8
	Appearance	Transparent film	1	1	1	1	1
Optical	Total optical , %T						
	UV cutoff , nm	355	351	356	343[a.]	353	360
	Color *, %T 400 nm	colorless	1	1	62.3	45.7	55.0
Elect.	Dielct. Stgth., V/mil		n/a	n/a	n/a	n/a	n/a
	Leak current , ma		b.	b.	b.	b.	b.
Corrosion	Copper dust, %T	n/a	n/a	n/a	n/a	n/a	n/a
	Copper metal	—					
	Aluminum	—					
	60/40 Solder	—					
	Nickel	—					
	Titanium	—					
	Silver	—					

Notes : a. levels off to 0.3%T at this wavelength
b. insufficient test specimen

1 = no change
2 = faint color
3 = moderate color
4 = strong color
5 = degraded
6 = extreme degradation
7 = melted
8 = broken
9 = surface cracks

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Project No. 6072.1 — POLYMER AGING STUDIES — Table 3

Exposure Condition : RS/4 - WET

Material : EMA — Notebook No: A13439

Atmosphere : Air — Temperature : 50 °C

Description :

Specimen	Exposure, Hrs.	0 (control)	2,000	4,000	6,000	8,000	10,000
	Date :						
	Unit No.:	#9	9	9	9	9	End 9
	No. of Specimens	10	3	3	3	3	2
Physical	Tensile strength, psi	2,000	2,990	3,150	2,480	4,890	2,217
	Ult. elongation, %	590	585	643	650	580	600
	Modulus , psi	3,240	3,370	3,290	1,610	4,100	3,790
	Swell ratio	11.2	10.2	13.1	14.2	7.88	16.7
	Gel content , %	62%	62.2%	64.3%	55%	60 %	63.5
	Appearance	transparent film	1	1	1	1	1
Optical	Total optical , %T						
	UV cutoff , nm	354	355	354	353	355	363
	Color * , %T 400nm	colorless	1	1	56.4	45	60.0
Elect.	Dielct. Stgth., V/mil		b.	b.	b.	b.	b.
	Leak current , ma		b.	b.	b.	b.	b.
Corrosion *	Copper dust, %T	n/a	n/a	n/a	n/a	n/a	n/a
	Copper metal	—					
	Aluminum	—					
	60/40 Solder	—					
	Nickel	—					
	Titanium	—					
	Silver	—					

Notes : b. insuficient test specimen

1 = no change	4 = strong color	7 = melted
2 = faint color	5 = degraded	8 = broken
3 = moderate color	6 = extreme degradation	9 = surface cracks

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Project No. 6072.1 — POLYMER AGING STUDIES — Table 9

Exposure Condition : RS/4 - WET

Material : Z-2591 — Notebook No:

Atmosphere : Air — Temperature : 50 °C

Description : Development Associates aliphatic polyurethane

Specimen	Exposure, Hrs.	0 (control)	2,000	4,000	6,000	8,000	10,000
	Date :						
	Unit No. :	# 9	9	9	9	9	End 9
	No. of Specimens	10	5	3	3	3	2
Physical	Tensile strength, psi	160	210	115	80	320	241
	Ult. elongation, %	115	155	75	60	215	220
	Modulus , psi	254	172	214	74	181	219
	Swell index	2.7	3.4	3.51	3.64	4.5	3.8
	Gel content , %	93.2%	94.4%	97.2%	98%	97%	96.1
	Appearance	transparent sheet	1	1	1	1	1
Optical	Total optical , %T						
	UV cutoff , nm	366	367	365	354 a.	363	367
	Color * , %T 400nm	Clear	1	1	51.3	58.8	60
Elect.	Dielct. Stgth., V/mil		b.	b.	b.	b.	b.
	Leak current , ma		b.	b.	b.	b.	b.
Corrosion *	Copper dust, %T	n/a	n/a	n/a	n/a	n/a	n/a
	Copper metal	—					
	Aluminum	—					
	60/40 Solder	—					
	Nickel	—					
	Titanium	—					
	Silver	—					

Notes : a. levels off to 0.3%T at this wavelength
b. insufficient test specimen

1 = no change
2 = faint color
3 = moderate color
4 = strong color
5 = degraded
6 = extreme degradation
7 = melted
8 = broken
9 = surface cracks

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Project No. 6072.1 — POLYMER AGING STUDIES — Table 10

Exposure Condition : RS/4 - WET

Material : Tedlar — Notebook No: 100BG30UT

Atmosphere : Air — Temperature : 50 °C

Description :

Specimen	Exposure, Hrs.	0 (control)	2,000	4,000	6,000	8,000	10,000
	Date :						
	Unit No.:	# 9	9	9	9	9	End 9
	No. of Specimens	10	3	3	3	3	2
Physical	Tensile strength, psi	17,700	17,800	19,600	18,300	1,230	18,000
	Ult. elongation, %	71	65	73	68	80	55
	Modulus, psi	2.4×10^5	2.1×10^5	2.7×10^5	1.7×10^5	8×10^3	1.8×10^5
	Swell index, %	0	n/a	n/a	n/a	n/a	n/a
	Gel content, %	0	n/a	n/a	n/a	n/a	n/a
	Appearance	pale blue hasy film	1	1	1	1	1
Optical	Total optical, %T						
	UV cutoff, nm	356	355	353	344 [a]	351	358
	Color *, %T-400 nm	v. sl. blue	1	1	60.8	48.9	55.0
Elect.	Dielct. Stgth., V/mil		b.	b.	b.	b.	b.
	Leak current, ma		b.	b.	b.	b.	b.
Corrosion *	Copper dust, %T	n/a	n/a	n/a	n/a	n/a	
	Copper metal	—					
	Aluminum	—					
	60/40 Solder	—					
	Nickel	—					
	Titanium	—					
	Silver	—					

Notes :
a. levels off to 0.4%T at this wavelength
b. insufficient test specimen

1 = no change
2 = faint color
3 = moderate color
4 = strong color
5 = degraded
6 = extreme degradation
7 = melted
8 = broken
9 = surface cracks

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Project No. 6072.1 **POLYMER AGING STUDIES** Table 11

