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ANNUAL REPORT

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

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For

JET PROPULSION LABORATORY
 4800 Oak Grove Drive
 Pasadena, California 91103

ENCAPSULATION TASK OF THE LOW-COST
 SILICON SOLAR ARRAY PROJECT

The JPL Low-Cost Silicon 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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By

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I. SUMMARY**ORIGINAL PAGE 13
OF POOR QUALITY**

Springborn Laboratories, Inc. is engaged in a study of evaluating potentially useful low cost encapsulation materials for the Flat-Plate Solar Array project (FSA) funded by the Department of Energy and administered by the Jet Propulsion Laboratory. The goal of the program is to identify, evaluate, test and recommend encapsulant materials and processes for the production of cost-effective, long life solar cell modules.

During the past year technical investigations concerned the development of advanced cure chemistries for lamination type pottants; the continued evaluation of soil resistant surface treatments, and the results of an accelerated aging test program for the comparison of material stabilities.

New compounds were evaluated for efficiency in curing both ethylene/vinyl acetate and ethylene/methyl acrylate pottants intended for vacuum bag lamination of solar cells. One compound in particular, designated Lupersol - TBEC (Lucidol Division of Penwalt Corp.) was found to be unusually effective in promoting the rapid cure of both these materials. Formulation of these resins with TBEC resulted in compositions of very high gel content, lower temperatures of activation, and much lower cure times, even in the ethylene/methyl acrylate polymer that is more difficult to cure. It is expected that TBEC modified pottant formulations may permit the lamination/encapsulation step to be operated at lower temperatures, higher speed, higher throughput and a much wider tolerance for intentional or accidental variations in the cure schedule. Investigations of this new curing agent will be emphasized in the development of future of formulations.

Two component aliphatic urethane casting syrups were evaluated for suitability as solar module pottants on the basis of optical, physical and fabrication characteristics. One formulation was selected as being acceptable for industrial evaluation. This compound, designated Z-2591, is a prototype solar cell encapsulant manufactured by Development Associates, Inc., N. Kingstown, RI, and is available in pilot plant quantities. This urethane is characterized by high transparency, low mix viscosity, fast cure time and surprising lack of moisture sensitivity that has given trouble with previous urethane compositions. This material is produced with an ultraviolet stabilizer system already blended in and similar

formulations have a history of use in outdoor applications. Commercial quantities are available for module fabrication.

Mild steel is a readily available and easily worked material that holds the promise of being a cost-effective substrate. Its major deficiency is that of corrosion sensitivity. Experiments are underway to assess the durability and cost effectiveness of coatings for protection of steel. Test specimens were prepared with a variety of films, paints and pottants and then exposed to 35°C Salt Spray (ASTM B-117) and outdoor weathering conditions. The specimens were evaluated for degree of corrosion, delamination and other destructive effects at regular intervals. The salt spray and outdoor results generally correlated well, except for the degree of attack, which was much more severe in the heated salt fog. Untreated control specimens survived three hours under salt spray before extensive corrosion became apparent. The most successful coating identified so far is lamination with an EVA/Scotchpar polyester combination which has endured 5,000 hours of salt spray with no signs of change. Other coatings based on EVA modified with zinc chromate have also survived this period without change. These coatings are currently too expensive to be practical (approx. \$10/m²), however they serve to demonstrate proof of concept and show the effectiveness of chromate modification.

Investigations are continuing with commercial maintenance coatings based on fluorocarbon and silicone-alkyd chemistries. Tests of these coatings show good salt-spray resistance to 4,000 hours and the cost, including the steel and both sides coated, is in the order of \$3.50/m². This is well within the \$7.00/m² upper limit for substrate cost.

Wood products, such as hardboard, are potentially the lowest cost candidate substrates identified to date. The high modulus (0.5 to 1.0 x 10⁶ psi) and low cost (approximately \$0.14/ft²) satisfy the cost and load deflection requirements. The difficulty with the use of these materials lies in the very high hygroscopic expansion coefficients. Periods of dryout followed by subsequent moisture regain results in large expansions and contractions that result in cell fracture when these materials are used as substrates. Experiments were conducted to determine the effectiveness of occlusive coatings to prevent this effect. Both metal foils and organic films bonded to the hardboard with appropriate adhesives were found to dramatically decrease the hygroscopic response and lower the expansion coefficient by four orders

of magnitude. These results improve the position of wood products as potentially useful substrates and future experiments will continue to assess the viability of this approach and identify cost effective coating materials and techniques.

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. The treatments are based on silicone, acrylic, and fluorosilane chemistries. After one year of outdoor exposure, the most effective treatment for Sunadex glass appears to be a fluorosilane designated L-1668, and for both the organic films, a silane modified adduct of perfluoric acid gave the best results. These treatments gave improvements of 2.5 to 4% in power transmission measured with a standard cell. The surface treatments were found to be "self cleaning" and power transmissions varied with the degree of rainfall. After one year of time there is evidence that the treatments are slowly being lost and consequently a maintenance schedule may be required to maintain effectiveness over long periods of time.

Primers were evaluated for effectiveness in bonding candidate pottants to outer covers, glass and substrate materials. The bond strengths were determined by standard methods and measured in pounds per inch of bond line. Successful primers were also tested after two weeks of water immersion and two hours of boiling water. Good primers have been identified for bonding EVA (9918) to almost all candidate materials and a new primer that is effective with polyester films was identified that gave bonds of 35 psi. Despite the similarity in chemistry, the EMA is much more difficult to bond and, to date, successful results have only been obtained with glass and mild steel. The polyurethane casting syrup has been effectively bonded to Sunadex, Tedlar and Korad but additional work is required on steel and polyester. The butyl acrylate syrup is the most difficult pottant of all to bond and is additionally complicated by its inherently low tensile strength. Bonds to Tedlar and Sunadex glass that survive the water immersion and boiling tests have been achieved, however they are both low in bond strength, and do not exceed 1 to 2 pounds per inch of width.

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) generating empirical and practical data relating to longevity, and (b) generating data that may be used in a scheme to predict properties as a function of exposure time and condition.

The conditions being used for the exposure of candidate encapsulation materials include outdoor aging, thermal aging (air oven), RS/4 sunlamp exposure, RS/4 sunlamp with intermittent water spray, Controlled Environment Reactors (JPL equipment) and outdoor photothermal aging racks. The last mentioned condition involves the exposure of test specimens to natural sunlight but at elevated temperatures to accelerate the degradation reactions.

Data is reported for the RS/4 and thermal aging conditions only. Test results from continuation of these tests and the other conditions will be reported as it becomes available.

R/S 4 sunlamp exposure is a widely used industrial method of assessing the relative stability of plastics to the degrading effects of ultraviolet light. The results are useful for the ranking and comparison of the stabilities of polymeric materials and the effectiveness of additives and formulations. The EVA formulation A9918 is performing extremely well and has survived 27,000 hours exposure to date with no significant change in properties. In comparison, the uncompounded resin begins to degrade in about 500 hours. The other pottants are also surviving without change, however they have not yet accumulated the same number of hours. The fully compounded EMA has endured 10,000 hours, and the casting syrups, polyurethane and butyl acrylate, have been exposed for 8,600 and 5,700 hours, respectively. Pigmented back cover films of Tedlar and Scotchpar and outer cover films of transparent Tedlar (100BG3OUT) show no signs of deterioration to date. The low cost biaxially oriented acrylic film, Acrylar (3M Corporation) has been exposed to 12,000 hours so far and shows no change in useful properties, except that a 40% decrease in tensile strength (from 24,000 psi to 14,500 psi) occurred within the first 1,500 hours.

This is believed to be due to stress relaxation in the polymer and to have no effect on the final performance and intended use of the film.

A new candidate outer cover film from American Hoechst has recently been included in accelerated aging tests. This product is named "Hostaphan" (EH-723) and is claimed to be a permanently stabilized polyester. No results are available yet.

Based on a rough calculation of accumulated UV energy, one year of RS/4 exposure is approximately equal to 6.7 years of outdoor exposure in a hot climate. This indicates that the EVA 9918 specimen has survived the equivalent of 21 years of outdoor exposure.

Thermal aging was performed on three candidate pottant compounds; EVA, EMA and the aliphatic polyurethane. The specimens were aged at three temperatures (80°C , 105°C and 130°C) and in atmospheres of both air and nitrogen to discriminate between plain thermal instability (thermolysis) and reaction with heat and oxygen (oxidation).

EVA and EMA both behaved similarly under these conditions. Neither were particularly affected by the lower temperatures, however both developed slight yellow coloration after 400 hours at the 130°C exposure. This effect was probably due to thermolysis (cleavage of the ester groups) due to the fact that it was observed in both atmospheres. The coloration is not thought to present a limitation to the use of these materials as pottants and additionally the 130°C condition is an extreme condition that is not likely to be encountered in field service. The polyurethane was much more affected by exposure to thermal aging than either of the two polyolefins. Even at 80°C , the urethane developed slight yellow coloration, even though the physical properties did not change. At 105°C , the tensile strength and modulus steadily decreased to approximately 40% of the control values, but only in the nitrogen atmosphere, the air exposed specimens remaining intact. In both atmospheres, however, the specimen developed strong coloration and the surfaces became sticky, indicating chain scission at the surface. The 130°C condition was severe and the test specimens lost their physical integrity after the 100 hour mark with the development of dark brown coloration. At 400 hours, the specimens had melted to amorphous brown resinous masses that were beyond testing.

For all the pottants, no adverse effects from the presence of metals (60/40 solder, aluminum and copper) was noticed with the conspicuous exception of copper. Slight reaction (coloration) in the presence of copper was noticed in both EVA and EMA at temperatures as low as the 80°C exposure. At the 130°C, the degradation reactions resulting from the presence of copper are severe. At the 400 hour point, strong coloration, debonding and flow of the resins is noticable indicating severe degradation of the polymer. In the polyurethane pottant, these reactions were even more pronounced. Exposure to 105°C for 400 hours resulted in complete degradation of the resin in the presence of copper, and resulted in dark coloration and flow.

During the past year, Springborn Laboratories also conducted some activities in support of the FSA program by preparing test samples for two other contractors. Two cell experimental modules were constructed for Clemson University with a variety of candidate encapsulation materials and modules were fabricated in both substrate and superstrate designs. These test modules are being used for determination of cell electrical parameters under thermal/humidity aging and to examine the effect of the pottant.

Specialty modules were also prepared for Science Applications, Inc. and consisted of large arrays of individually wired cells encapsulated using glass superstrates of varying thickness. These test modules are being used to verify the predictions of computer optical analysis concerned with the passive concentration of sunlight by internal light trapping.

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 ($\$70/\text{m}^2$) (1987 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, pollutants, and mechanical supports for the solar cells.

a. JPL Document 5101-68

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

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; (e) 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):

<u>Construction Elements</u>	<u>Approximate Cost Allocation^(a) (\$/m²)</u>
● 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

(a) Allocation for combination of construction elements: \$14/m².

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 following chart shows the materials of current interest and their anticipated functions.

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 |
| 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) |
| 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 gal-
vanized & enameled) | Available |
| 6. Back covers | |
| a. Aluminum foils & polymer
laminates | Available |
| b. Tedlar, Mylar, Korad
(polymer films) | Available (DuPont, Excell, 3M) |
| c. Pigmented ethylene vinyl
acetate | Available (Springborn) |
| d. Others | Under development |
| 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) |

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:

- (1) the study of improved cure systems for the candidate lamination pottants, EVA and EMA. Curing agents are investigated that improve the quality of cure, improve the speed and lower the effective temperatures;
- (2) the extended investigation of aliphatic polyurethane compounds intended for use as pottants in the liquid-casting technique;
- (3) an investigation of corrosion protective coatings for use with mild steel to give a low cost long life substrate;

- (4) continued work on coatings to provide environmental stability to low cost candidate substrate materials based on wood (hardboard) products;
- (5) evaluation of the soil resistant coatings after one year of outdoor exposure;
- (6) a continuing survey of primers for use in coupling the various interfaces between encapsulation materials;
- (7) a discussion of accelerated aging test techniques being implemented at Springborn Laboratories and presentation of the results of RS/4 exposure testing of candidate encapsulation materials; and
- (8) other activities at Springborn in support of the FSA program.

III. POTTANTS

A. Advanced Cure Systems

a. Chemistry

Two compounds, ethylene-vinyl acetate and ethylene-methyl acrylate, were chosen for the development of candidate pottant compounds for the lamination process. Their selection was based on their transparency, low processing temperatures and low cost. In order to function effectively in a module application, the property of creep resistance (lack of flow) at the module operating temperatures is a necessity. In order to accomplish this requirement, the copolymers must be compounded with chemical additives that permit the resin to flow during the lamination cycle but then subsequently crosslink (cure) at a later time. Crosslinking and/or vulcanization is defined as a process for converting a thermoplastic material or elastomer into a thermo-setting material that will no longer flow upon the application of heat. This process converts the majority of the polymer molecules into a single network which then has the ability to retain many desirable physical and chemical properties of the base polymer under higher temperatures.

The two major chemical processes (not including radiation) that result in crosslinking are peroxide cure systems and sulfur cure systems. Only the peroxide cure systems have been considered for the two candidate elastomers. The main reason for this is that the sulfur cure systems, when used alone, will not cure these saturated compounds and in addition they result in the presence of dark sulfides that will reduce the optical transmission of the final compound. Peroxide cures, in addition, have many other desirable characteristics:

- Peroxide cures can be used with both saturated and unsaturated polymers,
- Peroxides produce vulcanizates with better heat aging properties, lower compression set, less color and lower odor,
- Peroxide vulcanizates generally have better low temperature flexibility than the sulfur cured compounds, and,

- Saturated elastomers that have been peroxide crosslinked have excellent aging and thermal stability characteristics. This is due to the lack of saturation in the polymer backbone and also to the higher bond energy of the carbon-carbon bond that results from peroxide crosslinking. The carbon-carbon bond energy is 82 Kcal/mole and is therefore as stable as most of the other bonds in the polymer. The sulfur cured elastomers have crosslinks composed of both carbon-sulfur and sulfur-sulfur bonds with energies of 66 Kcal/mole and 49 Kcal/mole, respectively. These are, therefore, weaker crosslinks and result in an inherently less stable compound.

The peroxide crosslinking of saturated polymers not only involves a large number of chemical reactions within the polymer itself, but also between peroxide decomposition residues, atmospheric oxygen (if present) and additives compounded into the rubber. The predominant reaction that gives rise to the formation of crosslinks is referred to as hydrogen abstraction. The basic steps of this chemical reaction are:

- (1) Peroxides thermally cleave to produce two oxy radicals. Acyl peroxides yield acyloxy radicals; alkyl peroxide yields alkoxy radicals.

$$\text{ROOR} \xrightarrow{\Delta} 2\text{RO}\cdot$$
- (2) Oxy radicals are very reactive and abstract hydrogen atoms from polymer chains, where P = polymer.

$$\text{PH} + \text{RO}\cdot \rightarrow \text{P}\cdot + \text{ROH}$$
- (3) Two polymer radicals then combine to form a crosslink, resulting in cure.

$$2\text{P}\cdot \rightarrow \text{P} - \text{P}$$

The ability of a radical, ($\text{R}\cdot$) to abstract hydrogen from a polymer, (P-H) to produce a new polymer radical, ($\text{P}\cdot$) is determined by the bond dissociation energies of R-H and P-H . In general, the more the bond dissociation energy of R-H exceeds that of P-H , the more rapid the hydrogen abstraction is likely to occur. The comparative ease with which hydrogens are abstracted by oxy radicals is a function of the hydrogen atom's reactivity. In order of descending reactivity, they are functionally; phenolic > benzylic > allylic > tertiary > secondary > primary. In polymers the degree of crosslinking varies depending on the type and number of hydrogens available for abstraction and the presence

of other reactive groups. The degree of crosslinking is affected by (a) the polymer type: saturated, unsaturated, chlorinated, etc.; (b) the peroxide type: dialkyl, diacyl, peroxyester, etc.; (c) the processing parameters: peroxide concentration, thermal decomposition rate, temperature, time, and (d) the interaction with other additives such as antioxidants, fillers, oils, stabilizers, etc.

Dialkyl peroxides are generally the most efficient and most widely commercially used for polymer crosslinking applications. Their high activation temperatures yields compounds of excellent thermal stability during compounding and reduced problems with "scorch" (premature curing). A wide variety of compounds are commercially available.

The factors guiding the selection of peroxide for the given application are as follows: (1) generation of crosslinks as the only modification of the polymer, (2) rapid decomposition at the desired cure temperature to yield efficient cure, but (3) survives the polymer compounding and processing steps, (4) effective in the presence of the other compounding ingredients such as antioxidants and UV stabilizers, (5) must be soluble in the polymer compound and preferably solid to prevent volatile losses, (6) is non-toxic before and after decomposition, and (7) does not sensitize the polymer to heat or ultraviolet light resulting in the accelerated aging of the cured elastomer. Peroxides containing aromatic groups (such as dicumyl peroxide) should be avoided due to their sensitizing effect on light stability.

Cure time and temperature can be determined in a peroxide cure system solely from knowledge of the rate of peroxide thermal decomposition. It is this reaction (homolytic cleavage and the generation of free radicals) that is the rate determining step in the curing or crosslinking sequence of reactions. The reaction follows first-order kinetics and is generally characterized by their half-life temperature. This term is more useful than "rate-constant" and is defined as the temperature at which fifty percent of the peroxide will decompose within a given time period. The half-life temperature is useful as an initial guide for the determination of processing safety and the selection of cure temperatures. The decomposition rate is independent of the amount of

peroxide present but does vary somewhat with the medium in which the decomposition is taking place. The thermal decomposition rates in polymer systems are usually slower (than in solutions) due to the reduced mobility of the resulting free radicals and the opportunity for recombination to occur.

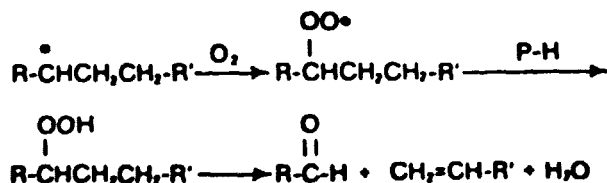
In commercial practice, polymer cure conditions are often selected to obtain six or seven half-lives in order to insure complete peroxide decomposition and the maximum development of physical properties. The following table illustrates the relationship between the half-life and the percent of peroxide decomposition:

<u>Number of Half-Lives</u>	<u>% of Original Peroxide Decomposed</u>
1	50.0
2	75.0
3	87.5
4	93.75
5	96.9
6	98.4
7	99.2
8	99.6

This general rule does not have to be followed providing that the following conditions are fulfilled: (a) the excess remaining peroxide is economically and chemically acceptable, (b) the ultimate in tensile strength and compression set is not required, and (c) the resulting gel content (degree of cross-linking) is acceptable for the intended application. It is found that the properties of modulus and tensile strength are within 90% of their ultimate values after the decomposition of approximately 80% of the peroxide. It is therefore recommended that the compound be cured for a minimum of three half-lives at the selected cure temperature.

A few cautions must be mentioned with respect to peroxide curing agents. These compounds decompose in the presence of strong oxidizing agents, reducing agents and accelerators (such as dimethyl aniline, cobalt naphthenate and metal salts). Acids in particular decompose the peroxide into ions. When this type of ionic decomposition occurs, alcohols and non-radical products result that cannot initiate the crosslinking reaction. Fillers and additives to the polymer should therefore be chosen that are not strongly acidic in nature.

Oxygen is also to be avoided during the cure stages of these compounds. Exposure to oxygen causes a competing reaction to occur that reduces the efficiency of the curing process, and more seriously, may lower the thermal stability of the final compound. In the presence of oxygen, the polymer radicals resulting from hydrogen abstraction may form hydroperoxides. The resulting hydroperoxides may then thermally decompose and result in polymer degradation according to the following mechanism:



Due to the fact that most cures are done either in closed molds or in vacuum bag laminators, as in the case of PV modules, the exclusion of oxygen is usually sufficient to prevent reactions such as these. Curing openly in the presence of air, however, must be avoided.

Ethylene/Vinyl Acetate

After an extensive investigation of transparent elastomers, ethylene/vinyl acetate (EVA) was selected from a class of low-cost polymers as being a likely candidate potting compound for use in the fabrication of solar cell arrays. Its selection was based on cost (approximately \$0.65 per pound) and an appropriate combination of high optical transparency and easy processing conditions. This polymer also showed the most promising properties for immediate use with a small amount of modification, but without extensive development efforts.^a

a. Willis, Baum, "Investigation of Test Methods, Material Properties and Processes for Solar Cell Encapsulants" DOE/JPL 954527-79/11, June 1979.

Fourteen commercial grades of EVA copolymers were surveyed from two manufacturers and a base resin, Elvax 150 (DuPont de Nemours Chemical Co.) selected on the basis of its high optical transmission and low melt viscosity. This resin formed the basis for the development of what is now a commercially available lamination grade solar cell pottant, Springborn Laboratories formulation number A9918. This compound has been widely evaluated and favorably received by the photovoltaic industry at large.

In addition to the many other technical activities, Springborn Laboratories is pursuing research concerned with the "technical optimization" of EVA, and other candidate encapsulation materials. Considerations include areas such as materials processing, lower temperature and faster cures, optimized thermal stability, optimized ultraviolet stability, adhesive reliability and lifetime prediction studies.

The first area to be reexamined in the formulation of potting compounds is that of cure parameters. Due to limitations imposed by the chemistry, the cure systems must be evaluated first and the other additives are subsequently selected for compatibility with the selection of curing agents. Experiments to evaluate new peroxide curing agents were conducted over the past quarter. The new compounds have only just become commercial and have the desirable properties of (a) aliphatic chemistry containing no UV sensitizing aromatic groups, (b) half life temperatures in the range of 90°C to 130°C (one hour half-life) for stable processing and rapid cure, (c) solubility and compatibility with ethylene copolymers and (d) the potential for faster and more efficient cure.

Curing (crosslinking) of the pottant is necessary to prevent thermal creep of the resin at module operating temperatures. Excessive flow of the pottant would result in deterioration of the module.

A preliminary study was conducted to determine if there existed a relationship between the type of EVA and the ability to be cured. A number of resins were selected, varying in gel content and melt index, and the efficiency of curing determined from the gel content. Using Lupersol-101 as the curing agent, the following results were obtained:

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<u>Resin</u>	<u>Melt Index</u>	<u>Vinyl Acetate Weight %</u>	<u>Gel Content (a)</u>
UE-646-04	25	28	79
Elvax 240	43	28	71
Elvax 250	25	28	83
Elvax 350	19	25	73
Elvax 420	15	18	62
Elvax 450	8	18	86
Elvax 550	8	15	82
Elvax 650	8	12	66
Elvax 750	7	9	61
PE-831	9	0	0

(a) All polymers cured with 1.5 phr Lupersol-101 at 150°C/15 minutes.

As may be seen, the acetate group appears to be essential for crosslinking in EVA resins. Even at 9% by weight, the acetate group results in a gel of 61%, however the pure polyethylene with no co-monomer gives no cure at all. The degree of cure (% gel) does not appear to be dependant on the amount of vinyl acetate present in the polymer as long as it is there. Experiments have shown that a minimum gel content of 65% is required to prevent thermal creep in EVA^(a). The use of Elvax 150 was continued for all subsequent experiments.

Four new liquid peroxides were evaluated. All are products of Lucidol Division, Pennwalt Corporation; Buffalo, New York, and have the following properties:

	<u>Half-Life Temperature</u>		<u>Flash Point (Volatility)</u>	<u>% Active</u>
	<u>One Hour</u>	<u>Ten Hour</u>		
Lupersol 331-80B ^a .	111°C	93°C	40°C	75%
Lupersol 99 ^b .	118°C	99°C	77°C	75%
Lupersol TBEC ^c .	120°C	86°C	101°C	100%
*D-S606 ^d .	96°C 117°C	76°C 97°C	77°C	100%
Lupersol 101 ^e . (for comparison)	138°C	119°C	43°C	100%

*Contains two peroxy groups with differing half-lives

a. Willis, Baum, "Investigation of Test Methods, Material Properties and Processes for Solar Cell Encapsulants" DOE/JPL 954527-79/11, June 1979.

These compounds were blended into EVA copolymer (Elvax 150, DuPont) by cold milling at room temperature on a differential two roll rubber mill at a level of 1.5 weight percent. No other additives were incorporated. The resulting compounds were then cured by compression molding 20 mil thick plaques at a temperature of 150°C for twenty minutes. This basic test was useful for determining if the basic cure chemistry of the peroxide was compatible with the resin. The following table indicates the relative effectiveness of the peroxides as judged by gel content (percent insolubles) and the swell ratio (indication of the crosslink density):

<u>Peroxide</u>	Cure in Elvax 150 [*]	
	<u>Swell Index</u> ^{**}	<u>Gel Content</u> ^{**}
Lupersol 331-80B	2,500	87%
Lupersol 99	2,800	89%
Lupersol TBEC	2,400	95%
D-S606	3,200	69%
Lupersol - 101	2,500	88%

*150°C/20 minutes

**In toluene

These initial results indicate that all the peroxides selected are successful in developing cure in the EVA base polymer, and subsequent experiments were conducted to determine chemical compatibility in a fully formulated system and also to determine the time/temperature profiles for processing. A standard formulation was prepared with each, based on Springborn Laboratories' composition A9918, as follows:

	<u>Parts</u>
Elvax 150	100.0
Cyasorb UV-531	0.3
Tinuvin 770	0.1
Naugard - P	0.2
Candidate Peroxide	1.5

-
- a. 1,1-di(t-butylperoxy) cyclohexane
 - b. di-t-butyl diperoxyazelate
 - c. O,O-t-butyl O-(2-ethylhexyl) monoperoxy carbonate
 - d. 4-(t-butylperoxycarbonyl)-3-hexyl-6-(7-(t-butylperoxycarbonyl) heptyl)cyclohexane
 - e. 2,5-dimethyl-2,5-di(t-butylperoxy) hexane

These compositions were then evaluated by determining gel content (degree of cure) as a function of time and temperature. The range of 110°C to 160°C was used to determine the speed efficiency of cure at the higher temperatures and to determine if problems would be encountered with premature cure at lower temperatures used in the sheet extrusion process (maximum temperature approximately 115°C). The results of these experiments are given in Table 1 of the Appendix A.

