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Solar Energy Systems - Standards for Absorber Materials

Larry W. Masters
James F. Seiler
Edward J. Embree
Willard E. Roberts

Structures and Materials Division
Center for Building Technology
National Engineering Laboratory
U.S. Department of Commerce
National Bureau of Standards
Washington, DC 20234

January 1981

Prepared for

**Department of Energy
Office of Solar Applications for Building
Washington, DC 20585**

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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, Secretary
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, Director

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ABSTRACT

Absorber materials used in solar heating and cooling systems absorb energy from the sun and convert it to thermal energy. These materials must perform their intended functions both when first installed and after extended use. The environment in which absorber materials are exposed can cause degradation in their performance. Numerous problems with absorber materials in solar energy systems have demonstrated the need for standards to assess their performance and durability.

This study was performed to aid in the development of accelerated test methods needed for the evaluation of absorber materials and to incorporate the methods into draft standards for consideration as consensus standards by the American Society for Testing and Materials (ASTM).

Performance requirements for absorber materials were identified and laboratory and field studies were performed to measure performance according to the requirements. The data obtained, using twelve absorber materials, were used as the technical basis for two draft standards.

This report presents the results of the research and includes the proposed draft standards.

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The authors gratefully acknowledge 1) the many suggestions provided by members of ASTM E44.04 on Materials Performance in planning and carrying out this study, 2) the interest demonstrated by the Department of Energy in supporting the research, 3) the cooperation of manufacturers who provided absorber materials for inclusion in the study and commercial exposures test sites who performed outdoor exposures, 4) the technical assistance of Ms. Mildred Post and Mr. David Ballard of NBS in performing SEM analyses, 5) the technical assistance of Mr. Elmer Streed in preparing the report and 6) the support and cooperation of Mr. Robert D. Dikkers and Dr. David Waksman of NBS throughout the study.

1. INTRODUCTION

1.1 BACKGROUND

The purposes of absorptive coatings used in solar energy collectors for heating or cooling applications are to absorb the sun's energy and convert it to thermal energy. Of prime importance are the optical characteristics of the absorptive coatings, i.e., absorptance (α) and emittance (ϵ), and the maintenance of these characteristics during the lifetime of the collector system.

A significant number of problems with absorber materials and other collector materials have occurred in the residential and commercial demonstration programs being conducted by the Department of Housing and Urban Development (DHUD) and the Department of Energy (DoE). Field inspections of operational systems by the National Bureau of Standards (NBS) have also revealed a number of materials related collector problems [1].¹ Many of these problems have been traced to the inability of solar collector materials to withstand prolonged exposure to stagnation conditions. Such conditions can be expected during the normal lifetime of a solar collector, either initially, when the collector is installed before the system is put into operation or subsequently when the system is shut down either for maintenance or because of seasonal considerations, e.g., with heating only systems.

Efforts in the development of reliability/durability tests for the materials comprising collectors have been hampered by the lack of data on real time and accelerated degradation. These difficulties point out the need to develop accelerated test methods for evaluating the reliability and durability of materials and to incorporate the methods into standards for use by the solar industry.

1.2 OBJECTIVES

This study, sponsored by the Department of Energy, was performed to aid in the development of accelerated test methods needed for evaluation of absorber materials and to incorporate the methods into draft standards for consideration as consensus standards by the American Society for Testing and Materials (ASTM).

1.3 SCOPE

In order to meet the stated objectives, tasks were performed to 1) identify performance requirements, 2) develop test methods to evaluate performance and durability according to the requirements, 3) perform laboratory and field evaluations to ensure that mechanisms of failure in accelerated tests are the same as those to be expected in-service, and 4) develop, based upon the research findings, draft standards for consideration as consensus standards.

¹ Numbers in brackets indicate references included in the Bibliography.

The laboratory and field evaluations included four selective and eight nonselective absorber materials used primarily for building heating and cooling and domestic hot water applications. The optical properties of the absorbers were measured in conjunction with aging tests intended to induce degradation in the materials. The aging tests included accelerated laboratory exposure as well as outdoor exposure in simulated solar collectors. Measurement of properties before and after aging allowed the amount of degradation caused by the aging process to be determined. The accelerated laboratory aging tests emphasized elevated temperature, thermal cycling, ultraviolet radiation and moisture.

The test data contained in this report should not be used for design purposes. The properties of absorber materials are likely to vary from manufacturer to manufacturer and from one production run to another. Therefore data to aid design of collectors must be obtained for the specific absorber material which is to be used in the collector. In addition, the emittance data reported are total normal emittance rather than total hemispherical emittance.

2. PROBLEM ASSESSMENT

2.1 PERFORMANCE REQUIREMENTS

In order to perform their primary function, which is to absorb energy from the sun and convert it to heat energy, absorber materials for heating and cooling collector systems should possess, and maintain under in-use conditions, a high solar absorptance in the wavelength range of 0.3 to 3.5 μm . The absorber material, if a coating, should adhere to the substrate. In general, the absorber material should be capable of performing its intended functions when initially installed and after long-term exposure to service conditions (i.e., it should be durable). In particular, the material should resist degradation resulting from exposure to elevated temperatures, temperature cycles, ultraviolet (UV) radiation, moisture, and atmospheric constituents. The material should be chemically and physically compatible with adjoining materials and degradation products emanating from the material should not affect the performance of other collector components.

2.2 KEY PROPERTIES

Key properties of absorber materials are solar absorptance (α) and infrared emittance (ϵ). Other relevant properties are adhesion to the substrate and visual appearance.

2.3 KEY DEGRADATION FACTORS

Key degradation factors which could affect the properties of absorber materials and thereby reduce their ability to perform their intended functions were identified as elevated temperature, temperature cycles, UV radiation, and moisture.

Secondary degradation factors include freezing, oxygen, ozone and airborne contaminants. Secondary factors were not addressed in this study.

3. LABORATORY AND FIELD STUDIES

3.1 MATERIALS

Absorber materials included in the test program were nickel coated foil, anodized aluminum, copper oxide, black chrome, polyvinylidene fluoride (two), urethane, alkyd, silicone, modified polyester, epoxide, and porcelain enamel. These were selected to provide a cross-section of generic types of absorber materials which have been or could be used in solar collectors. Substrates included steel, copper, and aluminum although not all absorbers were tested on all substrates. Table 1 includes a list of the materials and the substrates on which they were applied.

A single test specimen was used at each measurement point in the laboratory tests and triplicate specimens were used in the outdoor exposures.

3.2 TEST METHODS

3.2.1 Property Measurement Tests

Absorptance was calculated from reflectance as measured using ASTM E424-71, Method A, [2] which utilizes an integrating sphere spectrophotometer, and total normal infrared emittance was measured using ASTM E408-71 [3]. Absorptance is reported as an integrated value from 0.35 to 2.1 μm for an Air Mass 2 solar spectrum. In addition to optical measurements, the specimens were visually inspected before and after aging.

3.2.2 Accelerated Laboratory Exposure Tests

The accelerated laboratory exposure tests were selected based upon the assumption that the primary degradation factors for solar absorber materials are elevated temperature, thermal cycling, ultraviolet (UV) radiation, and moisture. Temperatures for heat aging of 150, 200 and 250°C were selected, based upon absorber temperatures recorded in stagnating collectors and upon calculations of maximum expected temperatures [4], to provide data over the range of temperatures that can occur under these conditions.

3.2.2.1 Elevated Temperature (Oven Aging)

Test specimens were exposed in an oven to elevated temperatures of 150, 200 and 250°C and removed at various time increments for measurement of properties. While few absorbers in heating and cooling or domestic hot water applications would be expected to reach temperatures greater than about 175°C, higher temperatures were used in the laboratory tests to aid in acceleration of degradation. The 150°C specimens were evaluated at 1, 3, 11 and 14 weeks, 200°C specimens were evaluated at 1, 2, 4, 6 and 12 weeks and 250°C specimens evaluated at 1, 2, 4 and 12 weeks.

