Research and Development in Solar Mirror Quality Assurance Performance

Annual Report

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September 1977

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RESEARCH AND DEVELOPMENT
in SOLAR MIRROR QUALITY
ASSURANCE PERFORMANCE

ANNUAL REPORT

APRIL 1977 - SEPTEMBER 1977

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SUMMARY

A survey of the current technological status of solar reflectors has been initiated for the Energy Research & Development Administration (ERDA). The survey is directed toward the areas of quality assurance and performance of solar mirrors. This report is intended to present a program overview and give the initial results of some preliminary studies currently underway. More detailed results will be presented as these studies mature. Specific topics that are covered in this report include:

- An extensive literature survey of the weatherability, durability, and life expectancy of solar materials has been initiated. Some preliminary results of that survey are discussed.
- General optical degradation effects on solar materials are discussed.
- Preliminary results of recently initiated studies on the aging of solar materials are presented. The need for careful materials preparation is emphasized.
- A study which addresses the problem of the cleaning of solar reflectors has been initiated. Some preliminary results on cleaning agents are presented.
- The need for higher accuracy of laboratory instrumentation for aging studies is emphasized.
- The development activities associated with a low-cost, easy to use instrument to measure specularities are presented.

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INTRODUCTION

This report covers the progress of the program since funding authorization was received in April, 1977 until the end of the fiscal year in September, 1977.

The purpose of this program is to stimulate the development of better quality solar reflector products and contribute to the commercial development of solar power as a viable and cost-effective energy alternative. There are four main program elements: 1) the quantitative evaluation of reflector materials both for their intrinsic optical properties and their environmental stability, 2) the development of new instrumentation necessary to quantify the quality assurance parameters, 3) rapid technology transfer to the solar reflection community and information dissemination, and 4) the development of recommended testing procedures and standards for the quality assurance and performance of solar mirrors. The initial phase of the program was to survey the literature and the current technological status of solar reflectors.

Specific tasks include the following:

- Identify the quality assurance parameters that best reflect the initial and sustained performance of solar mirrors.
- Identify materials currently used or potentially useful in the construction of solar reflectors.
- Identify degradation mechanisms that lead to loss of performance.
- Look into the problem of dirt accumulation and cleaning techniques.
- Survey measurement techniques and instrumentation used to quantify reflector performance.
- Review testing procedures used to project sustained performance and lifetime.
- Review literature data on natural and accelerated aging of mirror materials.
- Initiate experimental studies aimed at correlating the natural and accelerated aging.

- Initiate development of new instrumentation and testing procedures necessary to quantify the identified quality assurance parameters.
- Initiate studies aimed at obtaining sufficient background data to establish standards and recommend uniform testing methods.
- Interact with ASTM and other relevant standards organizations to establish standards for solar reflector materials testing.
- Aid in the search for and the selection of optimum performance materials.

SCOPE OF QUALITY ASSURANCE PROGRAM

The design and construction of today's heliostats depend heavily on the cost performance tradeoffs in numerous areas. Each of these areas will affect the overall performance of the solar reflector and therefore should be the subject of some scrutiny whereby the relevant quality assurance parameters are identified and measured so that meaningful performance criteria can be established. In order to illustrate the scope of this program in comparison to the total quality assurance problem, we have divided the heliostat construction into several distinct but mutually interacting areas. Each of these areas, which has its own quality assurance problems is illustrated schematically in Figure 1.

First consider the solar energy reflector itself which can be formed several ways. It can be a metallic reflector or a multi-layer dielectric. Practical cost considerations rule out the multi-dielectric at this time. Thus, one is left with either a bulk metallic or metallized film reflector. Furthermore the solar reflectivities of common metals limit the reflector materials to silver (highest reflectivity) or aluminum (lowest cost and highest durability).⁽¹⁾

The reflector material is usually provided with a transparent protective overlayer for environmental protection. This can be in the form of a protective bubble, an integrally bonded cover material such as transparent oxide coatings, or glass and plastic overlays. The reflector material may be metallized directly to the protective cover material forming a second surface mirror. The back surface of the mirror can also be covered with a protective material such as an impregnable self-bonding coating or an adhesively bonded plastic, glass or metallic material.