With the exception of Lupersol D-S606, the results of advanced cure studies with completely formulated compounds appear very encouraging. The peroxides investigated all results in much higher cures of the EVA in shorter periods of time and at lower temperatures. Additionally, they should all be compatible with the extrusion process in which the temperature never exceeds approximately 115°C and the barrel residence time is in the order of only three minutes. Of the three, Lupersol 99 and Lupersol TBEC are a little more tolerant of premature crosslinking in the lower temperature ranges and both result in very rapid cures at higher temperatures.

The performance of the new peroxide curing agents may also be summarized as the times required for a specific gel content at known temperatures;

In EVA:	<u>Time Required for 70% Gel Content</u>				
	<u>120°C</u>	<u>130°C</u>	<u>140°C</u>	<u>150°C</u>	<u>160°C</u>
Lupersol 101	N/A	N/A	45	15	6
Lupersol 99	30	20	12	8	2
Lupersol 331-80B	15	10	5	2	2
Lupersol TBEC	30	10	4	2	1

These results indicate that, when compared to cure with Lupersol 101, the new peroxide, Lupersol TBEC, may be capable of resulting in equivalent cure in one third to one tenth the time, depending on the temperature selected. High degree of cure at a lower temperature is also desirable due to the energy saving, and reduced time required for heat transfer during lamination.

The rate of cure is dependent on the rate of peroxide decomposition and a close correlation has been found between the development of acceptable gel content (>55%) in EVA and the half-life vs temperature curve of peroxide decomposition. This graph is, therefore, useful for providing time and temperature data points required for cure. The half-life graphs for the peroxides of interest appear in Appendix A, Figure 1.

Of the four efficient peroxides presented, Lupersol TBEC currently appears to be the material of choice and should be considered as a replacement for the Lupersol-101 in future formulations. Its selection is based on; (a) it has the highest curing efficiency of the crosslinking agents examined to date, (b) it is 100% active and contains no DOP^a or mineral spirit dilutents based on its flash point, it has the lowest vapor pressure and consequently is less prone to volatile losses. Lupersol TBEC appears to be a highly efficient hydrogen abstractor in the ethylene/vinyl acetate base resin.

Ethylene/Methyl Acrylate

EMA has always been much more difficult to cure than EVA. Experiments were performed to see if the new peroxides presented an advantage in the fully compounded EMA potant formulation. Compositions were prepared in the laboratory, as before and a standard EMA formulation (EMA 13439) was used as the base for this evaluation. The composition was:

Ethylene/Methyl Acrylate (Gulf Oil Chemicals, TD-938)	100.0
Cyasorb UV-531	0.3
Tinuvin 770	0.1
Naugard - P	0.2
Candidate Peroxide	1.5

The time/temperature gel profiles were determined as for the EVA, except over a slightly narrower temperature range. Table 2 gives the results for the new peroxides from 120°C to 150°C, as was done for EVA. As may be seen the new peroxides are also of benefit in the EMA resin and result in much faster cure times and higher gel contents than the usual formulation employing Lupersol 101.

a. Dioctyl phthalate, a frequently used diluent.

Experiments so far have not indicated the necessity for curing the candidate EMA pottant. At 90°C (the upper module operating temperature) the base polymer shows no tendency to creep, even after three months exposure. Curing is, however, generally recommended as a precaution against long term creep and additionally provides a chemical mechanism that is compatible with many primers and adhesion promoting agents. A gel content of 50% is currently thought to be adequate for this composition.

As was found with the EVA, Lupersol TBEC is overall the most efficient curing additive, however at lower cure temperatures (130°C) the Lupersol 331-80B gave the highest gel contents.

Comparing these new curing agents, the minimum times to a 50% gel level are given for each peroxide as a function of temperature.

Minimum Time to 50% Gel Content

	<u>130°C</u>	<u>140°C</u>	<u>150°C</u>
Lupersol 101	N/A	> 60	30
Lupersol 99	30	15	5
Lupersol 331-80B	12	10	5
Lupersol TBEC	25	5	< 2

It is apparent that the cure times in EMA may be reduced by a factor as much as fifteen and that gel contents as high as 73% may be obtained in the range of times and temperatures investigated. This is a considerable improvement over previous formulations.

Of the four efficient peroxides presented, Lupersol TBEC currently appears to be the material of choice for EMA also and should be considered as a replacement for the Lupersol-101 in future formulations. Its selection is based on: (a) it has the highest curing efficiency of the crosslinking agents examined to date; (b) it is 100% active, and (c) it has the lowest vapor pressure and consequently is less prone to volatile losses.

The EVA and EMA elastomers compounded with these agents can be processed like any other rubber and, in addition to lamination, are suitable for injection molding, compression molding, transfer molding and profile extrusion. The low softening point of these compounds allows processing at low temperatures, minimal tendency to scorch and the ability to be rapidly cured by an increase in temperature in the order of 30 to 40°C higher than the processing temperature.

The use of these new peroxides, especially Lupersol TBEC, presents obvious advantages to the PV industry. The lamination/encapsulation step may be operated at lower temperatures, higher speed, more efficient cure and wider cure latitudes. It is expected that a TBEC modified pottant would be much more tolerant of accidental or intended variations in the time/temperature cure schedule, thereby allowing a wider margin for equipment malfunction or process adjustment.

Before the development of a future commercially acceptable formulation based on Lupersol TBEC, other evaluations must be conducted to assess overall performance. Some of the concerns that remain are: (a) volatility - does the peroxide evaporate from the pottant during storage; (b) thermal stability - does the peroxide retain its activity in the pottant during storage at room temperature; (c) does the new cure system give rise to volatiles and bubbles during cure; (d) will the peroxide comfortably survive the extrusion process in plant trials, (e) are any chemical species developed that are incompatible with the other additives or result in photosensitization of the polymer?

In the near future, a pilot plant extrusion will be conducted with TBEC modified formulations of both EVA and EMA to assess the production scale performance of this compound as well as module fabrication, adhesion experiments, and accelerated aging experiments.

Aliphatic Polyurethanes

The pottants developed and investigated to date have emphasized production in sheet form and consequently a fabrication method based on sheet lamination. Although the vacuum bag lamination process has been found to be very successful on experimental modules prepared to date, other methods of fabrication may be desirable to provide manufacturers with alternative production methods.

Liquid casting systems have been used in the past by the solar module industry with considerable success. A disadvantage with these systems is that they almost invariably employ high cost silicone resins. Alternative low cost casting materials were therefore surveyed and a few were identified as being potentially good candidates. Although not yet widely used, castable urethanes have been employed as solar module pottants.

They are typically two part liquid systems that cure to transparent solids after mixing. The time required for cure is temperature dependant and is also limited by the pot life of the system. Urethanes may be formulated to have cured physical properties ranging from hard and tough to extremely soft and flexible. A wide range of chemistries are available for both parts, the isocyanate and the polyol (parts "A" and "B"). These are sometimes referred to as ASTM type V urethanes.

Due to the application in solar modules, some desirable characteristics may be specified as the mixed syrup and the subsequently cured material. The mixed syrup must be pumped into a preformed cavity holding the cells and consequently must be low enough in viscosity not to disrupt the cell arrangement; the cure characteristics (time and temperature) must be appropriate to the fabrication process and must yield good throughput or production rates; the cured modulus must preferably be below the 2,000 psi level to provide protection to the cells at a "no thickness requirement" level; the chemistry should be aliphatic (not aromatic) in order to have optimum resistance to ultraviolet light and outdoor exposure; the cured resin should have no glass transition (T_g) within the temperature range of operation (-40°C to $+90^{\circ}\text{C}$); and the components should be pure and solvent free. These properties are the most important, although the list could be extended considerably. This list of properties may be considered as the criteria for the selection of candidate commercial materials for this application.

The aliphatic urethanes were surveyed due to the general interest in these compounds and manufacturers were contacted to determine if commercial products were available with the desired properties. The following is a summary of this investigation with a specific material recommendation.

Specific companies contacted included Mobay Chemical Co., H.J. Quinn Co., Henkel Corporation, Morton Chemical Company, and Upjohn Chemical Company. Information

on stabilizers was also obtained from Borg Warner, American Cyanamid, and Ciba Geigy. Henkel, Upjohn, and Morton Chemical Companies offer no commercial aliphatic systems that would be usable in this application. Mobay has no off-the-shelf products that could be used; however, they showed interest in having a meeting at Springborn in the future to discuss the requirements more fully and possibly offer a specialized product for this purpose. They suggest that products could result based on their Desmodur-W (fully hydrogenated methylene diphenyl diisocyanate) or from adducts employing hexamethylene diisocyanate (HMDI).

Only two suppliers of potentially usable systems were identified in this search, H.J. Quinn Company, Malden, MA and Development Associates, Inc., Kingstown, R.I. H.J. Quinn offers only one commercial product designated Q-621/Q-626 (for the isocyanate and polyol, respectively). This system has the following properties.

MIXED SYRUP
(uncured)

Viscosity at room temperature	3000 cps
Pot Life, 70 ^o F	3 hours

CURED RESIN

Tensile Strength	9000 psi
Ultimate elongation	300 psi
Total integrated transmission	89%
Color	light yellow
Hardness, Shore A	65
Cure requirement	2 hours/ 95 ^o C
Specific gravity	1.03
Cost: (mixed)	approx. \$2.20
(1982)	\$0.011/ft ² /mil

Plaques of the Quinn Q-621 urethanes were prepared and exposed to RS/4 radiation conditions in order to determine its stability in comparison to other candidate pottants. The unprotected specimens were found to be badly degraded after 1000 hours and flowed to diffuse shapes of dark yellow/brown color. The protected urethanes survived the remaining test periods, however, deterioration of the physical properties indicates that the degradation process is still in operation. Glass provided the best stability to the urethane at the 240 day exposure period, the tensile specimens retaining 960 psi of tensile strength and 440% elongation. The specimens behind Korad film lost about 90% of the original tensile strength and the urethane behind Tedlar film discolored and flowed completely to destruction.

During the survey of industrial compounds, some good input was obtained concerning stabilization of aliphatic urethanes. Mobay and Ciba-Geigy both recommended the same system as follows: 0.5 phr Tinuvin 770, 0.5 phr Tinuvin 328, 0.1 phr Irganox 1010. This is thought by both companies to be a synergistic combination that has a minimal effect on the cure of the resin. American Cyanamid offered a different formulation: 0.5 phr Cyasorb UV-5411 (a benzotriazole) with about 0.1 phr of Cyanox 1735, a phenolic/phosphite combination as the antioxidant.

Attempts at Springborn Laboratories to incorporate these stabilizers into the Q-621 system were not effective. In all cases, it was found that each of the recommended stabilizers was sufficiently chemically reactive with the components of the mixed urethane system to severely inhibit the cure mechanism and also result in the production of bubbles.

An additional difficulty experienced in the laboratory use of the pourable urethane systems has been that of moisture reactivity with consequent bubbling of the pottant. Experimental modules prepared at Springborn all showed difficulty in this respect and no modules could be prepared without small bubbles appearing. Modules prepared with hardboard substrates were conspicuously the worst due to the hygroscopic nature of the wood fibers and the high moisture content.

A series of specially formulated prototype encapsulation syrups were prepared by Development Associates, Inc. and were subsequently evaluated for cure requirements and physical properties. The casting syrups are two-part liquid 100% active urethanes and require the usual type of procedure involving mixing under low shear conditions for several minutes and then degassing under vacuum. The formulations supplied were variations of a commercial product used as a bottle coating and as over-coatings on decorative emblems in automotive use. This product is claimed to have outstanding weatherability and to date, has endured six years of outdoor exposure with no appreciable degradation. All the formulations submitted appear to have fast gel times, in the order of 10 minutes at 30°C, and have recommended cure temperatures of 65°-120°C. Cured films were tested for optical and physical properties, the results of which are given in Table 1 in Appendix A.

The first property examined on any of the formulations was the total integrated light transmission values, most of which were excellent. The second property was glass transition temperature (T_g), due to the requirement for stress relief at low operating temperatures. The first candidate, Z-2211 was found to have a T_g of +12°C. Tangent modulus was run on this resin at -30°C and found to be 8×10^4 psi, indicating that the composition becomes very hard, as expected.

The subsequent candidates had more promising properties. The Z-2451 and Z-2391 both had glass transitions in the range of -30°C and also have high integrated transmission. As the T_g decreases, the tensile strength also appears to decrease; however, the low tensile strength should not affect performance when used in a pottant (no-load) application. New formulations continued at Development Associates with the goals of: (1) T_g below -40°C; (2) tangent modulus below 2,000 psi; and (3) tensile strengths of 350 psi or better.

These goals were never quite achieved; however, a product resulted, Z-2591, that is considered acceptable for the Industrial Evaluation phase of this program. Z-2591 has a mixed viscosity of approximately 250 centipoise, a

gel time of 20 minutes at room temperature, a glass transition temperature of -23°C , and cured properties of 160 psi tensile strength and 115% elongation. (See Table 1, Appendix A.) In terms of overall properties, this formulation is thought to be the best choice at this time for further investigation.

Cured specimens of these resins are water white and very clear in appearance. The bubbling difficulties experienced with other urethane compounds when cured in the presence of moist air do not appear with these products. The manufacturer claims that the catalyst system that they use does not favor the isocyanate-water reaction that results in the presence of CO_2 bubbles in plaques cured under high humidity conditions. Small two-celled modules have been prepared with these syrups with no difficulties.

These candidate urethanes are completely formulated with UV screeners, antioxidants, etc., so that no further formulation work is being considered by Springborn at this time. Formulations similar to these have also been used for coatings applied to automobile vanity strips and consequently have a successful history of outdoor performance. Improvements in the formulation may be considered after studies of aging and durability have been completed.

Recent laboratory experiments with module building show that these urethanes are easy to mix and pour due to their low viscosities and that bubble-free castings are fairly easy to prepare. A current limitation is that the mixed pot life is very short, about 15 minutes. The mixed system must be degassed and used in fabrication within this time. Development Associates claims that the cure time may be easily controlled by reformulation and that the pot life may be increased to hours, if necessary.

Of the materials evaluated to date, Z-2591 is recommended for trial encapsulation studies. It was selected over the Z-2391 on the basis of its slightly higher optical transmission (Table 3) and longer cure time that made it easier to handle in a laboratory setting. Its low modulus, high transparency and low glass transition temperature make it a usable first-cut formulation for commercial exploration.

Specimens of Z-2591 have been included in RS/4-50 $^{\circ}\text{C}$ sunlamp exposure in order to provide a relative assessment of the ultraviolet light stability. To date,

specimens have survived 6,000 hours of exposure and retained the original tensile strength elongation. These are good results for transparent polymers, in general. As a reference point, polyethylene loses 90% of its tensile strength within 500 hours of this type of exposure. The resin will also have the significant advantage of being behind glass or a UV screening film when used as a pottant in a fabricated module.

Some preliminary adhesion studies were performed using Z-2591 as a pottant and bond strengths were measured to other candidate encapsulation materials; the results are as follows:

Z-2591 To:	<u>Adhesion Tests (a)</u>		
	<u>Control</u>	<u>2 Hours Boiling Water</u>	<u>2 Weeks Water Immersion</u>
Sunadex Glass	31	45	37
Tedlar 100BG3OUT	5	2.5	0
Scotchpar 10CPW	0.2	0	0
Korad 63000-White	5	3	2

(a) surfaces primed with thin coating of Dow Corning Z-6020 amino silane (10%) in methanol

The primer appeared to be very effective with the glass surface, however, gave poor to marginal performance on the other materials. This is thought to be due to the chemical incompatibility between the primer and the surfaces attempted for bonding. Some type of surface activation will be necessary to generate a surface that is chemically reactive with the silane primer composition. An attempt was also made to combine the silane component of the primer directly into the urethane to create a self-priming composition. A level of 0.5% of the Z-6020 was blended into the urethane and subsequently cast onto Sunadex low-iron glass and Mild steel sheets. This approach did not appear to be effective and gave bond strengths of 2 lbs/in (Sunadex) and 2 lbs/in (steel), neither of which survived the boiling water test.

This urethane has been successfully used for the fabrication of laboratory prototype solar cell modules by the casting method. In this process, the

the two components of the urethane composition are held in stirred containers and degassed under vacuum. The vacuum is then released and the two components, "A" and "B", are pumped into a common mixing chamber by a pair of "Zenith" metering pumps that have a common gear drive. The two drives mesh and the ratio of the two components is permanently set by selection of the gear sizes. The composition is, therefore, held constant regardless of pump speed. The output end of the mixer contains a section of static mixer to insure homogeneity. Compositions have been prepared continuously at a rate of approximately one liter per minute. Using this device, modules as large as 4 feet by 4 feet have been successfully prepared by simply permitting the mixed composition to flow over the cell strings in a substrate design of module. In a large scale automated factory operation, the composition would most likely be pumped into a preformed and heated module cavity and permitted to cure to at least a "demold" condition. A scheme such as that used in reactive injection molding (RIM) may be envisioned. The urethane would be handled in a manner to that shown in Figure 1. Directions for laboratory casting and data sheets for Z-2591 are included in Appendix B.

The Z-2591 is available in plant quantities from Development Associates, Inc., 300 Old Baptist Road, North Kingstown, Rhode Island, 02852; Contact Mr. Bud Nannig, (phone: 401-884-1350). The price, based on the mixed system, is expected to be in the order of \$3.00 per pound; however, it may fluctuate slightly due to raw material costs. Development Associates also has a few specialty primers available that may be effective for certain applications.

IV. SUBSTRATES

Springborn Laboratories, Inc. has conducted extensive surveys into materials that may be useful as cost-effective substrates for photovoltaic modules ^(a). The results of these surveys suggest that the load bearing element, either substrate or superstrate will be the most expensive single component in the encapsulation package. Given the overall encapsulation cost goal of \$14.00/m² (1980 dollars), the load bearing element may amount to as much as 50% of the cost, or up to \$7.00/m².

Surveys have identified potential construction materials on the basis of the flexural strength required to meet the load deflection specifications and the cost of the material at the required thickness. The materials identified to date are as follows:

<u>Candidate Material</u>	<u>Estimated Cost</u>	
	<u>\$/ft²</u>	<u>\$/m²</u>
Hardboards (Masonite, "Super-Dorlux", Ukiah Standard Hardboard)	0.14	1.52
Strandboard (Potlatch-under development)	0.17	1.80
Glass-reinforced concrete (MBA Associates)	0.60	6.50
Mild steel (28 gauge) (base cost appx. 1¢ per sq. ft. per mil of thickness)	0.25	2.70

A. Mild Steel

Mild steel is the least expensive metallic material found to date and offers the advantage of easily shaped into structures that have integral stiffening ribs incorporated into the manufactures structure. The stiffening ribs may permit the reduction of panel weight and thickness in order to meet the deflection load specifications and additionally result in a cost optimized structure.

(a) Willis, P. and Baum, B., Investigation of the Test Methods, Material Properties and Processes for Solar Cell Encapsulants, Annual Reports II and III to Jet Propulsion Laboratories, Contract 954527, July 1978 and July 1979.

The difficulty with the use of mild steel is its inherent corrosion sensitivity. Modules deployed outdoors without some protection provided for the steel, will probably not last the twenty year period without rust, resulting in delamination of the encapsulated cell strings from the surface and possible mechanical deterioration of the steel structure itself. The solution to the corrosion problem depends on the form the corrosion takes. The forms of corrosion found in metals are (a) uniform attack over the exposed surface, (b) galvanic corrosion between two dissimilar metals, (c) crevice corrosion in localized shielded areas, (d) pitting corrosion and the formation of cavities, (e) intergranular corrosion at the metal grain boundaries, (f) selective leaching of metals from alloys, (g) erosion from moving solids/fluids and, (h) stress corrosion caused by the presence of a tensile stress and a corroding medium simultaneously. Probably several of these mechanisms would come into action in steel exposed to an outdoor environment.

The application of protective coatings is the easiest and most obvious way of preventing the corrosion chemistry from occurring. Coatings form a barrier between the metal and its environment and isolate it from the electrolytes that are required for any of the corrosion mechanisms to occur. A good protective coating must resist acids, alkalis, salts, moisture, ultraviolet light and have good adherence to metal surface for which it is intended.

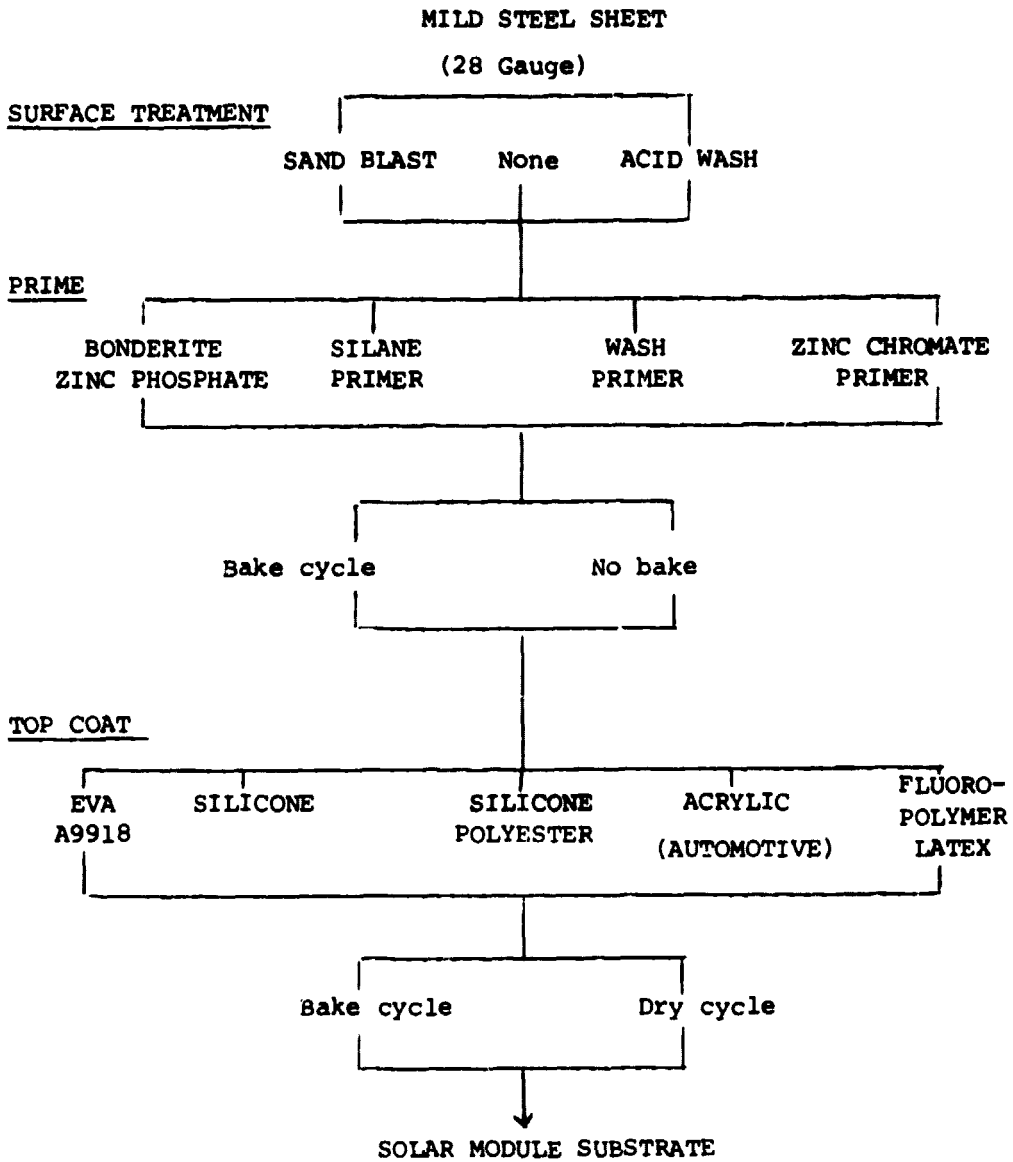
Coatings may be divided into three groups; metallic, inorganic, and organic.

Metallic coatings include metal spraying, cladding, hot-dip coatings and electroplating. The least expensive metallic coatings is hot-dip galvanizing with a cost increment of about 20% over plain cold rolled mild steel. Aluminum clad rolled steel is also available, however it is almost twice as expensive (varies with grade and manufacturer).

Inorganic coating refers basically to porcelainization - a process of applying a glass frit to the surface of the steel and then firing until the glass fuses to the surface. This approach works well in terms of corrosion protection, however it is sensitive to mechanical flexing and is also expensive. The steel sheet that is suitable for porcelain enameling costs about 15% more than mild steel and the enameling process itself adds, perhaps an additional 50% to the overall cost.

Due to the ease of use, the ability to coat complex geometries, and cost benefits, our approach to the corrosion problem has emphasized the use of organic coatings. Several approaches are under consideration. The possibilities include (a) encapsulation of the entire steel substrate with the weatherable pottant compound, (b) lamination with an occlusive foil (i.e. aluminum foil) and the use of a hot melt adhesive, (c) lamination with organic films, such as pigmented polyester, and (d) combinations of these techniques. The goal is to systematically identify, assess and cost out candidate coating systems that can meet the twenty year life criterion at the lowest possible cost. The following scheme is proposed:

Corrosion Protection Scheme



The type of coatings that are expected to fit into this scheme are the automotive and the maintenance coatings employed for durable siding on buildings. A brief list of possibilities follows:

Coatings ^{a.}	Cost, Both Sides ^{b.} ¢/ft ²
Polyvinylidene Fluoride (Primer + Enamel) PPG Industries, 10 years outdoor to date	11.2
Silicone/polyester Dexter-Midland, prototypes to 20 years	5.4
Polyester Dexter-Midland, 50-10 years outdoors	4.0
Acrylic Coating PPG Industries, 5 years outdoors	4.0
Polyester (Compliance Coat) Dexter-Midland, 5 years outdoors	4.0
Acrylic Emulsion Coating Dexter-Midland, 5 years (extrapolated)	5.2
Polyester Powder Coating Dexter-Midland	5.6
"Bonderite" Primer treated conversion coating; to be applied prior to coating	0.2

To date, a number of corrosion test specimens have been prepared with a variety of coatings and evaluated for performance in outdoor exposure and indoor heated salt spray (ASTM B-117) tests. These coatings are based on adhesive/film combinations and also some maintenance coatings. The results of these tests is given in Tables 4 and 5. The key for these tables is given in Table 6.