3.2.2.2 Thermal Cycling

Test specimens were exposed to thermal cycling with each cycle consisting of:

1. Heating at 200°C for 7.5 hours
2. Cooling to room temperature over a 30 minute period.
3. Cooling to -10°C for 15.5 hours
4. Warming to room temperature over a 30 minute period.

Properties of specimens were measured after 7, 15, 28, 42, and 84 cycles.

3.2.2.3 Ultraviolet (UV) Radiation

Test specimens were exposed to UV radiation using ASTM G26-77 [5], using a Xenon arc accelerated weathering machine of measured solar intensity. A quartz window was used around the light source and low iron glass was mounted between the light source and the test specimen to simulate the effect of a cover plate in a solar collector. The air temperature inside the weathering machine was approximately 60°C during the exposures. Specimens were removed at time increments of 125, 625, 1100 and 2100 hours for measurement of properties.

3.2.2.4 Moisture

Test specimens were exposed in a humidity cabinet at 92°C and 97 percent relative humidity and removed at time increments of 1, 2, 6 and 21 weeks for evaluation. Specimens were also tested according to ASTM D2247-68 (1973) [6], which provides for the formation of condensation on the absorber surface. Specimens were evaluated at time increments of 1, 3, 6 and 12 weeks of condensation cycle exposure.

3.2.2.5 Cumulative Exposure

Tests were performed to expose materials sequentially to elevated temperature (200°C), thermal cycling, as in 3.2.2.2, UV radiation, as in 3.2.2.3 and moisture (92°C and 97% r.h.). Properties of the specimens were measured after each exposure condition.

This exposure was performed to evaluate the effect of cumulative exposure relative to the effect of single aging tests described in 3.2.2.1 through 3.2.2.4. Exposures were not performed to study the synergistic effects of combined degradation factors.

3.2.3 Outdoor Exposure Tests

Specimens were exposed outdoors in test boxes which simulate a solar collector (see figure 1). The exposure boxes included a single, low iron glass cover plate, a coated metallic mounting plate, and glass fiber insulation behind the mounting plate. For selective coatings, the boxes contained a black chrome coated mounting plate, while the boxes for nonselective coatings contained a flat black coated mounting plate. Exposures were performed

at three sites having distinctly different climates: Gaithersburg, Maryland; Phoenix, Arizona; and Miami, Florida. The procedure used was in general accordance with a draft standard being developed by ASTM Committee E44 on Solar Energy Conversion [7]. Test specimens (triplicate) were retrieved at various time increments (approximately every four months) for measurement of properties.

3.2.4 Outgassing

Several specimens were evaluated at 250°C for outgassing, a phenomenon in which degradation products condense on the underside of cover plates. The deposits formed can result in reduced ability of the cover plates to transmit sunlight. The outgassing test method consisted of collecting condensable materials on a glass plate of known transmittance. As part of the outgassing test, the transmittance was remeasured to determine the effect of the condensable materials. The method is further described in an NBS report [8]. Appendix B, Standard Practice for Determining the Effect of Outgassing on the Transmittance of Glass Test Plates which Simulate Solar Collector Covers, contains the details of the test procedure used.

4. RESULTS AND DISCUSSION

4.1 ACCELERATED LABORATORY EXPOSURE TESTS

Absorptance (α) and infrared emittance (ϵ) of the absorber materials were determined prior to laboratory exposure using the methods described in 3.2.1. The optical properties of ten randomly selected specimens of each absorber were measured to assess the uniformity of the test specimens. With the exception of the emittance values for absorber C5 (copper oxide), the properties of each absorber material were reproducible within 0.01 unit from specimen to specimen. The average initial absorptance and emittance values of the ten specimens of each absorber are shown in table 2. The values reported in table 2 are used as a basis for comparison of absorptance and emittance before and after accelerated laboratory exposure tests and outdoor exposure tests. During the study, a set of test specimens was stored as controls in the laboratory at $20 \pm 3^\circ\text{C}$ and 50 ± 5 percent r.h. Measurement of the absorptance and emittance after completion of all accelerated laboratory tests demonstrated that no changes in the optical properties resulted in the control specimens.

4.1.1 Elevated Temperature (Oven Aging)

4.1.1.1 150°C Exposure

The results of oven aging at 150°C for up to 14 weeks are presented in table 3. The absorptance of copper oxide specimens decreased from 0.95 to 0.87 after eleven weeks and was 0.88 after 14 weeks. Black chrome on copper decreased in absorptance from 0.96 to 0.93 after 14 weeks. The absorptance of the modified polyester specimens on all three substrates decreased as shown in the table. The 150°C exposure had little, if any, effect on the absorptance of other absorber materials.

The observed change in the infrared emittance of copper oxide specimens must be interpreted with caution because, as previously noted, the emittance of unexposed specimens varied considerably from specimen to specimen. Emittance of other absorber materials was not significantly changed by the exposure.

4.1.1.2 200°C Exposure

The results of the 200°C oven aging exposure are summarized in table 4. Decreases in absorptance of more than 0.01 unit were observed for test specimens of copper oxide, black chrome on copper and modified polyester on steel, copper and aluminum.

Figure 2 shows the reflectance curves for unaged and aged (12 weeks at 200°C) copper oxide specimens. Figure 3 shows the shift observed from 0.8-2.1um in the reflectance curves of black chrome on copper after oven aging at 150°C, 200°C and 250°C.

After 12 weeks exposure, emittance changes of more than 0.01 unit were noted for copper oxide, polyvinylidene fluoride [on galvanized steel(G9), bonderized steel(H1) and aluminum (H8)], urethane, silicone on copper and aluminum, and modified polyester on aluminum. The values for copper oxide are of questionable significance because of the variability of the absorber. The G9 polyvinylidene fluoride increased in emittance from 0.85 to 0.91 after 12 weeks exposure while the emittance for the H series specimens decreased.

One absorber material, the epoxide, decomposed during the exposure and was removed from the copper and aluminum substrates. The same absorber on steel was unaffected by the exposure. Although the nickel foil absorber exhibited no degradation in optical properties during the exposure, the adhesive which bonded the foil to the substrate was observed to lose adhesion. As a result, the foil blistered substantially (See figure 4).

4.1.1.3 250°C Exposure

The results of the 250°C oven aging exposure are presented in table 5. Absorbers which exhibited little or no change in absorptance at 250°C were nickel foil, anodized aluminum, black chrome, alkyd on steel, silicone on steel and aluminum, and porcelain enamel. Polyvinylidene fluoride (H1 and H8) exhibited little change in absorptance but showed a decrease in emittance from 0.85 and 0.88 to 0.54 and 0.52, respectively, after 12 weeks.

A number of absorbers exhibited degradation or loss of adhesion during or after the 12 week exposure. These included copper oxide (figure 5), polyvinylidene fluoride on galvanized steel (figure 6), urethane on copper and aluminum (figures 7 and 8), alkyd on copper and aluminum (figures 9 and 10), epoxide on all three substrates, silicone on copper and modified polyester on all three substrates.

Figure 3 shows the reflectance curve for black chrome on copper after the 250°C exposure.

4.1.2 Thermal Cycling

The results of the thermal cycling exposures are presented in table 6. Thermal cycling after 84 cycles, led to a change in absorptance for copper oxide (from .95 to .86) and black chrome on copper (from .96 to .92); these changes probably resulted from the high temperature portion of the cycle, since losses in acceptance were observed during the 200°C oven aging (see Table 4). Figures 2 and 11 illustrate the effect of thermal cycling on the reflectance curves of copper oxide and alkyd on steel, respectively.

The modified polyester coating exhibited the most dramatic failure in that, upon putting the specimens in the freezer during the first cycle, the coating delaminated. Figure 12 illustrates the appearance after failure. Thermal cycling also resulted in loss of adhesion of urethane on steel, alkyd on steel and copper, epoxide on steel and copper, and silicone on steel.