From this point on, the construction varies greatly depending on the rigidity of the cover material. The reflector structure may be further bonded to a rigid substrate to obtain and maintain the optical figure of the mirror. Laminates, various compositions of honeycombs, glasses, glass and plastic foams and metallic frames have been used to maintain the structural stiffness of the mirror under thermal and aerodynamic loading.

MIRROR ASSEMBLY SUPPORT STRUCTURE

- MECHANICAL SYSTEM STABILITY AND CONTROL
 - POINTING CONTROL
 - DRIVE MECHANISM
 - PHYSICAL STRUCTURE

REFLECTOR SURFACE SUPPORT STRUCTURE

- MIRROR FIGURE FORMULATION AND STABILITY

REFLECTOR SURFACE STRUCTURE

- PERFORMANCE CRITERIA
- MATERIALS SUITABILITY
 - OUTER PROTECTIVE MATERIAL
 - INTEGRALLY ATTACHED
 - COVER BUBBLES
 - METALIC REFLECTOR
 - CHEMICAL DEPOSIT
 - VAPOR DEPOSIT
 - BACK SURFACE PROTECTION
 - BONDING AGENTS

FIGURE 1. Solar Mirror Quality Assurance Problem Areas

The final support and pointing structure may house single or multiple mirrors. The structure is responsible for holding the reflective mirrors in a rigid attitude and for tracking the sun so as to direct the radiation toward the desired target area. This entire structure is usually anchored to the earth in some way so as to provide overall stability. It is controlled either by a computer or by an active feedback servo system.

Other areas of interest for quality assurance can be lumped into the catch-all categories of mechanical and electrical systems. These categories are comprised of the electrical service, mechanical linkages and bearings, and gears and motors that are responsible for moving the reflector structure.

This program to date has been directed mainly toward the quality assurance and performance of the reflector and its protective overlay materials. Initial studies will concentrate on the optical rather than the mechanical performance of the materials.

STATUS OF LITERATURE SURVEY

The initial phase of the Solar Mirror Quality Assurance program involved an extensive literature search to generate a data base from which to assess the current technology and plan further experimentation. The search identified techniques currently used for performing measurements of the optical properties of solar mirrors and pointed out areas where measurement deficiencies exist. The search was also useful in defining pertinent degradation mechanisms and identifying key parameters affecting these mechanisms.

The search was confined primarily to the materials currently being considered for solar mirror applications. Such materials as plastics, glasses, adhesives and sealants were investigated. Under these material categories, key words and phrases were chosen for the search. These categories included aging properties, weathering and accelerated weathering, measurement techniques, mirror performance criteria, physical and optical properties of thin films and other protective coatings for mirrors, and the reflective materials.

Three computer services were employed for the initial phase of the survey. The data bases searched under the ERDA RECON system were the Nuclear Science Abstracts (1967 to June 1976) and the Energy Data Base (1974 to present). The data bases searched in the Lockheed DIALOG system included the National Technical Information Service (1964 to present), Science Abstracts (1970 to present), Chemical Abstracts (1970 to present) and Engineering Index (1970 to present). Searches compiled by the Smithsonian Science Information Exchange were also scanned. In addition numerous in-house communications and limited distribution publications from private companies and various ERDA laboratories were perused.

The initial phase of the search produced over 8000 titles and abstracts. These were scanned to yield over 400 core articles containing pertinent information and references to begin a more comprehensive search.

Approximately 200 of the 400 core articles have been reviewed to date and have led to roughly an additional 100 references of interest. The

remaining articles are being reviewed at this time and a detailed synopsis of the pertinent results of the search will be presented in a later report.

A few general, although not unexpected, conclusions that can be inferred from the literature already reviewed are:

- The complexity of the weathering process should not be underestimated.⁽²⁾
- Severe drawbacks of accelerated testing stem from the lack of a real environmental condition.⁽³⁾ Correlations between natural and accelerated aging are possible if these difficulties can be overcome.⁽⁴⁾
- Experimental design will play a key role in the reliability of accelerated testing.⁽⁵⁾
- Some attempts at accelerated aging of the materials using previously accepted methods have proven unreliable.⁽⁶⁾
- Extensive efforts are underway to screen solar materials based on pass/fail criteria.^(7,8)
- Some acrylics, weatherable mylar, Teflon, Tedlar, and glasses offer exceptional weatherability characteristics.⁽⁹⁾
- Glass is probably the best alternative in the short term for the protective covering material.