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- a. Recommended by industrial consultant, Mr. Milt Glaser, former Vice-President of Dexter - Midland Company.
- b. The prices shown are for finished product cost, i.e., RMS and labor costs.

The salt spray condition is conducted in a closed chamber at 35°C with a continual spray of 5% salt solution sprayed on the test specimens. This condition is widely used in the plastics and coatings industries for the assessment of protective coatings, but is recognized as being a severe test. Very often, the lifetime of test specimens is measured in hours. This may be seen in the case of the mild steel control (Table 4), in which extensive corrosion is observed after only 3 hours exposure.

All the tests specimens prepared for this experiment were sealed around the edges with butyl rubber sealant tape (3M Corporation No. 5354) and an EPDM rubber gasket to form a water tight seal.

The first specimens to show a signs of attack used Acrylar acrylic film, Scotchpar polyester and aluminum foil glued to the steel with an acrylic pressure sensitive adhesive, number 4910 (3M Corporation). These specimens gave indications of change after 200 hours of exposure. The other coatings all lasted for at least 500 hours before any change was noticed, still few were found to be effective. Specimens prepared with Korad, Stainless steel, Tedlar and EVA (primed) coatings all showed sufficient attack that they were removed at or before the 2,500 hour mark.

A few of the candidate systems have survived with no signs of deterioration. The best, to date, is a combination of Scotchpar 20CP white pigmented polyester film that is bonded to the steel with EVA 9918 and the appropriate primers at the interfaces. This specimen has endured 5,500 hours with no noticeable change. The other coatings that are performing well are EVA 9918 compression molded to the steel with the use of a zinc chromate modified silane primer, and a commercial fluorocarbon based topcoat from PPG Industries, Pittsburgh, PA. with its recommended epoxy primer. These two have both reached the 4,000 hour mark with minimal deterioration.

Other coatings under test include an acrylic based automotive enamel and a silicone modified alkyd paint. Both are surviving without change, however they have not reached the 1,500 hour mark yet. The specimens that survive the exposure period will be continued until deterioration does occur and new materials will be brought into test as they are identified.

The outdoor aging exposure (Table 5) is not nearly as severe as the salt spray condition, however the results correlated fairly well between the two conditions. Every specimen that showed no signs of attack under salt fog also showed no deterioration under outdoor weathering, and most of the specimens that did show signs of change in salt fog also changed in outdoor conditions, although to a lesser degree. Three exceptions were found; aluminum foil, Acmitite and Tedlar 200 BS30 White. Specimens prepared with these films were destroyed in salt spray but survived the 5,500 hour outdoor period with no effect. The control resulted in a light layer of corrosion within the first 200 hours and rusted badly with 500 hours.

As with the salt spray condition, the specimens will be exposed until deterioration becomes severe and new coating candidates will be added on a continuing basis.

An economic analysis of the coatings attempted is given in Table 7. These tables calculate a cost for the corrosion protective systems in $\$/m^2$ and $\$/ft^2$ based on the known raw materials costs and an approximate cost for the application and bake treatment where required. The cost analysis permits an immediate comparison of the candidate coating systems for cost effectiveness and add-on cost to the mild steel.

The cost analysis indicates that spray-on maintenance coatings are the most cost effective approach considered to date. The least effective appears to be vacuum bag lamination of the steel with EVA at a cost of approx. \$10-\$11 per m^2 . This is based on current cost and thickness, however, and was included to demonstrate proof of concept. Thinner layers of EVA or some other resin could prove to be much more cost competitive. Due to the high cost of the adhesive, glued films applied to the surface also result in expensive laminates in the order of \$6 per square meter, although these are much closer to the upper limit of \$7.00 per meter total substrate cost. Of the coatings examined to date, the best cost/performance is probably found for the Dexter 75x102 coating, with a cost of $\$3.13/m^2$. After 4,000 hours of salt spray,

this coating does show a few small spots of rust and the occasional blister, however its performance is judged as being quite good. Future experimental work in this price range and more emphasis will be placed on corrosion inhibiting primers such as zinc rich epoxies and low fire ceramics.

B. Hardboards; Coatings

Wood products (hardboards) are potentially the most cost-effective substrate materials available. To become viable candidates for this function, the deficiency of hygroscopic expansion must be overcome. Water absorption results in large dimensional changes (approximately 5×10^{-5} inches/inch/% RH) that result in warping and cell fracture as the hardboard expands. Over the 0% to 100% relative humidity range, the hardboard can expand by as much as 0.4% (see Figure 3).

A series of experiments were run to determine if the hardboard substrates could be "passivated" to humidity effects by coating the surfaces, coating the edges, or a combination of the two. Additionally, the idea of equilibrating the hardboard at a high humidity prior to fabrication was briefly investigated in order to examine the contraction (cell/potential compression) effects.

If the module is prepared with hardboard that has been equilibrated at 100% RH, then it is bound to lose moisture in the outdoor environment until it reaches the National average of 60% (providing that the coating supplied an efficient damping factor).

Initially, the effects of just coating the edges and/or the surfaces with polymer films was tried to determine the magnitude of the effect. Table 8 gives the results of this experimentation. The measurements indicate the change in weight with respect to the entire module weight (Column A) and percent change with respect to the weight of the hardboard only (Column B).

The least variation in weight changes was found for the specimens coated with stainless foil and aluminum foil due to their lack of water vapor transmission. In this case, moisture intrusion must have come through the edge

seal and gasket. In the best case (stainless foil) the overall variation over the test period was a total of 0.06% based on the weight of the hardboard alone. The linear expansion coefficient of the hardboard used ("Super Dorlux", Masonite Corporation) is approximately 0.04% per weight percent of absorbed water. Using this approximation, the overall variation of the foil laminated hardboard is in the order of 2.4×10^{-5} . Of the combinations of organic coatings examined, white 2.0 mil polyester 'Scotchpar 20CP - 3M Corporation) bonded with a pressure sensitive acrylic adhesive had the lowest overall variation of weight amounting to 0.35%. This calculates to a linear expansion of 14×10^{-5} , or approximately six times the expansion found with the foil coated specimens.

The uncoated control steadily gained weight and increased by 4.0% over the sixteen week exposure, corresponding to 0.16% linear expansion. This is almost four orders of magnitude more than the linear expansions observed in the foil coated boards.

These experiments have been preliminary attempts to get an idea of the potential effectiveness of using coatings of metals and polymers for the passivation of candidate hardboard substrates in an outdoor environment. The general conclusions are that this approach may be viable; however, a more expanded study will be required to generate practical recommendations for materials and techniques. The approach envisioned at this time is (1) determine the moisture vapor transmission (MVT) through candidate coatings by the ASTM "per cup" method, E-96, (2) determine the seasonal variation in relative humidity from climatic tables, (3) calculate the thickness of the coating required to "damp" out the humidity variations to maintain the hygroscopic expansions with intolerable limits, (4) prepare a cost analysis to determine cost/effectiveness, and (5) prepare test specimens for outdoor exposure to verify performance.

V. 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 properties 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 consists of low-iron glass, Tedlar fluorocarbon film (DuPont) and a 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.

A survey of coating materials showed that very few commercial materials exist that could be useful for this purpose and that experimental compounds may also have to be synthesized.

A series of antimigration coatings designated FC-721 and FC-723 are available from 3M Corporation and are claimed to have extremely low surface energies in the order of 11-12 dynes/cm. These compounds are based on a fluorinated acrylic polymer and are so effective in reducing surface tension that silicone oil beads up on the surface of glass treated with this material. The difficulty with these coatings is that they are very easily removed and have virtually no permanence on the surfaces attempted. They were, therefore, not used in the experimental soiling work and more durable candidates were selected.

A total of seven coatings/treatments were selected for soiling resistance evaluations, as follows:

1. L-1668, an experimental fluorochemical silane produced by 3M Corporation that is used to impart water and oil repellency 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, and 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.

5. Glass resin 650, produced by Owens-Illinois (commercially available).
6. SFC-1000, a silicone based hardcoat resin produced by General Electric (commercially available).
7. WL-81 acrylic resin produced by Rohm and Haas (commercially available).

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.^(a) 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 correlate 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} , at negligible voltage drop (high input impedance) when the soiling specimen is placed between the standard cell and the light source. This method was found to be the measurement of optical transmission with a spectrometer. Poor correlation with I_{SC} and %T resulted from large experimental errors due to difficulties with mounting the soiling specimen to the port of the spectrometer.

The results of one year of outdoor exposure are recorded in Tables 9A through 11B in the Appendix. The soiling data is given in two forms; the change in short circuit current, I_{SC} , using a standard cell (Tables -A) and percent change in the short circuit current with respect to the unexposed control measurement (Tables -B). Examination of the -B Tables reveals the general trends in soiling which are also presented in graphical form, Figures 4,5, and 6. Only the control and the three most effective treatments are graphed, for clarity.

a. Royal M6112 acrylic pressure sensitive adhesive-Uniroyal Chemical Co.

Observation of the data reveals that a fluctuating but generally increasing loss in power is found for all specimens. The degree of loss varies according to the type of surface treatment and the particular month of exposure.

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 ninth month (winter) showed a dramatic decrease in power in all cases. A constant differential was found between the control measurements and the two most effective coatings, as may be seen, Figure 4. The two most effective coatings were L-1668 and the E-3820 fluorosilane treatments. Both showed significant improvements over the control specimens, and after 12 months gave power loss values of -1.0% and -1.3% respectively. The uncoated control specimen lost -3.1% of power throughput. All the other coatings/treatments gave inferior performance to the control. The specimens may be ranked according to the average % power loss over the twelve month period as follows:

<u>Coating/Treatment</u>	<u>Mean Power Loss</u>
L-1668	-1.18%
E-3820	-1.58%
Control	-2.59%
OI-650	-3.27%
SHC-1000	-4.16%
WL-81	-4.24%

The Acrylar acrylic film formulations soiled much more severely than the Sunadex glass 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. After the twelfth month, the control value returned to a -7.8% power loss, with most of the treated specimens showing a 4 to 5% loss. The effectiveness of the coatings/treatments may be compared by ranking them according to the average power loss, as before. The results are as follows:

<u>Coating/Treatment</u>	<u>Mean Power Loss</u>
Ozone, E-3820	-3.07%
L-1668	-3.61%
E-3820	-3.69%
Ozone, L-1668	-4.03%
WL-81	-4.14%
OI-650	-4.39%
SHC-1000	-6.29%
Control	-6.35%

After the twelfth month, the treatment with the best final transmission resulted from the ozone treatment followed by E-3820. The results of the performance of the control and the three best coatings is displayed in Figure 5.

The third, and last, candidate outer surface to be investigated was Tedlar (100BG30UT), a transparent UV absorbing film of poly(vinyl fluoride) manufactured by DuPont. As with the Acrylar film, this material was mounted on glass squares with a pressure sensitive acrylic adhesive and deployed with the usual series of coatings/treatments. The overall performance of these specimens was better than the acrylar, but worse than the Sunadex glass. The control degraded steadily in power throughput reaching almost 9% loss in the tenth month and recovering to a total -6.5% loss by the twelfth month. All the coatings/treatments applied to the Tedlar were more efficient in retarding soil accumulation than the control. As with the previous two candidates, the fluorosilane treatments gave the best performance, the best being the E-3820 compound, which consistently gave a 4% to 5% improvement in performance over the exposure period and recovered to a loss of only 2.4% in the twelfth month measurement. Ranking the effectiveness of the coatings by mean power loss, as before:

<u>Coating/Treatment</u>	<u>Mean Power Loss</u>
E-3820	-1.70%
Ozone, L-1668	-3.17%
L-1668	-3.40%
Ozone, E-3820	-3.75%
WL-81	-4.00%
SHC-1000	-4.06%
Control	-5.06%
OI-650	-5.16%

The most severe soiling and consequent loss of power is seen in the eighth, ninth, and tenth months of exposure. These months were January, February, and March, during which period of time there was precipitation as snow, but virtually none as rain. All the specimens began to regain their transmission as the spring rains occurred in the eleventh and twelfth months (April and May). Increases were also seen earlier during the fourth month (September) in which there was also a large amount of rain (5.92"). Although even more rain occurred in the fifth month (October, 6.72") the specimens failed to regain much of their power transmission, and the overall values tend to decline after this point. (A Table of rainfall is included in the Appendix, Table 12). This may be due, in part, to the loss of surface treatment in some cases. In Acrylar, treatment with L-1668 appears to outperform the specimen that is treated with ozone + L-1668 for the first five months, and then becomes gradually worse. This may be due to gradual loss of the L-1668 treatment that is prevented by the chemical activation with ozone in the latter case. Weathering effects that alter the surface chemistry are also likely. All the specimens retrieved from the outdoor aging racks were found to have lost a good deal of their water repellency. When sprayed with a jet of distilled water, all the exposed surfaces showed wetting, even the Sunadex/L-1668 specimen. In contrast, freshly treated surfaces are conspicuously water repellent and water droplets bead up instantly. An attempt was made to determine the surface energy of the exposed specimens by the contact angle technique, employing liquids of varying surface tension, however difficulties were encountered with the measurements and no meaningful data resulted.

In addition to these surfaces and candidate treatments, specimens of glass and polymers coated with experimental liquid glasses developed at ICI/University of Delaware are also included in the test scheme. These include soda-lime glass and acrylic panels coated with chromium phosphate, iron phosphate and titanium dioxide film. One specimen of glass that was iron plated with magnesium fluoride was also put under test. These are more expensive coatings, due mainly to the application method, however they were considered to be worth trying. The results are given in Table 13. As may be seen, the surface treatments are less effective than the control. In a number of cases, discoloration of the specimen had occurred and the results were felt to be less significant than these previously reported. This series of exposures were terminated after seven months.

A new candidate outer surface has been included in the outdoor exposures. This material is a stabilized polyester film designated "Hostaphan" EH-723 (American Hoechst) and has been deployed with all the surface treatments of current interest.

In summary, low surface energy treatments based on fluorosilane chemistry appear to be effective in retarding the accumulation of dirt on the candidate outer surfaces of interest. The most effective soil retardant treatments identified to date are: for Sunadex glass, L-1668; for Acrylar, ozone activation followed by E-3820; and for Tedlar, treatment with E-3820.

After one year of outdoor exposure, the best treatments gave improvements of 2 1/2% to 4% in light throughput measured with a standard cell and light source. The removal of accumulated soil correlated well with rainfall but not with precipitation as snowfall.

The obvious visual difference in the wetting of exposed versus freshly prepared specimens indicates that the low surface tension treatments are prone to either chemical degradation or physical loss and may have to be replenished on a periodic basis. A maintenance schedule needs to be determined based on the cost of produced power gained by employing the coatings versus the cost of routine maintenance required for cleaning and recoating the surfaces. This study will be performed in the proceeding months of this program and the cost effectiveness of these approaches will be determined.

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VI. PRIMERS AND ADHESIVES

Adhesives, primers or some other mechanism are necessary for the high reliability bonding of the assembly components to one another in order to insure the structural integrity and long life performance of the module. The adhesion between the pottant and other components, i.e., substrate, superstrate and outer cover, was investigated in the past year and some encouraging results were obtained with the use of primers.

A primer operates by creating a reactive chemical interface between two components, whereas an adhesive is a discreet compound that constitutes a separate phase to which the two other components may bond. Primers have been emphasized in the bonding studies due to a number of advantages they present in use. Primers are (a) used in exceedingly small quantities, (b) are cost effective, are (c) easily applied to surfaces, (d) function by the formation of high strength chemical bonds, and (e) may possibly be combined into the pottant systems to eliminate the priming step.

Table 14 shows the results of adhesion bond strength evaluations of materials and primers investigated to date. The test specimens were prepared in a manner similar to that which would be encountered in a actual module fabrication. All substrate/superstrate specimens were evaluated by ASTM method D-903 for the peel or stripping strength of laminates, in which the polymer layer is pulled back off the substrate at a 180 degree angle. For flexible specimens, such as polymer bonded outer cover materials, ASTM method D-1867 ("T" - Peel) was employed. All values are reported as pounds of stress per inch of width of bond line. Specimens showing high control values were further tested after water immersion for two weeks and exposure to boiling water for periods of two hours.

The tables record the measured stress values at break, and are shown as separate tables for each of the pottants; EVA, EMA, polyurethane and butyl acrylate.

Primers that are effective for bonding EVA to almost all the other candidate surfaces have been identified, as may be seen on the chart. One extremely useful primer has recently been identified and added to the list. This primer is effective for bonding EVA to polyester film, one of the most difficult surfaces to prime. This primer, which was developed at Dow Corning, is a silane modified melamine compound which is thought to bond by forming an interpenetrating polymer network as well as chemical bonds. The ingredients of this formulation, designated 14719 (Springborn number), are as follows:

	<u>Parts</u>
. Dow Corning Z-6040 (glycidoxypropyltrimethoxy silane)	1.25
. Monsanto "Resimene 740" (melamine/formaldehyde resin)	23.75
. Isopropanol, anhydrous solvent	<u>75.00</u>
	100.00

The above mixture may be further diluted with more solvent, if desired. The mixture should be kept tightly closed and free of moisture and water contamination. This primer results in extremely high strength bonds when applied to polyester film with subsequent lamination and curing with EVA. Scotchpar 20CP white polyester film, a substrate back cover candidate, was swabbed with the mixture, allowed to dry for 10 minutes at room temperature and then compression molded with EVA 9918 at 150°C for 15 minutes. The test specimens gave peel strengths of 30 pounds per inch of width and survived two hours of boiling water with a bond strength of twenty pounds per inch.

Despite the similarities in cure chemistry, EMA is much more difficult to bond than the EVA. Primer formulations effective with EVA are sometimes only marginally useful with the EMA. To date, the only primer that has given good results with this potant is A11861, which gave excellent strength to Sunadex glass and good performance with mild steel.

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A number of new primers were evaluated for the adhesive bonding of the aliphatic urethane and the butyl acrylate (BA) syrup pottants. Neither of these pottants have any measurable bond strength to unprimed surfaces. Z6032W primer was effective with the butyl acrylate system and Tedlar film but only marginally effective with other surfaces such as polyester or Korad acrylic film. These materials may require surface activation or a different primer system. A recommendation from Dow Corning resulted in an excellent primer for bonding the BA pottant to glass. This primer, Springborn number 14588, consists of Dow Corning Z-6020 crosslinked with a small amount of ethyl silicate to hold it to the glass surface. This primer appears to work well and gives cohesive failure to glass, even after two weeks water immersion. Exposure to two hours of boiling water gives a bond strength of 1.4 lbs per inch of width, or about half the cohesive break strength. The bond strength of the butyl acrylate specimens is limited by the low tensile strength of the polymer, which appears to be approximately 3 lbs per inch width in optimally bonded specimens.

The most recent prototype urethane formulation from Development Associates, Z-2591, was used with Dow Corning Z-6020 primer with a variety of surfaces. Marginal bond strengths were found with Korad and Tedlar but excellent bonds resulted with Sunadex low iron glass. Values in excess of 30 lbs per inch of width were measured after the three conditions of control, boiling water immersion and room temperature water immersion. Development Associates has also recently supplied us with their own proprietary compositions, one air dry and one bake primer. These formulations were not found to be effective.

The identification of primers and/or adhesives for the high reliability of module components will continue until a recommendation can be made for each interface. Adhesion specimens will also be evaluated in a program of outdoor exposures to determine the long term weathering effects on bond stability.

VII. ACCELERATED AGING EXPERIMENTS

A. Methodology

The materials and designs selected for use in constructing solar cell modules 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 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 inaccurate.

Many degradation processes, including those that ultimately result in the failure of polymers are associated with thermal, chemical, mechanical, electrical, and radiation induced disruption of the chemical bonds. These stresses, either alone or in combination, can produce certain active chemical intermediates that may continue to react further with the polymer chain and result in macroscopic changes in the electrical, mechanical and optical properties of the material. In most polymers, the degradation mechanisms involve the stress-induced separation of electrons from the covalent bond that results in bond rupture and the formation of two free radical intermediates. These active free radicals may then propagate a series of reactions in which oxidation, discoloration, bond scission and loss of physical properties result.

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 many 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, however. Plastics vary considerably in their ultraviolet absorbing properties, but few are completely transparent in the 290 to 400 nm range. Once the radiant energy has been absorbed, the likelihood of chemical action will depend on the degree of absorption and the stability of the chemical bonds in the polymer. The induced chemical modifications are responsible for the deterioration of optical and mechanical properties and usually result in reductions of tensile strength, elongation and transparency.

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 to 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 often poor. 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) generating empirical and practical data relating to longevity, and (b) generating data that may be used in a scheme to predict properties as a function of exposure time and condition. If the resulting test data can be interpreted statistically, then plots of log property vs. temperature (Arrhenius) or log time vs. change in property (induction period) may provide quantitative information regarding formulation effectiveness and possibly life prediction analysis.

For the evaluation of individual materials and/or combinations of materials, seven types of exposure conditions are being used, as follows:

1. Outdoor aging: this is the simplest approach to accelerated aging when an exposure site is selected at which the environmental effects are the most severe and at which the polymer degrades most rapidly. To accomplish this, the selected sites, Arizona and Florida, have conditions of intense sunlight and sunlight plus high humidity. This method has been used extensively for the testing and rating of stabilized formulations and is valuable in that it simulates the actual use conditions of the candidate polymers. This approach has been widely used to establish regional acceleration factors and to provide reasonable estimates of the service life in specific localities.
2. Thermal Aging: this exposure involves the simple thermal aging of test specimens in a circulating air oven at varying times and temperatures. All the tests will be performed in sealed jars to prevent the abnormal loss of volatile stabilizers that is often encountered in forced air ovens and also to prevent cross-contamination of materials.^(a) Candidate encapsulation materials are being exposed at temperatures of 60°C, 80°C, 105°C and 130°C in atmospheres of both air and nitrogen. The first three of these temperatures are close to the worst case temperatures that may be expected for in modules mounted in open air (60°C), roof top mounted (80°C), and solar cell hot spotting (105°C). The highest temperature, 130°C, is being used to provide

a. This also represents the "hermetic" or non-breathable design of module in which additives are prevented from diffusing out.

an upper acceleration limit. Exposure in both air and nitrogen in the absence of light should also provide information concerning the inherent heat stability of compounds with and without oxidation reactions and without photo-induced reactions.

3. Outdoor Photothermal Aging racks (OPA): these are devices recently constructed at Springborn Laboratories that constitute a new approach to accelerated weathering. 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 OPA reactors, natural sunlight is used as the light source and the specimen temperature is increased. The OPA 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, 110°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.
4. Controlled Environment Reactors (CER): this is a device designed and constructed at JPL^a and subsequently provided to Springborn Laboratories. It consists of a circular test chamber utilizing a filtered medium pressure mercury arc lamp, optional heaters and a water spray nozzle. The chamber permits the acceleration of solar ultraviolet up to 30 suns in intensity while maintaining a temperature of the absorbing surface at 30°C to 60°C. It is operated at a 60°C specimen temperature with twenty-two hours of "on" time and 2 hours of distilled water spray in the dark.
5. RS/4 Sunlamp: this 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 ballasted by a tungsten filament. The assembly is mounted in an inert gas

a. E. Laue, A. Gupta, "Reactor for Simulation and Acceleration of Solar Ultraviolet Damage" JPL Document 5101-135, September 21, 1979

filled bulb with a reflective coating and a transmission cut off near 290 nm. The bulb is additionally filtered with a piece of pyrex (cut off 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°C.

6. RS/4 Sunlamp - Wet: this condition is identical to the previous description but with the addition of a twenty minute spray of distilled water once every two hours. The water reservoir is thermostated to 50°C so that there is no fluctuation of temperature during the spray cycle.
7. RS/4 - 85°C/85% R.H.: this condition is identical to that described in (5.) except that the operating temperature has been raised to 85°C to increase the severity of the condition and to simulate the highest temperature suspected to result from the rooftop mounted solar module under the highest isolation. The relative humidity has also been increased to 85% to further initiate chemical reactions that may result from atmospheric moisture.

For a general program of materials evaluation, the failure of the polymer should be based on those properties that are relevant to the particular service application. With respect to candidate encapsulation materials, four life-limiting classes of properties were selected for evaluation: physical, optical, electrical and corrosion. These general properties were used for the preparation of a universal chart for polymer aging studies and serves as a universal chart for recording exposure dates, control properties, exposure hours and aging test results (see Tables 15 thru 24). These charts will be used to monitor the results of all the exposure conditions under consideration. Most of the test conditions have been set up and are in operation, however only the RS/4 (50°C - Dry) and thermal aging will be reported.

B. RS/4 Exposures

Specimens of all the candidate potting, outer covers and back covers have been, or are continuing under RS/4 exposure at 50°C. Although the test periods in the past have varied, the current "pull" schedule is in multiples of 2,000 hours.

As a point of comparison, unstabilized polypropylene is physically degraded after approximately 160 hours and unstabilized low density polyethylene is degraded after approximately 450 hours of exposure. Outdoors, the degradation rates of these polymers varies according to their location. At Enfield, Connecticut, polypropylene with no stabilizers degrades to brittleness in approximately 8 months (5,700 hours) and low density polyethylene fails at about 18 months (12,000 hours). Areas where the sunlight is more intense, and there are fewer cloudy days, results in more rapid degradation. Exposure to higher temperatures is also significant; the degradation rate in polypropylene is almost doubled for every 10°C increase in temperature.

Due to the dependence variations in temperature and light exposure, the deterioration of plastics is also location dependent. Exposures in Mexico City have been found to be about twice the acceleration of the Enfield location.

Based on these actual outdoor lifetimes, approximate correlation factors can be calculated for RS/4 to outdoor weathering. In comparing RS/4 to Mexico City, for polypropylene the acceleration factor is approximately x18 and for polyethylene approximately x13. Although these acceleration factors provide a useful basis of comparison, it should be remembered that considerable variations may be found between different outdoor locations and/or simulated weathering conditions. Factors affecting the degradation rates include specimen thickness, spectral distribution, heat history, additives, temperature, polymerization catalyst impurities, etc. Due to the difference in degradation pathways, acceleration factors are also material dependent.

