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SUMMARY

The following highlights key findings from this reporting period:

- While "standard cure" A9918P EVA encapsulant, laminated between low iron glass, shows significant yellowing after 17 weeks in a xenon-arc Weather-Ometer, "neat" EVA with no additives shows little or no yellowing after the same exposure.

- When similar laminates were prepared and exposed in the Weather-Ometer, using A9918P with the Lupersol 101 crosslinker removed from the encapsulant, color development after 10 weeks was reduced by approximately 2/3. This result strongly implicates Lupersol 101 in the discoloration of EVA encapsulant.

- Similar Weather-Ometer aging studies of other laminates, prepared using EVA with various combinations of the A9918P additives, suggests that EVA discoloration arises primarily from Naugard P and an interaction of Lupersol 101 with Cyasorb UV-531. Transformation products of these additives appear to be giving rise to yellowing, rather than the Elvax 3185 resin itself.

- When Lupersol TBEC was substituted for Lupersol 101 in the encapsulant (i.e. "fast cure" 15295P formulation rather than the "standard cure" A9918P), the rate of yellowing was reduced by a factor of approximately 2.5 based on 17 weeks in the Weather-Ometer.

- Use of a cerium-oxide containing low-iron glass superstrate reduced the rate of yellowing of A9918P EVA by approximately 75%, based on 17 weeks U.V. exposure in the Weather-Ometer, presumably by screening out most of the incident U.V.-B light.

- When laminates were prepared and exposed using 15295P EVA and cerium-oxide containing glass superstrate, there was no visible yellowing after 17 weeks in the Weather-Ometer.

- Preliminary analytical results show no measurable loss of acetic acid from very browned, field-aged EVA and no evidence of conjugated unsaturation.

- Analysis also reveals the loss of Cyasorb UV-531 in both field-aged and laboratory U.V. aged samples, but only in the presence of Lupersol 101. This result supports the above noted finding of an interaction of Lupersol 101 with UV-531 as contributing to color formation in the presence of U.V.

1.0 INTRODUCTION

The goals of the NREL PVMaT program are, among others, to reduce module manufacturing costs and improve the quality, and we might add here the reliability, of manufactured PV products. But lower production costs will require economies of scale, and this means that the large potential market of central power generating stations needs to be opened up. In a 1989 report, DOE concluded, "...that utilities are 'a key factor in achieving large-scale markets' that would drive down costs." (1)

The report goes on to say, "However, in general, utility companies are not ready to embrace the PV technology on a large scale, in spite of several potential advantages of PV as a large-scale power-generating source." (1) Electric utilities seem to be in a "wait-and-see" mode, and show no interest at the present time in making investments of the magnitude that would make PV more competitive with other power sources. (1)

One component critical to the service life of PV modules is the useful life of the EVA encapsulant which is employed extensively by module manufacturers on a worldwide basis. This pottant has been in commercial use since 1982 (2), and over that time has proven to be a dependable material from the standpoint of production, module fabrication, and end-use. But despite the widespread acceptance of EVA (ethylene-vinyl acetate copolymer) for PV encapsulation, some module producers, end-users, and investigators have reported a yellowing or browning phenomenon with EVA in the field. While the incidence of this discoloration/degradation appeared at comparatively few sites at the time that this present program was conceived, it raised serious concern as to the long term reliability of EVA encapsulated systems.

Most notable was the browning degradation of the EVA encapsulant at Carrizo Solar Corporation's Carrisa Plains Photovoltaic Power Plant in California, which had a profound effect on the PV industry with respect to consumer confidence and reliability standards. The news of the browning and ultimate demise of this plant quickly transcended boundaries of small circulation PV industry newsletters, making headlines in national publications such as Barron's.

Surprisingly, while there had been considerable discussion of the discoloration/degradation of EVA in the industry at the time this study was proposed to NREL, there was insufficient published information from which to draw meaningful conclusions regarding its cause(s).

Consequently, under the NREL PVMaT program, Springborn Laboratories proposed to conduct a thorough review of published information and internal reports and documentation, where available, from proposed PVMaT team members and other sources. More importantly, Springborn Labs proposed to conduct a detailed survey of module manufacturers, primarily proposed team members (see Appendix 1 - Team Member List) - both those who had experienced EVA discoloration and those who had not, with an emphasis on well documented case histories.

Prior to December 1992, the discoloration of EVA, reported at the Carrisa Plains facility had been attributed to high operating temperatures, approximately

90°C, and increased light intensity resulting from mirror-enhanced light exposure (3,4,5). It is interesting that field survey findings on modules operated at normal conditions of temperature and light intensity were consistent with this speculation - that is, the discoloration was not nearly as severe with these other modules as that experienced at Carrisa Plains.

The Phase I survey of case histories of EVA-based encapsulant discoloration in fielded modules in the U.S., conducted during the first year of this program, revealed that the problem is limited to areas of the West and Southwest that have comparatively high solar insolation and ambient temperature. There has been only one confirmed case of discolored EVA encapsulant from modules fielded in the Northeast, and that occurred after 12 years in Maryland.

The absence of hard data regarding module operating temperatures, solar insolation, onset of discoloration, and quantitative evaluation has made correlations difficult if not impossible. However, the degree of discoloration does appear to correlate with increasing average daily direct normal solar radiation and approximate maximum module operating temperature, as estimated from maximum ambient temperatures.

Also, it is clear that the discoloration problem is not limited to the modules of any one manufacturer, however, the rate and degree of discoloration do appear to vary from company to company. Also, discoloration is not limited to EVA encapsulant sheet from any one supplier.

During the first year of this program, an accelerated U.V. aging method was selected. On careful review of the various types of accelerated U.V. aging equipment available, an Atlas Ci35A Weather-Ometer Xenon Exposure System was selected as the preferred equipment for this work. To summarize, some of the more significant advantages of the Ci35A include:

1. The spectral irradiance and wavelength dependence of filtered xenon light in the UV and visible range of the spectrum closely simulates that of natural sunlight, with no large spikes as are often found with mercury lamps or carbon arc sources.

2. The xenon-arc source is widely accepted by industry (e.g. textile, automotive, plastic) and Government for accelerated weathering.

3. The Ci35A is flexible in that the operator is able to set, monitor, and control the irradiance, temperature, humidity, and water spray.

4. The Ci35A has the capacity for many more samples than the table top models - more than sixty 2.6 x 5.0 inch samples, and twice that number if 2.6 x 2.5 inch samples are used. This is particularly important considering the scope not only of the Task 2 problem definition studies, but also the Task 5 evaluation of improved encapsulant formulations.

Disadvantages of the xenon-arc include degradation of filters and the air-cooled lamp, requiring periodic replacement of both, and comparatively high cost of the equipment and replacement parts.

On balance, however, this device was superior to any others. Consequently, a Ci35A device was purchased for the program, and was calibrated for black panel temperature and irradiance.

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1) A. Zipser, "Solar Eclipse, Will the Mideast Crisis Make it a Hot Item Again?," Barron's, pp 16, 31 (August 20, 1990).

2) J.H. Wohlgemuth and R.C. Petersen, Solar Cells: Their Science, Technology, Applications and Economics, Solarex Experience with Ethylene Vinyl Acetate Encapsulation, (Elsevier Sequoia, 1991). pp 383-387.

2.0 FURTHER PROBLEM DEFINITION - LABORATORY AGING STUDIES

2.1: Purpose: Task 2 of this PVMaT project involves conducting laboratory problem definition work with an emphasis on controlled accelerated U.V. aging studies (AAS) to evaluate the influence of various compositional, processing, and operating parameters on EVA (ethylene-vinyl acetate copolymer) discoloration. In support of these AAS of coupon-size EVA laminates, an Atlas xenon arc Ci35A Weather-Ometer was procured, installed, and calibrated for temperature and irradiance (See Annual report under this subcontract, for the period December 30, 1992 to March 31, 1994).

2.2: Sample Preparation: For these comparative accelerated aging studies, coupon-size laminates, measuring 2.7 x 2.75 inches and preferably less than 0.255 inches thick, were used. These were prepared by vacuum lamination using the commercial time/temperature/vacuum schedule recommended for encapsulation work when using EVA formulation A9918P, except when the cure schedule was purposely varied in order to assess its effect. A laboratory-scale vacuum laminator and pump were used for this work. A data logger and multiple thermocouples were used to verify the temperature profile during cure for samples cured in the laminator.

For most of this work, glass/glass laminates are being used to facilitate visual, colorimetric, and spectrographic measurements. However, some laminates contain cells in order to investigate such effects as cell/EVA and metallization/EVA interfacial chemical changes. The general constructions used are shown at the top of Table 1.

2.3: Superstrates: Glass superstrate used was low iron glass so as to allow the maximum amount of UV-B through (ie. ultraviolet light in the range of 285 to 350 nm): that wavelength region suspected as being responsible for EVA discoloration/degradation. Also, low iron glass is the superstrate most commonly used in those fielded modules which have shown a discoloration problem. TPE refers to standard Tedlar/polyester/EVA laminate backing material, where the EVA layer is a non-conformal 4% vinyl acetate content grade (ie. this EVA is a tie layer rather than an encapsulant).

Low iron glasses used in this task included Solite (AFG - samples from the mid 1980s), Starphire (PPG), Solatex II (AFG - containing cerium oxide, estimated to be at less than 4% by weight) and Airphire (PPG - also containing cerium oxide). Airphire and Solatex II benefit this application by removing most of the UV-B radiation between 280 and 330 nm, a region known to be detrimental to polymer stability (see Annual report under this subcontract, for period from December 30 1992 to March 31, 1994, NREL/TP-411-7352, for further details on these glass superstrates).

2.4: Sample Exposure Conditions: Coupon laminates were exposed to 0.55 watts/square meter (taken @ 340 nm) and 100° C in a Ci35A Atlas xenon-arc Weather-Ometer using quartz/borosilicate glass filters. The nominal lower end U.V. cut-off is 285 nm. Samples were exposed for a minimum of 17 weeks or until significant degradation/discoloration of the EVA had occurred. In all cases, samples were exposed in duplicate.