4.1.3 Ultraviolet (UV) Radiation

Accelerated UV radiation of more than 2000 hours had little, if any, effect on the optical properties of the absorber materials, as indicated by the data in Table 7. Visual inspection of the absorbers after exposure indicated no change in appearance, no loss of adhesion and no surface degradation. Figures 2 and 11 illustrates the effect of exposure on the reflectance curves of copper oxide and alkyd on steel, respectively.

4.1.4 Moisture

Two laboratory tests were performed to determine the effect of moisture exposures. As described in 3.2.2.4, one test consisted of continuous exposure at 92°C and 97 percent r.h. The second included a moisture condensation cycle. Tables 8 and 9 summarize the optical property data obtained following these exposures.

The moisture exposure for 21 weeks at 92°C and 97 percent r.h. resulted in decreased absorptance of more than 0.01 unit for urethane on steel (0.97 to 0.95), alkyd on steel (0.97 to 0.90), epoxide on steel (0.97 to 0.90), epoxide on aluminum (0.97 to 0.90) and modified polyester on aluminum (0.90 to 0.88). Figures 13, 14 and 15 illustrate the visual appearance of alkyd test specimens on steel, copper and aluminum, respectively. Surface degradation of the coating was evident in the 21 week test specimens on all three substrates and steel and aluminum specimens exhibited metallic corrosion.

Despite the presence of corrosion products on the surface of the alkyd on aluminum specimen, the absorptance and emittance values remained nearly the same as those for unexposed specimens. Figure 11 illustrates the shift in the reflectance observed for the alkyd on steel following the 21 week exposure at 92°C and 97 percent r.h.

Figures 16 and 17 depict the appearance of epoxide test specimens on steel and aluminum. Figures 18 and 19 show cross-sections of the unexposed and exposed epoxide on aluminum specimens using Scanning Electron Microscopy (SEM). These latter figures show that the epoxide matrix degraded, cracked

and delaminated from the graphite particles as a result of the exposure, thereby providing a path for moisture penetration to the metallic surface. Further details of the SEM analysis have been reported by Post and Ballard (9).

Figure 20, of polyvinylidene fluoride on galvanized steel (G9), shows that the coating lost adhesion after 21 weeks at 92°C and 97 percent r.h. Although this coating showed little change in absorptance and emittance (Table 8), degradation had occurred in its bond to the substrate. Figures 21 and 22 show cross-sections of unexposed and exposed polyvinylidene fluoride on galvanized steel (G9) using SEM. The loss of adhesion between the galvanized surface and the epoxide primer (Arrow B) and between the steel substrate and the galvanizing layer (Arrow A) may be noted in Figure 22 (9).

Table 9 illustrates that the 12 week moisture exposure using a moisture condensation cycle led to a decrease in absorptance of more than 0.01 unit for nickel foil (0.98 to 0.95), anodized aluminum (B6) (0.92 to 0.90) and black chrome on copper (0.96 to 0.93). Coatings which exhibited change in absorptance in the moisture exposure at 92°C and 97 percent r.h. (Table 8), i.e., urethane on steel, alkyd on steel, epoxide on steel and aluminum and modified polyester, did not exhibit those same changes in the condensation cycle.

Analysis of cross-sections of the epoxide on aluminum specimens by SEM, however, showed that the epoxide matrix degraded in the same manner as observed in the exposure at 92°C and 97 percent r.h. For example, when SEM cross-sections of the epoxide on aluminum specimens exposed for 6 weeks at 92°C and 97 percent r.h. were compared to cross-sections exposed for 6 weeks using the condensation cycle, degradation of the epoxide matrix was evident following both exposures, although the extent of the degradation was less using the condensation cycle.

Also, visual and SEM analysis of the polyvinylidene fluoride on galvanized steel specimens following condensation cycle exposure indicated signs of loss of adhesion, as had been observed using the 92°C and 97 percent r.h. exposure. Microscopic analysis of the alkyd on steel specimens following 12 weeks of condensation cycle exposure indicated signs of surface cracking and it is probable that continued exposure would have led to the degradation observed visually and optically after 21 weeks exposure at 92°C and 97 percent r.h.

It appears from these analysis that both moisture exposures induce the same mechanisms of degradation but that the condensation cycle exposure is less severe than the exposure at 92°C and 97 percent r.h.

4.1.5 Cumulative Exposure

As mentioned in 3.2.2.5, tests were designed to study the effect of sequential exposure of the same test specimens to 1) oven aging, 2) thermal cycling, 3) UV radiation and 4) moisture. However, the tests were terminated after 28 cycles of the thermal cycling because of the large number of the failures which were observed. At the point at which testing was terminated, specimens had been exposed to 12 weeks of oven aging at 200°C and 28 cycles from 200°C to -10°C (as described in the procedure for Thermal Cycling in 3.2.2.2).

The test specimens used for this test were those that had been previously exposed to oven aging at 200°C for 12 weeks. Absorptance and emittance values for these specimens at the end of the 200°C oven aging are given in table 4.

Upon commencing the thermal cycling phase of the sequential testing, many of the absorber materials exhibited rapid degradation leading to delamination from the substrate. For example, figures 23 and 24 show delamination of the alkyd on aluminum and the urethane on copper after 28 temperature cycles. In the 84 thermal cycles completed without prior oven aging (table 6), these same coatings did not delaminate.

At the end of 28 cycles, the following absorber materials remained intact: anodized aluminum (B6 and B7), copper oxide, black chrome on steel and copper, polyvinylidene fluoride on steel and aluminum (H1 and H8), silicone on copper and aluminum and porcelain enamel on steel and aluminum. All other absorber materials had delaminated.

4.2 OUTDOOR EXPOSURE

Table 10 contains the results of outdoor exposures performed on the grounds of the National Bureau of Standards, Gaithersburg, Maryland. Specimens were exposed in test boxes as shown in figure 1 to simulate exposure to stagnation conditions. Tables 11 and 12 summarize the data from outdoor exposures performed using identical test boxes at Phoenix, Arizona and Miami, Florida.

The Maryland exposures were started in June 1978. Specimens were first retrieved for evaluation in October 1978 and re-exposed from November 1978 to March 1979. They were then exposed from April 1979 to August 1979. The Arizona exposures were initiated in November 1978. The first evaluation was performed in March 1979. The second exposure period included exposure from April 1979 to August 1979.

The first four months of Florida exposure covered a period from June 1978 to October 1978. They were re-exposed from November 1978 to May 1979, prior to evaluation for the second time. During this exposure increment, the specimens were not exposed for a two month period due to storm damage at the test site. The third exposure period was from July 1979 to November 1979.

The data in tables 10-12 indicate that little change occurred in the absorptance and emittance of most absorbers as a result of the exposures. Changes in absorptance and emittance are noted for copper oxide but these data must be interpreted with caution because of the large variability noted in emittance for unexposed specimens. Also, the limited amount of data available to date makes it difficult to explain the few changes that have occurred. For example, the absorptance and emittance of modified polyester on copper (M4) decreased in Arizona but increased in Maryland and Florida. The relatively small changes observed in the outdoor exposure tests indicate that the accelerated laboratory exposures, which resulted in degradation of some materials (i.e., oven aging at 200°C and 250°C, thermal cycling and moisture exposure), provide more severe exposure conditions than outdoor exposure in

the test boxes. This is not surprising. Measurements of temperatures in similar test boxes [10] show that attainment of 200°C is unlikely, at least for extended periods of time. Also, thermal cycles and moisture conditions experienced in test boxes outdoors are less severe than the accelerated laboratory conditions. The outdoor exposure will be continued to obtain additional data. These additional data will be used to study rates of degradation so that improved comparisons and mathematical models of laboratory and field test data can be made.

Figures 25 and 26 show the reflectance curves for black chrome on steel (D2) and copper (D4), respectively, following outdoor exposure in Maryland.

Figure 27 contains reflectance curves for black chrome on copper following Florida exposures. Figures 26 and 27 show that the observed shift in reflectance curves for black chrome on steel occurred during the first four months of exposure.

4.3 OUTGASSING

The outgassing test data are shown in Table 13. The test at 250°C resulted in no change in transmittance of the glass collecting plate for nickel foil, anodized aluminum, copper oxide and black chrome. Polyvinylidene fluoride, urethane, and alkyd caused a decrease in transmittance of 0.4, 1.8 and 5.5 percent, respectively.