QUALITY ASSURANCE PARAMETERS FOR OPTICAL PERFORMANCE

The key question that needs to be answered in order to determine the performance of a heliostat is how much of the sun's radiation can be directed into a target of finite size. In other words, one would like to relate spatial and spectral power distribution of the reflected flux to the spatial and spectral distribution of the incident flux.

One way to answer this question is to build a prototype heliostat and measure the spatial and spectral composition of the radiation reflected into a simulated aperture by the sun. This can be simultaneously compared to the incident spatial and spectral distribution of the sun. These data could then presumably be combined in some uniform way to formulate an overall figure of merit for the heliostat.

While this approach may be viable, although non-trivial, for monitoring the performance of existing heliostat fields it has practical limitations when applied to materials development activities, not the least of which is cost. Another, more practical approach to the problem is to identify certain key optical parameters that can be measured in the laboratory on materials that make up the reflector. These key parameters could then be used to calculate the overall performance of the completed heliostat. There are four measurement techniques which are currently used to characterize performance of a mirror surface. These measurements are of particular importance when applied to the central receiver heliostat concept. They are 1) spectral reflectivity, 2) spectral transmittance, 3) specularity, and 4) mirror figure.

In order to be meaningful, the spectral reflectivity or transmittance of mirror materials should be measured in the 300-3000 nanometer wavelength region. When weighted by the solar insolation at a particular location and time this measurement is an indication of the highest possible performance obtainable by the mirror structure. Both the reflectivity and transmittance

measurements commonly take two forms. In hemispherical measurements all the reflected (transmitted) light in the hemisphere in front of (in back of) the test specimen is collected and measured. In specular measurements only the flux reflected or transmitted into a predetermined solid angle about the specular angle is collected and measured. This solid angle varies with the instrumentation and measurement technique but usually subtends an angle between 6 and 10 degrees. Since central receiver applications aperture sizes can be limited to tens of milliradians, further characterization of the spatial distribution of the reflected beam is required.

One such characterization is specularity. In this case specularity is taken to mean a measure of the angular spread or divergence that results when an incident collimated beam is either reflected from or transmitted through a material. The specularity measurement is usually a strong function of wavelength and incident angle. It contains information on the microstructure smoothness of the reflected surface.⁽¹⁰⁾ The measurement provides the heliostat designer with information that relates the maximum reflected power to the power that will be accepted by a receiver of finite aperture size.

The one measurement that cannot be performed without a prototype heliostat is mirror figure. Mirror figure is the exact geometrical shape of the reflective surface. Since macrostructure surface irregularities and stiffness of the overall reflector play an important role in overall heliostat performance, the figure of the mirror should be measured under actual operating conditions which include thermal and wind loading. Again this measurement is useful for relating the maximum flux that will be accepted by a receiver of finite aperture size and is indicative of the flux variation on the target.

INSTRUMENTATION DEFICIENCIES

Several statements can be made about the accuracies obtainable with the measurement techniques described above and their importance to the solar mirror quality assurance program. Our observations of various laboratories engaged in materials related research and our conversations with personnel

doing these measurements lead us to believe typical laboratory accuracies for specular reflectance and transmittance that are routinely obtained by careful experimentalists are on the order of 1% to 5%. This accuracy can be compared with the stated 0.2% obtainable at the National Bureau of Standards for similar measurements.⁽¹¹⁾ Diffuse hemispherical reflectivity is also measured to 0.2% at NBS but diffuse transmittance usually cannot be measured more accurately than 5%.

The 1% measurements which most laboratories can achieve are adequate to screen solar reflector materials. However, these measurements are not accurate enough to perform definitive aging studies on good wearable materials as described later in this report. Accuracies are at least as high as are obtainable from NBS are needed to make reliable projections of materials lifetime performance in a reasonable length of time.