Calibration work on the Ci35A revealed that slight temperature (T) and irradiance (I) variations exist between samples placed in the top, middle, and bottom racks. Some samples were placed so as to assess the effect of this variation. However, since the purpose of the testing was to develop comparative data, most of the samples were rotated between racks on a weekly basis to normalize any minor T/I differences.

Again, it should be emphasized that the Weather-Ometer is being used only as a screening tool - that is, a laboratory technique for conducting preliminary evaluation of various module encapsulation materials/constructions in order to assess their relative U.V. aging resistance and to obtain a relative ranking of those materials/constructions. There will be no attempt to correlate accelerated aging results with field information or to develop acceleration factors, both of which are beyond the scope of this investigation.

2.5: Sample Evaluation: Coupons were monitored for color/chemical changes during the exposure. Non-destructive tests on the samples included visual fluorescence at 360 nm under a hand held "mineral light" (qualitative test for development of unsaturation), Yellowness Index per ASTM D-1925, and percent light transmission (%T) between 250 and 900 nm by U.V.-VIS (U.V.-visible spectroscopy).

Some destructive testing for analysis of additive concentrations and vinyl acetate content was also done. At the conclusion of the accelerated UV exposure period, selected samples were forwarded to Al Czanderna and John Pern at NREL for fluorescence spectroscopy and to UCONN/IMS (University of Connecticut, Institute of Materials Science) for Task 3 analysis (see section 3.0 of this report for details).

2.6 Aging Results: Quantitative yellowing results can be found in Table 1. Based on these results, contributions of each formulation ingredient to the browning process appear to be as follows:

EVA Resin (Elvax 150, now Elvax 3185): EVA, as received from the supplier without additional additives of any kind, showed little or no color development after 17 weeks exposure in the Ci35A (see samples 29164-3c through -1b in third grouping, Table 1), with either Starphire or older Solite glass superstrate, i.e., 0.7 to 1.4 Yellowness Index and no visual yellowing. By contrast, control samples containing the standard A9918P EVA show significant color change over the same period (samples 29168-1a and -2b in fourth grouping and 29201-13a and -14b at the bottom of Table 1, page 3), again with either older Solite or Starphire glass, i.e., 39.1 to 49.6 Yellowness Index and, visually a medium brown color (see photos - figure 1).

These results suggested that the browning might be related only to the additives and not to the EVA resin at all. Analytical results seem to verify this (see section 3.0 of this report for details).

Peroxide Crosslinker - Lupersol 101: Surprisingly, samples using A9918P EVA, but without the peroxide crosslinker [Lupersol 101; 2,5-dimethyl-2,5-di (t-butylperoxy) hexane] developed comparatively little color after 10 weeks of exposure (Yellowness Index of 5.4 to 7.1 versus 18.8 to 19.6 for fully formulated

A9918P). These data suggested that Lupersol 101 peroxide is playing a significant role in the discoloration. However, the Yellowness Index for these samples (5.4 to 7.1) points out that one or more of the other additives is also playing a role in the discoloration.

As a comparison, a set of samples was prepared and exposed using EVA 15295P and Solite superstrate. The only difference between 15295P and A9918P is the use of Lupersol TBEC in place of Lupersol 101 to provide a "faster cure."

The following recommended commercial lamination cycles illustrate the "faster cure" nature of 15295P:

Formulation	EVA Type	Laminator Platen Temp., Degrees C	Time in Laminator, Min.
A9918P	standard cure	150	60
15295P	fast cure	140	15

After 17 weeks in the Ci35A, these samples developed a Yellowness Index of only 14.2 to 16.7 (see samples 28937-5 and -6, center of page 4, Table 1) compared to 39.1 to 40.4 for the A9918P. Again, this comparison implicates using a peroxide crosslinking agent in the EVA, and Lupersol 101 as more detrimental than Lupersol TBEC in the color development process.

Phosphite Heat Stabilizer (Naugard P): In the second series of samples on page two of table 1, one additive each was systematically removed from the A9918P formulation. After 17 weeks of exposure, the samples with no phosphite additive (29163-2 and -1) showed significantly less yellowing (ie. 18.7 to 23.6) than the A9918P control (39.1 to 40.4).

Next a series was run using Elvax 3185 with only one additive in each sample (center of page 3 of table 1). Interestingly, the only samples to develop a significant degree of color were those with Naugard P, which exhibited a Yellowness Index of 10.7 to 11.4 after 17 weeks in the Ci35A.

However, the above experiments also caused us to suspect that the color formation might be caused by an interaction of two or more additives, likely Lupersol 101 and Naugard P, but possibly Lupersol 101 with others. Consequently, we conducted a third series with binary combinations of additives in Elvax 3185 - Lupersol 101 plus one other additive (page four of table 1, top series 29208-1a through -10A).

After 17 weeks exposure in the Ci35A, the glass/EVA/glass laminates with Lupersol 101 and Naugard P showed significant color development (Yellowness Index of 11.4 to 11.5) but no more so than with Naugard P alone (see above). Samples with Lupersol 101 in combination with Tinuvin 770 or Z6030 silane did not.

These results seem to discount a Lupersol 101/Naugard P interaction leading to chromophore development.

U.V. Absorber (Cyasorb UV 531): As indicated above, in the second series of samples listed on page two of table 1, one additive each was systematically removed from the A9918P formulation. Removal of the UV-531 greatly reduces the color development (samples 28938-5 and -6) when compared with the A9918P control.

In addition, in the series which explored binary additive combinations (page four of table 1, first series, 29208), samples with Lupersol 101 plus UV-531 showed significant color development after 17 weeks exposure in the Ci35A (Yellowness Index of 22.3). Also, analytical results by UCONN/IMS on Weather-Ometer aged samples support a Lupersol 101/UV-531 interaction.

Glass Superstrates (Solite versus Solatex II, Starphire and Airphire): After 17 weeks of aging, some significant differences in discoloration showed up in samples of A9918P using different types of glass superstrate (page one of table one, fourth grouping and bottom of page three of table one). Airphire appears to be the most effective at slowing the rate of discoloration (Yellowness Index of 9.3 at 17 weeks), but Solatex II is also very effective (Yellowness Index of 9.8 to 10.3) and the results with these two cerium-oxide-containing glasses may be within experimental error.

The control, Solite, allows a 17 week Yellowness Index of 39.1 to 40.4, while the EVA discoloration with Starphire superstrate is somewhat worse, with a Yellowness Index of 48.7 to 49.6. It is noteworthy that Starphire transmits more light in the 280 to 320 nm wavelength region than does Solite, and this could account for the difference in discoloration rate (see figures 8-11 in the Annual Report under this subcontract for the period December 30, 1992 to March 31, 1994, NREL/TP-411-7352).

2.7: Outdoor EMMA Accelerated Weathering Tests: For added confirmation of laboratory accelerated aging data based on Altas Ci35A xenon-arc Weather-Ometer exposure, selected samples were submitted to DSET Laboratories in Arizona, where they are being subjected to EMMA (Equatorial Mount with Mirrors for Acceleration) accelerated outdoor exposure. Samples, prepared in duplicate, include (for descriptions of the glass superstrates and substrates, EVA formulations, and EVA additives referred to below, see "KEY TO MATERIALS APPEARING IN TABLES," on page 12):

Solite (circa 1980s)/A9918P/Starphire (substrate)

Solatex II/A9918P/Starphire

Tefzel/A9918P/Starphire

Solite/15295P/Starphire

Solatex II/15295P/Starphire

Solatex II/15295P with no Naugard P/Starphire

Solite/A9918P/PV cells/Tedlar film laminate

These samples are being evaluated monthly by DSET Labs for Yellowness Index. Data thus far is very preliminary and inconclusive.

2.8: Conclusions from Aging Studies: These Task 2 results suggest that the photochemistry of EVA encapsulant A9918P is related to the additives - to the presence of Naugard P and an interaction of Lupersol 101 with Cyasorb UV-531. The EVA base resin, Elvax 3185, does not appear to be a significant contributor to color, unless the reaction products of Naugard P and Cyasorb UV-531 with Lupersol 101 are in turn involving the polymer in some way.

Analytical results corroborate these findings, as discussed on page 10, Section 3.0 of this report.

The use of cerium oxide-containing glass or window glass greatly reduces the rate of discoloration of EVA A9918P, presumably by filtering out much of the UV-B radiation (ie. 285 to 350 nm).

Also the use of Lupersol TBEC, as a replacement for Lupersol 101, significantly reduces the rate of EVA discoloration.

When Lupersol TBEC-based EVA is employed with Airphire or Solatex II cerium-oxide containing superstrate, essentially no color development occurs during 17 weeks exposure in the Ci35A (see page four of table one, second grouping).

