REFLECTIVE MATERIALS EVALUATION

**Final Report, Task III
for Period July 1975 — April 1977**

William M. Arden

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**UNDER CONTRACT NO. EY - 76 - C - 02 - 2699
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ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

**Sheldahl, Inc.
Northfield, Minnesota 55057**

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FOREWORD

The Solar Power Array for the Concentration of Energy (S.P.A.C.E.) project, originally scheduled as a twelve-month program in 1973-74, was later extended to include work on modifications to the specular photometer, evaluation of new reflective materials, and analysis of a heliostat array. This report discusses the second of those tasks, evaluation of reflective materials, which was performed during the period July 1975 through April 1977.

The following personnel from Sheldahl made significant contributions to the preparation of this document and/or the work reported:

D. E. Anderson
W. M. Arden
M. E. Berendt
D. A. Robinson
R. A. Stickley
D. A. Thayer

1. INTRODUCTION

1.0 General

This report covers the work performed under Task III of Contract E(11-1)-2699, later renumbered EY-76-C-02-2699. This task involved an investigation of "specific reflective membrane composites and protective coatings which . . . (appeared) . . . capable of providing the economical, efficient, durable reflective surfaces required for use with solar concentrating systems."*

1.1 Implementation of the Statement of Work

The main part of the work on this task was the exposure of candidate materials to an outside environment. This took place at Desert Sunshine Exposure Tests, Inc. (DSET), which is located near Phoenix, Arizona. All the materials and composites tested were selected from combinations which had previously performed satisfactorily under salt-spray and humidity/temperature cycling tests. Specular reflectance of specimens to be tested was measured using the Sheldahl specular photometer, both before and after exposure at DSET. Description of these tests and discussion of the results are the topics of this report.

*Statement of Work, Contract E(11-1)-2699.

2. TEST METHODS

2.0 General

This section discusses the apparatus and procedure used to investigate the properties of the candidate materials. These techniques fall naturally into two classes: Exposure at DSET and optical measurements at Sheldahl.

2.1 Desert Sunshine Exposure Tests (DSET)

Two different exposure periods were used in these tests. The shorter (18 days) involved the use of DSET's EMMA (Equatorial Mount with Mirrors for Acceleration) and EMMAQUA (a version of EMMA which incorporates a periodic distilled water spray). The longer period (6 months) used the EEK (Equatorial) and EEKQUA (an EEK with water spray) sample exposure mounts. All these devices are described below.

EMMA & EMMAQUA

The EMMA machine is a follow-the-sun rack having ten flat mirrors so positioned that the sun's rays strike them almost normally all day and reflect to the samples in the target area. The mirrors are 6" x 72" sheets of electro-polished aluminum treated by the Alzac process to prevent corrosion. The samples receive about eight times as much radiation as samples exposed on a follow-the-sun rack during equal periods of time. Two sun cells keep the machine in focus during operation. A shadow maker mounted above the cells shades them so that as one of the cells receives more radiation than the other, their balance is disturbed and a signal is provided through an amplifier to a reversible motor which returns the machine to proper focus. The machine's axis is oriented in the north/south direction. A blower provides a cooling airstream which is directed over and under the samples by an adjustable lip along the side of the target area. If the airstream

is cut off for any reason, a Dietz airflow switch mounted inside the air tunnel releases a solenoid which in turn, permits a spring-loaded flap to swing between the target area and the mirrors. The only difference between the EMMA and EMMAQUA machines is the addition of a system for spraying the samples on the EMMAQUA. The samples are sprayed for about eight minutes out of each operating hour with distilled water. Triple steam-distilled water is used.

EEK & EEKQUA

The EEK is a follow-the-sun (polar equatorial mount) non-concentrating exposure rack. Tracking and size details are similar to those for EMMA. No cooling air is included. Again, EEKQUA incorporates a water spray system. Samples exposed on such a rack receive about 33% more Langleys than stationary samples facing 45° south.

2.2 Optical Tests (Sheldahl)

Measurements of reflectance were performed at Sheldahl using two different instruments. Total reflectance, the fraction of an incident light beam reflected into a hemisphere, is measured on a standard Beckman Instruments DK-2A spectrophotometer. This unit gives total reflectance as a function of wavelength, and can be used to determine the reflectivity of a sample to the overall solar spectrum. Specular reflectance, the ability of a surface to change the direction of an incident light beam without modifying its other spatial or spectral characteristics, is quantified by the use of the Sheldahl bidirectional reflectance distribution function (BRDF) photometer. This instrument consists of a collimator and telescope which are used to illuminate the sample and observe the image reflected by the sample. It is described in detail elsewhere.*

*Report NSF/RANN/SE/GI-41019/PR/74/2, *Solar Power Array for the Concentration of Energy, Semi-Annual Progress Report* (1 January - 30 June 1974) pp. 156-159.