Exposure Condition : RS/4 - WET

Material : Acrylar Notebook No: X-22417

Atmosphere : Air Temperature : 50 °C

Description : Biaxially oriented acrylic film - 3M

Specimen	Exposure, Hrs.	0 (control)	2,000	4,000	6,000	8,000	10,000
	Date :						
	Unit No.:	# 9	9	9	9	9	End 9
	No. of Specimens	10	3	3	3	3	2
Physical	Tensile strength, psi	24,000	18,700	13,400	12,580	1,160	9,200
	Ult. elongation, %	1	28	~0	~1%	0	1
	Modulus, psi	4.4×10^5	4.4×10^5	4.9×10^5	1.2×10^5	1.2×10^4	2.5×10^5
	Swell index, %	0	n/a	n/a	n/a	n/a	n/a
	Gel content, %	0	n/a	n/a	n/a	n/a	n/a
	Appearance	transparent film	1	1	1	1	1
Optical	Total optical, %T						
	UV cutoff, nm	382	351 a.	315	311 b.	350 c.	321
	Color *, %T 400 nm	colorless	1	1	75.6%	70.8	66.0
Elect.	Dielect. Stgth., V/mil		d.	d.	d.	d.	d.
	Leak current, ma		d.	d.	d.	d.	d.
Corrosion *	Copper dust, %T	n/a	n/a	n/a	n/a	n/a	n/a
	Copper metal	—					
	Aluminum	—					
	60/40 Solder	—					
	Nickel	—					
	Titanium	—					
	Silver	—					

Notes :
a. this is the lowest value (0.7%) in the usual range . Zero %T is not reached until 316 nm .
b. levels off to 0.4%T at this wavelength
c. 2.1% level at this value.
d. insufficient test specimen

1 = no change
2 = faint color
3 = moderate color
4 = strong color
5 = degraded
6 = extreme degradation
7 = melted
8 = broken
9 = surface cracks

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Project No. ______ **POLYMER AGING STUDIES** Table 12

Exposure Condition : OPT

Material : EVA 9918 Notebook No:

Atmosphere : Air Temperature : 70 °C

Description :

Specimen	Exposure, Hrs.	0 (control)	1,000	2,000	3,000	4,000	5,000
	Date :						
	Unit No.	A	A	A	A	A	
	No. of Specimens	10	25	6	5	5	
Physical	Tensile strength, psi	1,890	2,885	2,778	2,340	2,650	
	Ult. elongation, %	510	590	587	610	580	
	Modulus, psi	890	1,210	840	1,090	953	
	Swell index, %	32.2	15.6	18.7	17.3	16.2	
	Gel content, %	74	80.3	91.5	89.1	85.6	
	Appearance	Clear	1	1	1	1	
Optical	Total optical, %T						
	UV cutoff, nm	355	354	360	[illegible]	[illegible]44	
	Color *	76.0	45	16	17	15.7	
Elect.	Dielect. Stgth., V/mil		NT	NT	NT	NT	
	Leak current, ma		NT	NT	NT	NT	
Corrosion *	Copper dust, %T	n/a	n/a	n/a			
	Copper metal	—					
	Aluminum	—					
	60/40 Solder	—					
	Nickel	—					
	Titanium	—					
	Silver	—					

Notes :

1 = no change
2 = faint color
3 = moderate color
4 = strong color
5 = degraded
6 = extreme degradation
7 = melted
8 = broken
9 = surface cracks

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Project No. ____________ **POLYMER AGING STUDIES** Table 13

Exposure Condition : OPT

Material : EMA 15257 Notebook No:

Atmosphere : Air Temperature : 70 °C

Description :

Specimen	Exposure, Hrs.	0 (control)	1,000	2,000	3,000	4,000	5,000
	Date :						
	Unit No. :	A	A	A	A	A	
	No. of Specimens	10	25	5	5	5	
Physical	Tensile strength, psi	2,850	2,327	2,539	2,610	2,530	
	Ult. elongation, %	640	590	600	610	598	
	Modulus, psi	3,480	3,390	3,890	3,420	3,624	
	Swell index, %	11.4	9.3	12.4	10.2	9.8	
	Gel content, %	81	65.6	86.6	83.2	87.2	
	Appearance	Clear	1	1	1	dusty	
Optical	Total optical, %T						
	UV cutoff, nm	351	364	363	361	359	
	Color %T-400 nm	65	21	20	32	29.0	
Elect.	Dielct. Stgth., V/mil		NT	NT	NT	NT	
	Leak current, ma		NT	NT	NT	NT	
Corrosion *	Copper dust, %T		n/a	n/a	n/a	n/a	
	Copper metal	—					
	Aluminum	—					
	60/40 Solder	—					
	Nickel	—					
	Titanium	—					
	Silver	—					

Notes :

1 = no change
2 = faint color
3 = moderate color
4 = strong color
5 = degraded
6 = extreme degradation
7 = melted
8 = broken
9 = surface cracks

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Project No. ______ **POLYMER AGING STUDIES** Table 14

Exposure Condition : OPT

Material : PU Z-2591 Notebook No:

Atmosphere : Air Temperature : 70 °C

Description :

Specimen	Exposure, Hrs.	0 (control)	1,000	2,000	3,000	4,000	5,000
	Date :						
	Unit No. :	A	A	A	A	A	
	No. of Specimens	10	25	5	3	3	
Physical	Tensile strength, psi	160	197	253	250	247	
	Ult. elongation, %	115	155	207	200	190	
	Modulus, psi	254	258	264	214	235	
	Swell index, %	2.7	3.6	2.7	2.8	3.1	
	Gel content, %	93.2	94.6	97.5	93.4	92.1	
	Appearance	Clear	1	1	1	dusty	
Optical	Total optical, %T						
	UV cutoff, nm	366	369	364	375	369	
	Color *	63.3	22	26	24	9.4	
Elect.	Dielct. Stgth., V/mil		NT	NT	NT	NT	
	Leak current, ma		NT	NT	NT	NT	
Corrosion *	Copper dust, %T		n/a	n/a			
	Copper metal	—					
	Aluminum	—					
	60/40 Solder	—					
	Nickel	—					
	Titanium	—					
	Silver	—					

Notes :

1 = no change
2 = faint color
3 = moderate color
4 = strong color
5 = degraded
6 = extreme degradation
7 = melted
8 = broken
9 = surface cracks

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Project No. ________ **POLYMER AGING STUDIES** Table 15

Exposure Condition : OPT

Material : EMA 16717 Notebook No: 16729

Atmosphere : Air Temperature : 70 °C

Description : EMA/TBEC/UV2098/Tinuvin 770

Specimen	Exposure, Hrs.	0 (control)	1,000	2,000	3,000	4,000	
	Date :						
	Unit No. :	A	A	A	A		
	No. of Specimens	10	12	5	5		
Physical	Tensile strength, psi	2,887	2,650	2,583	2,432		
	Ult. elongation, %	644	600	593	621		
	Modulus, psi	3,940	3,580	3,480	3,251		
	Swell index, %	11.2	11.5	10.8	11.6		
	Gel content, %	80.0	79.3	82.1	84.3		
	Appearance	Clear	1	1	1		
Optical	Total optical, %T						
	UV cutoff, nm	363	363	361	347		
	Color, %T-400 nm	43	21%	24.8	29.5		
Elect.	Dielct. Stgth., V/mil		NT	NT	NT		
	Leak current, ma		NT	NT	NT		
Corrosion	Copper dust, %T						
	Copper metal	—					
	Aluminum	—					
	60/40 Solder	—					
	Nickel	—					
	Titanium	—					
	Silver	—					