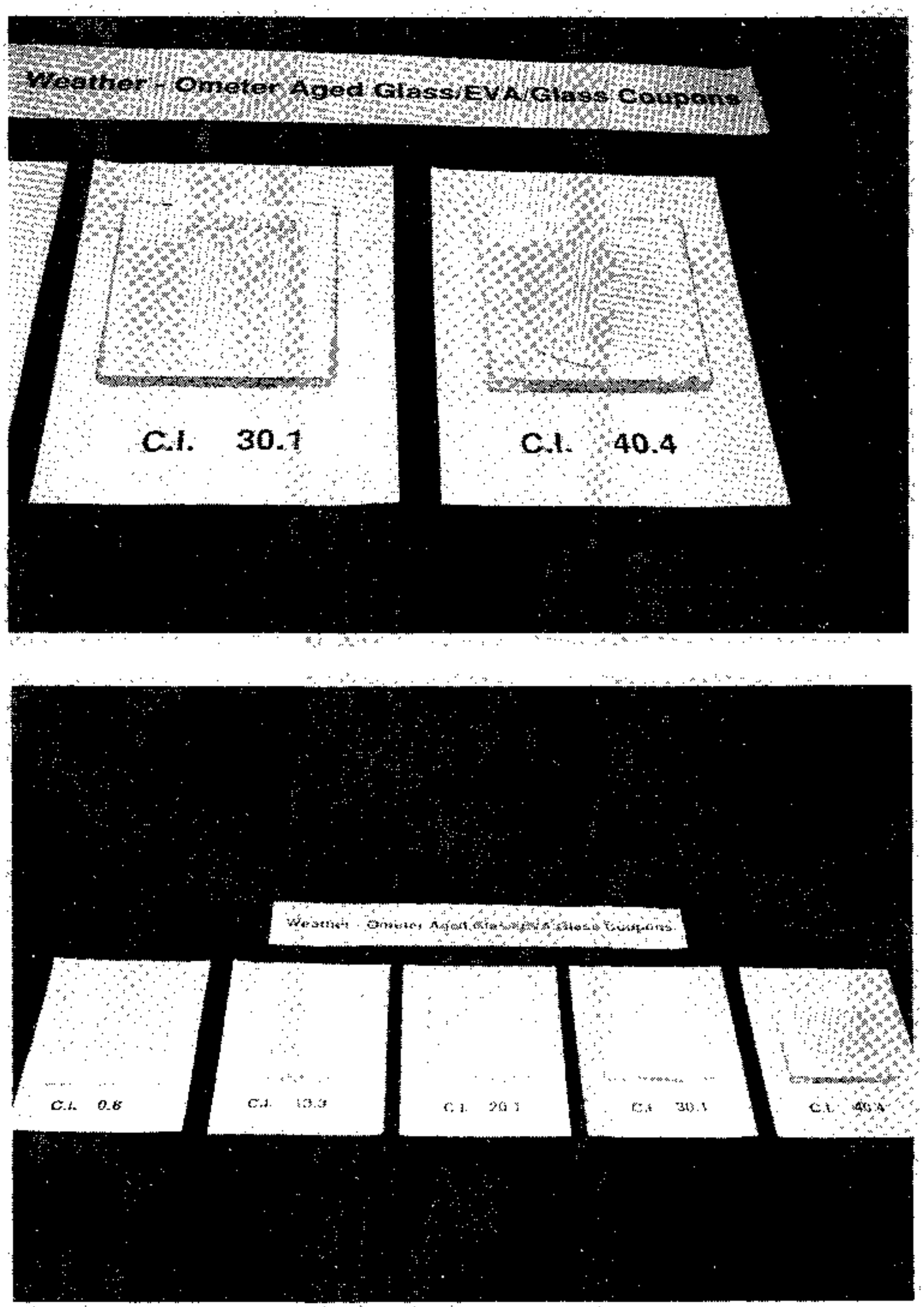

Figure 1 : Color Indexes: 0.8 through 40.4

3.0 DEFINE POSSIBLE DEGRADATION MECHANISMS

3.1; Purpose: Task 3 involves instrumental analysis and polymer characterization to verify suspected chemical degradation mechanisms. Both field-aged and laboratory Weather-Ometer-aged EVA-based modules and laminates were evaluated by a variety of analytical methods including GC/MS (gas chromatography/mass spectrometry) for UV absorbers, GC, FTIR (Fourier transform infrared spectroscopy) for unsaturation and evidence of oxidation, thermogravimetric analysis for vinyl acetate content of the EVA, DSC (differential scanning calorimetry) for residual peroxide, and microscopy for morphological changes.

This task is being performed with assistance from the University of Connecticut, Institute of Materials Science, Storrs, CT (UCONN/IMS).

The following abbreviated discussion summarizes preliminary and somewhat speculative conclusions that have been drawn from the work to date. However, an expanded and complete Task 3 report on this work is being prepared and will be included in the next annual report.

The various field aged modules referred to in the tables are identified in Table 2. Panels #1 through #3 were taken from the Carrisa Plains arrays.

* Based on TGA analysis, there is no measurable loss of acetate group from the EVA resin in field aged modules (Carrisa Plains - both moderately and severely browned). See Table 3 at the end of this report.

* IR analysis shows no significant level of double bond formation (669 cm-1) in browned EVA, functionality that would be present were there conjugated unsaturation in the EVA. See figure 2.

Based on these two observations, there appears to be no measurable photo-thermolysis of the vinyl acetate groups, and this is consistent with our finding of no discoloration of weather-Ometer aged "neat" EVA - that is, EVA without additives of any kind. These above two findings favor another mechanism.

* GC/MS and GC/FID analysis by UCONN reveals loss of both Cyasorb UV-531 in both field aged and laboratory Weather-Ometer aged EVA samples (see Tables 4 and 5 at the end of this report). This confirms, by another analytical method, what John Pern and Al Czanderna had found and reported previously. (1)

In addition, preliminary GC/MS results suggest that the hindered amine light stabilizer (HALS) Tinuvin 770 is also depleted.

* However, more importantly, GC/FID analysis shows that in Weather-Ometer-aged control EVA samples, in A9918P with no Lupersol 101 and in EVA with UV-531 or 770 as the only additive, there was no significant loss of either additive. See Table 6.

The above results are consistent with our hypothesis of a Lupersol 101 interaction with both of these additives in A9918P, that the color formation is largely the result of Naugard P and the interaction of UV-531 with Lupersol 101 and has little or nothing to do with the base EVA resin.

Such interactions are apparently minimal when Lupersol TBEC is used in place of the 101, since there is comparatively little color formation taking place with the Weather-Ometer aged 15295P formulation.

* Infrared analysis indicates significant oxidation of field-aged EVA areas that are in proximity to a comparatively permeable backing material and little or no oxidation in those areas, namely between the cells and the glass, where oxygen is largely excluded. Oxidation in the aged EVA above cracks in the cells or between cells shows up as hydroxyl groups with strong absorbance at approximately 3,550 cm-1. See Figures 3, 4, and 5.

Since these oxidized areas are water-white and colorless, it is speculated that any chromophores developed in these areas are being "photobleached," as previously postulated by Czanderna and others. But again, the bleaching appears to involve chromophores other than conjugated unsaturation.

REFERENCES

1. F.J. Pern and A.W. Czanderna, Solar Energy Materials and Solar Cells, Characterization of Ethylene Vinyl Acetate (EVA) Encapsulant: Effects of Thermal Processing and Weathering Degradation on its Discoloration, (Elsevier Science Publishers, 1992). pp. 3-23.

KEY TO MATERIALS APPEARING IN TABLES

GLASS AND FILM SUPERSTRATES

- Solite: low iron glass (AFG Industries Inc.), early (circa mid 1980s) production lot (stippled surface pattern on one side)
- Solatex II: low iron glass containing cerium oxide (AFG Industries Inc.) (also available as Solite II with stippled pattern on one side)
- Airphire: low iron glass containing cerium oxide (PPG Industries, Inc.)
- Starphire: low iron glass (PPG Industries, Inc.)
- Tedlar and Tefzel; fluoropolymer cover films (Du Pont Co.)

ADDITIVES FOR EVA RESIN

- Lupersol 101: peroxide crosslinking agent (Elf Atochem North America, Inc.)
- Lupersol TBEC: peroxide crosslinking agent (Elf Atochem North America, Inc.)
- Tinuvin 770: hindered amine light stabilizer (Ciba Geigy Corp.)
- Cyasorb UV 531: U.V.absorber (CYTEC Industries Inc.)
- Z6030: silane coupling agent/primer (Dow Corning Co.)
- Naugard P: phosphite stabilizer (Uniroyal Chemical Co., Inc.)

EVA FILM FORMULATIONS

- A9918P: "standard cure" encapsulant which uses Lupersol 101
- 15295P: "fast cure" encapsulant which uses Lupersol TBEC

TABLE 1

Yellowness Index Measurements (not corrected for yellowness due to 100°C Oven Aging)
For Glass/EVA/Glass Laminates (¹)