Another way in which an acceleration factor may be determined is by measuring the total energy in the ultraviolet range. Sunlight has approximately 4% of its total energy in the ultraviolet between the wavelengths of 295 nm and 400 nm. At air mass 1.5, with a total insolation of around $650 \text{ milliwatt/cm}^2$, the total ultraviolet energy received is in the order of 2.34 mw/cm^2 .^a Measurements of the RS/4 bulbs^b show that the integrated energy over the same wavelength range averages to 3.44 mw/cm^2 . This equals approx. 1.4 suns, however the

a. Brandhorst, "Terrestrial Photovoltaic Measurement Procedures" NASA TM 7370, 1977.

b. Estey, "Ultraviolet Spectra of Mercury Lamp" JPL-IOM [REDACTED] September 4, 1979.

RS/4 lamp is on continuously whereas the sun, averaged over the year, is equivalent to only 5 hours of exposure per day. This, then, results in an overall acceleration factor of 6.7 for the RS/4 sunlamp, excluding the effect of increased temperature (50°C). Equivalently, one 1 year of outdoor exposure is accomplished in approximately 1,300 hours of RS/4. If one uses the general rule that reaction rates double for every 10°C increase in temperature, then an additional factor of 2 to 2.5 may be used to correct for temperature.

This results in an overall acceleration factor of between 14 and 17, which is in accordance with the experimental data from the aging of a number of plastics.

The test results and control properties of candidate encapsulation materials exposed to RS/4 sunlamp are given in Tables 5 thru 16, and reports the results of recently terminated exposures as well as materials still under exposure. The properties evaluated include tensile strength at break, ultimate elongation, tensile modulus (extrapolated to zero strain) and two measurements, gel content and swell ratio, that are sensitive to changes in the crosslink density. Changes in optical properties are monitored by visual appearance, the ultraviolet cut-off wavelength and total optical transmission. No values are given for the total integrated transmission at this time due to a change in the type of equipment to be used for these measurements. Due to the fact that solar cells have a response in the near infrared, and extended range spectrometer will be used for these measurements and will be reported at a later time. There is no intention to examine dielectric or corrosion properties in the RS/4 condition at this time, consequently these values are not given.

The candidate pottants are discussed first. By far, the longest specimen exposure accumulated to date is a small piece of an EVA formulation designated A8910C (Table 15). This compound is a prototype of the now commercial A9918 EVA formulation and was started in July, 1979. It has accumulated 30,000 hours of RS/4 exposure with little change in properties. The specimen is still clear, although a faint yellow color has appeared, and total integrated optical transmission in the range of 400 to 750 nm still gives a value of 89%. The surface

is free from any signs of fracture or tackiness and the specimen is still easily flexible. The test results show that tensile strength and elongation at break have decreased slightly and that the gel content has dropped from 72% to 45%. The change in properties is not considered to be deleterious to the function of this compound as a solar module pottant. However, its high temperature creep resistance should be re-evaluated to determine if an acceptable level has been retained.

Following the obvious successful performance of this prototype EVA compound, a full set of specimens of the commercial A9918 formulation were placed under exposure (Table 16). The total accumulated exposure of this formulation reached 15,120 hours before an equipment malfunction (thermal override) degraded the remainder of specimens. At the end of the 15,120 hour exposure, the test results showed no change in the physical or optical properties and the compound appeared the same as the control specimens. These are excellent results for a transparent stabilized polyolefin. The base polymer, uncompounded Elvax 150 (DuPont), shows significant signs of degradation after only 500 hours of RS/4 and loses most of its tensile strength and surface hardness.

The second candidate lamination pottant is based on ethylene-methyl acrylate copolymer and was also exposed in its fully compounded and stabilized form as formulation number EMA 13439 (Table 17). This compound is continuing under exposure and to date has accumulated 7,600 hours. This material shows no significant change in tensile strength, however the modulus has decreased to 60% of control value, the ultimate elongation has increased by 20% and the swell ratio has doubled. These results indicate that there may be a decrease in the degree of cure (number of crosslinks) even though the gel content appears to be unaffected. These changes in properties are not considered to be deleterious to the use of this compound as a solar module pottant.

The candidate casting syrup pottants are also under RS/4 test evaluation, the first of which is an aliphatic urethane compound designated Z-2591 produced by Development Associates, Inc., N. Kingstown, Rhode Island (Table 18). This formulation contains a proprietary stabilizer system and prototypes of this formulation are claimed to have endured over six years of unprotected outdoor exposure with no loss of properties. Test specimens have so far endured 6,000 hours

of exposure with virtually no change in properties. The slight increase in tensile strength with time is probably due to residual curing reactions that slowly continue to postcure the compound. At the 6,000 hour mark the formation of a faint yellow color was noticed; however, the integrated transmission remains high at approximately 90%. This is excellent performance for a urethane compound, judging from previous testing of urethane compounds.

The second casting syrup pottant is an experimental poly(butyl acrylate) compound (BA 13870) developed jointly between Springborn Laboratories and JPL. The formulation contains a first-cut stabilizer system and crosslinking additives to generate the cure. Specimens of this formulation are continuing to be exposed and, to date, have accumulated 7,600 hours of time, (Table 19). The performance of these materials has also been very good and, except for uniformly lower tensile strength values, shows no significant signs of change. The specimens are still clear, colorless, flexible and have optical transmissions of approximately 89%.

In substrate designed modules in which no glass is used, outer cover materials are essential. Pottants, by nature, must be rubbery and low in surface hardness, consequently they have a strong tendency to accumulate soil. A transparent outer cover is necessary to provide a weatherable, cleanable, and hard surface for the top of the module. Four candidate outer cover materials have also been under RS/4 exposure for some time. The first is Tedlar 100BG30UT (DuPont) poly(vinyl fluoride) film of 1 mil thickness that also contains a UV screening agent and costs $5¢/ft^2/mil$. This film is aging well and has accumulated 15,200 hours of exposure to date (Table 20). Although there has been a decrease of 20% in its tensile strength, no other properties appear to be affected. The optical transmission is still found to be close to 90% (400-750 nm) and the slightly hazy (natural) film shows no other signs of change. The other Tedlar, type 4462 (Table 21) does not appear to be quite as stable. After 10,800 hours the elongation was found to be only 38% of the control value and the tensile strength had increased by 40%. This indicates that perhaps some crosslinking is occurring in the film.

Of the four outer covers being examined, the most cost effective of these candidates is Acrylar film (X-22417) from 3M Corporation, ($2.25¢/ft^2/mil$ of thickness) and is a biaxially oriented acrylic film intended for outdoor applications.

To date, this film has been exposed to 12,000 hours of RS/4 exposure with no major change in properties, except a decrease in strength at break (Table 22). A drop in tensile strength to 50% of control value was observed after the first 1,500 hours and was initially thought to be due to stress relaxation of the polymer at the exposure temperature (50°C). To verify this speculation, aged and unaged specimens were compared for molecular weight degradation by intrinsic viscosity measurements. The unaged Acrylar X-22417 had an intrinsic viscosity of 0.54 dl/gm or an approximate molecular weight of 116,000 (M_v). The aged specimens were found to have viscosity average molecular weights of 100,000 at 1,440 hours exposure and 94,800 after 12,000 hours exposure. Although there has been little change in the tensile strength since the drop in the first 1,000 hours, the results indicate a slow decrease in molecular weight subsequent to this time. Apart from this observation, no other change in properties could be noticed.

The last outer cover to be examined is Fluorex-A available from Rexham Corp., Matthews, North Carolina. This film is a polymer alloy of poly(methyl methacrylate) and poly(vinylidene fluoride) with a UV absorber also blended in. This material is very expensive, at a cost of approximately 18¢/ft²/mil of thickness and was initially selected as an alternative in the event that the other candidates did not perform well. The test specimens were extended as far as 8,640 hours exposure (Table 23) and appeared to perform well with the exception of the scattered points measured for ultimate elongation. Due to the superior performance of the Tedlar film and the high cost of this product, experiments with Fluorex-A will not be continued.

A new outer cover film candidate has been included in RS/4 and other aging studies. This material is designated "Hostaphan" EH-723 (American Hoechst) and is a polyester film containing a UV stabilizer system that is claimed to be non-fugitive. The use of primers and the construction of laboratory scale modules with this film has been successful, however no results of accelerated aging are yet available.

The last category of materials to be evaluated for RS/4 aging are the candidate back cover films. These films perform the function of providing a reflective back surface for superstrate designed modules that aid in heat dissipation and

also additionally provide environmental protection to the back layer of pot-tant. Three candidates were selected; Scotchpar 20CP-white (3M Corp.), Tedlar 150BS30WH (DuPont), and Korad 63000 (Xcel-Georgia Pacific Corp.), Tables 24, 25, and 26, respectively. All these candidates have endured 8,000 hours of exposure to date and show no major change in any property.

RS/4 has proven to be a useful tool for determination of the relative stabilities of polymeric materials and assessing the efficiency of stabilizing additives and other compounding approaches. The difficulty encountered in the current program is that the candidate encapsulation materials are so stable that extremely long times are required before failure points result that may be used for the comparison of materials and formulations.

The more rigorous conditions that will be imposed in some of the other accelerated tests, such as CER and RS/4-85°C, should overcome this problem and provide methods for materials stability evaluations in shorter time frames.

The specimens currently under test will continue until signs of degradation become apparent and new compounds will be added to each test condition as new candidates and formulations are identified.

C. Thermal Aging

Heat aging is one of the simplest accelerated tests for determining polymer stability and the effectiveness of formulations in resins intended for service at elevated temperatures. Specimens of the candidate compounds are heated at known temperatures for known periods of time and examined for appearance, mechanical properties, chemical composition, etc. Other indications of the stability of the composition may be drawn from measurements of plasticity, solution viscosity and the formation of insoluble gel or the loss of cure in vulcanized systems.

Although this method is simple in concept and easy to implement there are certain potential sources of error that should be considered prior to running the tests. For example, forced air ovens may result in an abnormally rapid rate of loss of the antioxidants and other compounding ingredients. Even stabilizers of reasonably high molecular weight are subject to loss by

evaporation and continual extraction by the air stream. The transfer of stabilizers and other ingredients between different polymer specimens also present a problem. One additive contaminating a commonly shared oven may tend to destabilize another polymer and result in a distorted test result. Although the changes in polymer properties may be studied by accelerated aging tests at high temperatures, the correlation with performance at use temperatures is often inaccurate. Changes in the degrees of chain scission to crosslinking at different temperatures and oxygen concentrations make it difficult to use high temperature data to predict performance at lower temperatures. For this reason, it is desirable to heat age the resins under test conditions that are close to the expected service conditions. Over narrow temperature ranges where the degradation rates at different temperatures may be plotted in a linear fashion with reasonable accuracy.

Two general types of thermal degradation may take place in the polymer systems of interest; (a) thermal oxidation, in which a chemical reaction occurs between the polymer and oxygen in the atmosphere, and thermolysis, in which the energy provided by heating causes a change in the chemical structure of the resin by itself.

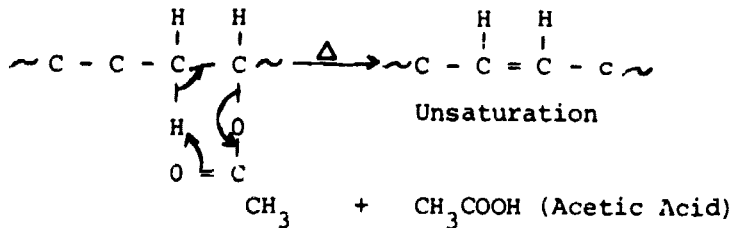
In the thermal aging tests at Springborn, the encapsulation test specimens are aged in sealed jars to prevent loss of stabilizer, cross contamination of compounds, and also to provide aging in atmospheres of both air and nitrogen. An individual set of specimens is evaluated for each condition so that inconsistencies in rate do not occur from allowing an entire set of aging specimens to cool to room temperature before being returned to the elevated temperature. The results of the testing are given in tables 27 through 44, using the universal form that was also used for RS/4 data previously presented.

The results are given for the first 400 hours of aging at temperatures of 80°C, 105°C and 130°C in both air and nitrogen. Three polyesters have been examined to date; EVA, EMA and the polyurethane (Z-2591).

The EVA compound, A9918, is the first to be tested (Tables 27 thru 44). For temperatures of 80°C and 105°C, the properties of the EVA appear to be essentially unchanged after the 400 hour exposure time. A slight increase in tensile strength and a decrease in solvent swell ratio seems to happen in all cases.

This suggests that residual cure reaction may still be taking place due to remaining peroxide activity although this reaction is not usually observed at temperatures in this range. The only notable effect at these temperatures is the reaction with metallic copper. At the 400 hour point, at 80°C and 100 hours at 105°C, slight reaction with metallic copper may be noticed as a faint yellow color appearing around the edges of the metal strip. This effect is typical of polyolefins in general and the wire and cable industry has used "metal deactivators" in polyethylene insulation for many years to inhibit copper reaction. The faint discoloration observed in the EVA specimen is not thought to be detrimental to the performance of the potant at these temperatures, however observations of this phenomenon will be made up to the 3,000 hour mark, as indicated on the test chart. No color reaction was noticed with the other encapsulated metals, aluminum and solder (60/40).

At 130°C, changes in EVA become more noticable. The physical properties, such as tensile strength, elongation and modulus, have not changed appreciably after 400 hours exposure, however a yellow color can be noticed. This is due to a well documented reaction in EVA which is based on simple thermal degradation (thermolysis), the chemistry of which is represented as follows:



The thermal energy imparted to the molecule results in the cleavage of the acetate group and the abstraction of a hydrogen atom from the polymer backbone to yield acetic acid. This results in the formation of double bonds in the resin that (when conjugated) gives rise to the yellow color. This reaction has been shown to be approximately first order with respect to the liberation of acetic acid and has an activation energy of 30 - 40 kcal/mole. The formation of coloration at this temperature is not felt to be detrimental to the use of EVA as a potant material, as the 130°C is well beyond the range of solar module operation. In a previous report, Springborn Laboratories reported on specimens of EVA that had been thermal aged for over 7,000 hours at 90°C with no formation of color or degradation in physical properties.

At the 130°C temperature the major antagonistic reaction is that with metallic copper. In as little as 25 hours coloration and flow may be noticed in the area where the EVA comes in contact with metallic copper. The effect is more pronounced in air (compare Tables 31 and 32) than in nitrogen. This is consistent with the theory that the metal-discoloration reaction involves a hydroperoxide intermediate that will form in the presence of oxygen.

All the experiments concerning the thermal aging of EVA will be continued out, at least to the 3,000 hour mark, and a subsequent report will give additional details such as the total integrated transmission, dielectric strength and the reaction with copper dust (monitored by optical transmission).

EMA, commercial formulation 13439, was the next material examined by the thermal aging and is reported in Tables 33 through 38. This compound appears to be stable throughout the 80°C and 105°C exposures with respect to its mechanical properties, however an increase in solvent swell ratio and a decrease in gel content suggest that some scission of the crosslinks may gradually be taking place. However, this effect will be verified as the exposure is continued. As with the EVA, the main effect noticed in EMA is that of copper metal reaction, again more noticeable in the presence of air than nitrogen. After 400 hours at 105°C in air, the specimen molded around a strip of copper had a strong yellow color and showed signs of degradation (blistering, separation from the metal, flow). This effect is typical for polymers at high temperature and isolation from copper is a requirement. No reaction was noticed in contact with aluminum or 60/40 lead/tin solder. In future experiments nickel, titanium and silver will also be included in the temperature-metal corrosion tests.

The 130°C condition also resulted in the formation of coloration in the EMA specimens. Although no acetic acid is produced, a similar reaction involving the cleavage of the acrylic ester group is likely, as the C-O bond is less stable than the C-C bonds in the backbone of the resin. This is a high

temperature for polyolefin copolymer service and considerably above the maximum module operating temperatures expected in field services.

The aliphatic polyurethane, Z-2591, was comparatively the most thermally sensitive of the three candidate pottants tested to date. Even at 80°C the development of a small amount of yellow color (although faint) was noticeable at the 400 hour point. The 105°C condition brought more noticeable changes in property. The tensile strength and modulus were found to steadily decrease to about 40% of control, but only in the nitrogen atmosphere, the air exposed samples remaining unchanged. The major material change at this temperature was the formation of coloration. After 400 hours, in both air and nitrogen, the test specimens had developed a strong yellow-brown color and the surfaces exposed to air had become sticky, indicating chain scission. The reactions with copper metal at 105°C were intense and at the 400 hour mark the corrosion specimens were found to have degraded with melting and dark brown coloration. The specimens had to be scrapped off the bottom of the test container to be retrieved.

The 130°C exposure was by far the most severe. The physical integrity of the test specimens lasted to the 100 hour mark, however at 400 hours the tensile bars had all melted to amorphous masses of dark brown sticky resin. Coloration developed within the first 25 hours and became dark within 100 hours. The reaction with copper resulted in melting and degradation of the resin with the first 25 hour period. No reaction between the urethane and other metals, aluminum or solder, was detectable at any of the test times or temperatures.

In conclusion, the polyolefin based pottants, EVA and EMA, are considered to have good thermal stability over the times and temperatures explored so far. The polyurethane is more questionable. The formation of color in this compound at temperatures as low as 80°C could possibly place a limitation on its use in solar module applications. All the pottants remain to be evaluated for performance over long periods of time. One conspicuous result of the thermal aging work is the adverse reaction with copper. It is felt that in no circumstances should the pottant compound contact metallic copper, as signs of "corrosion" are noticed in almost all cases.

VIII. SUPPORTING ACTIVITIES

During the past year, Springborn Laboratories has engaged in other activities in support of the FSA effort administered by JPL. Arrangements were made to provide two other contractors with experimental test modules fabricated within materials and techniques designed to evaluate a particular facet of PV module operation.

A. Science Applications, Inc.

Science Applications, Inc. (SAI) has invested considerable effort in the development of light trapping technology and, as a result, holds the United States Patent No. 4,246,042 "Fixed Solar Energy Concentrator" for light trapping techniques. Because of the importance of using light trapping techniques in the design of solar PV panels, JPL funded a study at SAI to investigate the cost benefits of light trapping used in PV modules under an agreement that SAI's patent rights would not be affected.

Three pairs of Springborn Laboratories' 12 inch by 16 inch modules were prepared for this study. One module (the control module) of each pair used the "standard" design. The other module of each pair employed design modifications, only to the degree needed, to incorporate desired light trapping features. The two modules of each pair were then used side-by-side under natural sunlight or a test source to demonstrate the benefits of light trapping in terms of potential module costs and the amount of silicon required to provide a given panel energy output. Two cell configurations were used, the Solar Power Corporation 100 mm diameter silicon photovoltaic solar cell and the 75 mm half cell. Pairs of modules include:

- . One pair using 100 mm diameter cells; the packing fraction of light trapping module is anticipated to be 0.75.
- . One pair using 75 mm diameter half cells, packing fraction of light trapping module is anticipated to be ~ 0.50 .
- . One pair using 75 mm diameter half cells, packing fraction of light trapping module is anticipated to be ~ 0.25 .

Design details for each pair of modules include:

- . Maximum and minimum performance tolerances of the solar cells to be used with both modules.
- . The relative location and the physical and material definition of the several layers (back cover, spacers, potants, substrate and/or superstrate, and the edge seal and gasket) that make up the modules.
- . Type and application of diffuse reflective coating at the bottom of substrate and on cell (top-surface) metallization.
- . Individual cell interconnections.

Side-by-side tests will be conducted in sunlight and under a test source. The panels' performances will be evaluated and compared under conditions of no load, short circuit, and peak power tracking for typical operational sun angles. The relative contributions of direct and scattered sunlight to panel output will also be evaluated. Test results will be made available to JPL.

B. Clemson University

Clemson University has a contract with JPL for the accelerated stress testing of encapsulated silicon solar cells. The accelerated stress tests include bias-temperature tests, bias-temperature-humidity tests, thermal cycle testing, thermal shock testing, and power cycle tests. The encapsulated cells are characterized prior to stress exposure and at periodic down times using electrical measurement techniques, visual inspection and metal adhesion tests. The electrical parameters being measured include short circuit current, open circuit voltage, and current at the maximum power point. Data is also obtained on the cell series and shunt resistances.

Springborn Laboratories has assisted Clemson University by manufacturing encapsulated cell test modules for this program. The modules supplied to Clemson consist of 5" x 9-1/2" modules containing from one to three cells. Silicon solar cells were obtained from nine manufacturers and used in the construction of over one 100 test modules using five different encapsulation schemes. The encapsulation systems used were as follows:

- Type 2 - Soda lime glass/EVA/cells/EVA/Tedlar 150BL30WH
- Type 3 - Soda-lime glass/EMA/cells/EMA/Tedlar 150BL30WH
- Type 5 - Soda-lime glass/EVA/cells/EVA/soda-lime glass
- Type 6 - Soda-lime glass/EVA/cells/EVA/aluminum foil (1.5 mil)
- Type 7 - Tedlar 100BG30UT/EVA/cells/EVA/mild steel substrate
laminated with EVA and Scotchpar 20 CP white polyester
film to yield a corrosion proof steel.

Clemson University is in the process of exposing these modules to the stress conditions previously described and is determining the response to these stresses for each cell type and encapsulation system. The results of this work will yield data concerning failure probabilities and be useful in establishing reliability and qualification test protocols.

IX. CONCLUSIONS AND RECOMMENDATIONS

1. The new aliphatic peroxide, Lupersol TBEC (Lucidol Division, Pennwalt Corporation) has been found to be much more effective curing agent than the commercially used Lupersol 101 in both the EVA and EMA candidate pottant systems of interest. This new compound permits the cure temperature to be lowered in both these resins, results in faster cure, may be found to be less prone to volatile losses, and gives higher gel contents than previously achieved. The advantages to the use of this new curing agent are lower temperature operation, faster cure and consequently higher throughput, higher cure reliability and wider cure latitude. Future work should definitely emphasize this peroxide as a replacement for Lupersol 101.
2. In addition to the lamination type of pottant, candidates for the liquid casting process have also been researched. One class of compounds, aliphatic polyurethane have been investigated for this purpose. After contacting a number of industrial suppliers and formulating a product with the required properties, a candidate pottant is now ready for this type of encapsulation scheme. The urethane is a two part system designated Z-2591 and is available from Development Associates, Inc., North Kingstown, Rhode Island. The system features low viscosity, low color, rapid cure time and surprisingly high resistance to ultra-violet light. The cost for the mixed system is in the order of \$3.00 per pound and commercial quantities are available.
3. Mild steel is an attractive substrate candidate due to its cost to deflection resistance ratio. The steel is produced in sheet form and has the potential to be shaped and formed with integral ribs to further enhance its mechanical rigidity. The deficiency with mild steel is its poor resistance to corrosion in an outdoor environment. Costings to inhibit or prevent rusting of mild steel are being selected and evaluated by outdoor exposure and 35°C salt fog testing. To date, several coatings have been discovered that appear to be effective and have prevented any observable attack to the steel after 5,000 hours of

salt spray (unscrubbed). To date, the best coatings appear to be combinations of EVA lamination pottant with a polyester film topcoat and EVA modified with a zinc chromate containing primer. This approach is too expensive to be practical, however it serves to demonstrate the concept of using laminated films and the effectiveness of chromate modification. Thinner films of less expensive resin may still be a cost effective technique.

The most promising coatings discovered to date are based on silicone modified polyester chemistry and a bakeable fluorocarbon maintenance coating. These materials have survived over 4,000 hours so far with no signs of deterioration, and cost in the order of \$3.00 to \$3.50 per square meter (including steel cost) for both sides coated. Coating materials such as these should result in a weathered mild steel based substrate well within the maximum cost limit of \$7.00/m². Future work will identify, evaluate and report on further work with these and other candidates.

4. The results of testing soil resistant surface treatments show that the most effective treatments are based on fluorocarbon chemistry, however these compounds appear to be slowly lost as outdoor exposure time increases. More development is required in the area of permanence of these treatments to maintain the effectiveness for longer periods of time. This approach could also benefit from an extended structure-activity correlation to generate compounds that reduce the surface energy to the practical minimum.
5. The polyolefin based pottants, EVA and EMA, are considered to have good thermal stability over the time and temperatures explored so far. The polyurethane is more questionable. The formation of color in this compound at temperatures as low as 80°C could possibly place a limitation on its use in solar module applications. All the pottants remain to be evaluated for performance over long periods of time. One conspicuous result of the thermal aging work is the adverse reaction with copper. It is felt that in no circumstances should the pottant compound contact metallic copper, as signs of "corrosion" are noticed in almost all cases.