Measurement accuracies comparable to those given by NBS can be obtained with only slight modifications of commercially available equipment. There is also good reason to believe significantly higher accuracies than NBS can be obtained by the application of modern electrical optical technology utilizing solid state detectors, and amplitude stabilized lasers. Such a tool, which requires no technological breakthroughs, would be invaluable for aging studies.

Although laboratory measurements are fairly well in hand, field measurements present quite another problem. Our survey revealed no commercial instruments capable of making good field measurements on solar materials in any of the four categories listed above. This is an area that requires further development.

Although the more advanced laboratories have instruments capable of making specular measurements in the laboratory, no known commercial vendor for such apparatus exists. Since alignment is critical on these instruments, they are generally not suitable for field applications. We have addressed this problem and the results of our investigations are presented in another section of this report.

Mirror figure has also been measured by several laboratories. The techniques utilize either mechanical or optical measurements. Optical measurements use laser ray-trace techniques to compare the shape of the actual mirror surface to a calculated shape.⁽¹²⁾ These techniques are generally easy to implement and provide sufficient accuracies for quality assurance. At present however these instruments are limited to the laboratory again because of alignment difficulties. Other techniques more suitable for field application employ vidicons to intensity analyze an image of the sun reflected onto a suitable target or diode arrays which scan the solar image and map an intensity profile. Both these techniques provide information on the overall static deformation of the mirror surface but are too slow to give real time detailed information for the analysis of the mirror figure under thermal and aerodynamic loading in this area.

NEW INSTRUMENTATION DEVELOPMENT

A critical factor in determining a materials suitability for a solar application is its specularity. The specularity of a mirror surface is a measure of its ability to reflect light at the incident angle, while the specularity of a transmitting material is a measure of its ability to transmit the incident illumination with no deviation from its original path.

Several techniques are currently used for the measurement of solar material specularity. In particular, one approach utilized laser beam illumination, an integrating sphere and precision circular pupils as entrance apertures.⁽¹³⁾ This approach requires extremely precise optical alignment in two dimensions as well as a highly accurate pivoting arrangement with small tolerances on spacial reproducibility. It has also been found by our own experimental observations that unless extremely small beam diameters are used, interactions of roll marks in the material with the highly monochromatic, coherent illumination may produce undesirable effects, which mask the directional scattering effects.

A second approach, developed by R. Pettit⁽¹⁴⁾ uses a monochromator as a source, a pair of lenses, and one fixed and one bilateral slit of adjustable width. Detection is achieved with either a photomultiplier tube or a silicon detector. This system has the advantage of requiring precise optical alignment in only one dimension and is not largely affected by roll marks on the material surface. The collector slit width however must be increased in incremental changes and a number of data points taken. This leads to long measurement times as well as data that must be deconvolved either by hand or with computer assistance.

The need for a high precision, low cost, easy to use instrument that could be modified for field use is clearly evident. A feasibility study was initiated to build such a tool.

Initially, attention was focused on mixing wavelengths of laser illumination to eliminate the interference effects. This proved unsatisfactory for a number of reasons and was abandoned.

A number of optical arrangements were explored before finally adopting an approach similar to the bi-directional reflectometer technique described by R. Pettit. The approach uses a tungsten-halogen lamp, concentrator, interference filters, bilateral slit and collimating lens in the collimation optics. The prototype is illustrated by the photograph in Figure 2(a). The collimation optics produce a Fourier transform of the slit function in the front focal plane of the collimating lens. The scattering sample is placed in this focal plane and a collection lens is located one focal length from the sample. The resultant, modified slit image is focused on a charge-coupled diode (CCD) array located a focal length from the collection lens as shown in the photograph in Figure 2(b). The CCD array then displays the resulting intensity distribution in a video format. A direct measure of the materials specularity is then made by comparing the video output of an unscattered beam with the video output as seen with the sample in the collimated light beam. Two typical video outputs are depicted in the photographs in Figure 3(a) and 3(b).