Samples [illegible]	Construction (²)	0 weeks	1 week	2 weeks	3 weeks	4 weeks	6 weeks	6 weeks	7 weeks	6 weeks	9 weeks	10 weeks	11 weeks	12 weeks	13 weeks	14 weeks	16 weeks	16 weeks	17 weeks
	"No Backing"																		
29167-4c	A9918P/Starphire/no back	0.6	0.6	0.6	1.0	1.5	1.3	2.8	2.0	2.0	1.8	0.8	-	-	-	-	-	-	-
29167-3a	A9918P/Starphire/no back	0.7	0.6	0.6	1.5	1.7	1.5	2.8	2.0	2.4	2.3	1.3	-	-	-	-	-	-	-
29167-2b	A9918P/Solite/no back	1.2	1.4	1.8	2.5	2.5	2.5	3.8	3.3	3.2	3.2	2.8	3.5	3.7	3.3	3.2	3.1	3.4	3.1
29167-1b	A9918P/Solite/no back	1.4	1.5	1.5	2.0	2.6	3.6	3.8	3.1	3.2	3.1	3.1	3.3	3.7	3.2	3.3	3.3	3.5	3.3
29166-3c	Solatex II (Cerium)/no back	1.4	1.8	1.6	2.2	2.7	3.8	4.6	3.1	4.0	3.7	3.3	4.6	4.6	4.3	4.6	4.3	4.6	4.2
29166-4a	Solatex II (Cerium)/no back	1.6	1.6	1.3	2.3	2.5	2.5	3.6	2.2	3.2	3.0	2.6	3.7	4.1	3.6	3.5	3.3	3.7	4.4
	"Special Backing"																		
28938-1	101/Starphire/10 mil Tedlar Back	0.0*	-0.7*	-0.4*	-1.3*	-0.7*	2.6*	-0.2*	-0.2*	0.1*	0.1*	-0.3*	0.3*	0.2*	0.6*	0.4*	0.5*	0.3*	0.7*
28938-2	101/Starphire/10 mil Tedlar Back	0.0*	-1.0*	-1.0*	-1.6*	-1.0*	1.9*	-0.3*	-0.2*	0.1*	-0.1*	-0.1*	-0.0*	-0.2*	0.1*	0.1*	-0.2*	-0.2*	0.2*
	"Sample edges sealed with epoxy"																		
29164-3c	Elvax 3185 as received/Starphire	0.1	0.1	0.1	0.1	0.9	0.3	1.6	0.9	1.0	0.9	0.3	-	-	-	-	-	-	-
29164-4a	Elvax 3185 as received/Starphire	0.6	0.3	0.2	0.0	1.0	0.8	1.7	0.8	1.1	0.7	0.3	2.0	1.6	0.9	1.3	1.2	1.3	1.4
29164-2c	Elvax 3185 as received/Solite	0.4	0.7	0.6	0.5	1.6	1.2	2.0	0.9	2.0	1.3	1.1	2.7	2.2	1.7	2.0	2.1	2.0	2.1
29164-1b	Elvax 3185 as received/Solite	0.8	1.0	0.9	0.8	1.6	1.1	2.0	1.1	2.0	1.3	1.2	2.6	2.1	1.7	2.1	2.0	2.2	2.3
29163-3c	No peroxide/Solite	0.5	1.0	1.0	1.3	2.2	1.7	3.4	3.1	4.7	5.3	5.4	-	-	-	-	-	-	-
29163-4a	No peroxide/Solite	0.6	1.2	1.2	1.9	2.5	2.2	4.2	3.9	5.5	6.6	7.1	-	-	-	-	-	-	-
29165-3	A9918P/Solite	1.5	2.8	4.4	6.7	7.3	7.0	11.0	12.3	15.0	18.1	19.6	-	-	-	-	-	-	-
29165-4	A9918P/Solite	0.9	2.9	4.1	5.8	7.1	8.4	10.5	11.8	14.1	17.2	18.8	-	-	-	-	-	-	-
29175-2c	Vacuum cured /Starphire	-0.3	-0.1	1.6	6.0	13.8	19.1	23.6	27.4	29.4	30.2	32.6	34.5	36.3	36.3	37.4	38.2	38.3	40.5
29175-1b	Vacuum cured /Starphire	-0.1	0.1	1.1	4.9	9.9	17.7	21.8	25.2	30.9	33.5	37.9	39.8	41.1	44.4	46.4	47.4	49.1	50.9
29174-4a	15' oven post cure/Starphire	-0.8	1.2	3.4	5.7	6.4	8.7	9.7	11.3	14.6	17.2	21.8	24.9	27.9	31.9	36.1	40.5	43.9	47.6
29174-3c	15' oven post cure/Starphire	-0.7	1.5	3.8	7.0	7.7	10.1	10.3	13.0	16.0	18.7	22.9	26.2	28.9	32.6	36.9	40.9	44.7	48.4
29174-1a	A9918P/Starphire	0.5	1.6	4.6	7.3	7.7	10.0	11.1	14.0	16.9	19.5	-	-	-	-	-	-	-	-
29174-2b	A9918P/Starphire	0.7	1.8	4.9	7.0	7.6	9.8	11.3	14.2	17.3	19.9	-	-	-	-	-	-	-	-
	"A9918P Standard"																		
29166-2c	Solatex II (Cerium)	1.7	2.4	3.2	4.7	5.8	5.7	7.2	6.7	6.7	7.0	6.9	8.5	8.4	8.3	8.8	9.3	9.8	10.3
29166-1b	Solatex II (Cerium)	1.8	2.6	3.5	4.6	6.1	6.5	7.2	6.4	7.0	7.1	6.8	8.4	8.2	8.1	8.7	8.9	9.4	9.8
29176-6c	Window Glass	-1.1	0.0	1.6	3.2	3.2	4.2	4.0	5.0	5.3	5.0	6.9	7.7	7.6	8.6	9.8	10.7	11.6	12.9
29176-5b	Window Glass	-1.1	0.3	1.7	3.4	3.8	3.9	4.1	5.0	5.2	4.9	7.3	7.7	7.4	8.6	9.6	10.5	11.3	12.4
29176-3c	Airphire (Cerium)	1.0	2.6	3.8	4.9	4.5	6.9	5.8	6.2	6.5	5.6	7.4	7.7	7.3	7.5	7.8	8.0	8.2	-
29176-4a	Airphire (Cerium)	0.6	2.8	3.9	5.2	6.1	7.3	6.2	6.6	7.0	6.2	8.2	8.2	7.9	8.3	8.3	8.8	8.9	9.3
29168-1a	Solite	0.7	2.8	4.1	6.2	7.3	8.2	10.2	11.4	13.5	15.8	18.3	21.8	23.8	25.9	29.0	32.3	35.7	39.1
29168-2b	Solite	1.2	2.9	4.3	5.6	7.1	7.6	10.8	12.0	14.2	16.7	19.2	22.6	25.0	27.3	30.3	33.6	37.2	40.4
29154-8a	Starphire	0.4	1.8	3.6	4.2	6.3	7.2	9.6	12.7	14.9	17.8	21.1	24.8	26.7	-	-	-	-	-
29154-7a	Starphire	0.2	1.9	4.4	5.0	6.2	8.2	11.0	13.9	16.4	19.1	23.5	26.6	28.7	-	-	-	-	-
	"Thin EVA layer"																		
29176-2b	EVA 9.5 mils /Starphire	0.4	0.6	2.5	3.2	3.9	8.6	10.7	15.6	19.2	22.3	-	-	-	-	-	-	-	-
29176-1a	EVA 9.5 mils /Starphire	-0.5	0.7	1.7	3.7	4.4	8.9	11.4	13.4	18.7	21.6	-	-	-	-	-	-	-	-
29154-15m	EVA 12 mils/Starphire	-0.1	1.3	0.2	2.9	4.8	7.8	11.2	14.0	18.8	21.6	26.6	30.6	32.9	-	-	-	-	-
29154-15m	EVA 12 mils/Starphire	-0.2	1.3	3.1	3.0	5.0	7.7	11.0	13.4	18.6	21.9	26.2	29.8	32.5	-	-	-	-	-

1) ASTM D1925-70 Standard Test Method for Yellowness Index of Plastics, Byk Gardner Colorgard System 1000

2) 150°C laminator for 5.5 minutes; post cured in an oven at 150°C for 1 hr ; 18 mil EVA layer

* Yellowness Index was normalized to eliminate contribution from haze

Table 1 (continued -2)

Yellowness Index Measurements (not corrected for yellowness due to 100°C Oven Aging)
For Glass/EVA/Glass Laminates (¹)

Samples	Construction (²)	0 week	1 week	2 weeks	3 weeks	4 weeks	5 weeks	6 weeks	7 weeks	8 weeks	9 weeks	10 weeks	11 weeks	12 weeks	13 weeks	14 weeks	15 weeks	16 weeks	17 weeks
	"18 mil A9918P"																		
29154-8a	Starphire/ "A" rotation	0.4	1.5	3.6	4.2	5.3	7.2	9.5	12.7	14.9	17.5	21.1	24.6	26.7	-	-	-	-	-
29154-7a	Starphire/ "A" rotation	0.2	1.9	4.4	5.0	6.2	8.2	11.0	13.9	16.4	19.1	23.5	26.6	28.7	-	-	-	-	-
29154-9b	Starphire/ "B" rotation	0.1	1.6	3.3	4.3	5.3	7.0	9.4	12.5	14.5	17.6	-	-	-	-	-	-	-	-
29152-1b	Starphire/ "B" rotation	0.4	2.3	4.6	5.0	6.3	7.6	9.8	10.8	13.7	16.3	-	-	-	-	-	-	-	-
29152-2c	Starphire/ "C" rotation	-0.4	1.7	3.7	4.1	6.3	7.6	9.8	12.9	15.6	18.2	-	-	-	-	-	-	-	-
29154-10c	Starphire/ "C" rotation	0.4	2.2	4.2	5.7	6.7	8.7	11.2	14.9	17.1	19.5	-	-	-	-	-	-	-	-
29154-2u	Starphire/ upper rack	0.3	2.2	4.3	5.3	6.4	8.3	11.0	13.6	16.4	19.3	-	-	-	-	-	-	-	-
29154-1u	Starphire/ upper rack	0.2	2.3	4.6	5.7	6.8	8.6	11.1	12.9	16.2	18.9	-	-	-	-	-	-	-	-
29154-3m	Starphire/middle rack	0.1	1.9	4.2	5.2	5.5	8.6	11.4	15.9	17.6	20.8	25.2	28.7	32.4	-	-	-	-	-
29154-4m	Starphire/middle rack	-0.0	2.1	4.3	5.3	6.6	8.4	11.7	15.3	17.8	20.8	24.9	28.4	31.7	-	-	-	-	-
29154-11m	Solite/ middle rack	0.6	2.8	4.4	5.1	6.2	8.1	10.3	12.6	15.0	17.7	21.7	24.4	26.6	-	-	-	-	-
29154-12m	Solite/ middle rack	0.6	2.6	4.8	5.4	6.2	7.5	9.5	11.2	13.9	16.2	18.9	21.6	23.2	-	-	-	-	-
29154-5l	Starphire/lower rack	0.1	1.8	5.7	5.4	6.9	8.7	11.3	13.5	16.8	20.1	-	-	-	-	-	-	-	-
29154-6l	Starphire/lower rack	0.1	2.1	4.7	5.3	6.8	8.4	11.1	14.0	16.3	19.6	-	-	-	-	-	-	-	-
	"Process and Formulation Variations"																		
29161-4a	Milled "A9918P"/Starphire	0.8	1.6	2.4	3.8	5.7	6.3	11.0	13.3	-	-	-	-	-	-	-	-	-	-
29161-3c	Milled "A9918P"/Starphire	0.9	2.1	3.4	4.7	6.2	6.8	10.1	11.5	14.7	17.2	18.7	-	-	-	-	-	-	-
29154-13m	A9918P/Starphire/tin side inward	0.1	2.0	4.4	5.8	6.9	9.2	11.9	15.4	18.4	21.1	25.7	29.8	33.6	37.9	40.7	44.0	47.5	51.3
29154-14m	A9918P/Starphire/tin side inward	0.0	2.2	4.4	5.7	7.0	9.0	12.3	15.0	19.0	21.6	26.1	29.7	33.4	37.7	40.3	43.1	46.8	49.9
29161-1a	Milled "A9918P"/Solite	2.1	3.2	4.6	5.9	7.4	7.9	10.6	11.8	-	-	-	-	-	-	-	-	-	-
29161-2b	Milled "A9918P"/Solite	1.5	3.2	4.3	5.1	6.6	6.9	9.5	10.6	12.2	15.6	16.8	-	-	-	-	-	-	-
29163-2	No phosphite /Solite	1.1	2.5	3.9	4.9	5.5	5.8	6.8	7.0	8.0	8.7	9.3	11.5	12.1	12.8	14.3	15.6	17.1	18.7
29163-1	No phosphite /Solite	2.2	4.5	5.8	6.5	7.2	7.2	8.6	9.2	11.0	11.6	12.6	15.1	15.7	16.6	18.4	19.9	21.7	23.6
29162-4	No silane/Solite	1.5	3.0	4.1	5.3	6.7	7.6	9.4	10.2	-	-	-	-	-	-	-	-	-	-
29162-3	No silane/Solite	1.6	3.2	4.6	6.2	7.8	8.2	10.2	10.5	13.3	15.1	17.0	-	-	-	-	-	-	-
29162-2	No Tinuvin 770/ Solite	1.9	3.7	4.6	6.0	7.4	7.7	9.9	10.1	13.3	14.7	16.8	-	-	-	-	-	-	
28938-5	No UV531/Starphire	-0.4	1.9	2.4	2.6	4.1	6.6	5.0	5.5	6.0	6.0	5.9	6.5	6.6	7.1	7.0	6.9	6.8	7.2
28938-6	No UV531/Starphire	-0.4	1.8	2.3	2.5	4.0	6.6	4.8	5.3	5.8	6.0	5.9	6.3	6.3	6.9	6.9	6.8	6.8	7.0