Notes :

1 = no change
2 = faint color
3 = moderate color
4 = strong color
5 = degraded
6 = extreme degradation
7 = melted
8 = broken
9 = surface cracks

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Project No. ________ **POLYMER AGING STUDIES** Table 16

Exposure Condition : OPT

Material : EVA 16718-A   Notebook No: 16729

Atmosphere : Air   Temperature : 70 °C

Description : EVA with TBEC, UV-2098, Tinuvin 770

Specimen	Exposure, Hrs.	0 (control)	1,000	2,000	3,000	4,000	
	Date :						
	Unit No. :	A	A	A	A		
	No. of Specimens	10	12	5	5		
Physical	Tensile strength, psi	2,760	2,690	2,580	2,792		
	Ult. elongation, %	580	550	530	575		
	Modulus, psi	782	1,200	1,010	953		
	Swell index, %	7.5	11.5	12.3	9.8		
	Gel content, %	91.7	90.2	89.4	3		
	Appearance	Clear	1	1			
Optical	Total optical, %T						
	UV cutoff, nm	360	362	358	347		
	Color %T-400nm	58	16%	18.3	17.5		
Elect.	Dielct. Stgth., V/mil		NT	NT	NT		
	Leak current, ma		NT	NT	NT		
Corrosion	Copper dust, %T						
	Copper metal	—					
	Aluminum	—					
	60/40 Solder	—					
	Nickel	—					
	Titanium	—					
	Silver	—					

Notes :

1 = no change
2 = faint color
3 = moderate color
4 = strong color
5 = degraded
6 = extreme degradation
7 = melted
8 = broken
9 = surface cracks

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Project No. ____________ **POLYMER AGING STUDIES** Table 17

Exposure Condition : OPT

Material : EVA 16718-B Notebook No: 16729

Atmosphere : Air Temperature : 70 °C

Description : EVA/TBEC/UV2098 no Tinuvin 770

Specimen	Exposure, Hrs.	0 (control)	1,000	2,000	3,000	4,000	
	Date :						
	Unit No.:	A	A	A	A		
	No. of Specimens	10	12	12			
Physical	Tensile strength, psi	3,658	1,950	180			
	Ult. elongation, %	600	430	220			
	Modulus , psi	810	526	417			
	Swell index , %	8.1	8.3	8.1			
	Gel content , %	83.4	37	23.7%			
	Appearance	Clear	1	1			
Optical	Total optical , %T						
	UV cutoff , nm	358	359	364			
	Color, %T-400 nm	72	50%	18 %			
Elect.	Dielct. Stgth., V/mil		NT	NT			
	Leak current , ma		NT	NT			
Corrosion *	Copper dust, %T						
	Copper metal	—					
	Aluminum	—					
	60/40 Solder	—					
	Nickel	—					
	Titanium	—					
	Silver	—					

Notes :

1 = no change
2 = faint color
3 = moderate color
4 = strong color
5 = degraded
6 = extreme degradation
7 = melted
8 = broken
9 = surface cracks

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Project No. ______ **POLYMER AGING STUDIES** Table 18

Exposure Condition : OPT

Material : EVA 9918 Notebook No:

Atmosphere : Air Temperature : 90 °C

Description :

Specimen	Exposure, Hrs.	0 (control)	1,000	2,000	2,500		
	Date :						
	Unit No. :	B	B	B	B	END	
	No. of Specimens	10	25	5	5		
Physical	Tensile strength, psi	1,890	2,527	a.	a.		
	Ult. elongation, %	510	590	a.	a.		
	Modulus , psi	890	1,190	a.	a.		
	Swell index , %	32.2	12.0	14.8	9.0		
	Gel content , %	74	60.3	85.7	42.4		
	Appearance	Clear	1	1	Hazy		
Optical	Total optical , %T						
	UV cutoff , nm	355	354	358	358		
	Color *	76.0	45	28	14		
Elect.	Dielct. Stgth., V/mil		NT	NT	NT		
	Leak current , ma		NT	NT	NT		
Corrosion *	Copper dust, %T						
	Copper metal	—					
	Aluminum	—					
	60/40 Solder	—					
	Nickel	—					
	Titanium	—					
	Silver	—					

Notes : a. Specimen too degraded to be tested . No color . "Cheesy" consistancy .

1 = no change
2 = faint color
3 = moderate color
4 = strong color
5 = degraded
6 = extreme degradation
7 = melted
8 = broken
9 = surface cracks

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Project No. ______ **POLYMER AGING STUDIES** Table 19

Exposure Condition : OPT

Material : EMA 15257 **Notebook No:**

Atmosphere : Air **Temperature :** 90 °C

Description :

Specimen	**Exposure, Hrs.**	0 (control)	1,000	2,000			
	Date :						
	Unit No.:	B	B	B			
	No. of Specimens	10	25	10	END		
Physical	**Tensile strength, psi**	2,850	1,752	700			
	Ult. elongation, %	640	490	220			
	Modulus , psi	3,480	3,970	3,800			
	Swell index , %	11.4	9.9	6.4			
	Gel content , %	81%	61.1	72%			
	Appearance	Clear .	1	9			
Optical	**Total optical , %T**						
	UV cutoff , nm	351	368	366			
	Color *	65%	12	12%			
Elect.	**Dielct. Stgth., V/mil**		NT	NT			
	Leak current , ma		NT	NT			
Corrosion *	**Copper dust, %T**						
	Copper metal	—					
	Aluminum	—					
	60/40 Solder	—					
	Nickel	—					
	Titanium	—					
	Silver	—					

Notes : a. Polymer has yellow color and "cheesy" consistency . Removed from further testing .

1 = no change	4 = strong color	7 = melted
2 = faint color	5 = degraded	8 = broken
3 = moderate color	6 = extreme degradation	9 = surface cracks

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Project No. ____________ **POLYMER AGING STUDIES** Table 20

Exposure Condition : OPT

Material : PU Z-2591 Notebook No:

Atmosphere : Air Temperature : 90 °C

Description :

Specimen	Exposure, Hrs.	0 (control)	1,000	2,000			
	Date :						
	Unit No. :	B	B	B			
	No. of Specimens	10	25	10	END		
Physical	Tensile strength, psi	160	162	a.			
	Ult. elongation, %	115	233	a.			
	Modulus , psi	254	139	a.			
	Swell index , %	2.7	4.2	3.5			
	Gel content , %	93.2	95.0	93.7			
	Appearance	Faint yellow	Yellow	V. Tacky!			
Optical	Total optical , %T						
	UV cutoff , nm	366	372	380			
	Color *	63.3	15	11%			
Elect.	Dielct. Stgth., V/mil		NT	NT			
	Leak current , ma		NT	NT			
Corrosion *	Copper dust. %T						
	Copper metal	—					
	Aluminum	—					
	60/40 Solder	—					
	Nickel	—					
	Titanium	—					
	Silver	—					

Notes : a. Mechanical properties appear to be OK, but the specimens have agressive surface tack and cannot be handled for testing.