(a)

(b)

FIGURE 2. Specularity Measurement (a) Optical layout (b) CCD array detector

(a)

(b)

FIGURE 3. CCD Array Video Output (a) No scattering sample in beam
(b) Sample with relatively high specularity in beam

The CCD array is a 256 element array with center to center element spacings of 13 microns. With this spacing, and proper optical components, typical measurements are able to detect deviations of the light path in the milliradian and submilliradian range.

It should be noted that precise optical alignment is not a critical factor for high resolution measurements with this arrangement and that deconvolution of the video output is not necessary, reducing the time requirement for data acquisition. The equipment required to build such a system is relatively inexpensive and readily obtainable.

The current design uses two matched achromatic lenses to insure minimal focal length changes throughout the spectral range of interest. The CCD array has an adjustable scan rate to accommodate variations of illumination levels if necessary. A full mathematical analysis of the "scatterometer" is currently underway and will be presented in detail in a later report.

Because the sample is illuminated by the Fourier transform of the slit function, the effect of roll marks in the material is not evidenced as interference structures on the array. Large sampling areas involved in this design lead to a more accurate evaluation of the specularity than previously realized with laser beam illumination.

Work will continue to further interface this instrument with data analysis instrumentation to yield a high quality, low cost analytical tool for comparison of solar mirror materials.

MATERIAL DEGRADATION MECHANISMS

Because of the wide variety of materials and construction techniques employed in the design of solar mirrors, it is perhaps not appropriate at this time to look at specific degradation mechanisms which are intimate properties of the materials themselves. In fact, in many cases these mechanisms may not have to be well understood to determine the degradation rates and project the useful lifetime of the materials. One can, instead, examine the effects of those environmental phenomena which promote the degradation of the material. The instantaneous performance and the useful lifetime of the material depends upon the action, and many times, the interaction of any one or a combination of these environmental parameters.

In general, the optical quality of a solar reflector will be degraded by both permanent and non-permanent effects. Non-permanent effects include surface contamination such as accumulated dust, which can cause an effective loss in performance of up to 50% in a few weeks depending upon reflector construction and atmospheric conditions. Another such effect is the plastic deformation of the reflector structure due to wind and thermal loading. Permanent damage to the surface, the bulk or the edge of either laminated structures, or the materials themselves may be caused by temperature, moisture, humidity, solar radiation, and mechanical effects.

Again, depending on the material properties, thermal cycling can generate or amplify internal stress in the material which in turn can lead to micro-structure cracking and eventual fracture. Differences in the expansion coefficients of materials used in laminated structures can lead to loss of mirror figure in less severe cases and fracture or delamination in the more severe cases.

Humidity can also affect the surface or the bulk of the material. Moisture penetration and absorption can cause loss of optical performance by fogging or delaminating the mirror structure. Moisture can also contribute to surface leaching which further degrades the optical performance and limits the useful life of the reflector material.

Solar radiation, particularly the ultraviolet part of the spectrum from 300 to 400 nanometers can cause chemical and molecular changes in the materials. This can lead to discoloration with subsequent loss of optical performance and also to embrittlement which often results in microstructure cracking. Bonding agents used to laminate structures are particularly susceptible to UV damage.

Mechanical effects due to wind and particle bombardment also play an important role in determining the overall optical performance of the reflector materials. Fatigue results in both microstructure and macrostructure damage to the reflector. Impact due to hail or other hard objects can result in permanent figure damage or fracture. Blowing dust often results in abrasion and chipping of the reflector surface or the protective cover material leading to a loss of specularly or in extreme cases fracture of the material.

Other effects which can affect the optical performance of the reflector include organic contaminants such as bird droppings, flying insect carcasses, fungus and mold growth, and bacterial attack. One must also consider the effects of corrosive atmosphere due to airborne chemical pollutants or local environmental contaminants such as salt and alkaline or acidic soils.

PRELIMINARY AGING EXPERIMENTS

Preliminary measurements were performed to determine the effects of natural aging, and environmental contamination on the optical properties of a few selected materials used in the construction of solar reflectors. A few commonly used solar materials were selected for exposure on a non-tracking, south facing solar rack. The rack is oriented at a vertical angle of 50° and is located in a semi-arid climate in eastern Washington. In particular, samples of FEP Teflon, Polyvinyl fluoride Tedlar, and non-tempered, low-iron ASG glass were placed on the rack and periodically monitored for changes in transmittance over a period of up to four months. Samples of plate glass, exposed to the same environment for somewhere on the order of 30-50 years, were obtained and measured for changes in optical transmissivity.