(1) ASTM D1925-70 Standard Test Method for Yellowness Index of Plastics, Byk Gardner Colorgard System 1000
(2) 150°C laminator for 6.5 minutes; post cured in an oven at 150°C for 1 hr ; 18 mil EVA layer

Table 1 (continued -3)

Yellowness Index Measurements (not corrected for yellowness due to 100°C Oven Aging)
For Glass/EVA/Glass Laminates (1)

Samples	Construction (2)	0 week	1 week	2 weeks	3 weeks	4 weeks	6 weeks	6 weeks	7 weeks	9 weeks	9 weeks	10 weeks	11 weeks	12 weeks	13 weeks	14 weeks	16 weeks	16 weeks	17 weeks
	"A9918P formulated with UV531 Concentration / Starphire"																		
28938-7	UV531	0.3	2.5	3.9	4.4	6.4	10.3	10.3	13.3	16.6	20.2	23.7	28.0	31.7	35.7	38.9	41.9	44.9	48.1
28938-8	UV531	0.2	2.7	4.4	4.2	6.3	10.3	10.2	12.9	16.3	19.4	22.9	26.6	30.6	34.0	37.6	44.2	44.4	47.4
28938-9	Double UV 531	0.6	3.1	5.7	7.0	9.3	12.9	12.9	15.3	18.2	21.4	24.3	28.3	-	-	-	-	-	-
28938-10	Double UV 531	0.6	3.4	5.7	6.7	9.1	13.0	12.9	15.6	18.8	22.0	24.9	29.0	32.2	35.8	38.8	42.1	45.1	48.2
28938-11	Triple UV531	-0.3	2.3	4.6	10.2	16.7	20.5	20.2	22.1	23.9	25.1	25.4	26.8	27.4	28.4	28.6	29.0	29.5	29.7
28938-12	Triple UV531	-0.2	2.4	5.0	11.7	17.6	22.2	22.7	24.7	26.4	27.4	27.9	29.6	30.2	31.1	31.4	32.1	32.6	32.7
	"EVA Plus One Ingredient/ Epoxy Sealed / Starphire"																		
29203-1a	Just 101 cured	-0.8	-0.4	0.4	-0.3	0.6	0.4	0.2	1.3	1.4	1.1	1.1	-	1.2	1.0	1.1	0.9	1.2	1.1
29203-2b	Just 101 cured	-0.6	-0.2	0.5	-0.1	0.6	0.6	-0.8	-	-	-	-	-	-	-	-	-	-	-
29203-3a	Just 101 uncured	0.4	0.0	0.8	-0.1	0.8	0.6	0.6	-	-	-	-	-	-	-	-	-	-	-
29203-4o	Just 101 uncured	0.6	0.1	0.6	0.3	0.9	0.8	0.4	-	-	-	-	-	-	-	-	-	-	-
29203-5b	Just 770	-0.2	-0.2	0.2	-0.7	0.1	0.2	-0.8	-	-	-	-	-	-	-	-	-	-	-
29203-6o	Just 770	-0.3	-0.4	0.0	-0.5	0.4	0.0	-0.8	-	-	-	-	-	-	-	-	-	-	-
29203-7a	Just Naugard P	0.8	-0.0	0.9	0.3	1.2	1.7	1.4	3.3	4.4	4.4	5.4	6.2	7.5	8.0	9.0	9.5	11.0	11.4
29203-8b	Just Naugard P	0.9	-0.1	1.0	0.3	1.1	1.6	1.5	3.6	4.6	4.2	5.2	5.9	7.0	7.5	8.5	9.2	10.3	10.7
29203-9a	Just Z6030	0.0	-0.6	-0.0	-0.2	0.5	0.1	-0.6	-	-	-	-	-	-	-	-	-	-	
29203-10a	Just Z6030	0.0	-0.2	-0.3	-0.2	0.3	0.3	-0.8	-	-	-	-	-	-	-	-	-	-	-
29203-11b	Just UV 531	-0.2	0.3	0.1	0.0	0.1	0.3	-0.9	-	-	-	-	-	-	-	-	-	-	-
29203-12c	Just UV 531	-0.1	-0.1	0.1	-0.4	0.5	0.3	-0.8	-	-	-	-	-	-	-	-	-	-	-
	"Alternative Cover Materials"																		
29202-1c	Tedlar Cover, TUT20BG3	0.0*	-1.1*	-0.5*	-0.7*	-1.3*	-0.3*	-0.8*	0.2*	0.9*	0.5*	0.6*	0.5*	1.5*	1.0*	1.3*	1.3*	1.3*	2.5*
29202-2b	Tedlar Cover, TUT20BG3	0.0*	-1.3*	-0.6*	-1.0*	-0.1*	-0.2*	-0.2*	0.9*	2.0*	0.9*	1.3*	1.4*	1.4*	1.1*	1.9*	2.1*	2.7*	2.9*
29202-3a	Tefzel T²ZM-C cover	1.0	4.2	0.9	0.6	1.6	1.8	1.3	1.8	2.2	1.9	2.1	2.1	2.1	1.7	2.0	1.9	2.4	2.0
29202-4c	Tefzel T²ZM-C cover	1.3	0.8	1.7	1.0	2.3	1.9	1.4	2.3	2.8	2.3	2.5	2.3	2.6	2.2	2.3	2.2	2.5	2.4
	"5/5/94 Control"																		
29201-13a	A9918P'/ Starphire Control 5/5/94	0.6	1.8	4.4	6.3	7.1	8.4	11.0	14.9	17.0	20.3	24.4	28.2	32.3	36.7	39.2	42.7	46.3	48.7
29201-14b	A9918P'/ Starphire Control 5/5/94	0.7	1.6	4.3	5.4	7.2	8.7	11.2	14.6	17.5	20.0	24.1	28.1	32.3	36.2	39.6	43.4	46.4	49.6
	""LLDPE / Starphire"																		
28938-15	Norchem 831/ No EVA	0.0*	2.2*	2.0*	1.2*	2.5*	4.7*	2.9*	3.0*	3.9*	3.9*	4.1*	5.1*	6.6*	6.4*	7.0*	8.0*	9.0*	10.2*
28938-16	Norchem 831/ No EVA	0.0*	1.8*	2.7*	1.3*	2.5*	4.9*	2.7*	2.9*	3.9*	3.8*	4.0*	5.0*	5.3*	6.1*	6.8*	7.6*	8.4*	9.4*

(1) ASTM D1925-70 Standard Test Method for Yellowness Index of Plastics, Byk Gardner Colorgard System 1000

(2) 150°C laminator for 5.5 minutes; post cured in an oven at 150°C for 1 hr ; 18 mil EVA layer

* Yellowness Index was normalized to eliminate contribution from haze

:able 1 (continued -4)