1 = no change
2 = faint color
3 = moderate color
4 = strong color
5 = degraded
6 = extreme degradation
7 = melted
8 = broken
9 = surface cracks

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Project No. ______ **POLYMER AGING STUDIES** Table 21

Exposure Condition : OPT

Material : EMA 16717 Notebook No: 16729

Atmosphere : Air Temperature : 90 °C

Description : EMA/TBEC/UV2098/Tinuvin 770

Specimen	Exposure, Hrs.	0 (control)	1,000	1,500	2,000		
	Date :					END	
	Unit No. :	B	B	B	B		
	No. of Specimens	10	12	10	10		
Physical	Tensile strength, psi	2,887	2,200	1,850	590		
	Ult. elongation, %	644	410	420	160		
	Modulus , psi	3,940	3,180	3,085	3,040		
	Swell index , %	11.2	12.3	10.2	8.8		
	Gel content , %	80.0	83.4	78.2	71%		
	Appearance	Clear	1	1	a.		
Optical	Total optical , %T						
	UV cutoff , nm	363	362	365	374		
	Color, %T-400 nm	43	20%	17	8 %		
Elect.	Dielct. Stgth., V/mil		NT	NT	NT		
	Leak current , ma		NT	NT	NT		
Corrosion *	Copper dust, %T						
	Copper metal	—					
	Aluminum	—					
	60/40 Solder	—					
	Nickel	—					
	Titanium	—					
	Silver	—					

Notes : a. "Cheesy" appearance , no visible color , specimens had to be scraped off the surface of the OPT .

1 = no change
2 = faint color
3 = moderate color
4 = strong color
5 = degraded
6 = extreme degradation
7 = melted
8 = broken
9 = surface cracks

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Project No. ________ POLYMER AGING STUDIES Table 22

Exposure Condition : OPT

Material : EVA 16718-A Notebook No: 16729

Atmosphere : Air Temperature : 90 °C

Description : EVA with TBEC, UV-2098, Tinuvin-770

Specimen	Exposure, Hrs.	0 (control)	1,000	1,500	2,000		
	Date :						
	Unit No.:	B	B	B	B		
	No. of Specimens	10	12	5	10	END	
Physical	Tensile strength, psi	2,760	a.	a.	a.		
	Ult. elongation, %	580	a.	a.	a.		
	Modulus , psi	782	a.	a.	a.		
	Swell index , %	7.5	10.7	12.8	9.7		
	Gel content , %	91.7	91.5%	96.8	56.8		
	Appearance	Clear	1	1	3		
Optical	Total optical , %T						
	UV cutoff , nm	360	359	358	361		
	Color %T-400 nm	58	30%	32.3	35%		
Elect.	Dielct. Stgth., V/mil		NT	NT	NT		
	Leak current , ma		NT	NT	NT		
Corrosion	Copper dust, %T		n/a	n/a	n/a		
	Copper metal	—					
	Aluminum	—					
	60/40 Solder	—					
	Nickel	—					
	Titanium	—					
	Silver	—					

Notes : a. Specimens too deformed to be tested . No color .

1 = no change
2 = faint color
3 = moderate color
4 = strong color
5 = degraded
6 = extreme degradation
7 = melted
8 = broken
9 = surface cracks

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Project No. ____________ **POLYMER AGING STUDIES** Table 23

Exposure Condition : OPT

Material : EVA 16718-B **Notebook No:** 16729

Atmosphere : Air **Temperature :** 90 °C

Description : EVA/TBEC/UV2098 no Tinuvin 770

Specimen	Exposure, Hrs.	0 (control)	1,000				
	Date :						
	Unit No. :	B	B				
	No. of Specimens	10	12	END			
Physical	Tensile strength, psi	3,658	a.				
	Ult. elongation, %	600	a.				
	Modulus, psi	810	a.				
	Swell index, %	8.1	797				
	Gel content, %	83.4	95.5				
	Appearance	Clear	6.7				
Optical	Total optical, %T						
	UV cutoff, nm	358	a.				
	Color, %T-400 nm	72%	a.				
Elect.	Dielct. Stgth., V/mil		NT				
	Leak current, ma		NT				
Corrosion *	Copper dust, %T						
	Copper metal	—					
	Aluminum	—					
	60/40 Solder	—					
	Nickel	—					
	Titanium	—					
	Silver	—					

Notes : a. Materials too degraded to perform tests. Polymer has "cheesy" consistancy, removed by scraping off the OPT surface.

1 = no change
2 = faint color
3 = moderate color
4 = strong color
5 = degraded
6 = extreme degradation
7 = melted
8 = broken
9 = surface cracks

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Project No. ____________ **POLYMER AGING STUDIES** Table 24

Exposure Condition : OPT

Material : EVA 9918 Notebook No:

Atmosphere : Air Temperature : 105 °C

Description :

Specimen	Exposure, Hrs.	0 (control)	1,000	2,000			
	Date :						
	Unit No. :	C	C	C			
	No. of Specimens	10	25	10	END		
Physical	Tensile strength, psi	1,890	1,885	240[a]			
	Ult. elongation, %	510	550	120			
	Modulus , psi	890	1,200	612			
	Swell index , %	32.2	16.1	16.2			
	Gel content , %	74.0	80.7	69%			
	Appearance	Clear	2	6, 7, tacky			
Optical	Total optical , %T						
	UV cutoff , nm	355	353	358			
	Color %T 400	[illegible]	38	15%			
Elect.	Dielct. Stgth., V/mil		NT	NT			
	Leak current , ma		NT	NT			
Corrosion *	Copper dust, %T						
	Copper metal	—					
	Aluminum	—					
	60/40 Solder	—					
	Nickel	—					
	Titanium	—					
	Silver	—					

Notes : a. Specimens degrading , little physical integrity , sticky, no color .