The FEP samples are 2-mil thick, clear samples with polished surfaces. The Tedlar samples are 4.5-mil thick and have slightly frosted surfaces. The low-iron glass was obtained from ASG and is a specialty product for use in photovoltaic and heliostat applications. It has a specified thickness range of 0.027 to 0.030 in.

The flat surface necessary for data acquisition on the polymers was obtained by using a specially designed sample holder. The aluminum 2 x 2 x 1/2 in. holder with a 1 1/4" diameter clear aperture is depicted in Figure 4. The holder design utilizes an "O" ring to uniformly pull the polymer flat across a machined surface. Concern was expressed about deformation of the plastic, however, measurements on the FEP show that less than 1% uniform radial elongation occurs across the aperture.

Transmission data were taken prior to exposure on all of the glass samples and on representative pieces of the plastics. Relative transmissivity was obtained over the spectral range of 340 nm to 950 nm using a Beckman DK-2A spectrophotometer. This instrument has an accuracy specification of 0.5% transmittance (photometric) and a reproducibility of 0.2% (photometric).

The instrument used for these studies was realigned, cleaned and calibrated approximately 13 months prior to this work. Work with this machine shows that the photometric accuracy is probably closer to 2% and the long-term reproducibility on the order of 1%.

All polymer samples were cleaned using methanol applied to an optics cleaning cloth, and dried with Freon gas prior to the rack mounting on 6/9/77. The glasses were ultrasonically cleaned using acetone and methanol and dried again with Freon prior to mounting on 8/31/77. Daily wind velocity, humidity, solar insolation, and sky cover records are kept throughout the duration of the experiment. Further studies plan to correlate dust retention and excessive aging to these environmental parameters.

As expected, after 30 days of exposure, the low iron glass has shown no indication of optical degradation, within our experimental error, and therefore will not be considered further in this report. Testing of these samples is ongoing and further results will be reported in a later report.

FIGURE 4. Polymer Film Support

The first polymer samples were removed from the rack after 40 days of exposure. Each 6"x6" sheet was subdivided into nine 2"x2" samples for mounting in sample holders.

The transmissivity of these samples was measured prior to cleaning and after cleaning and compared to an identical measurement on a reference sample. Reference samples were obtained from the teflon and tedlar sheet stock and stored in a sealed dark container throughout the duration of the aging studies. Initial transmissivity versus wavelength data were taken on each of four orientations of the reference samples. These data were then averaged and plotted as the reference transmissivity in Figures 5 and 6 along with their typical three standard deviation error bars. This averaging is performed to help eliminate errors due to gross surface irregularities; however, it should be noted that the transmission difference throughout the spectral range never exceeded 0.7% between any two orientations of the teflon reference and 1.5% for the tedlar reference.

Typical results for the aged and reference samples are shown in Figures 5 and 6 for various lengths of exposure. Figure 5 indicates that a 40-day exposure followed by cleaning with TEXO 481 resulted in an overall drop in transmissivity of roughly 4.5% for the Tedlar at wavelengths of 450 nm and longer while over the same spectral range a 53-day exposure followed by cleaning with Laminaide (spray) resulted in an overall drop of approximately 1.5%. Furthermore, a 118-day exposure followed by cleaning with Laminaide applied to an optics cleaning cloth resulted in a degradation of roughly the same 1.5%. Apparently the optical losses induced by improper cleaning can be significantly larger than the optical degradation due to aging for relatively short aging times. Also, the losses in transmissivity induced by physically wiping the sample seem to be small in comparison to the losses induced by poor cleaning of the materials.

A similar effect is seen to occur in Teflon samples as illustrated in Figure 6. A 40-day exposure followed by cleaning with Texo 481 resulted in approximately a 3.5% loss, a 53-day exposure cleaned with Laminaide spray

FIGURE 5. Transmission Loss in Aged Tedlar Samples

FIGURE 6. Transmission Loss in Aged Teflon Samples

resulted in a 4% loss and a 118-day exposure cleaned by wiping with an optics cloth wetted with Laminaide resulted in a 0.75% loss. Again cleaning is seen to be of critical importance in the aging studies of Teflon materials and the effects of aging over periods of four months may be extremely small.