Yellowness Index Measurements (not corrected for yellowness due to 100°C Oven Aging)
For Glass/EVA/Glass Laminates (¹)

amples (GROUPED BY PASS)	Construction (²)	0 week	1 week	2 weeks	3 weeks	4 weeks	6 weeks	6 weeks	7 weeks	6 weeks	9 weeks	10 weeks	11 weeks	12 weeks	13 weeks	14 weeks	15 weeks	16 weeks	17 weeks
	'Peroxide Plus / starphire'																		
29208-1a	1/3 101	-0.6	-0.9	0.1	-0.1	-1.2	1.4	1.0	0.6	0.7	0.4	0.8	0.4	0.6	0.7	0.9	0.7	1.0	0.7
29208-2c	1/3 101	-0.0	-0.6	0.0	-0.1	-0.7	1.4	0.2	0.5	0.6	0.5	0.8	0.5	0.6	0.7	0.9	0.9	1.0	0.7
29208-3c	101 plus 770	0.5	0.0	0.6	0.6	0.1	2.2	1.7	1.0	1.3	1.1	1.3	1.0	1.0	-	-	-	-	-
29208-4A	101 plus 770	-0.7	0.3	0.8	0.6	0.2	2.2	2.0	1.2	1.3	1.1	1.4	1.0	1.2	1.2	1.3	1.3	1.5	1.0
29208-5B	101 plus UV531	1.7	1.8	3.3	4.1	4.2	6.9	7.4	7.8	8.4	9.6	11.4	11.5	13.5	-	-	-	-	-
29208-6C	101 plus UV531	1.4	1.5	3.5	4.6	4.6	6.8	8.0	7.6	8.9	10.2	11.6	12.7	14.4	15.9	17.7	19.4	21.2	22.3
28938-3	101 plus 770 uncured	0.9	0.8	2.2	3.2	6.7	8.2	7.0	8.5	10.8	13.3	15.9	19.5	22.7	26.3	29.4	32.5	35.7	38.9
28938-4	101 plus 770 uncured	1.0	1.4	2.8	4.0	6.2	9.0	7.3	9.0	11.3	13.8	16.6	20.3	23.0	26.8	29.8	30.7	35.8	38.8
29208-7A	101 plus Naugard	0.1	2.8	4.9	5.7	6.1	8.5	8.5	8.4	9.1	9.4	10.0	9.9	10.5	10.8	11.2	11.3	11.8	11.5
29208-8B	101 plus Naugard	0.2	2.7	4.4	5.8	5.8	8.4	8.9	8.3	9.1	9.5	10.0	10.0	10.4	10.7	11.1	11.2	11.8	11.4
29208-9C	101 plus Z6030	-0.5	-0.7	-0.6	0.1	-0.5	1.3	1.8	0.6	0.8	0.6	0.7	0.5	0.6	0.7	0.8	0.9	0.9	0.6
29208-10A	101 plus Z6030	-0.3	-0.3	0.3	0.1	-0.7	1.1	1.8	0.5	0.8	0.6	0.7	0.5	0.6	0.6	0.8	0.8	1.1	0.5
	"TBEC Formulations (3)"																		
28937-1	TBEC/Solatex II	0.0	1.2	1.2	0.1	1.8	3.2	1.8	2.0	1.8	4.1	5.5	7.7	10.1	12.9	15.5	18.5	21.3	24.2
28937-2	TBEC/Solatex II	0.3	0.6	1.2	0.5	1.7	4.1	1.8	2.0	1.8	3.4	4.5	6.3	8.3	10.7	12.6	15.1	17.4	20.4
28937-3	TBEC/Starphire	-0.4	0.1	0.2	-0.3	0.8	2.5	1.3	1.8	2.9	3.5	3.8	4.7	5.8	7.4	8.7	10.4	12.5	14.2
28937-4	TBEC/Starphire	-0.3	0.1	0.3	-0.5	0.7	2.4	1.2	1.8	2.4	4.0	3.7	5.0	6.4	8.4	10.0	11.9	14.2	16.7
28937-5	TBEC/Solite	0.2	1.0	1.2	0.4	1.7	2.3	2.1	2.4	2.7	3.5	3.8	4.7	5.8	7.4	8.7	10.4	12.5	14.2
28937-6	TBEC/Solite	0.3	1.0	1.0	0.5	1.4	3.2	2.0	2.6	3.1	4.0	3.7	5.0	6.4	8.4	10.0	11.9	14.2	16.7
28937-7	TBEC/Tedlar cover	-0.0*	-0.3*	-0.3*	-0.3*	0.0*	2.5*	0.5*	0.9*	0.7*	1.1*	1.1*	1.1*	1.2*	1.6*	2.3*	1.8*	2.2*	2.3*
28937-8	TBEC/Tedlar cover	0.0*	-0.5*	-0.7*	-0.8*	-0.3*	2.5*	0.4*	0.5*	0.5*	0.6*	0.7*	1.1*	1.3*	2.1*	2.4*	2.1*	2.4*	2.6*
28937-9	TBEC/Airphire	0.3	1.8	1.5	0.7	2.0	4.0	2.4	2.3	2.5	2.9	2.9	3.2	3.4	3.8	3.7	3.7	3.8	4.0
28937-10	TBEC/Airphire	0.8	1.7	1.6	1.1	2.0	4.7	2.3	2.4	2.2	2.3	2.2	2.5	2.5	2.9	2.7	2.6	2.8	3.0
29209-3	15295 no Naugard/Airphire	1.5	1.8	1.0	2.6	3.8	2.3	2.6	2.5	2.7	2.3	2.5	2.4	2.8	2.7	2.9	2.6	3.1	2.7
29209-4	15295 no Naugard/Airphire	1.2	2.0	1.2	2.7	4.1	3.1	3.3	3.2	3.4	3.0	3.2	3.4	3.8	3.7	3.8	3.7	4.3	4.3
29230-1a	TBEC/Solatex II	0.2	1.0	1.1	1.1	1.3	1.3												
29230-2b	TBEC/Solatex II	0.1	1.1	3.4	1.1	1.3	1.5												

TABLE 2

Identification of Solar Panels

IMS - ID	Source of EVA	Appearance (Discoloration)	Serial No.
Panel #1	Richmond (Siemens)	Slight	700080
Panel #2	Richmond (Siemens)	Moderate	-
Panel #3	Richmond (Siemens)	Severe	-
Panel #A1	Springborn (Solarex)	None	90076
Panel #A2	Springborn (Solarex)	Slight	- *

* Part of a panel received from NREL

TABLE 3 % VINYL ACETATE CONTENT BY TGA[(1)]				
Sample No.	**Specimen History**	**Color**	**% VA, corrected for ash residue**	**Avg. Value**
28948-9	cured, unaged glass lam.	none	35.2, 34.6	34.9
Solar panel #2	full x sect. outside main circuit (near edge)	none	34.5, 34.5	34.5
	top of dark area	brown	34.4, 34.7	34.6
	bottom of dark area	none	35.8, 35.1	35.5
Solar panel #3	colorless x sect.	none	34.6, 35.7	35.1
	dark x sect.	brown	33.6, 34.2	33.9
	top of dark x sect.	brown	35.5	35.5

Solar Panels #2 and #3 from Carrisa Plains

(1) Thermogravimetric analysis

TABLE 4 CYASORB UV531 AND TINUVIN 770 CONTENT OF FIELD AGED SOLAR PANELS						
			UV531		TINUVIN 770	
Solar Panel #	Specimen Location	EVA Specimen Color	GC/FID (3) area/ mg. x 10^{-4}	% Consumed (1)	GC/FID area/ mg. x 10^{-3}	% Consumed (2)
A2	full x sect. inside main circuit	light brown	3.77	27	5.06 4.22 4.33 avg. 4.54	53
	full x sect. outside main circuit (near edge)	no color	5.13		3.41 4.23 4.18 avg. 3.94	59
	dark top sect. next to glass	brown	3.74	27	10.7	+11
1	edge to cond. #1	no color	3.68	28	9.6	0
	between cond. 4 and 5	brown	2.14	58	1.19	88
	over crack between cond. 8 and 9	no color	1.19	77	4.85	49
	between 17 and 18 - middle of cell	brown	0.13	97	4.28	55
3	over crack	no color	0.77	85	6.08	37
	0.5 mm away from colorless crack area	dark brown	0.75	85	0	100

Notes: (1) Relative to A2 no color area value of 5.13
(2) Relative to 9.60 value for panel #1, clear edge
(3) Gas chromatography with flame ionization detection

TABLE 5
UV531 AND TINUVIN 770 CONTENT OF GLASS/EVA/GLASS 18 MIL A9918P
AGED 9 - 11 WEEKS (1)

			UV531				TINUVIN 770			
Sample NB No.	History of EVA (2)	ASTM Yellowness Index (3)	GC/MS (4) area/mg x 10^{-7}	Avg.	% Remaining	% Consumed	GC/MS (4) area/mg x 10^{-7}	Avg.	% Remaining	% Consumed
28948-9	Unaged/ cured full formulation	0	1.48 1.48 1.54	1.50	100	0	1.09 1.21 1.08	1.13	100	0
29154-20	Aged 9 weeks/ Starphire	19.3	0.64 0.67	0.66	44	56	0.43 0.72	0.58	51	49
29154-61	Aged 9 weeks/ Starphire	19.6	0.57 0.64	0.61	41	59	0.60 0.61	0.61	54	46
29154-4M	Aged 11 weeks/ Starphire	28.4	0.71 0.56	0.64	43	57	0.38 0.32	0.35	31	69
29154-11M	Aged 11 weeks/ Solite	24.4	0.80 0.73 0.67	0.73	49	51	0.53 0.62 0.37	0.51	45	55

(1) By Xenon-Arc Weather-O-Meter, 0.55 w/m^2 (at 340 nm and 100°C)
(2) ASTM D1925-70, "Standard Test Method for Yellowness of Plastics
(3) Standard Cure A9918P
(4) Gas Chromotography/Mass Spectrometry

TABLE 6
CYASORB UV531, TINUVIN 770 AND LUPERSOL 101 CONTENT OF GLASS/EVA/GLASS LAMINATES UNAGED AND UV-AGED IN LABORATORY(1)

			UV531		TINUVIN 770		LUPERSOL 101	
Sample No.	**Composition and History** of EVA(2)	ASTM **Yellowness Index**(3)	**GC/FID**(4) **area/mg x** 10^{-4}	**% Consumed**	**GC/FID area/mg x** 10^{-3}	**% Consumed**	**DSC**(5) joules/g	**phr 101 present** (6)
28950-2A	UV531 100% std		6.20		8.88			
28950-4A	Uv531 50% std		2.38		9.44			
28948-9	full form unaged		5.17		9.39		3.47	0.11
29230-4	full form aged 2 wks		5.04	3 (rel. to 28948-9)	8.70	7 (rel., to 28948-9)	0.39	0.01
29227-4	101 only unaged						3.16	0.10