A P P E N D I X - A

Tables 1 - 44

Figures 1 - 6

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TABLE 1

Advanced Cure Studies: EVA

Time/Temperature/Gel Profile

EVA Formulation With Lupersol 331-80B
(Compound No. 14745-2)

<u>Time</u> <u>Minutes:</u>	<u>110°C</u>	<u>120°C</u>	<u>130°C</u>	<u>140°C</u>	<u>150°C</u>	<u>160°C</u>
2					79.5	84.5
5				88.8	86.9	88.7
10	0	68.2	84.2	89.3	88.0	87.6
15	0	80.4	87.4	92.4	88.9	
30	0	78.5	92.0	89.9		

EVA Formulation With Lupersol TBEC
(Compound No. 15259)

<u>Time</u> <u>Minutes:</u>	<u>110°C</u>	<u>120°C</u>	<u>130°C</u>	<u>140°C</u>	<u>150°C</u>	<u>160°C</u>
2			0	73.4	81.5	84.2
5			60.3	83.7	88.6	91.0
10	0	0	75.0	88.2	91.6	92.3
15	0	0	85.0	90.2	93.5	
30	0	65.0	82.7	92.2	92.6	

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TABLE 1- (Continued 2)
Advanced Cure Studies: EVA

Time/Temperature/Gel Profile

Standard EVA A9918 Formulation, for Comparison
(Lupersol 101)

<u>Time</u> <u>Minutes:</u>	<u>110°C</u>	<u>120°C</u>	<u>130°C</u>	<u>140°C</u>	<u>150°C</u>	<u>160°C</u>
2				1.0	4.1	29.5
5			0	11.8	21.1	73.0
10	0	0	1.0	23.5	63.2	82.6
15	0	0	2.3	59.3	88.3	
30	0	0	3.4	68.2		

EVA Formulation With Lupersol D-S606
(Compound No. 15267-A)

<u>Time</u> <u>Minutes:</u>	<u>110°C</u>	<u>120°C</u>	<u>130°C</u>	<u>140°C</u>	<u>150°C</u>	<u>160°C</u>
2					0	-
5				0	18.9	-
10	-	-	0	15.4	42.4	-
15	-	0	0	32.0	69.2	
30	-	0	0	40.0		

Advanced Cure Studies: EVA

Time/Temperature/Gel Profile

EVA Formulation With Lupersol-99
(Compound No. 14745-1)

<u>Time</u> <u>Minutes:</u>	<u>110°C</u>	<u>120°C</u>	<u>130°C</u>	<u>140°C</u>	<u>150°C</u>	<u>160°C</u>
2					low	75.2
5				low	70.7	79.0
10	0	low	low	72.2	77.7	79.9
15	0	8.1	69.5	74.9	78.4	
30	low	76.1	82.1	77.7	79.9	

TABLE 2

ORIGINAL PAGE IS
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(Compound No. 15268-B)

<u>Time Minutes:</u>	<u>120°C</u>	<u>130°C</u>	<u>140°C</u>	<u>150°C</u>
2				0
5			0	0
10	0	0	0	19.4
15	0	0	low	22.0
30	0	0	10.0	28.0

EMA Formulation With Lupersol 331-80B

(Compound No. 15257-B)

<u>Time Minutes:</u>	<u>120°C</u>	<u>130°C</u>	<u>140°C</u>	<u>150°C</u>
2				7.3
5		0	0	52.6
10	-	43.8	49.8	56.7
15	-	70.1	53.0	55.7
30	-	70.0	59.9	59.6

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TABLE 2 -(Continued 2)

Advanced Cure Studies: EMA

Time/Temperature/Gel Profile

EMA Formulation With Lupersol-99

(Compound No. 15257-B)

<u>Time Minutes:</u>	<u>120°C</u>	<u>130°C</u>	<u>140°C</u>	<u>150°C</u>
2			0	0
5		0	0	53.4
10	0	v. low	36.8	57.8
15	0	v. low	61.6	51.7
30	v. low	57.3	51.1	51.6

EMA Formulation With Lupersol TBEC

(Compound No. 15257-C)

<u>Time Minutes:</u>	<u>120°C</u>	<u>130°C</u>	<u>140°C</u>	<u>150°C</u>
2			0	69.3
5		0	53.2	68.8
10	0	26.3	51.6	74.0
15	0	40.7	54.2	71.3
20	low	46.3	59.6	71.3
30	15.0	52.8	63.2	72.4

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TABLE 2 - (Continued 3)

Advanced Cure Studies: FMA

Time/ Temperature/Gel Profile

Standard EMA Formulation No. A-13439, for Comparison

(Lupersol 101)

<u>Cure Time</u>	<u>120°C</u>	<u>130°C</u>	<u>140°C</u>	<u>150°C</u>	<u>160°C</u>
2 minutes					9.5
5 minutes					21.5
10 minutes				0	48.6
20 minutes			0	37.0	48.6
30 minutes	0	low gel	53.0		
40 minutes	low gel	34.0	63.0		
60 minutes	low gel	47.0	65.0		

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TABLE 3

CANDIDATE URETHANE POTTFANTS

Provided by Development Associates, Inc.

	<u>Z-2211</u>	<u>Z-2341</u>	<u>Z-2351</u>	<u>Z-2451</u>	<u>Z-2391</u>	<u>Z-2481</u>	<u>Z-2591</u>
Tensile strength (a) ASTM D-638, 25°C	3,600 psi	1,160 psi	2,750 psi	152 psi	215 psi	2,770 psi	160 psi
Ultimate elongation (a) ASTM D-638, 25°C	200%	208%	200%	62%	147%	49%	115%
Modulus, Young's or tangent (b) ASTM D-638, 25°C	2,450 psi	611 psi	635 psi	362 psi	142 psi	14 x 10 ⁵ psi	254 psi
Gel time (c): 25°C (mixed) 30°C	15 min 7 min	12 min 4 min	12 min 4 min	10 min 3 min	15 min 3 min	20 min 8 min	20 min 10 min
Brookfield Viscosity: Mixed, 25°C, RVT #2 50 rpm	approx. 500 cps	approx. 175 cps	approx. 165 cps	approx. 150 cps	approx. 150 cps	approx. 400 cps	approx. 250 cps
Cure rate, 65°C	-	5 min	5 min	5 min	5 min	5 min	-
Hardness: Shore A, 23°C	(Shore D) 60	65-75	65-75	45	45	65	45
Specific Gravity, 25°C	1.07	1.04	1.04	1.04	1.04	1.04	1.03
Total integrated transmission: ASTM E-424-A	91%	90.4%	88.7%	--	89.1%	--	90.2%
UV cutoff wavelength:	350 nm	360 nm	350 nm	--	--	--	360 nm
Glass transition temperature:	+12°C	-10°C	-4°C	-30°C	-31°C	-6°C	-23°C

(a) Crosshead speed, 10"/min

(b) Crosshead speed, 0.1"/min, measured at 1% strain

(c) Gel time may be controlled by catalyst concentration

TABLE 4

Corrosion Results

Coatings on: Mild Steel Cold Rolled, 60 mil

Notebook No.	Test Specimens Materials	Adhesive/Primer	Corrosion Conditions ASTM B-117 Salt Spray (Hours)							
			200	500	900	1500	2000	2500		
14304-1	X-22417 Acrylic film	3M 4910	II,b	II,3,c	II,3,c	III,4,c				
14304-2	Scotchpar 20CP-white	3M 4910	II,b	II,3,c,g	II,3,c,g	III,3,c,g				
14304-3	1.5 mil Aluminum foil	3M 4910	II,3,f,g	II,3,f,g	III,4,f,g	R				
14304-4	Korad 63000 white	3M 4910	I	II,a	II,a	II,b	II,c			R
14304-5	EVA 9918	All861	I	II,1	II,5	III,4				
14576-6	Korad X212-R	3M 4910	I	II,2,c	II,2,c	III,4,d				
14576-7	Acmitite	3M 4910	I	II,e	II,e	II,e	III,4,c			R
14576-8	Tedlar 200BS30WH	3M 4910	I	II,b	II,c	II,c	III,4,d			R
14576-9	Stainless steel 302	3M 4910	I	II,e	II,e	II,f	III,f			R
14576-10	EVA 9918/Scotchpar 20 CPW	All861/107D	I	I	I	I				I
14576-11	EVA 9918/Stainless 302	All861/All861	I	II,f	II,f	II,f	III,f			R
14576-12	EVA 9918/Tedlar 100BG30	All861/107D	I	II,2	II,2	II,2	III,3			R
14576-13	Scotchclad XB-5863	None	I	II,e	II,3,b	III,4,c	R			
14591-14	EVA 9918 (zinc chromate)	14590	I	I	I	I				
14701-15	5M932377 Fluorocarbon	3305 Epoxy	I	I	I	I				
14713-16	Dextar 75X102	9X165 Epoxy	I	I	I					
14713-17	DXD-889 Acrylic	9X165 Epoxy	I	I	I					
14746-19B	Mild Steel, 60 mil	Control	III-R (3 hrs.)							

TABLE 4 (Continued)

Corrosion Results

Coatings on: Mild Steel Cold Rolled, 60 mil

Notebook No.	Test Specimens Materials	Adhesive/Primer	Salt Spray		ASTM B-117	
			Hours	Condition	Hours	Condition
14576-10	EVA 9918/Scotchpar 20CP	All861/106	4,500	I	5,500	II,9
14591-14	EVA 9918 + Zinc Chromate	14590	4,000	II,e	5,000	III,4,abg
14701-1	5MM932377 Fluorocarbon	Epoxy 3305	3,100	III,4,a	4,500	III,4,afg
14713-16	Dextar 75 x 102	Epoxy 9 x 165	3,100	II,2,a	4,000	II,2,ag
14713-17	DXD-889 Acrylic	Epoxy 9 x 165	3,100	III,ag	4,000	III,3,ag

Date: 3/24/82

5/2/82

TABLE 5

Corrosion Results

Coatings on: Mild Steel Cold Rolled, 60 mil

Notebook No.	Test Specimens Materials	Adhesive/ Primer	Corrosion Conditions						
			Outdoors: Enfield, Conn. (Hours)						
			200	500	900	1500	2000	2500	
14304-1	X-22417 Acrylic film	3M 4910	I	I	II,2	II,2	II,2	II,2	II,2
14304-2	Scotchpar 20CP-white	3M 4910	I	I	II,b	II,b	II,b	II,b	II,b
14304-3	1.5 mil Aluminum foil	3M 4910	I	I	I	I	I	I	I
14304-4	Korad 63000 white	3M 4910	I	II,e	II,e,b	II,e,b	II,e,b	II,e,b	II,e,b
14304-5	EVA 9918	A11861	I	I	II,2	II,2	II,2	II,2	II,2
14576-6	Korad X212-R	3M 4910	II,2	III,4	III,4	III,4,c	R	-	-
14576-7	Acmite	3M 4910	I	I	I	I	I	I	I
14576-8	Tedlar 200BS30WH	3M 4910	I	I	I	I	I	I	I
14576-9	Stainless steel 302	3M 4910	I	I	II,e	II,e	II,e	II,e	II,e
14576-10	EVA 9918/Scotchpar 20 CPW	A11861/107D	I	I	I	I	I	I	I
14576-11	EVA 9918, Stainless 302	A11861/A11861	I	I	II,e	II,e	II,e	II,e	II,e
14576-12	EVA 9918/Tedlar 100BG30	A11861/107D	I	I	I	I	II,e	II,e	II,e
14576-13	Scotchclad XB-5863	6020	II,2,f	II,2,f	II,2,f	II,2,f	II,3,f	II,3,f	II,3,f
14591-14	EVA 9918 (Zinc Chromate)	14590	I	I	I	I	I	I	-
14701-15	5MW932377 Fluorocarbon	3305 Epoxy	I	I	I	I	I	I	-
14713-16	Dextar 75X102	9X165 Epoxy	I	I	I	I	I	I	-
14713-17	DXD-889 Acrylic	9X165 Epoxy	I	I	I	-	-	-	-
14746-19A	Mild Steel, 60 mil	Control	II,2	III-R					

TABLE 5 - Continued

Corrosion Results

Coatings on: Mild Steel Cold Rolled, 60 mil

Notebook No.	Test Specimens Materials	Adhesive/Primer	Corrosion Conditions					
			Outdoors: Enfield			Conn. (Hours)		
			Hours	Condition	Hours	Condition	Condition	
14304-1	X-22417 Acrylic film	3M 4910	4,500	II, 3,b	5,500	III, 4, bf		
14304-2	Scotchpar 20CP-white	3M 4910	4,500	II, b	5,500	II, b		
14304-3	1.5 mil Aluminum foil	3M 4910	4,500	I	5,500	I		
14304-4	Korad 63000 white	3M 4910	4,500	II, be	5,500	II,abe		
14304-5	EVA 9918	A11861	4,500	II, 1,2	5,500	II,1,2		
14576-6	Korad X212-R	3M 4910	R	R	R	R		
14576-7	Acmitite	3M 4910	4,500	I	5,500	II,1		
14576-8	Tedlar 200BS30WH	3M 4910	4,500	I	5,500	I		
14576-9	Stainless steel 302	3M 4910	4,500	II,e	5,500	II,2,e		
14576-10	EVA 9918/Scotchpar 20 CPW	A11861/107D	4,500	I	5,500	I		
14576-11	EVA 9918/Stainless 302	A11861/A11861	4,500	II,e	5,500	II,e		
14576-12	EVA 9918/Tedlar 100BG30	A11861/107D	4,500	II,e	5,500	II,2,e		
14576-13	Scotchpad XB-5863	6C20	4,500	II,a,f	5,500	III, 1,3,aef		
14591-14	EVA 9918 (Zinc Chromate)	14590	4,000	II,2,e	5,000	II, 2,e		
14701-15	5M932377 Fluorocarbon	3305 Epoxy	3,500	II,2,a	4,500	II, 2,a		
14713-16	Dextar 75X102	9X165 Epoxy	3,100	II,2,a	4,000	II,2,a		
14713-17	DXD-889 Acrylic	9X165 Epoxy	3,100	II,2,a	4,000	II,2,a		

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Table 6

CORROSION MONITORING

Key:

Specimen Condition

- I. No observable change
- II. Some signs of deterioration
- III. Noticeable deterioration
- R. Removed from further testing:
specimen deteriorating badly

Steel Condition

- 1. Dulling of surface
- 2. Light corrosion visible (scattered spots)
- 3. Medium corrosion visible (10% of surface)
- 4. Extensive corrosion visible (over 25% of surface)

Coating Condition

- a. Blistering
- b. Slight delamination
- c. Medium delamination
- d. Complete delamination
- e. Coating discoloring, some surface attack
- f. Coating degrading/corroding
- g. Failure of sealant/gasket

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Table 7
CORROSION PROTECTIVE TREATMENTS: COSTING

AL3

Notebook Number :	14304-1	14304-2	14304-3	14304-4	14304-5	
Steel Type :	mild	mild	mild	mild	mild	
Manufacturer						
Thickness, mils	28	28	28	28	28	
Cost, \$/m²	\$2.70	\$2.70	\$2.70	\$2.70	\$2.70	
Surface Treatment						
Type :						
Chemistry						
Cost, \$/m²						
Primer Treatment						
Designation	4910	4910	4910	4910	Al1861	
Manufacturer	3M	3M	3M	3M	Springborn	
Chemistry	acrylic	acrylic	acrylic	acrylic	silane	
Application method	3	3	3	3	1	
Cost, \$/m²	\$2.60	\$2.60	\$2.60	\$2.60	\$0.20	
Bake temp., °C	none	none	none	none	(air)	
Bake time, min.	-	-	-	-	-	
Bake cost, \$/m²	0	0	0	0	0	
Top Coat (first)	Acrylar	Scotchpar	Foil	Korad	EVA (a)	
Designation	X-22417	20CP-white	Aluminum	63000	A9918	
Manufacturer	3M	3M	Reynolds	excel	Springborn	
Chemistry	acrylic	polyester	metal	acrylic	olefin	
Thickness, mils	3.0	2.0	1.5	1.5	18	
Application method	roll	roll	roll	roll	vacuum bag	
Cost, \$/m²	\$1.46	\$1.10	\$0.76	\$1.26	\$7.40	
Bake temp., °C	none	none	none	none	150°C	
Bake time, min.	none	none	none	none	20 min.	
Bake cost, \$/m²	0	0	0	0	\$0.01	
Top Coat (second)	None	None	None	None	None	
Designation						
Manufacturer						
Chemistry						
Thickness, mils						
Application method						
Cost, \$/m²						
Bake temp., °C						
Bake time, min.						
Bake cost, \$/m²						
Total Cost :						
	\$/ft ²	\$0.63	\$0.59	\$0.56	\$0.61	\$0.96
	\$/m ²	\$6.76	\$6.40	\$6.06	\$6.56	\$10.31

(a)

Application method :

1. Dip 2. Spray 3. Flow coat 4. electrodeplate 5. electrodeposition 6. fluid bed

(a) Proof of concept only, cost does not reflect final material choices.

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Table 7 (Continued 2)

A14

CORROSION PROTECTIVE TREATMENTS :

	COSTING				
Notebook Number :	14576-6	14576-7	14576-8	14576-9	14576-10
Steel Type :	mild	mild	mild	mild	mild
Manufacturer					
Thickness, mils	28	28	28	28	28
Cost, \$/m²	\$2.70	\$2.70	\$2.70	\$2.70	\$2.70
Surface Treatment					
Type :					
Chemistry					
Cost, \$/m²					
Primer Treatment					
Designation	4910	4910	4910	4910	11861/107D
Manufacturer	3M	3M	3M	3M	Springborn
Chemistry	acrylic	acrylic	acrylic	acrylic	silane
Application method	3	3	3	3	3
Cost, \$/m²	\$2.60	\$2.60	\$2.60	\$2.60	\$0.20
Bake temp., °C	none	none	none	none	(air)
Bake time, min.	-	-	-	-	-
Bake cost, \$/m²	0	0	0	0	0
Top Coat (first)	Korad	Acmitite	Tedlar	Stainless	EVA
Designation	X212-R		150BS30WH	foil	A9918
Manufacturer	Xcel	Acme	DuPont	Teledyne	Springborn
Chemistry	acrylic	polyester	vinyl fluoride	metal	EVA
Thickness, mils	2.0	1.5	1.5	2 mil	18
Application method	roll	roll	roll	roll	vac. bag
Cost, \$/m²	\$1.30	\$2.14	\$1.62	\$5.40	\$7.40
Bake temp., °C	none	none	none	none	150°c
Bake time, min.	-	-	-	-	20 min
Bake cost, \$/m²	0	0	0	0	<2.01
Top Coat (second)	none	none	none	none	Scotchpar
Designation					20 CP white
Manufacturer					3M
Chemistry					polyester
Thickness, mils					2.0
Application method					vacuum bag
Cost, \$/m²					\$1.10
Bake temp., °C					included
Bake time, min.					
Bake cost, \$/m²					
Total Cost :					
\$/ft²	\$0.61	\$0.69	\$0.64	\$0.99	\$1.06
\$/m²	\$6.60	\$7.44	\$6.92	\$10.70	\$11.41

Application method :

1. Dip 2. Spray 3. Flow coat 4. electroplate 5. electrodeposition 6. fluid bed

(a) Proof of concept only, cost does not reflect final material choices.

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Table 7 (Continued 3)

A15

CORROSION PROTECTIVE TREATMENTS

Notebook Number : 14576-11 14576-12 14576-13 14591-14 14701-15

Steel Type :	mild	mild	mild	mild	mild
Manufacturer					
Thickness, mils	20	28	28	28	28
Cost, \$/m ²	\$2.70	\$2.70	\$2.70	\$2.70	\$2.70
Surface Treatment					
Type :					
Chemistry					
Cost, \$/m ²					
Primer Treatment					
Designation	A11861	A11861/107D	Z-6020	14590	Coil primer 3305
Manufacturer	Springborn	Springborn	DowCorning	Springborn	PPG
Chemistry	silane	silane	silane	silane	epoxy
Application method	1	1	1	1	3
Cost, \$/m ²	\$0.20	\$0.20	\$0.20	\$0.20	\$0.08
Bake temp., °C	(air)	(air)	(air)	(air)	200°C
Bake time, min.	-	-	-	-	15 min
Bake cost, \$/m ²	0	0	0	0	\$0.005
Top Coat (first)					
Designation	EVA	EVA	Scotchclad	EVA	Duranar
Designation	A9918	A9918	XB-5863	A9918	5MW932377
Manufacturer	Springborn	Springborn	3M	Springborn	PPG
Chemistry	olefin	olefin	urethane	olefin	fluorocarbon
Thickness, mils (dry)	18	18	6	18	0.8
Application method	vacuum bag	vacuum bag	3	vacuum bag	2, 3
Cost, \$/m ²	\$7.40	\$7.40	\$2.84	\$7.40	\$0.76
Bake temp., °C	150°C	150°C	none	150°C	200°C
Bake time, min.	20 min	20 min	-	20 min	15 min
Bake cost, \$/m ²	\$0.01	\$0.01	0	\$0.01	\$0.01
Top Coat (second)					
Designation	Stainless	Tedlar	None	None	None
Designation	302	100BG30UT			
Manufacturer	Teledyne	DuPont			
Chemistry	metal	vinyl fluoride			
Thickness, mils	2.0	1.0			
Application method	roll	vacuum bag			
Cost, \$/m ²	\$5.40	\$1.08			
Bake temp., °C	none	none			
Bake time, min.	-	-			
Bake cost, \$/m ²	included	included			
Total Cost :					
\$/ft ²	\$1.46 (a)	\$1.06 (a)	\$0.53	\$0.96	\$0.33
\$/m ²	\$15.71	\$11.39	\$5.74	\$10.31	\$3.56

Application method :

1. Dip 2. Spray 3. Flow coat 4. electroplate 5. electrodeposition 6. fluid bed

(a) Proof of concept only, cost does not reflect final material choices.

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Table 7 (Continued 4)

A16

CORROSION PROTECTIVE TREATMENTS

Notebook Number : 14713-16 14713-17

Steel Type :		mild	mild			
Manufacturer						
Thickness, mils		28	28			
Cost, \$/m ²		\$2.70	\$2.70			
Surface Treatment						
Type :						
Chemistry						
Cost, \$/m ²						
Primer Treatment		Dextar	Dextar			
Designation		9X165	9X165			
Manufacturer		Dexter-Mid	Dexter-Mid			
Chemistry		epoxy	epoxy			
Application method		roll	roll			
Cost, \$/m ²		\$0.08	\$0.08			
Bake temp., °C		250°C	250°C			
Bake time, min.		1 min	1 min			
Bake cost, \$/m ²		\$0.006	\$0.006			
Top Coat (first)		Dextar	Dextar			
Designation		75X102	DXD-889			
Manufacturer		Dexter-Mid	Dexter-Mid			
Chemistry		silicone-pstr	acrylic			
Thickness, mils (dry)		0.8				
Application method		roll	roll			
Cost, \$/m ²		\$0.34				
Bake temp., °C		250°C				
Bake time, min.		1 min				
Bake cost, \$/m ²		\$0.007				
Top Coat (second)						
Designation						
Manufacturer						
Chemistry						
Thickness, mils						
Application method						
Cost, \$/m ²						
Bake temp., °C						
Bake time, min.						
Bake cost, \$/m ²						
Total Cost :						
\$/ft ²		\$0.29				
\$/m ²		\$3.13				

Application method :

1. Dip 2. Spray 3. Flow coat 4. electroplate 5. electrodeposition 6. fluid bed

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TABLE 8
HARDBOARD COATINGS EXPERIMENTS

Notebook Number:	Protective Coating	Exposure Time							
		2 Weeks (a)		4 Weeks (b)		12 Weeks (c)		16 Weeks (d)	
		A (%)	B (%)	A (%)	B (%)	A (%)	B (%)	A (%)	B (%)
14737	None Control	----	----	+1.59	+1.9	+2.08	+1.68	+3.36	+4.00
14592-1	Acrylar 22417/4910 adhesive	-0.24 (e)	-0.32 (e)	-0.24 (e)	-0.33 (e)	+0.37 (e)	+0.49	+0.21	+0.29
14592-2	Korad 63000/4910 adhesive	-0.66 (f)	-0.85 (f)	-0.51 (f)	-0.66 (f)	+0.34 (f)	+0.44	+0.17	+0.22
14592-3	White rustoleum paint (latex)	+1.88	+2.43	+2.42	+3.14	+3.57	+4.63	+2.94	+3.8
14592-4	302 Stainless foil/4910 adhesive	-0.02	-0.03	-0.00	-0.01	-0.01	-0.01	+0.02	+0.03
14592-5	Aluminum foil/4910 adhesive	-0.06	-0.08	-0.05	-0.07	+0.12	+0.16	+0.06	+0.08
14592-6	Scotchpar 20CPW/4910 adhesive	-0.01	-0.01	+0.03	+0.04	+0.35	+0.46	+0.28	+0.34
14592-7	EVA 9918 pottant/11861 primer	+0.08	+0.11	+0.17	+0.24	+0.82	+1.12	+0.71	+1.0
14592-8	EVA 991R/melamine (other side)	+1.15	+1.41	+1.50	+1.83	+2.63	+3.22	+2.61	+3.2
14587-2	Tedlar 200 White/68960 adhesive	-0.31	-0.41	-0.31	-0.41	+0.42	+0.56	+0.17	+0.23

A. Weight change with respect to the weight of the whole specimen, including gasket and coating

B. Weight change calculated from the weight of the hardboard only.

(a) Rainfall during this period, 3.32"

(b) Rainfall during this period, 0.80"

(c) Rainfall during this period, 2.0" (some snow covered)

(d) Rainfall during this period

(e) Scattered areas of delamination

(f) Broad areas of delamination

(g) Coatings applied to hardboard equilibrated at 50% relative humidity and 21°C. All boards were of same weight and deployed with butyl edge seal and gasket

TABLE 9A
Soiling Experiments

Soil resistant coatings; change in short circuit current with standard cell. Twelve months outdoor exposure.

Treatment	% I _{sc} Sunadex (plain)													Δ
	0	1	2	3	4	5	6	7	8	9	10	11	12	
None	90.5	89.0	88.7	88.7	88.8	87.8	88.0	88.4	87.9	86.2	87.6	88.7	87.7	-3.1
L-1668	89.7	89.9	88.6	88.5	89.4	89.3	89.3	88.8	88.8	85.8	87.6	88.8	88.8	-1.0
Ozone, Then L-1668	-	-	-	-	-	-	-	-	-	-	-	-	-	-
E-3820	90.0	89.9	89.9	88.0	88.8	88.6	88.9	87.9	88.2	86.5	87.6	89.4	88.8	-1.3
Ozone, Then E-3820	-	-	-	-	-	-	-	-	-	-	-	-	-	-
OI-650 Glass Resin	91.0	90.5	89.6	89.3	89.3	88.0	88.7	87.3	87.5	85.3	85.8	87.6	87.1	-4.3
SHC-1000	91.9	89.6	89.4	89.3	88.3	88.3	87.8	87.4	87.1	86.0	87.8	88.0	87.4	-4.9
WL-81 Rohm & Haas	90.7	85.0	88.7	88.7	86.2	86.7	87.3	87.0	86.4	83.5	86.1	86.0	86.9	-4.2

Legend: 0 = control value before exposure; referenced to standard cell
 1-12 = number of months exposure; % of original short circuit current
 Δ = % change in I_{sc}

TABLE 90

Soiling Experiments

Soil resistant coatings; percent change in short circuit current with standard cell. Twelve months outdoor exposure.