The change of 0.75% for an aging time of 118 days indicates that if short-term aging studies are to be successful, high accuracy measurement techniques must be employed. The nominal 2% accuracy of the Beckman instrument is not adequate for this type of analysis, and more accurate instrumentation is obviously necessary.

This study also indicates that development of an optimal cleaning technique for each type of material being investigated is necessary and that this technique alone should be applied to the sample throughout the study. Standard procedures need to be established concerning the methods of cleaning and should be observed by all laboratories involved in this type of research if meaningful comparisons are to be made.

Since the aging effects in glasses manifests itself rather slowly, an attempt was made to measure glasses that had already been exposed to the environment for a long period of time. Glass samples were obtained from a house constructed in roughly 1925 located at the Hanford townsite. Samples were also obtained from a bank constructed in 1916 in the townsite of White Bluffs. Both towns were abandoned between 1943 and 1945. The glass obtained from the bank was facing north and was still in its frame. The glass from the house had been facing south but was no longer in place. All samples of the glass had both an exposed area as well as an area protected by the framework. In this way the covered glass could be compared to the exposed glass in order to determine the amount of transmission loss due to exposure. All samples were cleaned with a household dishwashing detergent prior to measurements. However, some samples were cleaned in 70% HNO_3 after the detergent. This acid cleaning produced little change ($<0.5\%$) in the covered area but showed as much as $\pm 2\%$ change in the exposed area. A decrease in transmissivity due to the HNO_3 is not completely understood.

Typical results of the measurements for these glasses cleaned with the detergent are shown in Figure 7. Note that the shaded area indicates the difference in transmittance between the exposed and covered portions of the glass. Also note that losses as large as 17% were seen to occur for the south facing glass and only 3% for the north facing sample, and that the largest amount of degradation occurs in the U.V. end of the spectrum. It is believed that these samples represent the largest amount of degradation expected for solar glasses as they have not been cleaned throughout a large portion of their exposure.⁽¹⁵⁾

EVALUATION OF CLEANING SOLUTIONS ON MIRROR MATERIALS

The major objective of this task is to develop methods for cleaning mirror surfaces. This objective is to be accomplished by developing techniques for evaluating cleaning solutions, evaluating the solutions and then comparing the best of them by cleaning dirty surfaces.

The best relative technique for comparing cleaning solutions is to determine how well they wet the surface to be cleaned. Wetting of a solid surface with a liquid is with few exceptions, a function of the difference in surface energy, or surface tension, between the two. When the surface tension of the solid is lower than the liquid it is not wet by that liquid, and when the surface tension is much higher than the liquid it is easily wet. The wettability of a surface by a liquid is generally identified by contact angle. The contact angle is the included angle formed by the surface on which the liquid is contacting and the line tangent to the liquid surface at the point of contact. A liquid which wets a surface poorly has a high contact angle.

Measurement of contact angle is very difficult to do and is highly judgemental. For this reason a different approach was taken to determine the wettability of the surfaces being evaluated on this project. A test apparatus was assembled in which a precise volume of liquid (4 or 8 microliters) was dropped onto the material to be tested from a prescribed distance (1 mm) and the contact diameter was measured using a microscope, with a reticle, in a horizontal position. The measurement obtained is fully adequate for the

FIGURE 7. Transmission Loss in Plate Glass Due To Extended Environmental Exposure

purposes of this study to evaluate cleaning solutions. If a contact angle should be needed in the future for comparison of the work of others it can be easily calculated using the equations for the volume of a spherical segment and the diameter of a circular arc.

Table 1 shows a compilation of all the wetting data obtained to date on cleaning solutions in contact with Teflon FEP; Tedlar polyvinyl fluoride; and ASG low iron, nontempered glass. Both of the plastics films were used as extruded. The FEP had a polished surface and the Tedlar had a rougher satin finish. Before the measurements were made all of the surfaces were cleaned with methanol, dried with a cotton ball and blown off with Freon 12 gas.