5. CONCLUSIONS

1. The data obtained in this study show that the environment experienced in solar collectors, e.g. elevated temperature, thermal cycling and moisture, can degrade some materials typically used as absorber materials.
2. Degradation of materials, which can be observed visually or with SEM, does not always result in a change in absorptance or emittance (or in the reflectance curves from 0.35-2.1 μm). It is important, therefore, to visually inspect exposed specimens and to note observable changes.
3. Accelerated laboratory tests can be used as an effective means of determining if absorber materials are likely to be degraded by specific degradation factors, such as high temperature, thermal cycling and moisture. These test methods, therefore, can provide a basis for evaluation standards which aid in screening materials.
4. Exposure to elevated temperature is an important test in evaluating absorber materials. Oven aging at 150, 200 and 250°C showed that, in general, the absorbers studied are stable up to 150°C. At temperatures of 200°C or higher, however, the polymeric materials may be susceptible to degradation resulting from thermal decomposition.
5. Thermal cycling proved to be an important test to aid in identifying potential adhesion problems which may be accentuated by expansion and contraction.

6. The accelerated UV radiation exposure of more than 2000 hours had little effect on the absorptance and emittance of the materials studied. Also, none of the materials exhibited visually detectable changes such as loss of adhesion, as a result of the exposures. It is uncertain whether the test, as performed, was not effective in inducing UV degradation or whether the absorber materials included in the study are not likely to be degraded by UV exposure.
7. Moisture exposure is an important test in evaluating absorber materials. Of the two test methods used, the exposure at 92°C and 97 percent r.h. appears to be a more severe test than the condensation cycle exposure.
8. Cumulative exposure testing appears to be much more severe than exposure of specimens to single degradation factors. Degradation induced in several absorber materials during the 12 week oven aging at 200°C decreased their ability to withstand thermal cycling.
9. The substrate to which a coating is applied affects its resistance to the various exposure tests. Therefore, it is essential to evaluate absorbers on the substrates to which they will be applied in solar collectors.
10. Little change was observed in the absorptance, emittance and appearance of most specimens exposed outdoors to stagnation conditions at three locations, Maryland, Arizona and Florida. This indicates that the outdoor exposure test is less severe for some absorber materials than the accelerated laboratory exposures. Despite the fact that little change was observed in the properties of most test specimens during outdoor exposure, the test method is a valuable tool for evaluating absorbers because the exposure conditions are more closely related to real-life than the accelerated laboratory exposures. Since correlations have not yet been established between laboratory tests and in-service performance, stagnation test data are particularly useful in selecting absorbers for specific applications.
11. The test procedure developed during this study to evaluate the effects of outgassing on the transmittance of a glass plate appears to provide an effective tool for identifying, in the laboratory, potential outgassing problems. Future work is needed to compare results of the test with those obtained in operational solar collectors.

6. PROPOSED STANDARDS

6.1 STANDARD PRACTICE FOR EVALUATING SOLAR ABSORPTIVE MATERIALS FOR THERMAL APPLICATIONS

Appendix A is a proposed practice for evaluating solar absorptive materials for thermal applications.

The practice provides two methods for evaluating absorber materials. Method 1 (Laboratory Exposure) includes exposure of separate test specimens to elevated temperature, thermal cycling, moisture and UV radiation. Test temperatures are linked to in-use or stagnation temperatures for the materials to be evaluated. Moisture exposure utilizes an environment at $90 \pm 5^\circ\text{C}$ and 95 ± 5 percent r.h. This exposure is the more severe of the two methods used in this study. Steps 1 (heating) and 3 (cooling) of the thermal cycling procedure were shortened from 7.5 and 15.5 hours, respectively, as used in the laboratory study, to one hour each. This permits the accumulation of an increased number of cycles per unit time.

Method 2 provides for outdoor exposure for approximately 12 months and references the practice being developed by ASTM E44 (7) and utilized in this study for outdoor exposure.

Before and after exposure, absorber materials are evaluated for reflectance, emittance and visual appearance.

The practice, as outlined, excludes its use for 1) concentrating collectors with concentrating ratios exceeding 5, 2) absorbers used in direct contact with, or suspended in, a heat transfer fluid and 3) absorbers used in evacuated collectors.

6.2 STANDARD PRACTICE FOR DETERMINING THE EFFECT OF OUTGASSING ON THE TRANSMITTANCE OF GLASS TEST PLATES WHICH SIMULATE SOLAR COLLECTOR COVERS

Appendix B is a proposed test method for determining the effect of outgassing on the transmittance of glass test plates which simulate cover plates used in solar collectors.

The method consists of heating a test specimen and collecting the condensable outgassing products on a glass plate. A filtered air stream serves to cool the glass plate. The transmittance of the glass plate is measured, using ASTM E424, Method A, before and after the test.

Key components in the test apparatus include a hot plate, a specimen holder, a Teflon gasket and sleeve, a glass test plate, a filtered air stream and an instrument for measuring the temperature of the test specimen.

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TABLE 1. ABSORBER MATERIALS AND SUBSTRATES USED IN THE STUDY

<u>Code Number</u> ^{1/}	<u>Absorber Material</u>	<u>Substrate</u>
A8	Nickel coated foil	Aluminum, alodine
B6	Anodized aluminum	Aluminum, 6061, anodized
B7	Anodized aluminum	Aluminum, 1100, anodized
C5	Copper oxide	Copper
D2	Black chrome	Steel, cold-rolled ^{2/}
D4	Black chrome	Copper, DHP 122 ^{3/}
G9	Polyvinylidene fluoride	20 gage, G90, hot dipped galvanized steel
H1	Polyvinylidene fluoride	Steel, bonderized
H8	Polyvinylidene fluoride	Aluminum, alodine
I1	Urethane	Steel, bonderized
I4	Urethane	Copper, DHP 122
I8	Urethane	Aluminum, alodine
J1	Alkyd	Steel, bonderized
J4	Alkyd	Copper, DHP 122
J8	Alkyd	Aluminum, alodine
K1	Epoxide	Steel, bonderized
K4	Epoxide	Copper, DHP 122
K8	Epoxide	Aluminum, alodine
L1	Silicone	Steel, bonderized
L4	Silicone	Copper, DHP 122
L8	Silicone	Aluminum, alodine
M1	Modified polyester	Steel, bonderized
M4	Modified polyester	Copper, DHP 122
M8	Modified polyester	Aluminum, alodine
N2	Porcelain enamel	Steel, cold-rolled
N8	Porcelain enamel	Aluminum, alodine

1/ The letter refers to the absorber material and the number to the substrate.

2/ Includes 0.5 mil Nickel flash.

3/ Includes 0.1 - 0.2 mil Nickel flash.

TABLE 2. ABSORPTANCE AND INFRARED EMITTANCE OF
ABSORBERS PRIOR TO EXPOSURE

<u>Code Number</u>	<u>Absorber Material</u>	<u>Absorptance (α)</u>	<u>Emittance (ϵ)</u>
A8	Nickel foil	0.98	0.09
B6	Anodized aluminum	0.92	0.81
B7	Anodized aluminum	0.90	0.82
C5	Copper oxide	0.95	0.74 ^{1/}
D2	Black chrome	0.95	0.07
D4	Black chrome	0.96	0.06
G9	Polyvinylidene fluoride	0.95	0.85
H1	Polyvinylidene fluoride	0.96	0.85
H8	Polyvinylidene fluoride	0.96	0.88
I1	Urethane	0.97	0.92
I4	Urethane	0.97	0.92
I8	Urethane	0.97	0.92
J1	Alkyd	0.97	0.92
J4	Alkyd	0.97	0.91
J8	Alkyd	0.97	0.92
K1	Epoxide	0.97	0.91
K4	Epoxide	0.97	0.91
K8	Epoxide	0.97	0.91
L1	Silicone	0.97	0.88
L4	Silicone	0.97	0.87
L8	Silicone	0.97	0.88
M1	Modified polyester	0.93	0.86
M4	Modified polyester	0.89	0.84
M8	Modified polyester	0.90	0.81
N2	Porcelain	0.93	0.85
N8	Porcelain	0.93	0.84

^{1/} Emittance for 10 specimens of this sample varied from 0.65 to 0.80.