Treatment	% Variation in I _{sc} Sunadex Glass												
	0	1	2	3	4	5	6	7	8	9	10	11	12
None	0	-1.5	-2.0	-1.9	-1.7	-3.0	-2.6	-2.3	-2.2	-4.7	-3.2	-2.0	-3.1
L-1668	0	+0.2	-1.2	-1.3	-0.3	-0.4	-0.4	-1.0	-1.0	-4.3	-2.3	-1.0	-1.0
Ozone, Then L-1668	-	-	-	-	-	-	-	-	-	-	-	-	-
E-3820	0	-0.1	-0.1	-2.2	-1.2	-1.5	-1.2	-2.3	-2.0	-3.8	-2.7	-0.6	-1.3
Ozone, Then E-3820	-	-	-	-	-	-	-	-	-	-	-	-	-
OI-650 Glass Resin	0	-0.5	-1.5	-1.9	-1.7	-3.3	-2.5	-4.1	-3.8	-6.3	-5.7	-3.7	-4.3
SHC-1000	0	-2.3	-2.7	-2.8	-3.6	-3.9	-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	-3.7	-4.1	-4.7	-7.9	-5.1	-5.2	-4.2

Legend: 0 = control value before exposure; referenced to standard cell
1-12 = number months exposure; % of original short circuit current

TABLE 10A

Soiling Experiments

Soil resistant coatings; change in short circuit current with standard cell. Twelve months outdoor exposure.

Treatment	I _{sc} Acrylar X-22417 On Glass												Δ	
	0	1	2	3	4	5	6	7	8	9	10	11		12
None	84.0	80.9	80.7	80.3	80.3	79.3	79.5	78.6	77.7	75.4	74.9	77.4	77.4	-7.8
L-1668	80.3	79.5	80.0	78.8	77.9	77.5	77.5	76.3	77.2	76.2	75.0	75.8	76.3	-5.0
Ozone, Then L-1668	84.5	81.6	82.4	82.1	82.0	81.5	81.8	80.7	80.3	79.2	79.3	80.7	80.6	-4.6
E-3820	80.0	78.5	78.7	78.1	77.7	77.7	77.9	76.9	76.9	74.6	74.5	76.5	75.7	-5.4
Ozone, Then E-3820	84.1	83.3	82.4	82.2	82.3	82.0	81.5	80.7	81.4	79.9	80.0	81.4	80.7	-4.0
OI-650 Glass Resin	81.1	79.3	78.9	79.5	78.4	78.1	77.8	76.9	77.3	75.3	75.1	76.9	76.8	-5.3
SHC-1000	82.1	78.9	77.8	76.5	77.9	76.2	77.1	77.0	76.7	74.9	75.9	77.1	75.7	-7.8
WL-81 Rohm & Haas	83.6	81.0	80.7	82.7	81.0	81.0	80.1	79.7	79.6	77.9	78.3	79.8	78.9	-5.6

Legend: 0 = control value before exposure; 1-12 = number months exposure; % of original short circuit current
Δ = % change in I_{sc}

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TABLE 108
Soiling Experiments

Soil resistant coatings; percent change in short circuit current with standard cell. Twelve months of outdoor exposure.

Treatment	% Variation in I_{sc} Acrylar X-22417 Acrylic Film												
	0	1	2	3	4	5	6	7	8	9	10	11	12
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
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
Ozcl. 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
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
Ozcl. Then E-3820	0	-0.8	-2.0	-2.3	-1.8	-2.5	-3.1	-4.0	-3.2	-5.0	-4.9	-3.2	-4.0
SHC-1000	0	-4.1	-5.2	-6.3	-4.2	-6.5	-5.1	-6.2	-6.6	-8.8	-7.6	-6.1	-7.8
WL-81 Rohm & Haas	0	-2.6	-3.5	-1.0	-2.6	-3.1	-4.2	-4.7	-4.8	-6.8	-6.3	-4.5	-5.6

Legend: 0 = control value before exposure; referenced to standard cell
1-12 = number months exposure; % of original short circuit current

TABLE 11A

Soiling Experiments

Soil resistant coatings; change in short circuit current with standard cell. Twelve months outdoor exposure.

Treatment	% I _{sc} Tedlar 100BG30UT On Glass												Δ	
	0	1	2	3	4	5	6	7	8	9	10	11		12
None	87.7	85.3	84.8	86.8	84.2	83.6	83.2	83.2	82.2	81.0	82.0	81.3	82.0	-6.5
L-1668	88.4	86.9	97.1	86.0	86.6	85.6	85.8	85.1	85.1	83.1	83.7	84.7	84.7	-4.2
Ozone, Then L-1668	88.1	87.4	87.3	86.2	85.9	85.6	85.4	85.0	85.1	82.9	83.7	84.8	83.9	-4.8
E-382	86.0	86.5	86.0	83.0	85.2	84.7	84.5	85.2	84.9	83.9	82.7	84.2	83.9	-2.4
Ozone, Then 3820	86.0	82.8	83.5	86.3	83.6	82.6	82.8	82.3	82.2	81.0	80.5	82.6	82.5	-4.1
OI-650 Glass Resin	89.0	86.3	86.4	85.3	85.5	85.0	84.7	82.6	84.9	80.9	83.2	83.3	83.7	-5.6
SHC-1000	89.0	86.5	86.9	86.3	86.4	85.7	86.2	85.2	85.0	82.0	84.0	85.0	84.9	-4.6
WL-81 Rohm & Haas	87.7	86.5	84.8	84.7	84.7	84.6	85.2	83.9	84.4	81.9	83.1	83.4	83.7	-4.6
RTV-615 Silicon	88.5	86.6	85.1	84.4	-	82.1	80.4	78.6	75.6	70.8	68.8	68.8	68.8	-22.3

Legend: 0 = control value before exposure; referenced to standard cell
 1-12 = number months exposure; % of original short circuit current
 Δ = % change in I_{sc}

TABLE 11B
Soiling Experiments

Soil resistant coatings; percent change in short circuit current with standard cell. Twelve months of outdoor exposure.

Treatment	% Variation in I _{sc} Tedlar 100BG30UT Film												
	0	1	2	3	4	5	6	7	8	9	10	11	12
None	0	-2.4	-3.3	-1.0	-3.5	-4.7	-4.7	-5.1	-6.3	-7.7	-8.8	-6.7	-6.5
L-1668	0	-1.5	-1.5	-2.7	-1.8	-3.8	-2.9	-3.5	-3.7	-6.0	-5.3	-3.9	-4.2
Ozone, Then L-1668	0	-0.7	-0.9	-2.1	-2.2	-2.8	-3.1	-3.5	-3.4	-5.9	-5.0	-3.7	-4.8
E-3820	0	+0.5	0	-3.5	-0.8	-1.5	-1.7	-0.9	-1.3	-2.4	-3.8	-2.1	-2.4
Ozone, Then E-3820	0	-3.2	-2.9	+0.3	-2.4	-3.9	-3.7	-4.3	-4.4	-5.8	-6.4	-3.9	-4.1
OI-650 Glass Resin	0	-2.7	-2.9	-4.1	-3.5	-4.5	-4.8	-7.2	-4.6	-9.1	-6.5	-6.4	-5.6
SHC-1000	0	-2.5	-2.4	-3.0	-2.6	-3.7	-3.1	-4.3	-4.5	-7.9	-5.6	-4.5	-4.6
WL-81 Rohm & Haas	0	-1.2	-3.3	-3.4	-3.0	-4.9	-2.8	-4.3	-3.8	-6.6	-5.2	-4.9	-4.6

Legend: 0 = control value before exposure; referenced to standard cell
1-12 = number months exposure; % of original short circuit current

C-2

TABLE 12

Soiling Experiments

Rainfall Throughout the Exposure Period
Inches of Rainfall at Springborn Laboratories, Enfield, Connecticut

Year:	1981												1982				
	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June				
Month: No.	1	2	3	4	5	6	7	8	9	10	11	12	13				
Rainfall, Inches:	4.3	4.75	2.82	5.92	6.72	3.13	1.5	*	*	2.23	4.45	3.4	10.3				

*No rainfall during this time, below freezing

TABLE 1.3
SOIL RESISTANT COATINGS
"LIQUID GLASS" and ION PLATED SPECIMENS
CHANGE IN SHORT CIRCUIT CURRENT-SEVEN MONTH EXPOSURE

Anti-Soiling Treatment Evaluation
Ion Plated and "Liquid Glass" Coated Specimens
Change in Short Circuit (I_{SC}) w/Standard Cell

Material & Coating	Month Number										(a)
	0	1	2	3	4	5	6	7(b)			
Magnesium Fluoride Ion Plated Glass	88.3	87.5	86.5	86.3	85.7	85.4	85.2	83.5	-5.44%		
Untreated Glass Blank	78.8	78.1	78.1	77.8	76.9	76.8	77.2	77.4	-1.8%		
Chromium Phosphate Coated Glass	77.8	70.2	69.0	69.5	69.3	69.5	69.2	68.9	-4.0%		
Iron Phosphate Coated Glass	74.9	72.8	72.7	71.7	73.1	73.5	72.8	72.8	-2.8%		
Uncoated Acrylic Bland	90.9	90.4	89.7	88.6	89.3	87.6	87.8	87.6	-3.6%		
Titanium Dioxide Coated Acrylic	90.5	89.3	89.5	88.2	88.2	87.2	88.1	86.9	-4.0%		

(a) Percent reduction of transmission compared to control value at 0 months
(b) Specimens removed from further testing after t is time

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TABLE 14
Adhesive Bond Strength Determination
Bond Strength by ASTM D-903 or ASTM D-1876

Notebook Number	Materials	Primer/ Adhesive	Control Value lbs. per inch (ppi)	2 Weeks Water Immersion (ppi)	2 Hours Boiling Water (ppi)
<u>Bonds to EVA A9918</u>					
A11861-2A	Glass/EVA 9918	A11861	39.6	37.9	27.1
A11866-A	Glass/EVA 9918 w/blend	A11861	35.4	41.9	c.
A11894-3	Galvanized/EVA 9918	A11861	2.5	NT	NT
A11894-4	Mild Steel/EVA 9918	A11861	56.0	42.6	50.7
A11895-1	Aluminum/EVA 9918	A11861	41.0	2.3	2.6
A11894-1	EVA 9918/Tedlar 100BG3OUT	A11861	4.5	NT	NT
A11894-2	EVA 9918/Korad 212	A11861	1.1	NT	NT
A12521-1	EVA 9918/Sunadex	A11861	34.8	Broke	32.3
A13881-1	EVA 9918/Tedlar 200BS30WH	68040	c. > 20	c.	c.
A13881-2	EVA 9918/Tedlar 200PT	68040	8.25	11.1	10.8
A13881-3	EVA 9918/Tedlar 100BG3OUT	68040	6.14	tore	7.8
14316-1	EVA 9918/Scotchpar 20CP	107D	11.5	26.8	1.09
14316-3	EVA 9918/Korad 63000	107D	1.65	NT	NT
14316-4	EVA 9918/Tedlar 100BG3OUT	107D	V. High	12.6	High
14316-6	EVA 918/mild steel	107D	2.26	2.28	3.07
14719-a,b,c	EVA /Scotchpar 20CP	14719	c. 35.7	c.31.3	c. 21.3

c. Cohesive failure in pottant

TABLE 14 Continued

Adhesive Bond Strength Determination
Bond Strength by ASTM D-903 or ASTM D-1876

Bonds to EMA 13439

Notebook Number:	Materials	Primer/adhesive	Control Value lbs. per inch (psi)	2 Weeks Water Immersion (psi)	2 Hours Boiling Water (psi)
Bonds to EMA 13439					
A13881-4	EMA 13439/Tedlar 100BG30UT	68040	0.47	NT	NT
A13881-5	EMA 13439/Tedlar 200BS30WH	68040	1.88	NT	NT
14316-2	EMA 13439/Scotchpar 10CP	107D	0.8	0.4	1.2
14316-5	EMA 13439/Tedlar 100BG	107D	0.77	NT	NT
14316-7	EMA 13439/mild steel	11861	5.64	14.6	13.9
14316-8	EMA 13439/Sunadex	11861	60.2	40	27.7
Bonds to Polyurethane Pottants					
14559-0	PU7-2211/Tedlar/Scotchpar Korad/Glass	None	0	NT	NT
14559-1A	PU7-2211/Tedlar 100BG	Z6020	4.8	2.5	0
14559-1B	PU2-2211/Scotchpar	Z6020	0.2	NT	NT
14559-1C	PU7-2211/Korad 63000	Z6020	3.1	low	
14316-9	PU7-2211/Sunadex	Z6020	28.0		
14566-1	PU2-2591/Sunadex	Z6020	31.4	37.2	45.2
14566-3	PU2-2591/Tedlar 100BG30UT	Z6020	4.8	0.6	2.5
14566-2	PU2-2591/Korad 63000	Z6020	4.14	2.55	2.7
Bonds to Butyl Acrylate Pottant					
14559-2A	BA13870/Tedlar/Korad	None	0	NT	NT
14559-2C	Scotchpar/Glass BA13870/Tedlar 100BG	Z6032W	2.35	2.35	2.27
14559-2A	BA13870/Scotchpar	Z6032W	1.53	NT	NT
14559-2B	BA13870/Korad 6300	Z6032W	0.71	NT	NT
14559-2D	BA13870/Sunadex	Z6032W	0.90	0.36	0.59
14588-3A	BA13870/Sunadex	14588	c. (3.0)	1.2	1.4

c. Cohesive failure in pottant

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Project No. 6072.1 Table 15
POLYMER AGING STUDIES

Page:
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Exposure Condition: RS/4 DRY

Material: EVA Notebook No: A8901C

Atmosphere: Air Temperature: 50 °C

Description: Prototype formulation of A9918 Candidate pottant

Specimen	Exposure, Hrs.	0 (control)	15, 520	22, 720	30, 000	35, 000	
	Date: (add 4Hrs)	7/9/79	11/8/80	7/8/81	5/8/82	12/2/82	
	Unit No.:	4	4	4	1		
	No. of Specimens	1	1	1	1		
Physical	Tensile strength, psi	1, 890	1, 590	1, 580	1, 450		
	Ult. elongation, %	677 %	600 %	605 %	480 %		
	Modulus, psi	at 100% strain 360	450	833	a.		
	Swell Ratio		b.	b.	12.9		
	Gel content, %	72%	b.	b.	45 %		
	Appearance	Clear	ok	ok	ok		
Optical	Total optical, %T						
	UV cutoff, nm	362	b.	365	367		
	Color *	Clear	1	1	2		
Elect.	Dielect. Stgth., V/mil		a.	a.	a.		
	Leak current, ma		a.	a.	a.		
Corrosion *	Copper dust, %T	n/a	n/a	n/a	n/a		
	Copper metal	==					
	Aluminum	==					
	60/40 Solder	==					
	Nickel	==					
	Titanium	==					
Silver	==						

Notes: a. insufficient specimen available
b. not measured

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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Table 16

Project No. 6072.1

POLYMER AGING STUDIES

Page:
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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
	Date :	7/15/80	11/12/80	3/13/81	7/13/81	4/13/82
	Unit No.:	3	5	5	3	3
	No. of Specimens	10	5	5	5	5
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	Transparen film	1	1	1	1
Optical	Total optical, %T					
	UV cutoff, nm	355	355	356	357	357
	Color *	Clear	1	1	1	1
Elect.	Dielect. Stgth., V/mil		b.	b.	b.	b.
	Leak current, ma		b.	b.	b.	b.
Corrosion *	Cooper dust, %T	n/a	n/a	n/a	n/a	n/a
	Cooper metal	---				
	Aluminium	---				
	60/40 Solder	---				
	Nickel	---				
	Titanium	---				
Silver	---					

Notes : a. not measured
b. insufficient material

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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Table 17

Project No. 6072.1

POLYMER AGING STUDIES

Page:

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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	
	Date :	5/26/81	9/27/81	1/27/82	4/13/82	7/22/82	
	Unit No.:	4	4	4	1		
	No. of Specimens	10	5	5	3		
Physical	Tensile strength, psi	2,000	2,690	2,420	2,400		
	Ult. elongation, %	570%	623%	647%	680%		
	Modulus, psi	3,240	a.	a.	2,000		
	Swell Ratio	11.2	a.	24.3	28.4		
	Gel content, %	62%	a.	20%	59%		
	Appearance	Clear	1	1	1		
Optical	Total optical, %T						
	UV cutoff, nm	354	a.	a.	360		
	Color *	Clear	1	1	1		
Elect.	Dielect. Stgth., V/mil		b.	b.	b.		
	Leak current, ma		b.	b.	b.		
Corrosion *	Copper dust, %T	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 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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Table 18

Project No. 6072.1

POLYMER AGING STUDIES

Page:
A31

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		
	Date :	10/26/81	1/20/82	4/13/82	6/30/82		
	Unit No. :	6	6	6	6		
	Remaining No. of Specimens	22	18	14	11		
	Physical	Tensile strength, psi	160	196	131	199	
Ult. elongation, %		115	143	105	143		
Modulus, psi		254	263	241	222		
Swell Ratio		2.7	a.	3.3	3.45		
Gel content, %		93.2%	a.	91.7%	93%		
Appearance		transparent sheet	1	1	2		
Optical	Total optical, %T						
	UV cutoff, nm	366	366	367	367		
	Color *	Clear	1	1	2		
Elect.	Dielect. Stgth., V/mil		b.	b.	b.		
	Leak current, ma		b.	b.	b.		
Corrosion *	Copper dust, %T	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	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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Table 19

Project No. 6072.1

POLYMER AGING STUDIES

Page :

Exposure Condition : RS/4- DRY

A32

Material : BA 13870 Notebook No: 13870

Atmosphere : Air Temperature : 50 °C

Description : Candidate pottant - casting system

Specimen	Exposure, Hrs.	0 (control)	2,880	5,760	7,608	10,000	
	Date :	5/26/81	9/27/81	1/27/82	4/13/82	7/22/82	
	Unit No. :	4	4	4	1		
	No. of Specimens	10	5	5	4		
Physical	Tensile strength, psi	293	147	162	172		
	Ult. elongation, %	110	95	98	97		
	Modulus, psi	90	87	85	91		
	Swell Ratio	2.39	a.	2.01	1.88		
	Gel content, %	86.4%	a.	88.3%	89.4%		
	Appearance	Clear	1	1	1		
Optical	Total optical, %T						
	UV cutoff, nm	385	a.	386	384		
	Color *	Clear	1	1	1		
Elect.	Dielect. Stgth., V/mil		b.	b.	b.		
	Leak current, ma		b.	b.	b.		
Corrosion *	Copper dust, %T	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 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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Table 20

Project No. 6072.1

POLYMER AGING STUDIES

Page :
A33

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 :	9/20/80	12/20/80	4/20/81	10/3/81	5/20/82	12/9/82
	Unit No. :	6	6	3	3	3	
	(Starting No.) No. of Specimens	10	20	13	8	5	
Physical	Tensile strength, psi	17,700	15,819	16,200	16,400	14,500	
	Ult. elongation, %	71%	70	78	69	65	
	Modulus, psi	2.4×10^5	6×10^5	2.5×10^5	10×10^5	2×10^5	
	Swell Ratio	na	na	na	na	n/a	
	Gel content, %	na	na	na	na	n/a	
	Appearance	hazy	1	1	1	1	
Optical	Total optical, %T						
	UV cutoff, nm	356	355	356	354	354	
	Color *	slight blue hazy	1	1	1	1	
Elect.	Dielect. Stgth., V/mil		a.	a.	a.	a.	
	Leak current, ma		a.	a.	a.	a.	
Corrosion *	Copper dust, %T	-	na	na	na	na	
	Copper metal	—					
	Aluminum	—					
	60/40 Solder	—					
	Nickel	—					
	Titanium	—					
	Silver	—					

Notes : a. insufficient sample

- | | | |
|--------------------|-------------------------|--------------------|
| 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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Table 21

Project No, 6072.1

POLYMER AGING STUDIES

Page :
A24

Exposure Condition ; RS/4 DRY

Material ; Tedlar 4462

Notebook No: 13406-3

Atmosphere ; Air

Temperature ; 50 °C

Description ; Candidate outer cover

Specimen	Exposure, Hrs.	0 (control)	2,880	5,760	8,640	10,800	16,000
	Date :	1/26/81	5/26/81	9/27/81	1/27/82	4/20/82	11/22/82
	Unit No. :	#7	#7.	#7	#7	#7	
	No. of Specimens	10	5	5	5	3	
Physical	Tensile strength, psi	10,600	14,900	15,200	17,000	15,000	
	Ult. elongation, %	180	53	71	75	70	
	Modulus, psi	2×10^5	a.	a.	a.	2.1×10^5	
	Swell Ratio	Insoluble	n/a	n/a	n/a	n/a	
	Gel content, %	insoluble	n/a	n/a	n/a	n/a	
	Appearance	hazy blue film	1	1	1	1	
Optical	Total optical, %T						
	UV cutoff, nm	365	a.	365	365	365	
	Color *	v. litz blue slt. phase	1	1	1	1	
Elect.	Dielect. Stgth., V/ml		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 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 22

Page:
A35

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
	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: \bar{M}_v^c 116,000 100,000 a. a. 94,800

a. not measured c. Viscosity average molecular weight
b. insufficient 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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Table 23
Project No. 6072.1 POLYMER AGING STUDIES

Page:
A36

Exposure Condition ; RS/4 DRY

Material ; Fluorex-A Notebook No; 13406-2

Atmosphere ; Air Temperature ; 50 °C

Description : Outer cover candidate ; Acrylic/vinylidene fluoride alloy

Specimen	Exposure, Hrs.	0 (control)	2,880	5,760	8,640		
	Date :						
	Unit No. :	7	7	7	7		
	No. of Specimens	10	5	5	3		
Physical	Tensile strength, psi	5,560	3,790	5,800	5,440		
	Ult. elongation, %	328	44	47	113		
	Modulus, psi	1.4×10^5	a.	a.	a.		
	Swell Ratio	Soluble	n/a	n/a	n/a		
	Gel content, %	Soluble	n/a	n/a	n/a		
	Appearance	Transparent film	1	1	1		
Optical	Total optical, %T						
	UV cutoff, nm	340	a.	340	341		
	Color *	Clear	1	1	1		
Elect.	Die/ct. Stgth., V/ml		b.	b.	b.		
	Leak current, ma		b.	b.	b.		
Corrosion *	Copper dust, %T	n/a	n/a	n/a	n/a		
	Copper metal	---					
	Alum. sur	---					
	60/40 Solder	---					
	Nickel	---					
	Titanium	---					
Silver	---						

Notes : a. not measured
 b. insufficient 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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Table 24

Project No. 6072.1

POLYMER AGING STUDIES

Page:

Exposure Condition : RS/4 DRY

A37

Material : Scotchpar 20CP

Notebook No: 14321-2

Atmosphere : Air

Temperature : 50 °C

Description : Back cover candidate

Specimen	Exposure, Hrs.	0 (control)	4,320	6,548	8,000		
	Date :	7/13/81	1/13/82	4/20/82	6/15/82		
	Unit No. :	8	8	5	5		
	Remaining No. of Specimens	10	12	8	6		
Physical	Tensile strength, psi	29,400	28,000	28,000	25,600		
	Ult. elongation, %	27	15	20	15		
	Modulus, psi	3.6×10^5	a.	a.	5×10^5		
	Swell Ratio	Soluble	n/a	n/a	n/a		
	Gel content, %	Soluble	n/a	n/a	n/a		
	Appearance	White film	1	1	1		
Optical	Total optical, %T	Opaque	n/a	n/a	n/a		
	UV cutoff, nm	n/a	n/a	n/a	n/a		
	Color *	White	1	1	1		
Elect.	Dielect. Stgth., V/mil		b.	b.	b.		
	Leak current, ma		b.	b.	b.		
Corrosion *	Copper dust, %T	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 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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Table 25

Project No. 6072.1

POLYMER AGING STUDIES

Page :

A38

Exposure Condition : RS/4 DRY

Material : Tedlar 100BS30WH Notebook No: 14321-3

Atmosphere : Air Temperature : 50 °C

Description : Back cover candidate

Specimen	Exposure, Hrs.	0 (control)	4, 320	6, 648	8, 000		
	Date :	7/13/81	1/13/82	4/20/82	6/15/82		
	Unit No. :	8	8	5	5		
	Remaining No. of Specimens	10	12	8	6		
Physical	Tensile strength, psi	14, 000	14, 500	14, 600	14, 300		
	Ult. elongation, %	59	68	62	65		
	Modulus, psi	2.8×10^5	a.	2.3×10^5	2.7×10^5		
	Swell Ratio	N/A	n/a	n/a	n/a		
	Gel content, %	N/A	n/a	n/a	n/a		
	Appearance	White film	1	1	1		
Optical	Total optical, %T	Opaque	n/a	n/a	n/a		
	UV cutoff, nm	N/A	n/a	n/a	n/a		
	Color *	White	1	1	1		
Elect.	Dielect. Stgth., V/mil		b.	b.	b.		
	Leak current, ma		b.	b.	b.		
Corrosion *	Copper dust, %T	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 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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Table 26

Project No. 6072.1

POLYMER AGING STUDIES

Page :
A39

Exposure Condition : RS/4 DRY

Material : Korad 63000

Notebook No: 14321-1

Atmosphere : Air

Temperature : 50 °C

Description : Back cover candidate

Specimen	Exposure, Hrs.	0 (control)	1, 440	4, 320	6, 648	8, 000	
	Date :	7/13/81	9/13/81	1/13/82	4/20/82	6/15/82	
	Unit No.:	8	8	8	5	5	
	Remaining No. of Specimens	10	12	8	4	3	
Physical	Tensile strength, psi	4, 250	5, 120	4, 690	3, 995	5, 040	
	Ult. elongation, %	28	18	16	19	15	
	Modulus, psi	2×10^5	a.	a.	1.3×10^5	1.5×10^5	
	Swell Ratio	Soluble	n/a	n/a	n/a	n/a	
	Gel content, %	Soluble	n/a	n/a	n/a	n/a	
	Appearance	White film	1	1	1	1	
Optical	Total optical, %T	Opaque	n/a	n/a	n/a	n/a	
	UV cutoff, nm	n/a	n/a	n/a	n/a	n/a	
	Color *	White	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 : a. not measured
b. insufficient sample

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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Table 27

Project No. 6072.1

POLYMER AGING STUDIES

Page :

Exposure Condition : Thermal Aging

A40

Material : EVA

Notebook No: A9918

Atmosphere : Air

Temperature : 80 °C

Description :