1 = no change	4 = strong color	7 = melted
2 = faint color	5 = degraded	8 = broken
3 = moderate color	6 = extreme degradation	9 = surface cracks

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Project No. ______ **POLYMER AGING STUDIES** . Table 25

Exposure Condition : OPT

Material : EMA 15257 Notebook No:

Atmosphere : Air Temperature : 105° C

Description :

Specimen	Exposure, Hrs.	0 (control)	1,000	2,000			
	Date :						
	Unit No. :	C	C	C			
	No. of Specimens	10	25	10	END		
Physical	Tensile strength, psi	2,850	1,420	320			
	Ult. elongation, %	640	455	30			
	Modulus , psi	3,480	3,110	1,610			
	Swell index , %	11.4	15.9	7.1			
	Gel content , %	81%	65.9	79.0			
	Appearance	Clear	1	9 a.			
Optical	Total optical , %T						
	UV cutoff , nm	351	367	385			
	Color %T-400 nm	65%	15	6%			
Elect.	Dielct. Stgth., V/mil		NT	NT			
	Leak current , ma		NT	NT			
Corrosion *	Copper dust, %T		n/a	n/a			
	Copper metal	—					
	Aluminum	—					
	60/40 Solder	—					
	Nickel	—					
	Titanium	—					
	Silver	—					

Notes : a. Degraded . "cheesy" consistancy

1 = no change
2 = faint color
3 = moderate color
4 = strong color
5 = degraded
6 = extreme degradation
7 = melted
8 = broken
9 = surface cracks

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Project No. | **POLYMER AGING STUDIES** | Table 26

Exposure Condition : OPT

Material : PU Z-2591 Notebook No:

Atmosphere : Air Temperature : 105 °C

Description :

Specimen	Exposure, Hrs.	0 (control)	1,000	2,000			
	Date :						
	Unit No.:	C	C	C			
	No. of Specimens	10	25	10	END		
Physical	Tensile strength, psi	160	220	a.			
	Ult. elongation, %	115	255	a.			
	Modulus, psi	254	195	a.			
	Swell index, %	2.7	3.8	5.1			
	Gel content, %	93.2	98.5	86.3			
	Appearance	Faint yellow	2	6. tacky			
Optical	Total optical, %T						
	UV cutoff, nm	366	373	370			
	Color %T - 400 nm	63.3	27	19%			
Elect.	Dielct. Stgth., V/mil		NT	NT			
	Leak current, ma		NT	NT			
Corrosion *	Copper dust, %T						
	Copper metal	—					
	Aluminum	—					
	60/40 Solder	—					
	Nickel	—					
	Titanium	—					
	Silver	—					

Notes : a. Too degraded to be tested, specimens had to be scraped off surface. Very sticky yellow material.

1 = no change
2 = faint color
3 = moderate color
4 = strong color
5 = degraded
6 = extreme degradation
7 = melted
8 = broken
9 = surface cracks

Project No. ____________ **POLYMER AGING STUDIES** Table 27

Exposure Condition : OPT

Material : EMA 16717 **Notebook No:** 16729

Atmosphere : Air **Temperature :** 105 °C

Description : EMA/TBEC/UV2098/Tinuvin 770

Specimen	Exposure, Hrs.	0 (control)	1,000	1,500			
	Date :				END		
	Unit No.:	C	C	C			
	No. of Specimens	10	12	6			
Physical	Tensile strength, psi	2,887	1,530	440			
	Ult. elongation, %	644	424	60			
	Modulus , psi	3,940	2,980	2,900			
	Swell index , %	11.2	11.2	11.5			
	Gel content , %	80.0	80.3	81.6			
	Appearance	Clear	1	a.			
Optical	Total optical , %T						
	UV cutoff , nm	363	365	374			
	Color, %T-400 nm	43	28	6.3			
Elect.	Dielct. Stgth., V/mil		NT	NT			
	Leak current , ma		NT	NT			
Corrosion *	Copper dust, %T						
	Copper metal	—					
	Aluminum	—					
	60/40 Solder	—					
	Nickel	—					
	Titanium	—					
	Silver	—					

Notes : a. The specimens were obviously depolymerized , "cheesy" in consistancy and had to be carefully removed form the module surface .

1 = no change
2 = faint color
3 = moderate color
4 = strong color
5 = degraded
6 = extreme degradation
7 = melted
8 = broken
9 = surface cracks

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Project No. ______ **POLYMER AGING STUDIES** Table 28

Exposure Condition : OPT

Material : EVA 16718-A **Notebook No:** 16729

Atmosphere : Air **Temperature :** 105 °C

Description : EVA-TBEC-UV2098 , Tinuvin 770

Specimen	Exposure, Hrs.	0 (control)	1,000	1,500			
	Date :				END		
	Unit No. :	C	C	C			
	No. of Specimens	10	12	10			
Physical	Tensile strength, psi	2,760	1,390	230			
	Ult. elongation, %	580	343	170			
	Modulus , psi	782	631	590			
	Swell index , %	7.5	8.4	10.1			
	Gel content , %	91.7	83.1	70			
	Appearance	Clear	1	1 a.			
Optical	Total optical , %T						
	UV cutoff , nm	360	360	359			
	Color	58%	34	25			
Elect.	Dielct. Stgth., V/mil		NT	NT			
	Leak current , ma		NT	NT			
Corrosion *	Copper dust, %T						
	Copper metal	—					
	Aluminum	—					
	60/40 Solder	—					
	Nickel	—					
	Titanium	—					
	Silver	—					

Notes : a. No color , polymer has degraded mechanical properties .

1 = no change
2 = faint color
3 = moderate color
4 = strong color
5 = degraded
6 = extreme degradation
7 = melted
8 = broken
9 = surface cracks

Project No. ____________ **POLYMER AGING STUDIES** Table 29

Exposure Condition : OPT

Material : EVA 16718-B Notebook No: 16729

Atmosphere : Air Temperature : 105 °C

Description : EVA/TBEC/UV2098 No Tinuvin 770

Specimen	Exposure, Hrs.	0 (control)	1,000				
	Date :			This material removed from further testing due to severe degradation ocurring within 200 hours of exposure .			
	Unit No. :	C	C				
	No. of Specimens	10	12				
Physical	Tensile strength, psi	3,658	a.				
	Ult. elongation, %	600	a.				
	Modulus , psi	310	a.				
	Swell index , %	8.1	887				
	Gel content , %	83.4%	67.1				
	Appearance	Clear	"melted"				
Optical	Total optical , %T						
	UV cutoff , nm	358	a.				
	Color, %T-400 nm	72%	a.				
Elect.	Dielct. Stgth., V/mil		NT				
	Leak current , ma		NT				
Corrosion *	Copper dust, %T						
	Copper metal	—					
	Aluminum	—					
	60/40 Solder	—					
	Nickel	—					
	Titanium	—					
	Silver	—					

Notes : a. Cannot be tested due to flow of specimens. No yellow color , surface tack noticable , "cheesy" consistancy .