Table 3. RESULTS OF 150°C OVEN AGING EXPOSURE

Code Numbers	Absorber Material	EXPOSURE TIME (WEEKS)							Emittance (ϵ)							
		Absorptance (α)														
		0	1	3	11	14	0	1	3	11	14	0	1	3	11	14
A8	Nickel Foil	.98	.98	.98	.98	.97	.09	.07	.08	.08	.08	.85	.84	.84	.83	.83
B6	Anodized	.92	.92	.92	.92	.92	.81	.81	.80	.81	.81	.81	.81	.81	.81	.81
B7	Anodized	.90	.90	.90	.90	.90	.82	.81	.81	.81	.81	.74	.65	.64	.69	.65
C5	Copper Oxide	.95	.92	.91	.87	.88	.74	.65	.64	.69	.65	.07	.07	.06	.06	.06
D2	Black Chrome	.95	.97	.96	.95	.95	.07	.07	.06	.06	.06	.06	.06	.06	.06	.06
D4	Black Chrome	.96	.93	.93	.92	.93	.06	.06	.06	.06	.06	.84	.84	.84	.83	.83
G9	Polyvinylidene Fluoride	.95	.95	.95	.95	.95	.85	.84	.84	.83	.83	.85	.84	.84	.83	.83
H1	Polyvinylidene Fluoride	.96	.95	.95	.95	.95	.85	.82	.80	.85	.85	.85	.82	.80	.85	.85
H8	Polyvinylidene Fluoride	.96	.96	.95	.95	.95	.88	.88	.88	.88	.88	.88	.88	.88	.88	.86
I1	Urethane	.97	.98	.97	.98	.97	.92	.92	.92	.92	.93	.92	.92	.92	.93	.93
I4	Urethane	.97	.97	.97	.98	.97	.92	.92	.92	.92	.92	.92	.92	.92	.92	.92
I8	Urethane	.97	.98	.98	.97	.97	.92	.92	.92	.92	.92	.92	.92	.92	.92	.92
J1	Alkyd	.97	.97	.97	.98	.97	.92	.92	.91	.91	.91	.91	.91	.91	.91	.91
J4	Alkyd	.97	.98	.98	.98	.97	.91	.91	.91	.91	.91	.91	.91	.91	.91	.91
J8	Alkyd	.97	.98	.98	.97	.97	.92	.91	.91	.91	.91	.91	.91	.91	.91	.91
K1	Epoxide	.97	.98	.98	.98	.98	.91	.91	.91	.91	.91	.91	.91	.91	.91	.90
K4	Epoxide	.97	.98	.98	.98	.97	.91	.91	.91	.91	.91	.91	.91	.91	.91	.91
K8	Epoxide	.97	.98	.98	.98	.97	.91	.91	.91	.91	.91	.91	.91	.91	.91	.91
L1	Silicone	.97	.97	.97	.97	.97	.88	.88	.87	.88	.87	.88	.88	.87	.88	.87
L4	Silicone	.97	.97	.92	.97	.96	.87	.86	.86	.88	.87	.86	.86	.86	.88	.87
L8	Silicone	.97	.97	.97	.97	.97	.88	.88	.87	.88	.88	.88	.88	.87	.88	.88
M1	Mod. Polyester	.93	.93	.91	.90	.90	.86	.85	.86	.87	.87	.86	.85	.86	.87	.87
M4	Mod. Polyester	.89	.91	.90	.87	.85	.84	.84	.87	.84	.84	.84	.84	.87	.84	.84
M8	Mod. Polyester	.90	.92	.87	.86	.85	.81	.84	.82	.84	.84	.81	.84	.82	.84	.84
N2	Porcelain	.93	.94	.94	.94	.93	.85	.85	.85	.85	.85	.85	.85	.85	.85	.85
N8	Porcelain	.93	.94	.94	.95	.95	.84	.84	.84	.84	.84	.84	.84	.84	.84	.84

TABLE 4. RESULTS OF 200°C OVEN AGING EXPOSURE^{1/}

EXPOSURE TIME (WEEKS)

Absorptance (α) Emittance (ϵ)

Code Number	Absorber Material	EXPOSURE TIME (WEEKS)												
		0	1	2	4	6	12	0	1	2	4	6	12	
A8	Nickel Foil	.98	.98	.98	.98	.98	.98	.98	.09	.07	.07	.09	.09	.10
B6	Anodized	.92	.92	.91	.91	.92	.91	.91	.81	.80	.80	.81	.81	.81
B7	Anodized	.90	.91	.89	.90	.89	.89	.89	.82	.81	.81	.81	.81	.81
C5	Copper Oxide	.95	.88	.88	.88	.89	.89	.89	.74	.67	.67	.67	.67	.69
D2	Black Chrome	.95	.97	.96	.97	.96	.96	.96	.07	.08	.06	.06	.06	.06
D4	Black Chrome	.96	.95	.93	.94	.93	.93	.93	.06	.06	.06	.05	.05	.05
G9	Polyvinylidene Fluoride	.95	.95	.95	.95	.95	.95	.95	.85	.85	.85	.85	.85	.91
H1	Polyvinylidene Fluoride	.96	.96	.96	.96	.96	.96	.96	.85	.80	.80	.83	.83	.78
H8	Polyvinylidene Fluoride	.96	.96	.96	.96	.96	.96	.96	.88	.87	.87	.89	.89	.85
I1	Urethane	.97	.98	.98	.98	.98	.98	.98	.92	.93	.93	.93	.93	.94
I4	Urethane	.97	.98	.97	.97	.97	.97	.97	.92	.94	.94	.93	.93	.94
I8	Urethane	.97	.98	.97	.97	.98	.98	.98	.92	.94	.94	.93	.93	.94
J1	Alkyd	.97	.98	.97	.98	.98	.98	.98	.92	.91	.91	.91	.91	.91
J4	Alkyd	.97	.98	.97	.98	.98	.98	.98	.91	.91	.91	.91	.91	.91
J8	Alkyd	.97	.98	.98	.98	.98	.98	.98	.92	.91	.91	.91	.91	.91
K1	Epoxide	.97	.98	.98	.98	.98	.98	.98	.91	.90	.90	.91	.91	.91
K4	Epoxide	.97	.98	+	+	+	+	+	.91	+	+	.91	+	+
K8	Epoxide	.97	.98	.98	.98	.98	.98	.98	.91	.91	.91	.91	.91	.91
L1	Silicone	.97	.97	.97	.97	.97	.97	.97	.88	.88	.88	.88	.88	.89
L4	Silicone	.97	.97	.96	.97	.96	.97	.96	.87	.88	.88	.88	.88	.89
L8	Silicone	.97	.97	.97	.97	.97	.97	.97	.88	.89	.89	.89	.89	.89
M1	Mod. Polyester	.93	.90	.89	.90	.89	.90	.90	.86	.87	.87	.87	.87	.87
M4	Mod. Polyester	.89	.87	.86	.85	.82	.83	.83	.84	.84	.84	.85	.85	.84
M8	Mod. Polyester	.90	.87	.88	.89	.88	.88	.88	.81	.84	.83	.84	.84	.85
N2	Porcelain	.93	.94	.93	.93	.93	.93	.93	.85	.85	.85	.85	.85	.85
N8	Porcelain	.93	.96	.96	.95	.96	.95	.95	.84	.85	.85	.84	.84	.84

^{1/} + designates removal of absorber material during exposure.