Specimen	Exposure, Hrs.	0 (control)	25	100	400	1,000	3,000
	Date :						
	Unit No. :						
	No. of Specimens	10	5	5	5		
Physical	Tensile strength, psi	1,890	2,890	2,820	3,020		
	Ult. elongation, %	510%	684%	648%	621%		
	Modulus, psi	890	980	878	922		
	Swell ratio, %	32.2	18.4	19	18.9		
	Gel content, %	74%	74.2%	79.1%	69.5%		
	Appearance	Colorless Clear	1	1	1		
Optical	Total optical, %T						
	UV cutoff, nm						
	Color *	Colorless	1	1	1		
Elect.	Dielect. Stgth., V/mil						
	Leak current, ma						
Corrosion *	Copper dust, %T						
	Copper metal	---	1	1	2		
	Aluminum	---	1	1	1		
	60/40 Solder	---	1	1	1		
	Nickel	---					
	Titanium	---					
Silver	---						

Notes :

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

Table 28
POLYMER AGING STUDIES

Page:
A41

Exposure Condition : Thermal Aging

Material : EVA

Notebook No: A9918

Atmosphere : Nitrogen

Temperature : 80 °C

Description :

Specimen	Exposure, Hrs.	0 (control)	25	100	400	1,000	3,000
	Date :						
	Unit No. :						
	No. of Specimens	10	5	5	5		
Physical	Tensile strength, psi	1,890	2,780	2,990	2,670		
	Ult. elongation, %	510%	696%	655%	592%		
	Modulus, psi	890	940	904	951		
	Swell ratio, %	32.2	24.4	37.8	12.5		
	Gel content, %	74%	70.8%	64.1%	76.8%		
	Appearance	Colorless Clear	1	1	1		
Optical	Total optical, %T						
	UV cutoff, nm						
	Color *	Colorless	1	1	1		
Elect.	Dielect. Stgth., V/mil						
	Leak current, ma						
Corrosion *	Copper dust, %T						
	Copper metal	---	1	1	2		
	Aluminum	---	1	1	1		
	60/40 Solder	---	1	1	1		
	Nickel	---					
	Titanium	---					
	Silver	---					

Notes :

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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Table 29

Project No. 6072.1

POLYMER AGING STUDIES

Page:

A42

Exposure Condition : Thermal Aging

Material : EVA

Notebook No: A9918

Atmosphere : Air

Temperature : 105 °C

Description :

Specimen	Exposure, Hrs.	0 (control)	25	100	400	1,000	3,000
	Date :						
	Unit No. :						
	No. of Specimens	10	5	5	5		
Physical	Tensile strength, psi	1,890	2,230	2,410	2,590		
	Ult. elongation, %	510%	670%	700%	659%		
	Modulus, psi	890	950	1,050	916		
	Swell ratio, %	32.2	42.9	26.8	25.5		
	Gel content, %	74%	50.2%	59.2%	66.1%		
	Appearance	Colorless Clear	1	1	1		
Optical	Total optical, %T						
	UV cutoff, nm						
	Color *	Colorless	1	1	1		
Elect.	Dielect. Stgth., V/mil						
	Leak current, ma						
Corrosion *	Copper dust, %T						
	Copper metal	---	1	2	4		
	Aluminium	---	1	1	1		
	60/40 Solder	---	1	2	2		
	Nickel	---					
	Titanium	---					
Silver	---						

Notes :

- | | | |
|--------------------|-------------------------|--------------------|
| 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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Table 30

Project No. 6072.2

POLYMER AGING STUDIES

Page:
A43

Exposure Condition : Thermal Aging

Material : EVA

Notebook No: A9918

Atmosphere : Nitrogen

Temperature : 105 °C

Description :

Specimen	Exposure, Hrs.	0 (control)	25	100	400	1,000	3,000
	Date :						
	Unit No.:						
	No. of Specimens	10	5	5	5		
Physical	Tensile strength, psi	1,890	2,640	2,610	3,110		
	Ult. elongation, %	510%	644%	668%	651%		
	Modulus, psi	890	855	849	916		
	Swell ratio, %	32.2	27.5	28.6	17.9		
	Gel content, %	74%	66.9%	53.0%	65.3%		
	Appearance	Colorless Clear	1	1	1		
Optical	Total optical, %T						
	UV cutoff, nm						
	Color *	Colorless	1	1	1		
Elect.	Dielect. Stgth., V/mil						
	Leak current, ma						
Corrosion *	Copper dust, %T						
	Copper metal	---	1	1	3		
	Aluminum	---	1	1	2		
	60/40 Solder	---	1	1	2		
	Nickel	---					
	Titanium	---					
	Silver	---					

Notes :

- | | | |
|--------------------|-------------------------|--------------------|
| 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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Table 31

Project No. 6072.1

POLYMER AGING STUDIES

Page:
A44

Exposure Condition : Thermal Aging

Material : EVA

Notebook No: A9918

Atmosphere : Air

Temperature : 130 °C

Description :

Specimen	Exposure, Hrs.	0 (control)	25	100	400	1000
	Date :					
Unit No. :						
No. of Specimens	10	3			5	
Physical	Tensile strength, psi	1,890	1,440		1,700	
	Ult. elongation, %	510%	703%		624%	
	Modulus, psi	890	910		873	
	Swell ratio, %	32.2	29.4		25.4	
	Gel content, %	74%	51.2%		48.8%	
	Appearance	Colorless Clear	1			3
Optical	Total optical, %T					
	UV cutoff, nm					
	Color *	Clear	1			3
Elect.	Dielect. Stgth., V/ml					
	Leak current, ma					
Corrosion *	Copper dust, %T					
	Copper metal	---	3,7		4,6,7	
	Aluminum	---	1		1	
	60/40 Solder	---	1		1	
	Nickel	---				
	Titanium	---				
Silver	---					

Notes :

- | | | |
|--------------------|-------------------------|--------------------|
| 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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Table 32

Project No. 6072.1

POLYMER AGING STUDIES

Page:
45

Exposure Condition : Thermal Aging

Material : EVA

Notebook No: A9918

Atmosphere : Nitrogen

Temperature : 130 °C

Description :

		Exposure, Hrs.	0 (control)	25	100	400	1,000
Specimen	Date :						
	Unit No. :						
	No. of Specimens	10	5			5	
	Tensile strength, psi	1,890	1,500			2,070	
Physical	Ult. elongation, %	510%	656%			558%	
	Modulus, psi	890	752			915	
	Swell ratio, %	32.2	11.1			9.2	
	Gel content, %	74%	35.0%			77.7%	
	Appearance	Clear colorless	1			3	
	Optical	Total optical, %T					
UV cutoff, nm							
Color *		Clear	1			3	
Elect.	Dielect. Stgth., V/mil						
	Leak current, ma						
Corrosion *	Copper dust, %T						
	Copper metal	---	1			4	
	Aluminum	---	1			1	
	60/40 Solder	---	1			1	
	Nickel	---					
	Titanium	---					
Silver	---						

Notes :

- | | | |
|--------------------|-------------------------|--------------------|
| 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

Table 33
POLYMER AGING STUDIES

Page:
A46

Exposure Condition: Thermal Aging

Material: EMA

Notebook No: 13439

Atmosphere: Air

Temperature: 80 °C

Description:

Specimen	Exposure, Hrs.	0 (control)	25	100	400	1,000	1,000
	Date:						
	Unit No.:						
	No. of Specimens	10	4	5	5		
Physical	Tensile strength, psi	2,000	2,260	2,940	2,500		
	Ult. elongation, %	570%	628%	654%	645%		
	Modulus, psi	3,240	3,580	3,000	3,250		
	Swell ratio, %	11.2	17.3	14.6	20.3		
	Gel content, %	62%	51.8%	52.8%	48.8%		
	Appearance	Clear	1	1	1		
Optical	Total optical, %T						
	UV cutoff, nm						
	Color *	Colorless	1	1	1		
Elect.	Dielect. Stgth., V/mil						
	Leak current, ma						
Corrosion *	Copper dust, %T						
	Copper metal	---	1	1	2		
	Aluminum	---	1	1	1		
	60/40 Solder	---	1	1	1		
	Nickel	---					
	Titanium	---					
Silver	---						

Notes:

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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Table 34

Project No. 6072.1

POLYMER AGING STUDIES

Page:
A47

Exposure Condition: Thermal Aging

Material: EMA

Notebook No: 13439

Atmosphere: Nitrogen

Temperature: 80 °C

Description:

		Exposure, Hrs.	0 (control)	25	100	400	1,000	3,000
Specimen	Date:							
	Unit No.:							
	No. of Specimens	10	5	5	5			
Physical	Tensile strength, psi	2,000	2,390	2,670	2,530			
	Ult. elongation, %	570%	652%	640%	650%			
	Modulus, psi	3,240	3,600	3,250	3,280			
	Swell ratio, %	11.2	13.9	21.5	23.9			
	Gel content, %	62%	59.1%	41.1%	29.4%			
	Appearance	Clear	1	1	1			
Optical	Total optical, %T							
	UV cutoff, nm							
	Color *	Colorless	1	1	1			
El. t.	Dielect. Stgth., V/mil							
	Leak current, ma							
Corrosion *	Copper dust, %T							
	Copper metal	---						
	Aluminum	---						
	60/40 Solder	---						
	Nickel	---						
	Titanium	---						
Silver	---							

Notes:

- | | | |
|--------------------|-------------------------|--------------------|
| 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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Table 35

Project No. 6072.1

POLYMER AGING STUDIES

Page:

A48

Exposure Condition: Thermal Aging

Material: EMA

Notebook No.: 13439

Atmosphere: Air

Temperature: 105 °C

Description:

		Exposure, Hrs.	0 (control)	25	100	400	1,000	3,000
Specimen	Date:							
	Unit No.:							
	No. of Specimens	10	5	5	5			
	Tensile strength, psi	2,000	2,340	2,220	2,300			
Physical	Ult. elongation, %	570%	650%	655%	575%			
	Modulus, psi	3,210	4,160	3,950	3,370			
	Swell ratio, %	11.2	23.4	20.0	22.2			
	Gel content, %	62%	38.0%	44.1%	44.4%			
	Appearance	Clear	1	1	1			
	Total optical, %T							
Optical	UV cutoff, nm							
	Color =	Colorless	1	1	1			
Elect.	Dielect. Stgth., V/mil							
	Leak current, ma							
Corrosion	Copper dust, %T							
	Copper metal	—	2	3	4, 5			
	Aluminum	—	1	1	1			
	60/40 Solder	—	1	1	1			
	Nickel	—						
	Titanium	—						
Silver	—							

Notes:

- | | | |
|--------------------|-------------------------|--------------------|
| 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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Table 36

Project No. 6072.1

POLYMER AGING STUDIES

Page:

Exposure Condition: Thermal Aging

A49

Material: EMA

Notebook No: 13439

Atmosphere: Nitrogen

Temperature: 105 °C

Description:

Specimen	Exposure, Hrs.	0 (control)	25	100	400	1,000	3,000
	Date:						
	Unit No.:						
	No. of Specimens	10	5	5	5		
Physical	Tensile strength, psi	2,000	2,550	2,640	2,390		
	Ult. elongation, %	570%	594%	603%	591%		
	Modulus, psi	3,240	3,340	3,250	3,660		
	Swell ratio, %	11.2	22.6	21.8	20.9		
	Gel content, %	62%	41%	32.5%	42.0%		
	Appearance	Clear	1	1	hazy		
Optical	Total optical, %T						
	UV cutoff, nm						
	Color *	Colorless	1	1	1		
Elect.	Dielect. Stgth., V/mil						
	Leak current, ma						
Corrosion *	Copper dust, %T						
	Copper metal	---	1	2	2		
	Aluminum	---	1	1	1		
	60/40 Solder	---	1	1	1		
	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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Table 17

Project No. 6072.1

POLYMER AGING STUDIES

Page:
A50

Exposure Condition: Thermal Aging

Material: EMA Notebook No: 13439

Atmosphere: Air Temperature: 130 °C

Description:

Specimen	Exposure, Hrs.	0 (control)	25	100	400	1,000
	Date:					
	Unit No.:					
	No. of Specimens	10	3	5	5	
Physical	Tensile strength, psi	2,000	1,870	1,430	1,750	
	Ult. elongation, %	570%	657	457%	533%	
	Modulus, psi	3,240	3,470	4,050	3,500	
	Swell ratio, %	11.2	23.4	18.4	17.3	
	Gel content, %	62%	36.4%	45.4%	48.6%	
	Appearance	Clear	hazy		3, hazy	
Optical	Total optical, %T					
	UV cutoff, nm					
	Color *	Colorless	1		3	
Elect.	Dielect. Stgth., V/ml					
	Leak current, ma					
Corrosion *	Copper dust, %T				6.7	
	Copper metal	—	1		4.7	
	Aluminum	—	1		1	
	60/40 Solder	—	1		1	
	Nickel	—				
	Tin/Lead	—				
Silver	—					

Notes:

- | | | |
|--------------------|-------------------------|--------------------|
| 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. 0072.1

Table 18
POLYMER AGING STUDIES

Page:
A51

Exposure Condition: Thermal Aging

Material: EMA

Notebook No: 13439

Atmosphere: Nitrogen

Temperature: 130 °C.

Description:

Specimen	Exposure, Hrs.	0 (control)	25	100	400	1,000
	Date:					
	Unit No.:					
	No. of Specimens	10	5	5	5	
Physical	Tensile strength, psi	2,000	2,160	1,080	1,330	
	Ult. elongation, %	570%	578%	430%	378%	
	Modulus, psi	3,240	3,080	3,290	3,200	
	Swell ratio, %	11.2	13.4	15.7	12.0	
	Gel content, %	62%	62.4%	52.9%	77.2%	
	Appearance	Clear	1	2	3-4	
Optical	Total optical, %T					
	UV cutoff, nm					
	Color *	Colorless	1	2	3-4	
Elect.	Dielect. Stgth., V/mil					
	Leak current, ma					
Corrosion *	Copper dust, %T					
	Copper metal	---	1	5	4.5	
	Aluminum	---	1	1	1	
	60/40 Solder	---	1	1	2	
	Nickel	---				
	Titanium	---				
Silver	---					

Notes:

- | | | |
|--------------------|-------------------------|--------------------|
| 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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Table 39

Project No. 6072,1

POLYMER AGING STUDIES

Page:

Exposure Condition: Thermal Aging

A52

Material: PU Z-2591

Notebook No: 2591

Atmosphere: Air

Temperature: 80 °C

Description:

		Exposure, Hrs.	0 (control)	25	100	400	1,000	3,000
Specimen	Date:							
	Unit No.:							
	No. of Specimens	10	5	5	5			
	Tensile strength, psi	160	183	273	201			
Physical	Ult. elongation, %	115%	114%	192%	138%			
	Modulus, psi	254	180	225	248			
	Swell ratio, %	2.7	3.4	2.6	2.9			
	Gel content, %	93.2%	96.6%	96.6%	96.7%			
	Appearance	Clear	1	1	2			
	Local optical, %T							
Optical	UV cutoff, nm							
	Color *	Faint yellow	1	1	2			
	Dielect. Stgth., V/mil							
Elect.	Leak current, ma							
	Copper dust, %T							
Corrosion *	Copper metal	---	1	1	2			
	Aluminum	---	1	1	1			
	60/40 Solder	---	1	1	1			
	Nickel	---						
	Titanium	---						
	Silver	---						

Notes:

- | | | |
|--------------------|-------------------------|--------------------|
| 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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Table 40

Project No. 6072.1

POLYMER AGING STUDIES

Page :

A53

Exposure Condition : Thermal Aging

Material : PU Z-2591

Notebook No: 2591

Atmosphere : Nitrogen

Temperature : 80 °C

Description :

Specimen	Exposure, Hrs.	0 (control)	25	100	400	1,000	3,000
	Date :						
	Unit No. :						
	No. of Specimens	10	5	5	5		
Physical	Tensile strength, psi	160	210	210	157		
	Ult. elongation, %	115%	123%	149%	185%		
	Modulus, psi	254	230	237	167		
	Swell ratio, %	2.7	3.1	3.4	4.5		
	Gel content, %	93.2%	96.5%	96.0%	89.2%		
	Appearance	Clear	1	1	2		
Optical	Total optical, %T						
	UV cutoff, nm						
	Color *	Faint yellow	1	1	2		
Elect.	Dielect. Stgth., V/mil						
	Leak current, ma						
Corrosion *	Copper dust, %T						
	Copper metal	---	1	1	2		
	Aluminium	---	1	1	1		
	60/40 Solder	---	1	1	1		
	Nickel	---					
	Titanium	---					
	Silver	---					

Notes :

- | | | |
|--------------------|-------------------------|--------------------|
| 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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Table 41

Project No. 6072.1

POLYMER AGING STUDIES

Page:

Exposure Condition : Thermal Aging

A54

Material : PU Z-2591

Notebook No: 2591

Atmosphere : Air

Temperature : 130 °C

Description :

Specimen	Exposure, Hrs.	0 (control)	25	100	400	1,000	3,000
	Date :						
	Unit No. :						
	No. of Specimens	10	5	5	5		
Physical	Tensile strength, psi	160	182	142	-0-		
	Ult. elongation, %	115%	191%	370%	-0-		
	Modulus, psi	254	130	50	-0-		
	Swell ratio, %	2.7	3.8	5.1	n/a		
	Gel content, %	93.2%	95%	86.7%	n/a		
	Appearance	Clear	3	sticky 3-4	destroyed 4.7		
Optical	Total optical, %T						
	UV cutoff, nm						
	Color *	Faint Yellow	3	3-4	4, brown		
Elect.	Dielect. Stgth., V/mil						
	Leak current, ma						
Corrosion +	Copper dust, %T		4.6.7	4.6.7	6		
	Copper metal	---	3	4.6.7	6		
	Aluminum	---	1	1	1		
	60/40 Solder	---	1	1	1		
	Nickel	---			1		
	Titanium	---					
Silver	---						

Notes :

- | | | |
|--------------------|-------------------------|--------------------|
| 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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Table 42

Project No. 6072.1

POLYMER AGING STUDIES

Page :

A55

Exposure Condition : Thermal Aging

Material : PU Z-2591

Notebook No: 2591

Atmosphere : Air

Temperature : 105 °C

Description :

	Exposure, Hrs.	0 (control)	25	100	400	1,000	3,000
	Specimen	Date :					
Unit No.:							
No. of Specimens		10	5	5	5		
Physical	Tensile strength, psi	160	180	166	204		
	Ult. elongation, %	115%	115%	127%	208%		
	Modulus, psi	254	140	170	172		
	Swell ratio, %	2.7	3.3	3.6	3.6		
	Gel content, %	93.2%	95.7%	95.3%	94.6%		
	Appearance	Clear	2	3	sticky, 4		
Optical	Total optical, %T						
	UV cutoff, nm						
	Color *	Faint yellow	2	3	4		
Elect.	Dielect. Stgth., V/mil						
	Leak current, ma						
Corrosion *	Copper dust, %T				4, 6, 7		
	Copper metal	—	1	3	4, 7		
	Aluminum	—	1	1	1		
	60/40 Solder	—	1	1	1		
	Nickel	—			1		
	Titanium	—					
	Silver	—					

Notes :

- | | | |
|--------------------|-------------------------|--------------------|
| 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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Table 43

Project No. 6072.1

POLYMER AGING STUDIES

Page :

Exposure Condition : Thermal Aging

A56

Material : PU Z-2591

Notebook No: 2221

Atmosphere : Nitrogen

Temperature : 105 °C

Description :

		0 (control)	25	100	400	1,000	3,000
Specimen	Exposure, Hrs.						
	Date :						
	Unit No. :						
	No. of Specimens	10	5	5	5		
Physical	Tensile strength, psi	160	209	215	69		
	Ult. elongation, %	115%	158%	190%	199%		
	Modulus, psi	254	221	197	61		
	Swall ratio, %	2.7	3.2	3.5	4.0		
	Gel content, %	93.2%	96.3%	95.7%	91.0%		
	Appearance	Clear	1	2	3-4		
Optical	Total optical, %T						
	UV cutoff, nm						
	Color *	Faint yellow	1	2	3-4		
Elect.	Dielect. Stgth., V/mil						
	Leak current, ma						
Corrosion *	Copper dust, %T				4, 6, 7		
	Copper metal	---	1	2	4, 6, 7		
	Aluminum	---	1	1	1		
	60/40 Solder	---	1	1	1		
	Nickel	---					
	Titanium	---					
Silver	---						

Notes :

- | | | |
|--------------------|-------------------------|--------------------|
| 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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Table 44

Project No. 6072.1

POLYMER AGING STUDIES

Page:

Exposure Condition : Thermal aging

A57

Material : PU Z-2591

Notebook No: 2591

Atmosphere : Nitrogen

Temperature : 130 °C

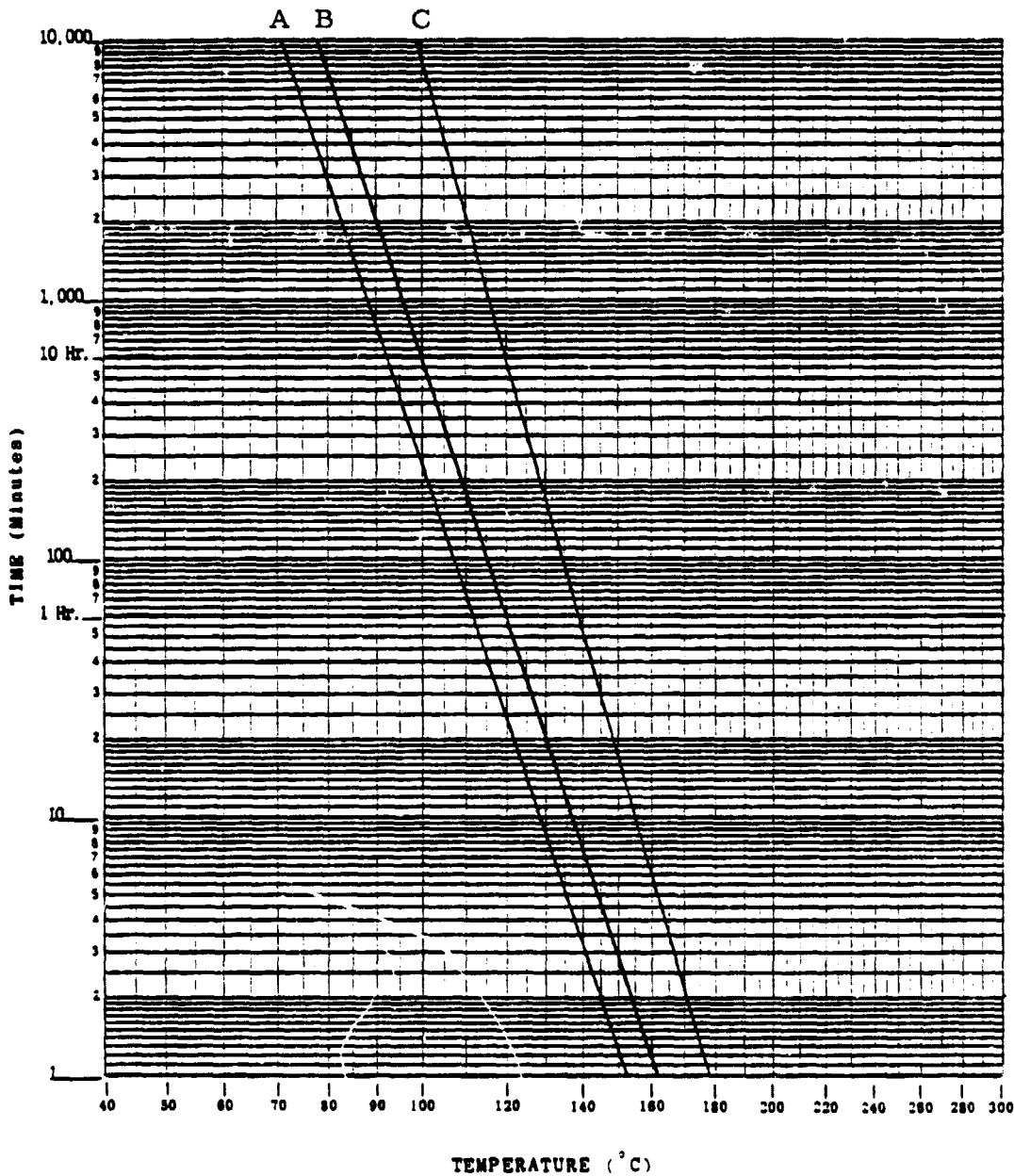
Description :

Specimen	Exposure, Hrs.	0 (control)	25	100	400	1,000	3,000
	Date :						
Unit No. :							
No. of Specimens	10	5	5	8			
Physical	Tensile strength, psi	160	172	149	(5)		
	Ult. elongation, %	115%	195%	387%	(5)		
	Modulus, psi	254	152	60	(5)		
	Swell ratio, %	2.7	3.9	5.1	NT		
	Gel content, %	93.2%	95.5%	86.6%	NT		
	Appearance	Clear	3	4, sticky	4, 6, 7		
Optical	Total optical, %T				NT		
	UV cutoff, nm				NT		
	Color *	Faint yellow	3	4	4		
Elect.	Dialct. Stgth., V/mil						
	Leak current, ma						
Corrosion *	Copper dust, %T			NT	NT		
	Copper metal	---	4	6.7	6.7		
	Aluminum	---	1	1	NT		
	60/40 Solder	---	1	1	NT		
	Nickel	---					
	Titanium	---					
	Silver	---					

Notes :