(1) By Xenon-Arc Weather-Ometer, 0.55 w/m^2 (at 340 nm and 100°C)
(2) Standard cure A9918P unless otherwise noted
(3) ASTM D1925-70, "Standard Test Method for Yellowness of Plastics"
(4) Gas chromatography with flame ionization detection
(5) Differential scanning calorimetry
(6) Parts per hundred parts of EVA

TABLE 6 (continued)

CYASORB UV531, TINUVIN 770 AND LUPERSOL 101 CONTENT OF GLASS/EVA/GLASS LAMINATED UNAGED AND UV-AGED IN LABORATORY(1)

			UV531		TINUVIN 770		LUPERSOL 101	
Sample No.	**Composition and History of EVA(2)**	ASTM **Yellowness Index(3)**	**GC/FID(4) area/mg x 10^{-4}**	**% Consumed**	**GC/FID area/mg x 10^{-3}**	**% Consumed**	**DSC(5)** joules/g	**phr 101 present** (6)
29227-3	no 101 unaged	0.5	5.30		17.1		0.72	0.02
29163-3	no 101 aged 10 wks	5.4	5.29	0	16.2	5		
29227-6	101 + UV531 unaged	1.7	5.39				2.92	0.09
29208-5	101 + UV531 aged 12 wks.	13.5	3.22	40				
29227-7	UV531 x 2 unaged	0.6	13.4		10.6		2.01	0.05
28938-9	UV531 x 2 aged 11 wks.	28.3	6.32	53	3.72	65		
29227-5	101 + 770 (no UV531) unaged	0.5			9.18		2.76	0.08
29208-3	aged 12 wks.	1			3.56	61		
29227-1	770 only unaged	-0.3			14.9			
29203-6	aged 6 wks	-0.8			15.6	+5		
29227-2	UV531 only unaged	-0.2	5.99					
29203-11	aged 11 wks	-0.9	6.09	0				

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Fourier Transform / Infrared Spectroscopy

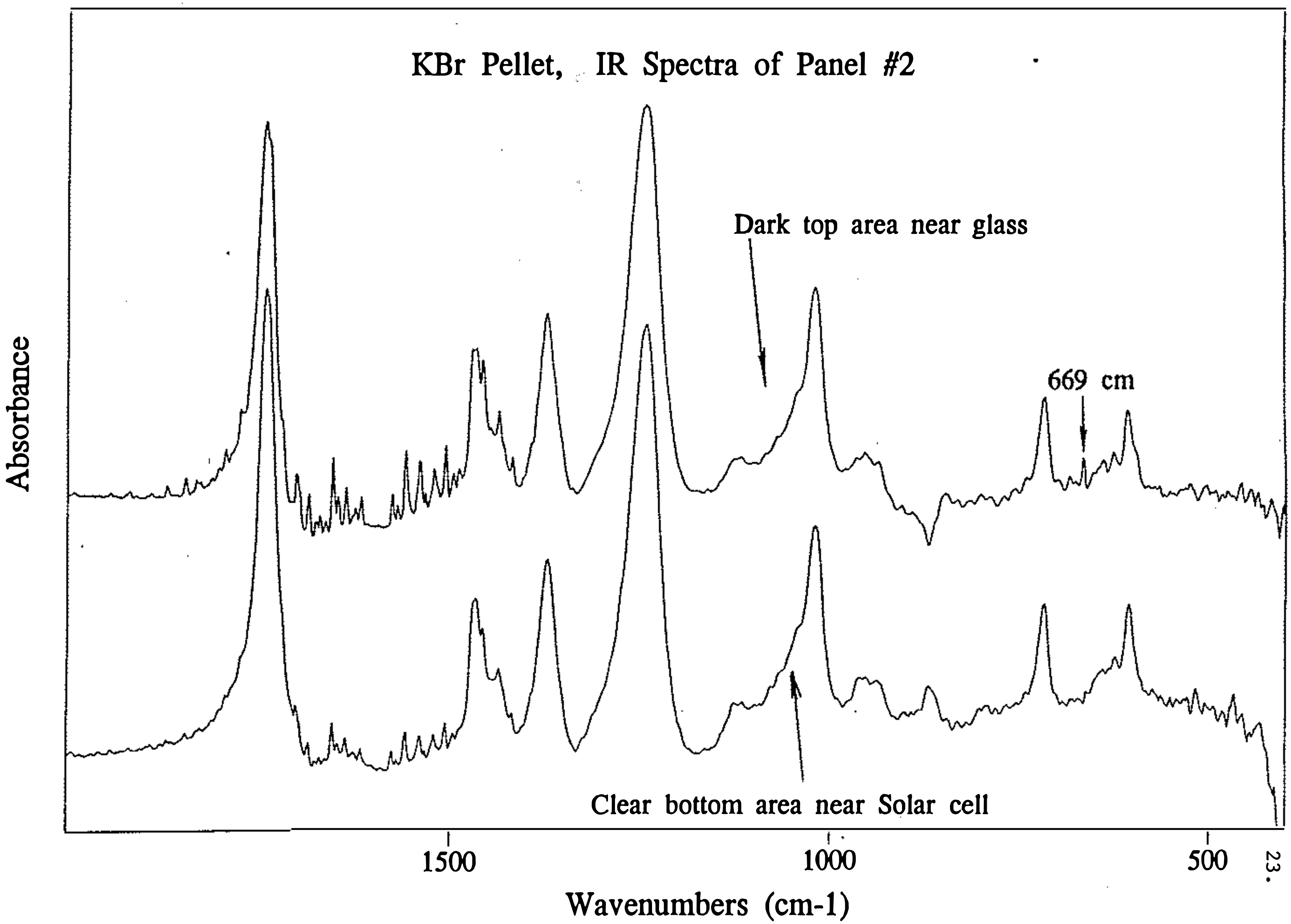
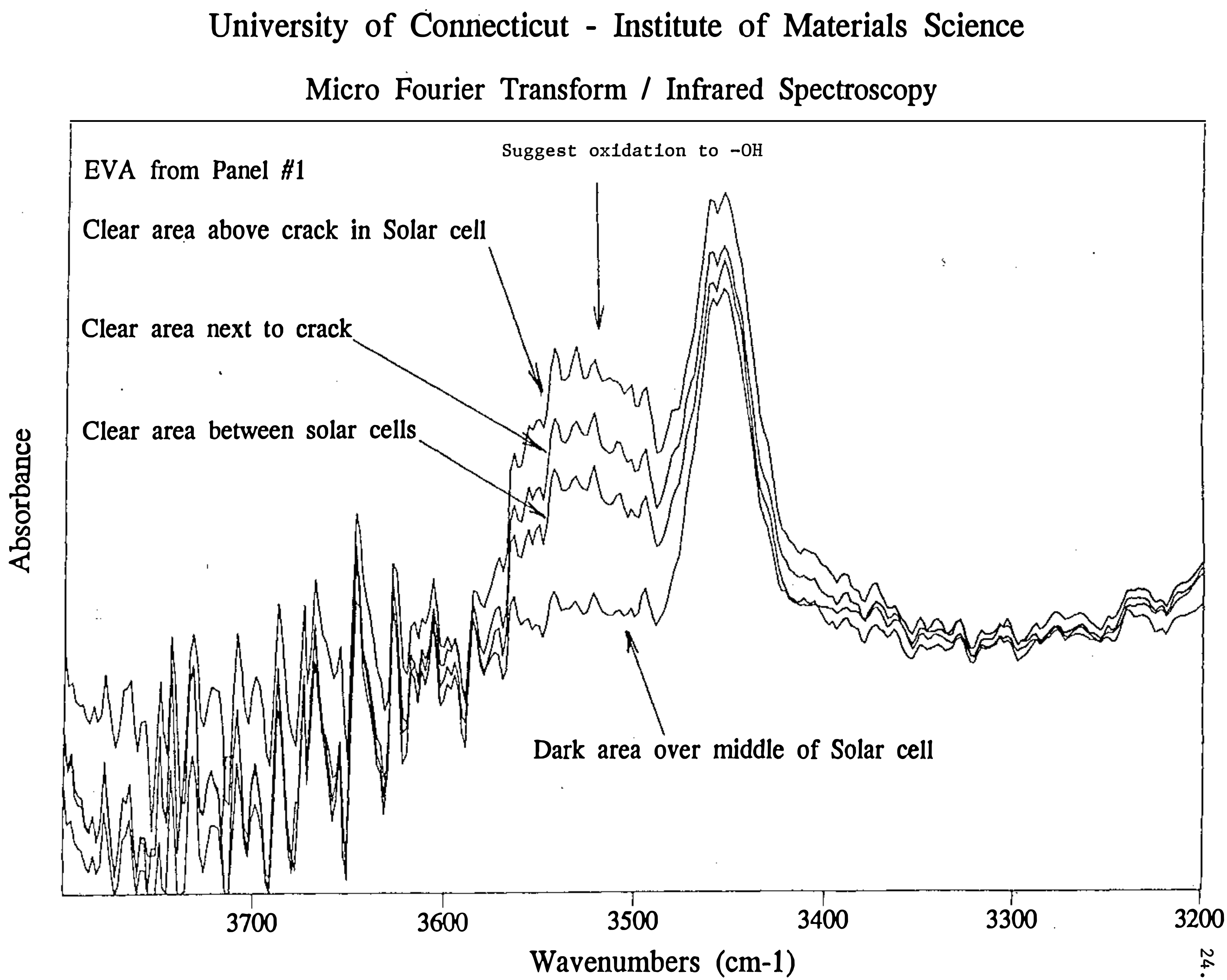