3. MATERIALS TESTED

3.0 General

A wide range of reflective materials were tested under this subtask. Most were laminates; due to the increased interest in glass mirrors as heliostat reflectors, however, samples of overcoated first-surface glass were also included.

Table III-1 categorizes the samples tested. The left-hand column describes the sample, in the format "(Front Surface) X Metallizations X (Rear Surface)". The different substrates are listed in the other columns.

3.1 Material Description

Each material in this test consisted basically of an outside coating, a metallized surface, and one or more substrates or backing materials. Specific details of fabrication are given below.

Laminated Samples

Each laminated sample consisted of a layer of 1 mil (0.001 inch) FEP Teflon and a layer of 1 mil polyester (PE) film, sandwiching a layer of vacuum deposited metal which varied from sample to sample. Some of these materials were further laminated to aluminum sheet, approximately 20 mils in thickness. Others were stretched taut and glued to rigid, open rectangular aluminum frames, about 3 x 5 inches in width and length.

Coated Samples

Coated samples included all those using Sheldahl's 12A or 12A/C acrylic coating. With one exception (the sample from Carolina Mirror Corporation, made on a production line curtain coater), the samples were coated by dipping them into a bath. The unsupported polyester films were vacuum metallized using copper overlaid with silver; the glass samples featured chemically - deposited silver.

TABLE III-1

Materials Subjected to Exposure at DSET

<u>Sample</u>	<u>Laminated to Al. Sheet</u>	<u>Taut Membrane</u>	<u>Film Sample</u>	<u>Glass</u>
<u>Laminated</u>				
(1 mil FEP) x Al x (1 mil PE)	X	X		
(1 mil FEP) x Ag Inc x (1 mil PE)	X	X		
(1 mil FEP) x Ag x (1 mil PE)	X	X		
<u>Coated</u>				
(12A) x Al x (3 mil PE)	X	X		
(12A/C) x Ag x Cu x (7 mil PE)			X	
(12A) x Ag x Cu x (7 mil PE)			X	
(12A) x Ag x (Glass)				X
(12A + UV x 10) x Ag x (Glass)				X
(12A + UV + AO) x Ag x (Glass)				X
(12A + UV) x Ag x (Glass)				X
(12A) x Ag* x (Glass)				X
(12A/C) x Ag x (Glass)				X

*Manufactured at Carolina Mirror Corp., N. Wilkesboro, N. C.

Abbreviations: Ag Inc = Silver Inconel Alloy
 Ag = Silver
 AO = Antioxidizing additive
 Cu = Copper
 FEP = FEP Teflon
 PE = Polyester film
 UV = Ultraviolet inhibitor additive
 12A, 12A/C = Sheldahl proprietary acrylic coatings

4. EXPERIMENTAL RESULTS

4.0 General

Two different exposure times were used in this program. One half of the samples were exposed for 18 days to accelerated test methods (EMMA & EMMAQUA) and the other half for 6 months to slower real time methods (EEK & EEKQUA). See Section 2.1. In addition, a set of samples was kept for use as a comparison standard. All samples were measured before exposure using the bidirectional reflectance function distribution apparatus (BRDF) and the Beckman DK-2A Spectroreflectometer as described in Section 2.2 of this report. The samples were then sent to DSET for exposure, returned to Sheldahl, and remeasured and compared to the standards. Statistical techniques* were used to detect significant changes in specular reflectance as a result of exposure.

Table IV-1 shows the sample and exposure combinations for which significant differences were found. Note that this does not mean that no change occurred in the other materials. Significance, in the statistical sense, results from two factors. First, the effect must be large enough to be measurable. Second, the random variations in the data, whether due to measurement technique, differences among samples, or other causes, must be small enough that they do not obscure the effects being observed. In other terms, "significance" is synonymous with a "high signal - to - noise ratio", which can be achieved either by increasing the signal or decreasing the noise. With all samples except those made with glass, difficulties in holding the sample flat tended to obscure true differences in specularity.