1 = no change	4 = strong color	7 = melted
2 = faint color	5 = degraded	8 = broken
3 = moderate color	6 = extreme degradation	9 = surface cracks

TABLE 30

Soiling Experiment

Material: Sunadex Low Iron Glass

Measurement: Percent variation in short circuit current (I_{SC}) during 28 month exposure period using standard cell.

Exposure: Months

Treatment	0	1 (1981)	2	3	4	5	6	7 (1982)	8	9	10	11	12	13
None	0	-1.5	-2.0	-1.9	-1.7	-1.0	-2.8	-2.1	-2.9	-4.7	-1.2	-2.0	-1.1	-1.0
L-1668	0	+0.2	-1.2	-1.1	-0.1	-0.4	-0.4	-1.0	-1.0	-4.1	-2.1	-1.0	-1.0	-1.6
Ozone, then L-1668	-	-	-	-	-	-	-	-	-	-	-	-	-	-
E-3820	0	-0.1	-0.1	-2.2	-1.2	-1.5	-1.2	-2.1	-2.0	-1.8	-2.7	-0.6	-1.1	-1.8
Ozone, then E-3820	-	-	-	-	-	-	-	-	-	-	-	-	-	
UI-650 Glass Resin	0	-0.5	-1.5	-1.9	-1.7	-1.1	-2.5	-4.1	-1.8	-6.1	-5.7	-1.7	-4.1	
SRC-1000	0	-2.1	-2.7	-2.8	-1.6	-1.9	-4.5	-4.9	-5.2	-6.4	-4.5	-4.2	-4.9	
WL-81 Rohm & Haas	0	-2.7	-2.2	-2.2	-4.5	-4.4	-1.7	-4.1	-4.7	-7.9	5.1	-5.2	-4.2	

Treatment	14	15	16	17	18	19 (1983)	20	21	22	23	24	25	26	27	28
None	-2.1	-1.9	-2.4	-2.5	-1.7	-4.1	-1.7	-2.2	-2.3	-1.2	-1.4	-2.8	-2.9	-2.9	-2.0
L-1668	-1.0	-2.1	-2.1	-2.0	-1.8	-1.1	-1.0	0	-2.9	-2.1	-1.6	-1.9	-0.9	-0.9	+0.1
Ozone, then L-1668	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
E-3820	-0.9	-1.7	-1.7	-1.6	-1.7	-2.7	-2.0	0	0.5	2.1	-1.6	-0.5	-1.6	-0.5	-1.0

Legend: 0 - control value before exposure; referenced to standard cell
1-28 - number months exposure; % of original short circuit current

TABLE 11

Soiling Experiments

Material: Tedlar 100BG30UT Film (Supported on glass carrier)

Measurements: Percent variation in short circuit current (I_{sc}) during 28 month exposure period using standard cell.

Exposure: Months

Treatment	0	1 (1981)	2	3	4	5	6	7 (1982)	8	9	10	11	12
None	0	-2.4	-1.1	-1.0	-1.5	-4.3	-4.7	-5.1	-6.1	-7.7	-8.8	-6.7	-6.5
L-1668	0	1.5	-1.5	-2.7	-1.8	-1.8	-2.9	-1.5	-1.7	-6.0	-5.1	-3.9	-4.2
Ozone, then L-1668	0	-0.7	-0.9	-2.1	-2.2	-2.8	-1.1	-1.5	-1.4	-5.9	-5.0	-1.7	-4.8
E-3820	0	+0.5	0	-1.5	-0.8	-1.5	-1.7	-0.9	-1.1	-2.4	-1.8	-2.1	-2.4
Ozone, then E-3820	0	-1.2	-2.9	+0.1	-2.4	-1.9	-1.7	-4.1	-4.4	-5.8	-6.4	-3.9	-4.1
GT-650 Glass Resin	0	-2.7	-2.9	-4.1	-1.5	-4.5	-4.8	-7.2	-4.6	-9.1	-6.5	-6.4	-5.6
SRC-1000	0	-2.5	-2.4	-1.0	-2.6	-1.7	-1.1	-4.1	-4.5	-7.9	-5.6	-4.5	-4.6
ML-80 Rohm & Haas	0	-1.2	-1.3	-1.4	-1.0	-4.9	-2.8	-4.1	-1.8	-6.6	-5.2	-4.9	-4.6

Treatment	13	14	15	16	17	18	19 (1983)	20	21	22	23	24	25	26	27	28
None	-5.8	-4.6	-5.0	-4.9	-4.7	-5.8	-6.3	-6.3	-6.3	-4.2	-7.4	.4	-5.8	-5.1	-5.1	-5.0
L-1668	-5.1	-4.6	-5.1	-5.1	-5.0	-5.4	-6.0	-6.0	-4.4	-5.0	-5.4	-6.7	-5.4	-5.8	-4.9	-3.7
Ozone, then L-1668	-5.1	-4.4	-5.0	-5.5	-5.8	-6.2	-5.1	-5.1	-7.1	-4.4	-6.0	-7.1	-6.1	-5.1	-4.6	-4.8
E-3820	-2.1	-2.3	-1.7	-1.9	-1.6	-1.7	-2.1	-2.8	+0.1	-0.9	-0.5	-3.1	-2.8	-0.7	-1.0	-1.6
Ozone, then E-3820	4.4	-1.1	-5.6	-5.8	-6.5	-5.8	-5.7	-7.0	-4.3	-4.2	-6.6	-7.1	-5.5	-5.9	-4.6	-3.7

Legend: 0 - control value before exposure; referenced to standard cell
1-28 - number months exposure; % of original short circuit current

TABLE 32

Soiling Experiments

Material: Acrylar X22417 Film (supported on glass carrier)

Measurement: Percent variation in short circuit current (I_{sc}) during 28 month exposure period using standard cell.