TABLE 5. RESULTS OF 250°C OVEN AGING EXPOSURE 1/

Code Number	Absorber Material	EXPOSURE TIME (WEEKS)									
		Absorptance (α)				Emittance (ϵ)					
		0	1	2	4	12	0	1	2	4	12
A8	Nickel Foil	.98	.98	.98	.98	.98	.09	.07	.06	.10	.08
B6	Anodized	.92	.92	.92	.92	.92	.81	.80	.81	.81	.81
B7	Anodized	.90	.89	.90	.90	.90	.82	.80	.81	.81	.81
C5	Copper Oxide	.95	+	.90	.90	+	.74	+	.58	.62	+
D2	Black Chrome	.95	.95	.93	.96	.96	.07	.06	.06	.06	.08
D4	Black Chrome	.96	.91	.92	.92	.93	.06	.05	.06	.05	.07
G9	Polyvinylidene Fluoride	.95	.95	.95	.95	+	.85	.89	.89	.90	+
H1	Polyvinylidene Fluoride	.96	.96	.95	.95	.95	.85	.76	.63	.57	.54
H8	Polyvinylidene Fluoride	.96	.96	.95	.95	.95	.88	.81	.63	.57	.52
I1	Urethane	.97	.97	.96	.95	.91	.92	.93	.93	.93	.90
I4	Urethane	.97	.95	.91	.80	+	.92	.93	.90	.89	+
I8	Urethane	.97	.97	+	+	+	.92	.93	+	+	+
J1	Alkyd	.97	.96	.96	.96	.97	.92	.90	.90	.91	.92
J4	Alkyd	.97	.95	.95	.96	+	.91	.90	.90	.91	+
J8	Alkyd	.97	.95	+	+	+	.92	.90	+	+	+
K1	Epoxide	.97	.98	.98	.98	+	.91	.90	.90	.92	+
K4	Epoxide	.97	.97	+	+	+	.91	.90	+	+	+
K8	Epoxide	.97	+	+	+	+	.91	+	+	+	+
L1	Silicone	.97	.97	.95	.95	.94	.88	.88	.89	.90	.90
L4	Silicone	.97	.97	+	+	+	.87	.87	+	+	+
L8	Silicone	.97	.97	.97	.97	.95	.88	.88	.88	.90	.88
M1	Mod. Polyester	.93	.90	.92	.90	+	.86	.85	.82	.81	+
M4	Mod. Polyester	.89	+	+	+	+	.84	+	+	+	+
M8	Mod. Polyester	.90	.86	+	+	+	.81	.85	+	+	+
N2	Porcelain	.93	.95	.95	.96	.96	.85	.84	.84	.85	.86
N8	Porcelain	.93	.96	.96	.97	.97	.84	.83	.83	.84	.85

1/ + designates removal of absorber material during exposure

TABLE 6. RESULTS OF THERMAL CYCLING 1/

NUMBER OF CYCLES

Emittance (ϵ)

Absorptance (α)

Code Number	Absorber Material	NUMBER OF CYCLES																
		0	7	15	28	42	84	0	7	15	28	42	84					
A8	Nickel Foil	.98	.98	.98	.98	.99	.98	.99	.98	.99	.98	.99	.98	.99	.10	.09	.09	.11
B6	Anodized	.92	.91	.91	.92	.91	.92	.91	.92	.91	.92	.91	.92	.91	.81	.81	.81	.82
B7	Anodized	.90	.90	.89	.90	.90	.90	.90	.90	.90	.90	.90	.90	.90	.81	.81	.81	.82
C5	Copper Oxide	.95	.90	.88	.85	.82	.86	.82	.85	.82	.86	.74	.86	.70	.68	.64	.64	.66
D2	Black Chrome	.95	.95	.96	.96	.94	.94	.94	.96	.94	.94	.07	.94	.09	.06	.06	.06	.07
D4	Black Chrome	.96	.94	.95	.94	.94	.92	.94	.94	.94	.92	.06	.94	.06	.06	.06	.06	.05
G9	Polyvinylidene Fluoride	.95	.95	.95	.95	.95	.95	.95	.95	.95	.95	.85	.95	.84	.84	.84	.84	.91
H1	Polyvinylidene Fluoride	.96	.95	.96	.96	.96	.96	.96	.96	.96	.96	.85	.96	.83	.84	.80	.80	.81
H8	Polyvinylidene Fluoride	.96	.95	.96	.96	.96	.96	.96	.96	.96	.96	.88	.96	.89	.88	.89	.89	.85
I1	Urethane	.97	.97	.97	.98	.97	.97	.97	.98	.97	.97	.92	.97	.92	.92	.93	.93	+
I4	Urethane	.97	.97	.97	.98	.97	.97	.97	.98	.97	.97	.97	.92	.92	.93	.93	.93	.94
I8	Urethane	.97	.97	.97	.98	.98	.97	.98	.98	.98	.97	.92	.98	.93	.93	.93	.93	.94
J1	Alkyd	.97	.97	.97	.93	.97	.97	.97	.93	.97	.97	.92	.97	.91	.91	.90	.90	+
J4	Alkyd	.97	.97	.97	+	+	+	+	+	+	+	.91	.91	.91	+	+	+	
J8	Alkyd	.97	.97	.97	.97	.97	.97	.97	.97	.97	.97	.92	.97	.91	.91	.91	.91	.91
K1	Epoxide	.97	.97	.97	.97	+	+	+	.97	+	+	.91	.97	.90	.91	.90	+	
K4	Epoxide	.97	.97	.97	+	+	+	+	.97	+	+	.91	.97	.90	.91	+	+	
K8	Epoxide	.97	.97	.97	.97	.97	.97	.97	.97	.97	.97	.91	.97	.90	.91	+	+	
L1	Silicone	.97	.97	.97	.97	.97	.97	.97	.97	.97	.97	.88	.97	.87	.87	.88	.88	+
L4	Silicone	.97	.97	.97	.97	.97	.97	.97	.97	.97	.97	.87	.97	.87	.88	.88	.88	.89
L8	Silicone	.97	.97	.97	.97	.97	.97	.97	.97	.97	.97	.88	.97	.87	.88	.88	.88	.89
M1	Mod. Polyester	.93	.91	.90	.92	+	+	+	.92	+	+	.86	.97	.87	.87	.87	.87	+
M4	Mod. Polyester	.89	+	+	+	+	+	+	+	+	+	.84	+	+	+	+	+	+
M8	Mod. Polyester	.90	.88	.89	.88	+	+	+	.88	+	+	.81	.86	.86	.86	.86	.86	+
N2	Porcelain	.93	.93	.94	.94	.94	.94	.94	.94	.94	.94	.85	.85	.85	.85	.85	.85	.85
N8	Porcelain	.93	.92	.94	.93	.93	.93	.93	.93	.93	.93	.84	.84	.83	.84	.84	.84	.84

1/ + designates removal of absorber material during exposure.