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

Half-Life / Temperature Graph
New Peroxides ^{a.}



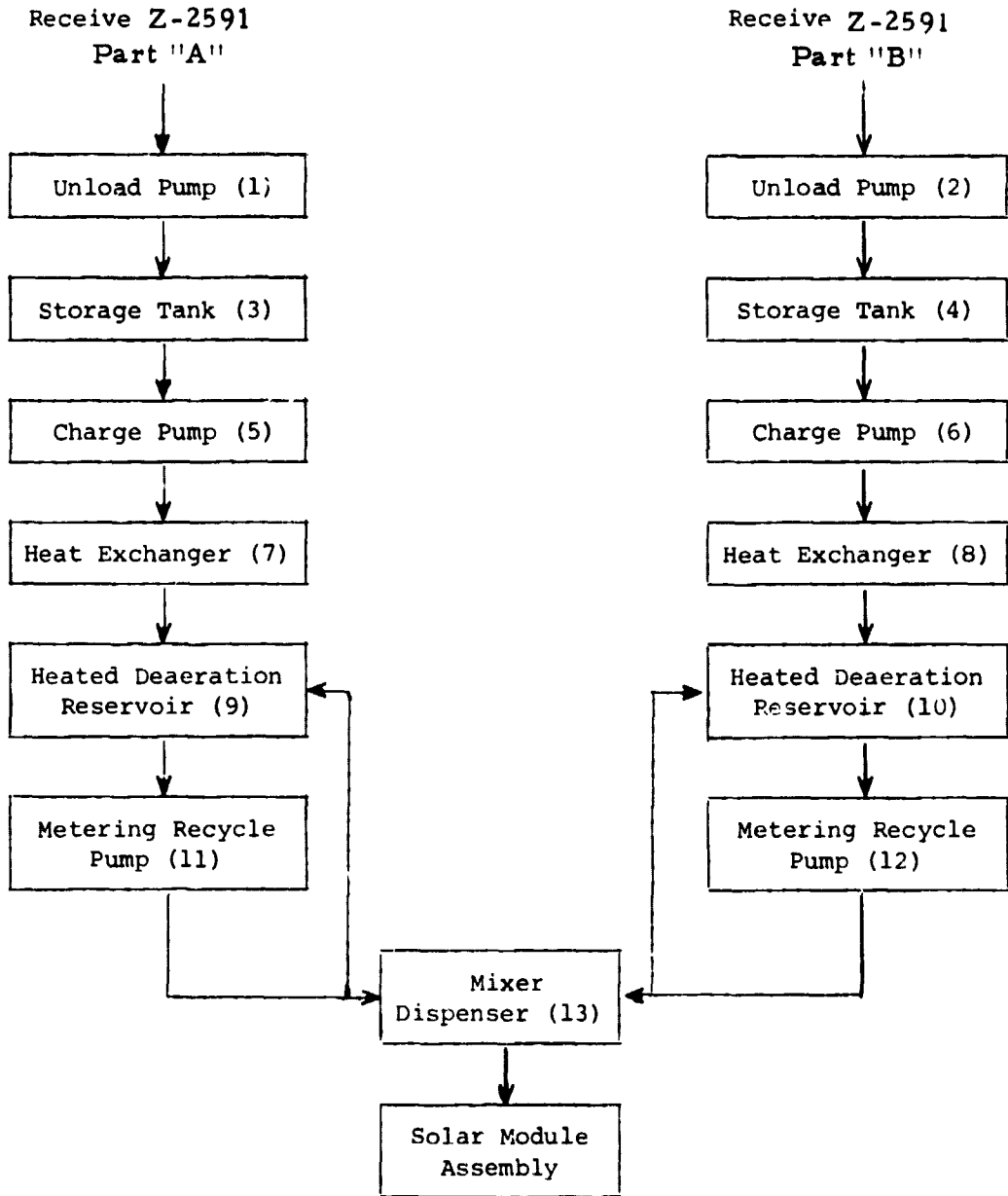
- A. Lupersol 331-80B
- B. Lupersol TREC, Lupersol-99
- C. Lupersol 101

a. Decomposition of 0.2 molar solutions in dodecane

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Figure 2

PRODUCTION FLOW CHART
ALIPHATIC POLYURETHANE
Development Associates; Z-2591

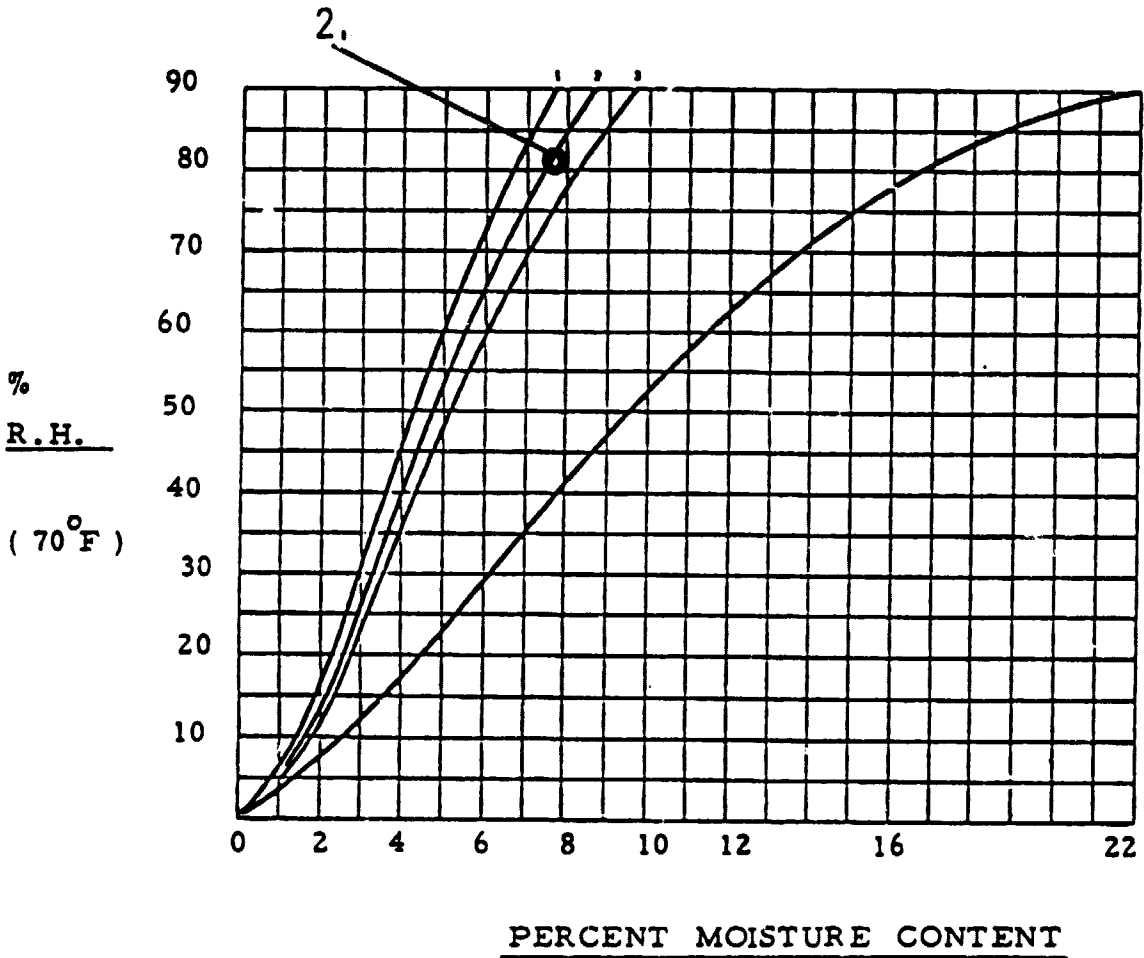


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Figure 3

HARDBOARD PRODUCTS

% MOISTURE / % R.H.



2. SUPER DORLUX

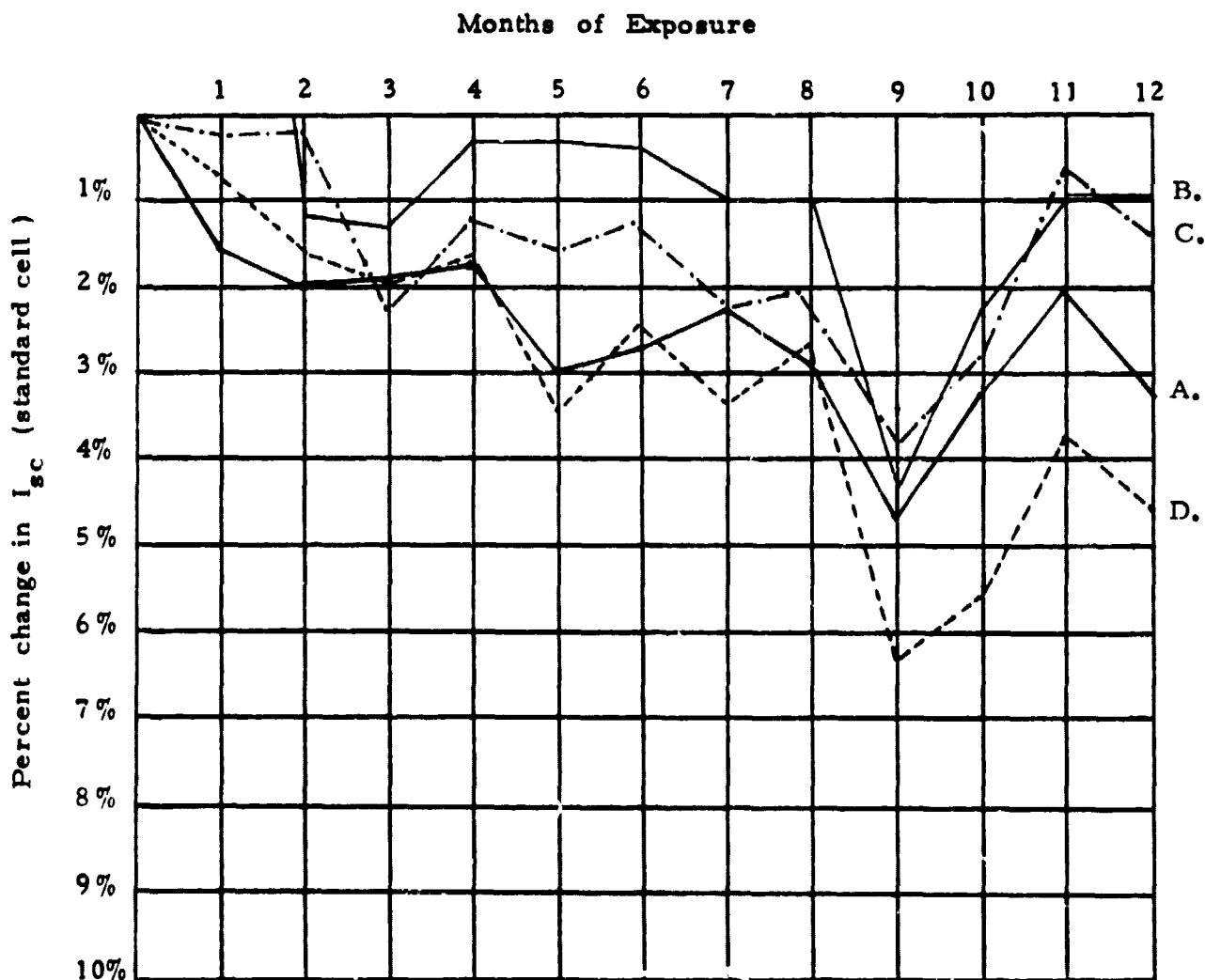
- LINEAR COEFFICIENT OF HYGROSCOPIC EXPANSION
0.35 TO 0.4 % OVER 0 TO 100 % R.H. RANGE

Figure 4

Soiling Experiments

Percent change in short-circuit current
after twelve months outdoor exposure .

Sunadex Glass

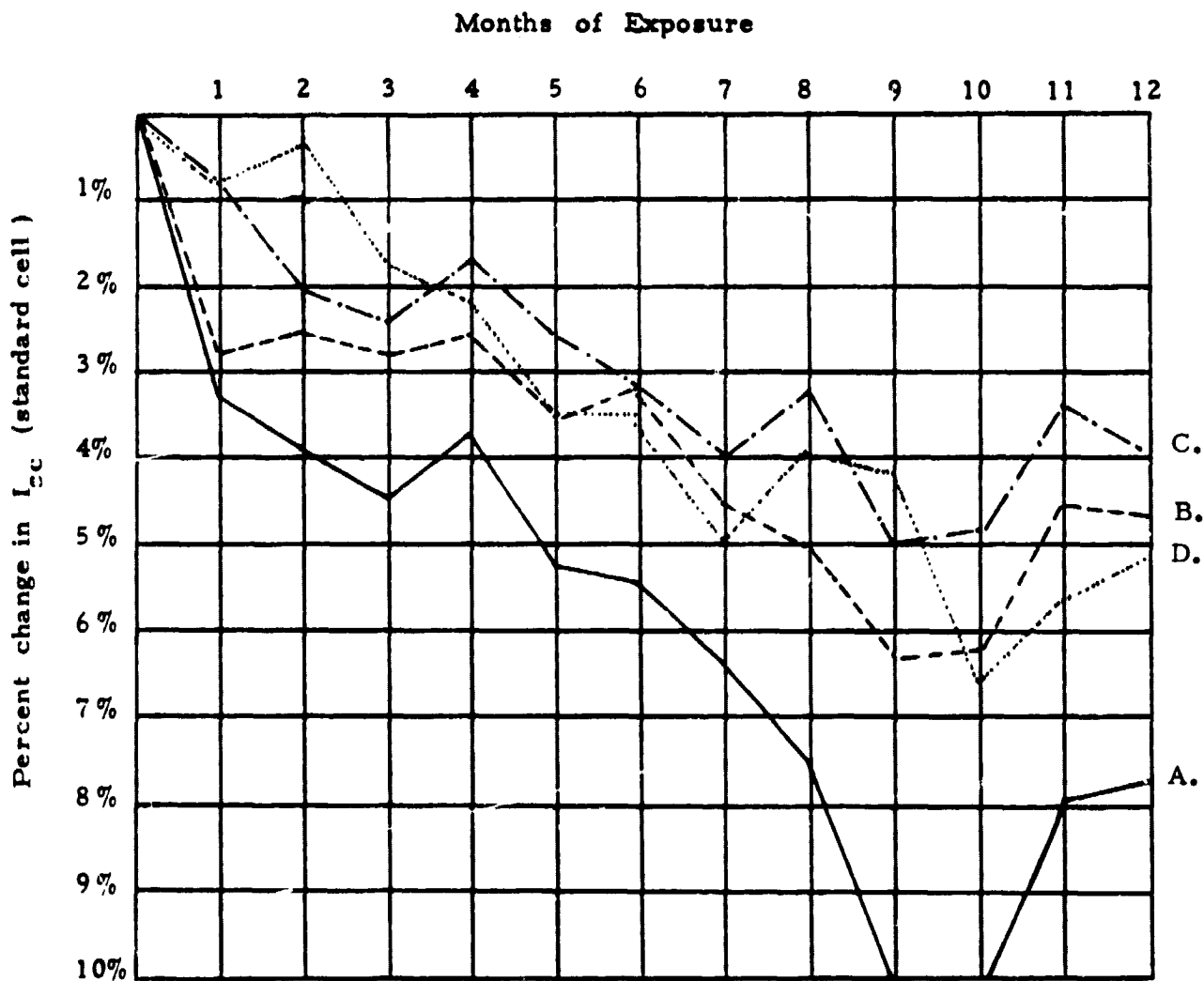


- A. Control , no coating
- B. L-1668 treatment
- C. E-3820 treatment
- D. OI-650 coating

Figure 5

ORIGINAL PAGE IS
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after twelve months of outdoor exposure .Acrylar Film

(X-22417 , 3M Corp.)



- A. Control , no coating
 B. Ozone followed by L-1668
 C. Ozone followed by E-3820
 D. L-1668 treatment

Figure 6

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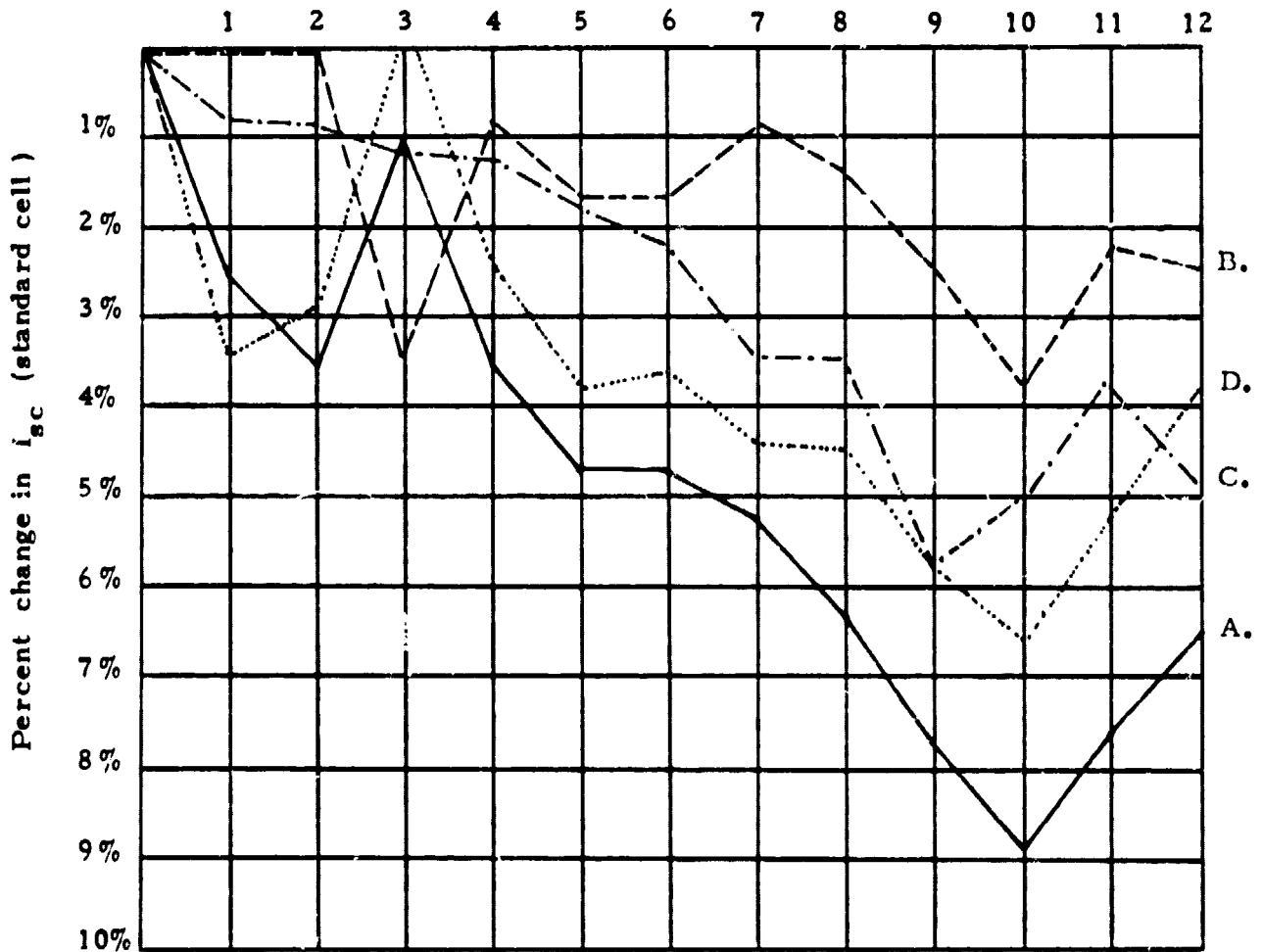
Soiling Experiments

Percent change in short-circuit current
after twelve months of outdoor exposure.

Tedlar Film

(100BG30JT , DuPont)

Months of Exposure



- A. Control , no coating
- B. E-3820 treatment
- C. Ozone followed by L-1668
- D. Ozone followed by E-3820

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APPENDIX B

Development Associates Laboratory Report

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DEVELOPMENT
TESTING**DEVELOPMENT ASSOCIATES**

LABORATORY REPORT FOR:

DATE:

12/81

Recommendations for the Hand Casting
of Development Associates 2-part Polyurethane Elastomers

The two-part casting systems developed by Development Associates Inc. are composed of a "Part A" which contains hydroxyl terminated components combined with various additives, and a "Part B" which contains a diisocyanate terminated prepolymer. These two parts when mixed together react to form the polyurethane polymer. The isocyanate (NCO) groups in the Part B are capable of not only reacting with the hydroxyl groups of the Part A to form the solid polyurethane elastomer, but also react with any group containing an active hydrogen ie: water, amines, carboxylic acids, etc. In normal use the most troubling of these undesirable reactions for the manufacture of solid elastomers is the NCO/water reaction. When water reacts with the diisocyanate the result is carbon dioxide gas. The CO₂ forms bubbles and uses up NCO groups which are needed for the proper formation of the elastomeric polymer. The formation of foam or large bubbles in the casting indicate that the compound has been contaminated with water.

The Part A is less reactive than the Part B but it is hygroscopic and if allowed to stand open it will absorb moisture from the air which will cause bubbles when the casting is made. At the time of manufacture, both Parts A and B are degassed to remove all traces of moisture and the containers' head space is purged with dry nitrogen. The containers should be kept closed whenever not in use, and the materials should be blanketed with dry nitrogen if they are to be stored for long periods of time.

To insure the dryness of the Parts A and B, warm them to approximately 50°C (125°F) and degass in a vacuum chamber until the bubbling stops. Remove the containers from the vacuum chamber and seal them until the material cools to room temperature. Determine the desired batch size and select a clean and dry mixing container which has at least twice the volume of the material to be mixed, using an oversized container helps when it comes time to degass the mix. Accurately weigh the two parts into the mixing vessel, too much or too little of either component will produce a final product which is soft and sticky. Mix the components until the mix goes clear and no more striations can be seen. Stir carefully so as not to entrap more air than necessary. Also scrape down the sides of the vessels and spatula to insure all the material gets mixed in. Next place the mixture in the vacuum and degass until the bubbling slows down or stops. It may be necessary to let air into the vacuum several times before the foam, formed by mixed-in air, "breaks" and the mixture bubbles freely. After the mixture is satisfactorily degassed, carefully pour on the previously prepared substrate. By pouring slowly at one spot, it will be easier to get the material to flow under embedments and reduce or eliminate entrapped bubbles.

DEVELOPMENT ASSOCIATESRESEARCH
DEVELOPMENT
TESTING

LABORATORY REPORT FOR:

DATE:

(page two)

12/81

cont'd

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The preparation of the substrates, molds and encapsulations is just as important as material preparation for successful castings. All surfaces must be free from grease, mold release, flux, acid residue and moisture. If the surface is to adhere to the urethane, it should be primed with the appropriate primer and thoroughly dried. If the surface is to release from the urethane, a suitable mold release must be applied. In order that moisture does not condense back onto the surfaces to be cast over, keep the parts warm--50°C (125°F).

After casting it may be desirable to vacuum the whole assembly before the casting material gels. Normally however, it is only necessary to pour carefully and as soon as possible after mixing. Keep the casting warm and undisturbed until the casting material has gelled. It is helpful to place a drop of the casting material next to the part being cast to test for degree of cure. After the material has gelled, the cure can be completed at a temperature of 50-70°C (122-158°F). The length of the cure cycle depends on the gel time of the material, the mass of the material, starting temperature of the components, the cure temperature, the heat transfer properties of the mold, etc. In general the longer gel time required for hand mix application makes room temperature cures impractical because of the long cure cycle (24-72 hours), increasing the chances that the casting will be disturbed or contaminated. Typically a casting can be cured at 65°C (150°F) in less than two hours. The material can be formulated for quick cures but the gel time becomes proportionately shorter making hand mixing more difficult.

Allow the casting to cool to room temperature before touching the front surface. The material will continue to post cure or "finish" at room temperature for several days until ultimate properties are reached.

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Common Problems, Causes and Remedies in
Casting 2-part Polyurethane System by hand

<u>Problems</u>	<u>Causes</u>	<u>Remedy</u>
Bubbles in casting	Moisture in the A or B components	Degas both components prior to use.
	Moisture in the mix- ture introduced by humid air.	Degas this mixed com- ponent.
	Contaminated substrate or encapsulation	Completely clean, dry and prime all surfaces in con- tact with the cast urethane. Keep parts warm to prevent readsorption of moisture on surfaces.
	Mechanical entrapment of air	Mix carefully and degas mix. Pour carefully while the ma- terial is still low in vis- cosity.
Soft, sticky castings	Improper mixing ratio	Accurately weigh components into clean and dry mixing vessel.
Swirls and striations	Bad mixing	Mix thoroughly but careful- ly until no more striation can be seen and material is clear.

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Material: Z-2591 Clear Aliphatic Urethane Compound

Use: Photo Voltaic Cell Pottant

Type: Two component reactive polyurethane

Hazards: Part A for industrial use only, non hazardous.

Part B contains an isocyanate. Good ventilation must be used.

Storage: Both materials should be protected from moisture. Storage temperature should be 60 - 80°F.

1. Component Z-2591 Part A

1-1 Appearance: clear liquid

1-2 Specific Gravity: 1.01 @ 25°C.
1.005 @ 38°C.1-3 Brookfield Viscosity:
as manufactured:150-220 cps @ 25°C RVT #2 spindle, 50 rpm
40-100 cps @ 38°C RVT #2 spindle, 50 rpm

1-4 Hydroxyl Value: 120-126

1-5 Acid Value: 0.1 max

1-6 Water Content: (as packaged) 0.1% max

2. Component Z-2591 Part B

2-1 Appearance: crystal clear liquid

2-2 Specific Gravity: 1.07 @ 25°C.
1.06 @ 38°C.2-3 Brookfield Viscosity:
as manufactured:100-500 cps @ 25°C RVT #2 spindle, 50 rpm
50-200 cps @ 38°C RVT #2 spindle, 50 rpm

2-4 % NCO: 27 - 29%

3. Mixing Information

3-1 Ratio by Weight: Part A $\frac{71.25}{28.75}$
" B3-2 Ratio by Volume: Part A $\frac{72.5}{27.5}$
" B

3-3 Gel Time: From 3 to 60 min. @ 25°C as required. As supplied for hand casting 20 - 40 min. @ 25°C.

3-4 Cure Rate: 5 min. to 72 hrs. dependent on temperature and gel time. As supplied for hand casting 1 - 2 hrs. @ 65°C.

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Z-2591 Data Sheet cont'd

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4. Physical Properties

- 4-1 Hardness - Shore A-2 45
- 4-2 Tensile Strength 160 psi
- 4-3 Elongation 115%
- 4-4 Tangential Modulus 254 psi
- 4-5 Transmissivity 90.5%
- 4-6 Tg Below -34°C , no sharp brittle point above -56°C