Exposure: Months

Treatment	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	1981							1982							
None	0	-3.1	-3.9	-4.4	-3.7	-5.1	-5.4	-6.4	-7.5	-10.2	-10.8	-7.9	-7.8	-8.1	-6.4
L-1668	0	-0.8	-0.4	-1.8	-2.1	-3.5	-3.5	-5.0	-3.9	-5.1	-6.6	-5.6	-5.0	-5.0	-3.2
Ozone, then L-1668	0	-2.9	-2.5	-2.8	-2.5	-3.4	-3.2	-4.5	-5.0	-6.3	-6.1	-4.5	-4.6	-6.2	-5.3
E-3820	0	-1.5	-1.6	-2.4	-2.3	-2.8	-2.6	-3.9	-3.9	-6.7	-6.8	-4.4	-5.4	-6.0	-4.3
Ozone, then E-3820	0	-0.8	-2.0	-2.1	-1.8	-2.5	-3.1	-3.0	-3.7	-5.0	-4.9	-3.2	-4.0	-5.0	-3.8
SHC-1000	0	-4.1	-5.2	-6.3	-4.2	-6.5	-6.1	-6.2	-6.6	-8.8	-7.6	-6.1	-7.8		
WL-81 Rohm & Haas	0	-2.6	-3.5	-3.9	-2.6	-3.1	-4.2	-4.7	-4.8	-6.8	-6.3	-4.5	-5.6		

Treatment	15	16	17	18	19	20	21	22	23	24	25	26	27	28
					1983									
None	-7.3	-7.6	-7.1	-7.4	-9.4	-9.8	-6.2	-7.4	-8.2	-9.1	-8.7	-7.8	-6.4	-8.1
L-1668	-4.6	-5.8	-4.7	-4.7	-6.4	-6.2	-1.8	-2.6	-5.3	-6.4	-4.6	-5.2	-5.3	-4.3
Ozone, then L-1668	-4.8	-5.6	-5.7	-5.3	-7.6	-6.7	-2.8	-6.2	-6.5	-8.0	-6.3	-7.6	-5.8	-5.4
E-3820	-4.0	-4.0	-3.6	-5.5	-6.0	-5.7	-1.4	-4.4	-4.6	-7.1	-6.4	-5.6	-5.7	-5.7
Ozone, then E-3820	-1.1	-2.1	-1.4	-1.1	-2.6	-3.0	+0.6	-2.0	-1.9	-3.9	-1.0	-1.8	-1.5	-1.9
SHC-1000														
WL-81 Rohm & Haas														

Legend: 0 - control value before exposure; referenced to standard cell
1-28 - number months exposure; % of original short circuit current

APPENDIX B

Figures 1 through 3

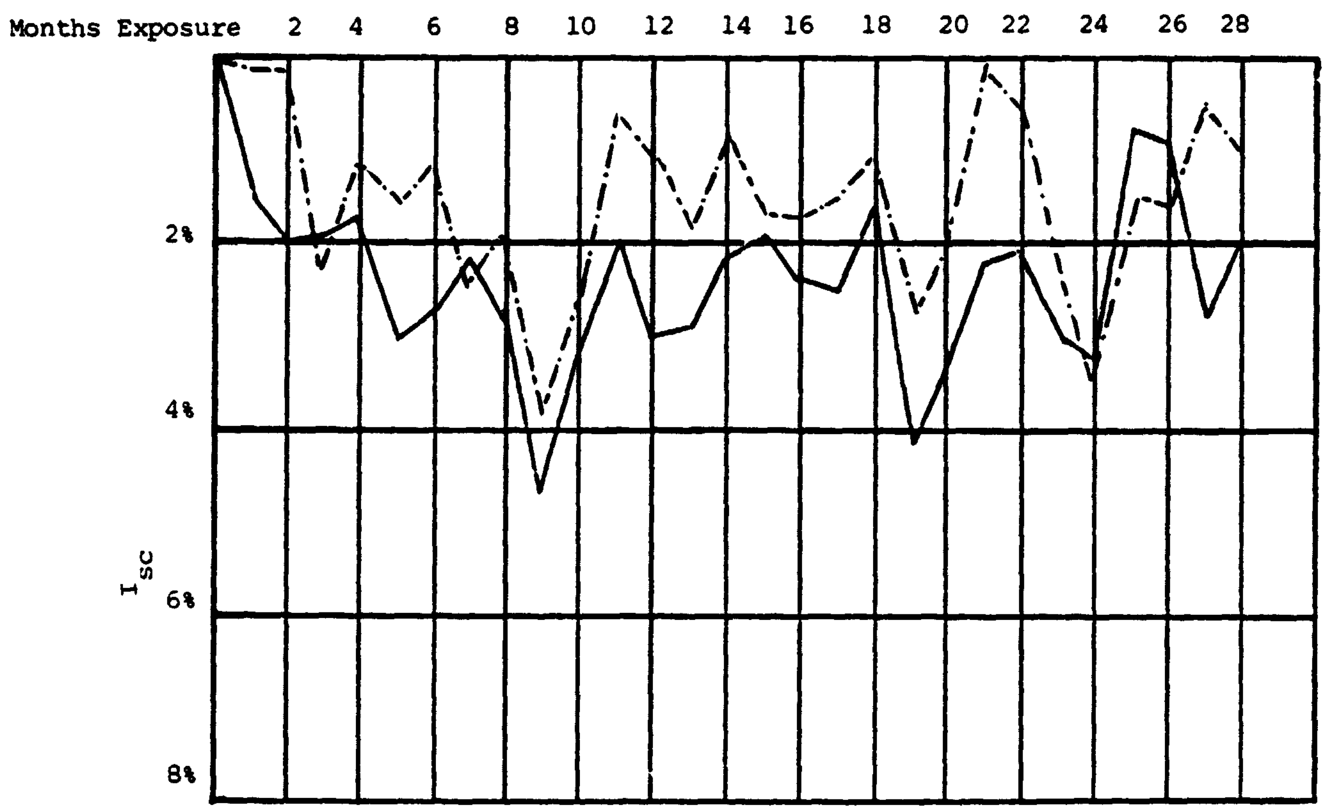
FIGURE 1

Soiling Experiments

Material: Sunadex Glass

Exposure: 28 months, Enfield, Connecticut

Measurement: Percent loss in short circuit current (I_{sc}) with exposure time



Control value, untreated

Treated with Ozone, then E-3820

FIGURE 2

Soiling Experiments

Material: Tedlar 100BG30UT (supported on glass carrier)