FIGURE 2



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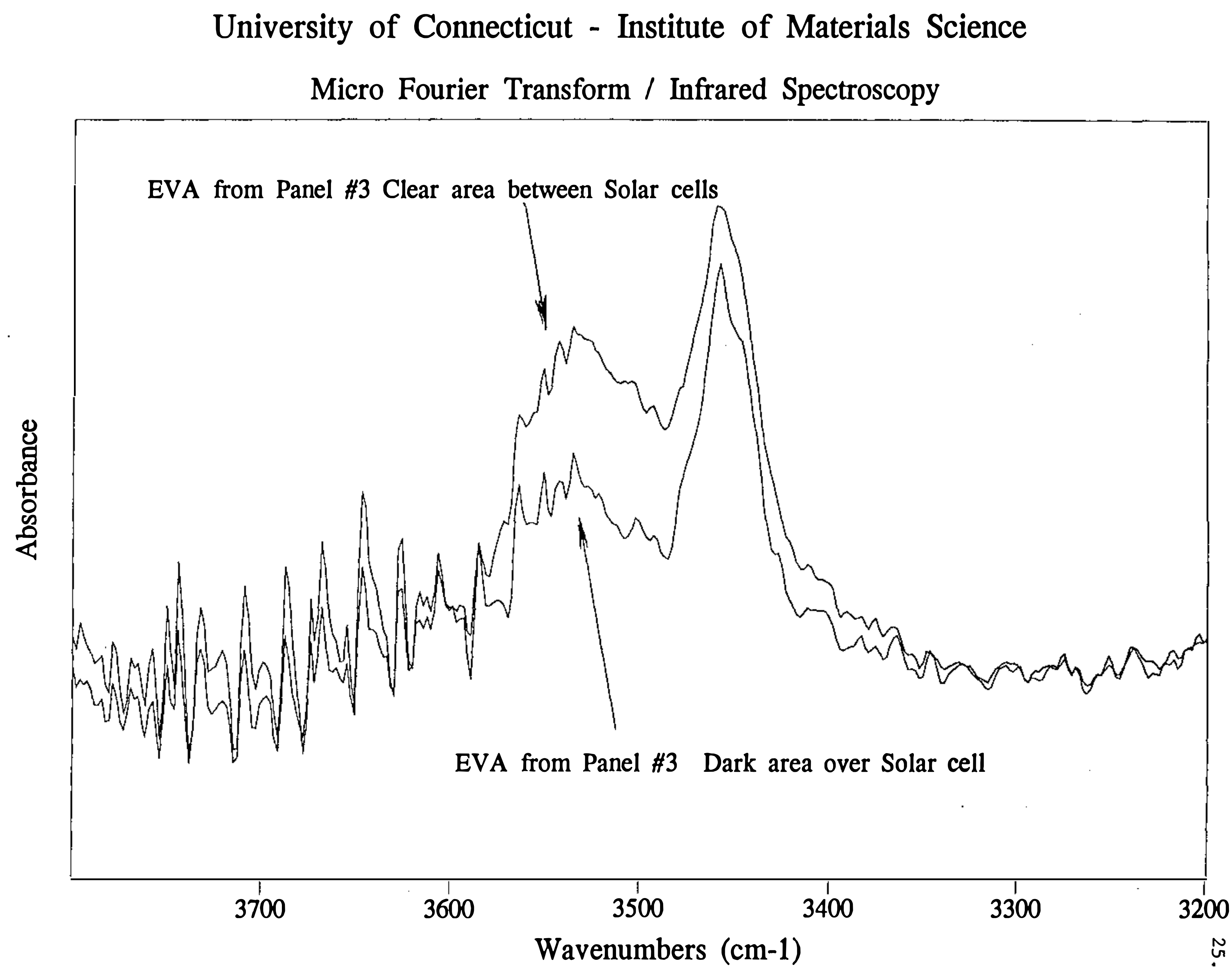
Micro Fourier Transform / Infrared Spectroscopy
Suggest oxidation to -OH
EVA from Panel #1
Clear area above crack in Solar cell
Clear area next to crack
Clear area between solar cells
Dark area over middle of Solar cell
Absorbance
3700
3600
3500
3400
3300
3200
Wavenumbers (cm-1)

FIGURE 3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Micro Fourier Transform / Infrared Spectroscopy
EVA from Panel #3 Clear area between Solar cells
EVA from Panel #3 Dark area over Solar cell
Absorbance
3700
3600
3500
3400
3300
3200
Wavenumbers (cm-1)

FIGURE 4

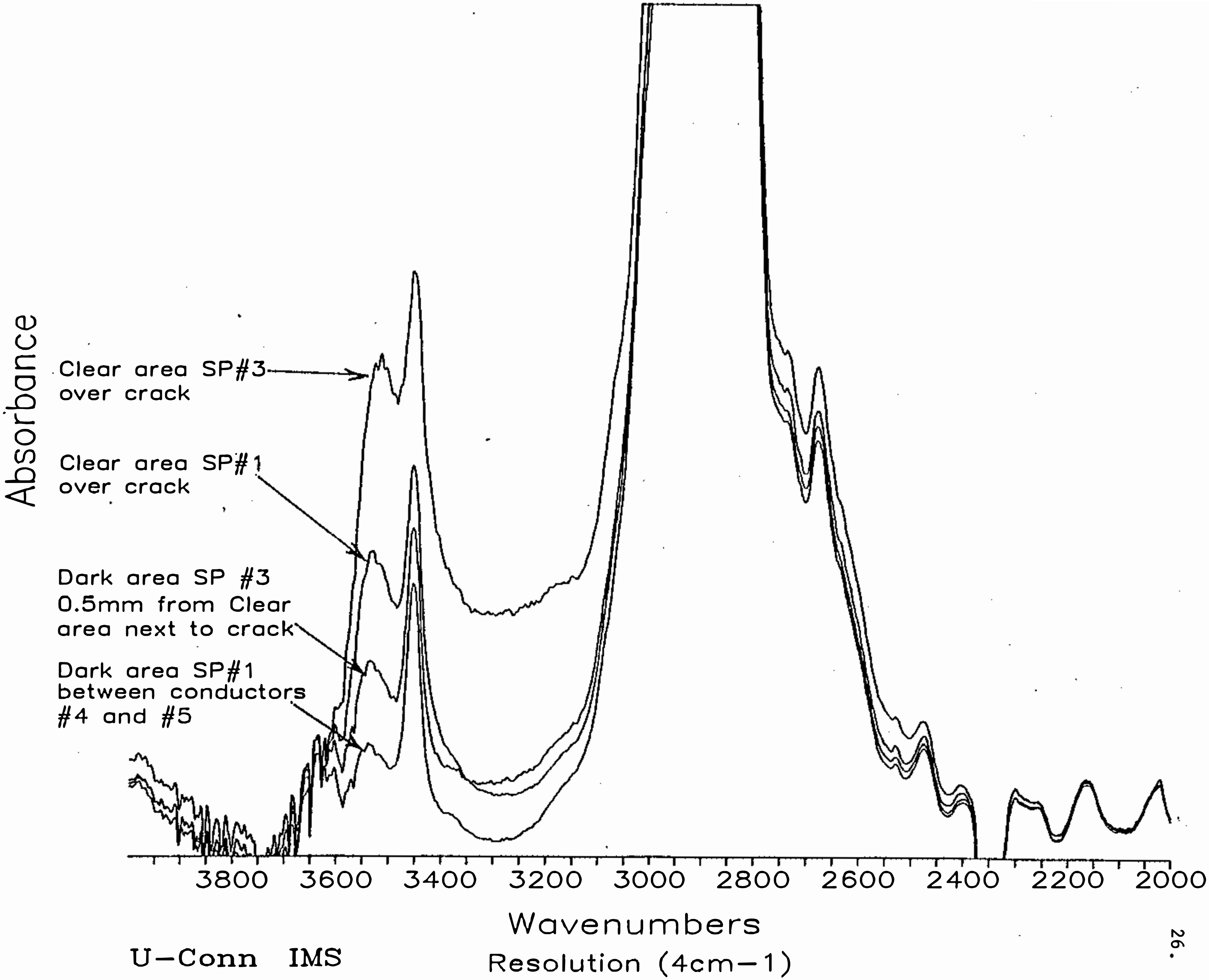
Absorbance
Clear area SP#3 over crack
Clear area SP#1 over crack
Dark area SP #3 0.5mm from Clear area next to crack
Dark area SP#1 between conductors #4 and #5
3800
3600
3400
3200
3000
2800
2600
2400
2200
2000
Wavenumbers
U-Conn IMS
Resolution (4cm-1)

FIGURE 5

REPORT DOCUMENTATION PAGE

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13. ABSTRACT ***(Maximum 200 words)***

This report describes work performed under the Photovoltaic Manufacturing Technology (PVMaT) Project. Major accomplishments reported in this document include the following: (1) While "standard cure" A9918P ethylene vinyl acetate (EVA) encapsulant, laminated between low-iron glass, showed significant yellowing after 17 weeks in a xenon-arc Weather-Ometer, "neat" EVA with no additives showed little or no yellowing after the same exposure. (2) Similar laminates, prepared and exposed in the Weather-Ometer using A9918P (standard cure EVA) with the Lupersol 101 removed from the encapsulant, showed approximately a 2/3 reduction in color development after 10 weeks. (3) Studies suggest that EVA with various combinations of the A9918P additives shows discoloration primarily from Naugard P and an interaction of Lupersol 101 with Cyasorb UV-531. (4) Lupersol TBEC (an organic peroxide) reduced the yellowing rate by a factor of approximately 2.5 based on 17 weeks exposure. (5) A cerium-oxide, containing a low-iron glass superstrate, reduced the rate of yellowing of A9918P EVA by approximately 75% after 17 weeks exposure.
(6) Laminates, prepared and exposed using 15295P (fast cure EVA) and cerium-oxide containing glass superstrate, showed no visible yellowing after 17 weeks. (7) Preliminary analytical results showed no measurable loss of acetic acid from very browned, field-aged EVA and no evidence of conjugated unsaturation. (8) Analysis also revealed the loss of Cyasorb UV-531 in both field-aged and laboratory ultraviolet (UV)-aged samples, but only in the presence of Lupersol 101.

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