TABLE 7. RESULTS OF ULTRAVIOLET (UV) RADIATION EXPOSURE

Code Number	Absorber Material	TIME OF EXPOSURE (HOURS)						Emittance (ϵ)								
		Absorptance (α)			Emittance (ϵ)			Absorptance (α)			Emittance (ϵ)					
		0	125	625	1100	2100	0	125	625	1100	2100	0	125	625	1100	2100
A8	Nickel Foil	.98	.98	.98	.98	.98	.09	.09	.08	.09	.10					
B6	Anodized	.92	.92	.92	.92	.92	.81	.81	.81	.81	.81					
B7	Anodized	.90	.90	.90	.90	.90	.82	.81	.81	.81	.81					
C5	Copper Oxide	.95	.97	.97	.97	.96	.74	.71	.71	.71	.69					
D2	Black Chrome	.95	.95	.95	.96	.95	.07	.06	.07	.06	.05					
D4	Black Chrome	.96	.94	.93	.92	.94	.06	.06	.06	.06	.05					
G9	Polyvinylidene Fluoride	.95	.95	.94	.95	.95	.85	.86	.84	.84	.85					
H1	Polyvinylidene Fluoride	.96	.95	.95	.95	.95	.85	.85	.84	.81	.85					
H8	Polyvinylidene Fluoride	.96	.96	.95	.95	.95	.88	.88	.88	.89	.89					
I1	Urethane	.97	.97	.97	.97	.97	.92	.92	.92	.92	.92					
I4	Urethane	.97	.97	.97	.97	.98	.92	.92	.92	.92	.92					
I8	Urethane	.97	.97	.97	.97	.98	.92	.92	.92	.92	.92					
J1	Alkyd	.97	.98	.97	.98	.98	.92	.91	.91	.91	.91					
J4	Alkyd	.97	.98	.98	.97	.97	.91	.91	.91	.91	.91					
J8	Alkyd	.97	.97	.97	.97	.98	.92	.91	.91	.91	.92					
K1	Epoxide	.97	.97	.97	.97	.98	.91	.91	.91	.91	.91					
K4	Epoxide	.97	.98	.97	.97	.98	.91	.91	.91	.90	.91					
K8	Epoxide	.97	.97	.97	.98	.98	.91	.91	.91	.91	.91					
L1	Silicone	.97	.97	.97	.97	.97	.88	.87	.88	.87	.88					
L4	Silicone	.97	.97	.97	.97	.97	.87	.86	.87	.87	.88					
L8	Silicone	.97	.97	.97	.97	.97	.88	.88	.88	.84	.88					
M1	Mod. Polyester	.93	.93	.92	.93	.93	.86	.85	.86	.87	.87					
M4	Mod. Polyester	.89	NOT EXPOSED	NOT EXPOSED	NOT EXPOSED	NOT EXPOSED	.84	NOT EXPOSED	NOT EXPOSED	NOT EXPOSED	NOT EXPOSED					
M8	Mod. Polyester	.90	NOT EXPOSED	NOT EXPOSED	NOT EXPOSED	NOT EXPOSED	.81	NOT EXPOSED	NOT EXPOSED	NOT EXPOSED	NOT EXPOSED					
N2	Porcelain	.93	.94	.94	.94	.94	.85	.85	.85	.85	.84					
N8	Porcelain	.93	.92	.94	.94	.94	.84	.84	.84	.84	.84					

TABLE 8. RESULTS OF EXPOSURE AT 92°C AND 97 PERCENT RELATIVE HUMIDITY

Code Number	Absorber Material	TIME OF EXPOSURE (WEEKS)									
		Absorptance (α)					Emittance (ϵ)				
		0	1	2	6	21	0	1	2	6	21
A8	Nickel Foil	.98	.99	.98	.98	.98	.09	.08	.08	.06	.09
B6	Anodized	.92	.95	.92	.93	.92	.81	.83	.83	.81	.82
B7	Anodized	.90	.94	.94	.93	.93	.82	.83	.84	.81	.84
C5	Copper Oxide	.95	.97	.96	.95	.94	.74	.61	.68	.59	.68
D2	Black Chrome	.95	.97	.97	.96	.97	.07	.07	.07	.08	.07
D4	Black Chrome	.96	.95	.94	.95	.95	.06	.06	.05	.06	.07
G9	Polyvinylidene Fluoride	.95	.94	.94	.95	.94	.85	.85	.85	.83	.86
H1	Polyvinylidene Fluoride	.96	.95	.95	.95	.95	.85	.82	.82	.85	.85
H8	Polyvinylidene Fluoride	.96	.95	.95	.95	.96	.88	.89	.89	.88	.89
I1	Urethane	.97	.97	.97	.97	.95	.92	.92	.92	.92	.93
I4	Urethane	.97	.97	.98	.98	.97	.92	.92	.92	.93	.93
I8	Urethane	.97	.97	.97	.97	.97	.92	.92	.92	.92	.93
J1	Alkyd	.97	.97	.97	.97	.90	.92	.93	.91	.91	.87
J4	Alkyd	.97	.98	.97	.98	.98	.91	.91	.91	.91	.91
J8	Alkyd	.97	.98	.97	.91	.98	.92	.91	.91	.91	.91
K1	Epoxide	.97	.98	.98	.98	.90	.91	.91	.91	.91	.89
K4	Epoxide	.97	.98	.97	.97	.98	.91	.91	.91	.91	.91
K8	Epoxide	.97	.98	.97	.98	.90	.91	.90	.90	.91	.92
L1	Silicone	.97	.97	.96	.96	.96	.88	.87	.87	.88	.88
L4	Silicone	.97	.97	.97	.97	.97	.87	.87	.87	.88	.87
L8	Silicone	.97	.97	.97	.97	.97	.88	.87	.87	.87	.88
M1	Mod. Polyester	.93	.96	.91	.93	.93	.86	.79	.81	.86	.86
M4	Mod. Polyester	.89	.88	.90	.91	.92	.84	.82	.83	.80	.80
M8	Mod. Polyester	.90	.90	.89	.89	.88	.81	.81	.81	.84	.80
N2	Porcelain	.93	.94	.94	.94	.94	.85	.85	.85	.85	.85
N8	Porcelain	.93	.94	.94	.95	.96	.84	.84	.84	.85	.85

TABLE 9. RESULTS OF EXPOSURE USING A CONDENSATION CYCLE

Code Number	Absorber Material	TIME OF EXPOSURE (WEEKS)									
		Absorptance (α)					Emittance (ϵ)				
		0	1	3	6	12	0	1	3	6	12
A8	Nickel Foil	.98	.99	.99	.99	.95	.09	.09	.09	.07	.08
B6	Anodized	.92	.95	.92	.94	.90	.81	.82	.81	.85	.90
B7	Anodized	.90	.94	.91	.91	.90	.82	.83	.82	.82	.91
C5	Copper Oxide	.95	.97	.98	.97	.97	.74	.74	.65	.71	.74
D2	Black Chrome	.95	.95	.96	.96	.97	.07	.08	.08	.08	.06
D4	Black Chrome	.96	.96	.95	.95	.93	.06	.08	.07	.05	.06
G9	Polyvinylidene Fluoride	.95	.95	.95	.95	.95	.85	.85	.85	.86	.85
H1	Polyvinylidene Fluoride	.96	.95	.96	.95	.95	.85	.86	.86	.84	.86
H8	Polyvinylidene Fluoride	.96	.95	.96	.95	.96	.88	.89	.88	.89	.88
I1	Urethane	.97	.97	.97	.97	.97	.92	.92	.92	.92	.92
I4	Urethane	.97	.97	.97	.97	.97	.92	.92	.92	.92	.92
I8	Urethane	.97	.97	.97	.97	.97	.92	.92	.92	.92	.92
J1	Alkyd	.97	.98	.98	.97	.98	.92	.91	.91	.91	.91
J4	Alkyd	.97	.97	.98	.98	.98	.91	.91	.91	.91	.91
J8	Alkyd	.97	.97	.98	.97	.98	.92	.91	.91	.91	.91
K1	Epoxide	.97	.98	.98	.97	.97	.91	.91	.90	.91	.91
K4	Epoxide	.97	.98	.98	.97	.98	.91	.91	.90	.90	.91
K8	Epoxide	.97	.98	.98	.98	.98	.91	.91	.90	.90	.91
L1	Silicone	.97	.97	.96	.96	.97	.88	.86	.86	.86	.87
L4	Silicone	.97	.96	.96	.96	.97	.87	.86	.86	.86	.87
L8	Silicone	.97	.96	.96	.96	.97	.88	.87	.87	.88	.87
M1	Mod. Polyester	.93	.94	.93	.94	.94	.86	.87	.85	.87	.86
M4	Mod. Polyester	.89	.87	.91	.92	.93	.84	.72	.83	.85	.85
M8	Mod. Polyester	.90	.91	.90	.88	.92	.81	.85	.84	.81	.83
N2	Porcelain	.93	.94	.94	.94	.94	.85	.85	.85	.85	.85
N8	Porcelain	.93	.94	.93	.93	.92	.84	.84	.84	.84	.85

TABLE 10. RESULTS OF OUTDOOR EXPOSURE AT GAITHERSBURG, MARYLAND

TIME OF EXPOSURE (WEEKS)