In addition to the wetting studies, evaluation of the effect of washing of the plastics films on their light transmission was begun. Washing was performed on films that had been out in the weather 2 months on a board facing south at an angle of 50° . The washing consisted of spraying the film with 20 cc of the cleaning solution using an air brush, spray rinsing with 20 cc of distilled water using the air brush and hanging vertically to air dry. Total light transmission through the samples was measured before and after washing with a Beckman DK-2A spectrophotometer. Weathering of the Tedlar film reduced the light transmission approximately 3%. Washing with cleaning solution 13 did not improve the transmission. Weathering of the Teflon reduced light transmission approximately 10%. Washing with cleaning solution 13 increased the transmission approximately 5% for a total loss after cleaning of 5%.

Future work will entail expansion of the effort to evaluate new cleaners and more materials as they become available. Both the wetting studies and the transmittance of cleaned samples will be continued.

TABLE 1. Wetting Effectiveness of Several Commerical Cleaning Agents

Cleaning Solution	Tedlar		FEP		Low Iron Glass	
	<u>4u1</u>	<u>8u1</u>	<u>4u1</u>	<u>8u1</u>	<u>4u1</u>	<u>8u1</u>
Distilled Water		0.050±0.001		0.036±0.002	0.066±0.002	
"Tap" Water		0.045±0.003			0.077±0.001	
1		0.093±0.005	0.042±0.002			
2	0.045±0.002	>0.100		0.045±0.003	0.088±0.001	
3		>0.100		0.043±0.001		
4		0.068±0.005		0.054±0.002		
5		0.061±0.006		0.050±0.001		
6	>>0.100	>>0.100		0.053±0.001	0.061±0.001	
7				0.055±0.001		
8		0.087±0.002		0.053±0.001		
9		0.073±0.001		0.051±0.002		
10	0.070±0.004	>0.100	0.040±0.002	0.054±0.002	0.071±0.001	
11	0.083±0.002	>0.100	0.044±0.001	0.055±0.004		
12		0.087±0.010	0.042±0.002	0.054±0.001		
13	>0.100	>0.100		0.052±0.002	0.074±0.002	
14			0.045±0.000		0.050±0.001	
15			0.076±0.002		0.060±0.005	
16		0.058±0.001	0.057±0.002		0.061±0.003	
17			0.053±0.001		0.067±0.002	
18			0.040±0.001		0.081±0.011	

TABLE 2. Cleaning Solution Cross Reference Guide

<u>Cleaning Solution</u>	<u>Name and Manufacturer</u>
1	Laminade, Brulin & Company, Inc., Indianapolis, IN 46206
2	Octagon 3677 (1/2 oz/gal) } Octagon Sales Co. Octagon 3677 (1/4 oz/gal) } Edgewater, NJ 07020
3	
4	Kleenmaster Brillianize, Chemical Products Co., Omaha, NE 68102
5	Spac B Kleen Chemical Mfg. Co., Chicago, IL 60614
6	Rez-N-Kleen A.S., Schwartz Chemical Co., Inc., Long Island, NY
7	Photo Flo, Eastman Kodak
8	L-45 Lubri-Clean
9	N.-10 Neutra-Lube
10	Weiman Chandelier Rinse, The Herbert Stanley Co. Skokie, IL 60076
11	Nokomis III, Nokomis Industries, Hayward, CA 94540
12	Texo Industrial APC, } Texo 481 } Texo Corp., Cincinnati, OH 45212
13	
14	Zonyl FSA (0.1% solids) } Zonyl FSB (0.1% solids) } DuPont Specialty Chemicals Zonyl FSC (0.1% solids) } Wilmington, DE 18898 Zonyl FSN (0.1% solids) } Zonyl FSP (0.1% solids) }
15	
16	
17	
18	

STANDARDS DEVELOPMENT

Interaction with ASTM for the purposes of providing technical guidance for standards preparation has been initiated. The first standards to be drafted will deal with recommended procedures for testing of mirror materials and mirror structures. Progress in this area will be reported as it develops.

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