Table IV-1, therefore, groups the sample/exposure combinations into two classes; those for which a change may (or may not) have occurred and those for which the change is almost certain.

*See appendix for a discussion of these techniques.

TABLE IV-1
EXPERIMENTAL RESULTS

*Indicates significant difference in 8 mrad Specular Reflectance After Exposure.

Sample Type/Exposure	←18 Days→		←6 Months→	
	EMMA	EMMA QUA	EEK	EEK QUA
<u>Laminated to Al Sheet</u>				
1 mil FEP x Al x 1 mil PE				*
1 mil FEP x Ag Inc x 1 mil PE				*
1 mil FEP x Ag x 1 mil PE				
12A x Al x 3 mil PE				*
<u>Film Samples</u>				
12A/C x Ag x Cu x 7 mil PE				*
12A x Ag x Cu x 7 mil PE				
<u>Taut Membrane</u>				
1 mil FEP x Al x 1 mil PE				*
1 mil FEP x Ag Inc x 1 mil PE				*
1 mil FEP x Ag x 1 mil PE				*
12A x Al x 3 mil PE				*
<u>Glass (All Chem. Ag)</u>				
12A			*	*
12A + UV x 10	*	*	*	*
12A + UV + AO		*	*	*
12A + UV				*
12A (CMC)	*		*	*
12A/C		*		*
Total Exposure (Langleys)	79,210		119,328	

5. CONCLUSIONS

Reference to Table IV-1 indicates a number of conclusions resulting from this work. These are listed, not necessarily in order of importance, below.

EMMA & EMMAQUA do not adequately simulate EEK & EEKQUA on a short-term basis, and are therefore not acceptable as fast screening methods for candidate reflective materials.

EEKQUA is the most stringent test method of those tried. Further investigation is needed, however, to discern whether or not it is the most representative or legitimate test for the evaluation of reflective materials. The possibility exists that it is more rigorous than necessary.

The Sheldahl 12A proprietary acrylic coating, especially with the addition of a UV screening agent, shows promise as an environmentally stable protection for first-surface silvered mirrors on glass.

APPENDIX

The Student t-Test for the Difference Between Two Means

The t-test is a standard method of discerning whether or not the mean values of two samples are significantly different. It is used instead of the normal (Gaussian) distribution in cases in which the sample sizes are small (i.e. <30) and the population standard deviation, σ_x , is unknown. The assumption of homoscedasticity must be made, stating that the samples under test have the same variance (and therefore standard deviation). Derivation of the Cauchy-based t-distribution will not be done here*, but the results are stated below.

The t-statistic for a test of the difference between two means is calculated as:

$$t = \frac{\bar{x} - \bar{y} - D}{\sqrt{\frac{1}{n_x} + \frac{1}{n_y}} \sqrt{\frac{\sum x^2 - n_x \bar{x}^2 + \sum y^2 - n_y \bar{y}^2}{n_x + n_y - 2}}}$$

where

$\bar{x}, \bar{y}$ = sample means

n_x, n_y = number of observations in samples x & y

D = hypothesized difference between $\bar{x}$ & $\bar{y}$

$\sum x^2, \sum y^2 = x_1^2 + x_2^2 + \dots + x_{n_x}^2, y_1^2 + y_2^2 + \dots + y_{n_y}^2$

*See, for example, *Data Analysis for Scientists & Engineers*, Stuart L. Meyer. John Wiley & Sons, New York, 1975. p. 274ff.

The use of the t-statistic is as follows:

- 1) State the "null hypothesis" H_0 . In the present case, the question is "are the means different?" The null hypothesis is that they aren't.

$$H_0: \bar{x} - \bar{y} = 0$$

Another way of stating this is that D in the equation for the t-statistic is zero.

- 2) Calculate the t-statistic.
- 3) Compare the calculated t-statistic to the value corresponding to the desired confidence level (95% was chosen for these tests) and number of "degrees of freedom" ($n_x + n_y - 2$). If the calculated t-value is larger than the value necessary for significance, the sample means are taken to be different, and the null hypothesis is disproved.

In the present investigation, $\bar{x}$ & $\bar{y}$ are the mean reflectances of each material in each sample type before and after exposure to a particular test method. In other words, a significant effect on a taut membrane of 1 mil FEP x Al x 1 mil polyester under exposure to EMMAQUA is determined by using measured values of reflectance for that material before and after EMMAQUA, calculating the t-statistic, and using it to confirm or deny the hypothesis that no change occurred as a result of the exposure.