Exposure: 28 months, Enfield, Connecticut

Measurement: Percent loss in short circuit current (I_{sc}) with exposure time

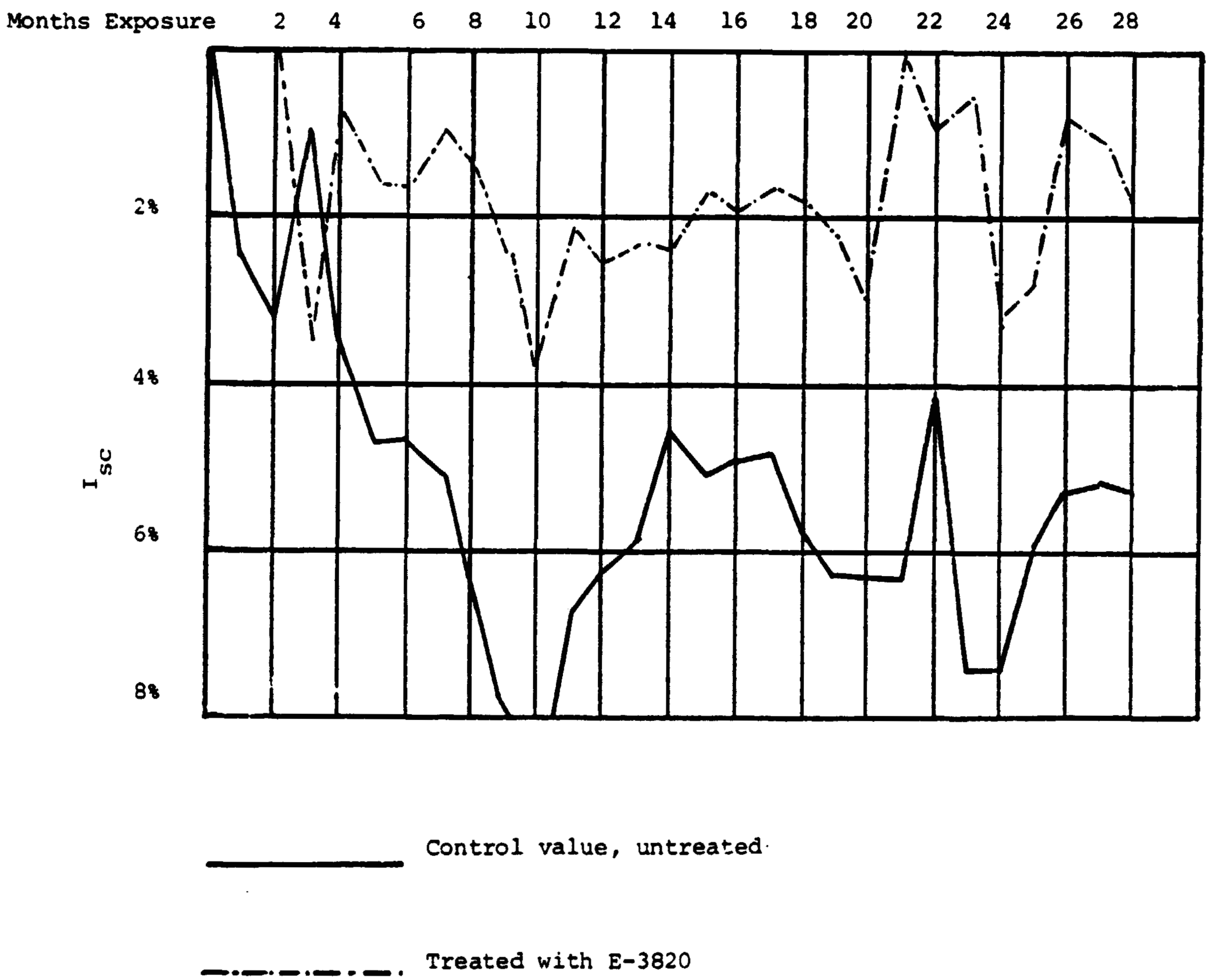


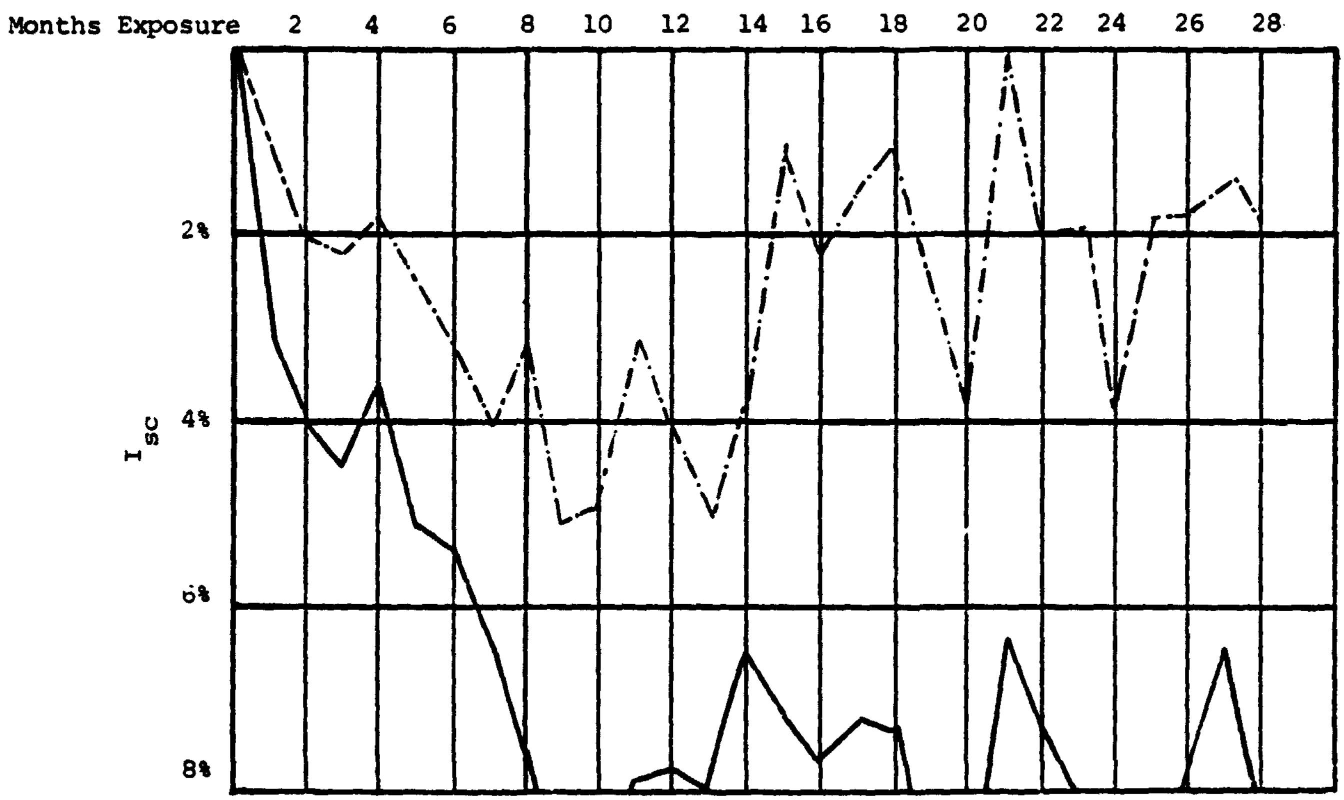
FIGURE 3

Soiling Experiments

Material: Acrylar X-22417 Acrylic Film (supported on glass carrier)

Exposure: 28 months , Enfield, Connecticut

Measurement: Percent loss in short circuit current (I_{sc}) with exposure time.



Control value, untreated

Treated with E-3820