Code Number	Absorber Material	Absorptance (α)				Emittance (ϵ)			
		0	4 ¹ / ₄	8 ² / ₄	12 ³ / ₄	0	4 ¹ / ₄	8 ² / ₄	12 ³ / ₄
A8	Nickel Foil	.98	.99	.99	.98	.09	.09	.09	.10
B6	Anodized	.92	.92	.91	.91	.81	.81	.81	.81
B7	Anodized	.90	.90	.90	.90	.81	.81	.81	.81
C5	Copper Oxide	.95	.92	.91	.91	.74	.54	.54	.57
D2	Black Chrome	.95	.97	.97	.96	.07	.06	.06	.07
D4	Black Chrome	.96	.93	.93	.93	.06	.06	.06	.05
G9	Polyvinylidene Fluoride	.95	.95	.95	.95	.85	.84	.85	.85
H1	Polyvinylidene Fluoride	.96	.95	.95	.95	.85	.82	.84	.83
H8	Polyvinylidene Fluoride	.96	.96	.96	.95	.88	.85	.87	.87
I1	Urethane	.97	.97	.97	.97	.92	.92	.92	.92
I4	Urethane	.97	.97	.97	.97	.92	.92	.92	.92
I8	Urethane	.97	.97	.97	.97	.92	.92	.92	.92
J1	Alkyd	.97	.98	.98	.98	.92	.91	.91	.91
J4	Alkyd	.97	.98	.98	.98	.91	.91	.91	.90
J8	Alkyd	.97	.97	.97	.98	.92	.92	.91	.91
K1	Epoxide	.97	.98	.98	.98	.90	.91	.91	.91
K4	Epoxide	.97	.98	.98	.98	.91	.91	.91	.91
K8	Epoxide	.97	.98	.98	.98	.91	.91	.90	.90
L1	Silicone	.97	.97	.97	.97	.88	.87	.88	.87
L4	Silicone	.97	.97	.97	.97	.87	.87	.87	.87
L8	Silicone	.97	.97	.97	.97	.88	.87	.88	.87
M1	Mod. Polyester	.93	.94	.94	.94	.86	.88	.90	.91
M4	Mod. Polyester	.89	.90	.91	.91	.84	.85	.88	.90
M8	Mod. Polyester	.90	.90	.91	.90	.81	.84	.88	.90
N2	Porcelain	.93	.94	.94	.94	.85	.85	.85	.85
N8	Porcelain	.93	.94	.94	.93	.84	.84	.84	.84

1/ Exposed from 6/78 to 10/78.

2/ Exposed from 11/78 to 3/79.

3/ Exposed from 4/79 to 8/79.

TABLE 11. RESULTS OF OUTDOOR EXPOSURE AT PHOENIX, ARIZONA

Code Number	Absorber Material	TIME OF EXPOSURE (WEEKS)					
		Absorptance (α)			Emittance (ϵ)		
		0	4 ¹ / ₄	8 ² / ₈	0	4 ¹ / ₄	8 ² / ₈
A8	Nickel Foil	.98	.99	.98	.09	.09	.09
B6	Anodized	.92	.92	.91	.81	.81	.81
B7	Anodized	.90	.90	.89	.82	.81	.81
C5	Copper Oxide	.95	.91	.89	.74	.54	.56
D2	Black Chrome	.95	.97	.96	.07	.07	.06
D4	Black Chrome	.96	.97	.95	.06	.09	.08
G9	Polyvinylidene Fluoride	.95	.95	.95	.85	.85	.84
H1	Polyvinylidene Fluoride	.96	.95	.95	.85	.83	.80
H8	Polyvinylidene Fluoride	.96	.95	.95	.88	.88	.87
I1	Urethane	.97	.97	.97	.92	.92	.88
I4	Urethane	.97	.98	.97	.92	.92	.93
I8	Urethane	.97	.97	.97	.92	.92	.92
J1	Alkyd	.97	.98	.98	.92	.91	.91
J4	Alkyd	.97	.97	.98	.91	.91	.91
J8	Alkyd	.97	.97	.98	.92	.91	.91
K1	Epoxide	.97	.98	.98	.91	.91	.90
K4	Epoxide	.97	.98	.98	.91	.91	.90
K8	Epoxide	.97	.98	.98	.91	.91	.91
L1	Silicone	.97	.97	.96	.88	.87	.87
L4	Silicone	.97	.97	.97	.87	.87	.87
L8	Silicone	.97	.97	.97	.88	.88	.87
M1	Mod. Polyester	.93	.91	.91	.86	.86	.86
M4	Mod. Polyester	.89	.85	.84	.84	.77	.77
M8	Mod. Polyester	.90	.87	.86	.81	.81	.81
N2	Porcelain	.93	.94	.93	.85	.85	.85
N8	Porcelain	.93	.93	.92	.84	.84	.84

1/ Exposed from 11/78 to 3/79.
 2/ Exposed from 4/79 to 8/79.

TABLE 12. RESULTS OF OUTDOOR EXPOSURE AT MIAMI, FLORIDA

TIME OF EXPOSURE (MONTHS)

Code Number	Absorber Material	Absorptance (α)				Emittance (ϵ)			
		0	4 ¹ / ₁	8 ² / ₁	12 ³ / ₁	0	4 ¹ / ₁	8 ² / ₁	12
A8	Nickel Foil	.98	.99	.98	.98	.09	.05	.08	.08
B6	Anodized	.92	.92	.92	.91	.81	.80	.81	.81
B7	Anodized	.90	.90	.90	.89	.82	.80	.81	.81
C5	Copper Oxide	.95	.90	.89	.88	.74	.50	.53	.52
D2	Black Chrome	.95	.97	.96	.95	.07	.04	.07	.06
D4	Black Chrome	.96	.94	.93	.92	.06	.06	.06	.06
G9	Polyvinylidene Fluoride	.95	.95	.95	.95	.85	.85	.86	.85
H1	Polyvinylidene Fluoride	.96	.95	.95	.95	.85	.82	.85	.83
H8	Polyvinylidene Fluoride	.96	.95	.96	.95	.88	.87	.88	.87
I1	Urethane	.97	.97	.97	.97	.92	.92	.92	.93
I4	Urethane	.97	.97	.97	.97	.92	.92	.93	.93
I8	Urethane	.97	.97	.97	.97	.92	.92	.92	.93
J1	Alkyd	.97	.98	.98	.98	.92	.91	.91	.91
J4	Alkyd	.97	.98	.98	.98	.91	.91	.91	.91
J8	Alkyd	.97	.97	.98	.98	.92	.91	.91	.91
K1	Epoxide	.97	.98	.98	.98	.91	.91	.91	.90
K4	Epoxide	.97	.98	.98	.98	.91	.91	.91	.90
K8	Epoxide	.97	.98	.98	.98	.91	.90	.91	.90
L1	Silicone	.97	.97	.97	.96	.88	.87	.87	.87
L4	Silicone	.97	.97	.97	.96	.87	.87	.87	.87
L8	Silicone	.97	.97	.97	.97	.88	.88	.85	.87
M1	Mod. Polyester	.93	.94	.95	.95	.86	.89	.92	.91
M4	Mod. Polyester	.89	.91	.93	.93	.84	.85	.90	.90
M8	Mod. Polyester	.90	.92	.94	.94	.81	.88	.92	.91
N2	Porcelain	.93	.94	.94	.93	.85	.85	.85	.85
N8	Porcelain	.93	.93	.92	.92	.84	.84	.85	.84

1/ Exposed from 6/78 to 10/78.

2/ Exposed from 11/78 to 5/79 (with a 2 mo. non-exposure period).

3/ Exposed from 7/79 to 11/79.

TABLE 13. RESULTS OF OUTGASSING TESTS AT 250°C

Code Number	Absorber Material	% Condensibles	% Loss in Transmittance
A8	Nickel Foil	0	0
B6	Anodized Aluminum	0	0
C5	Copper Oxide	0	0
D2	Black Chrome	0	0
H1	Polyvinylidene Fluoride	0.01	0.4
I1	Urethane	0.1	1.8
J1	Alkyd	0.2	5.5



Figure 1. Test Box Used for Outdoor Exposures

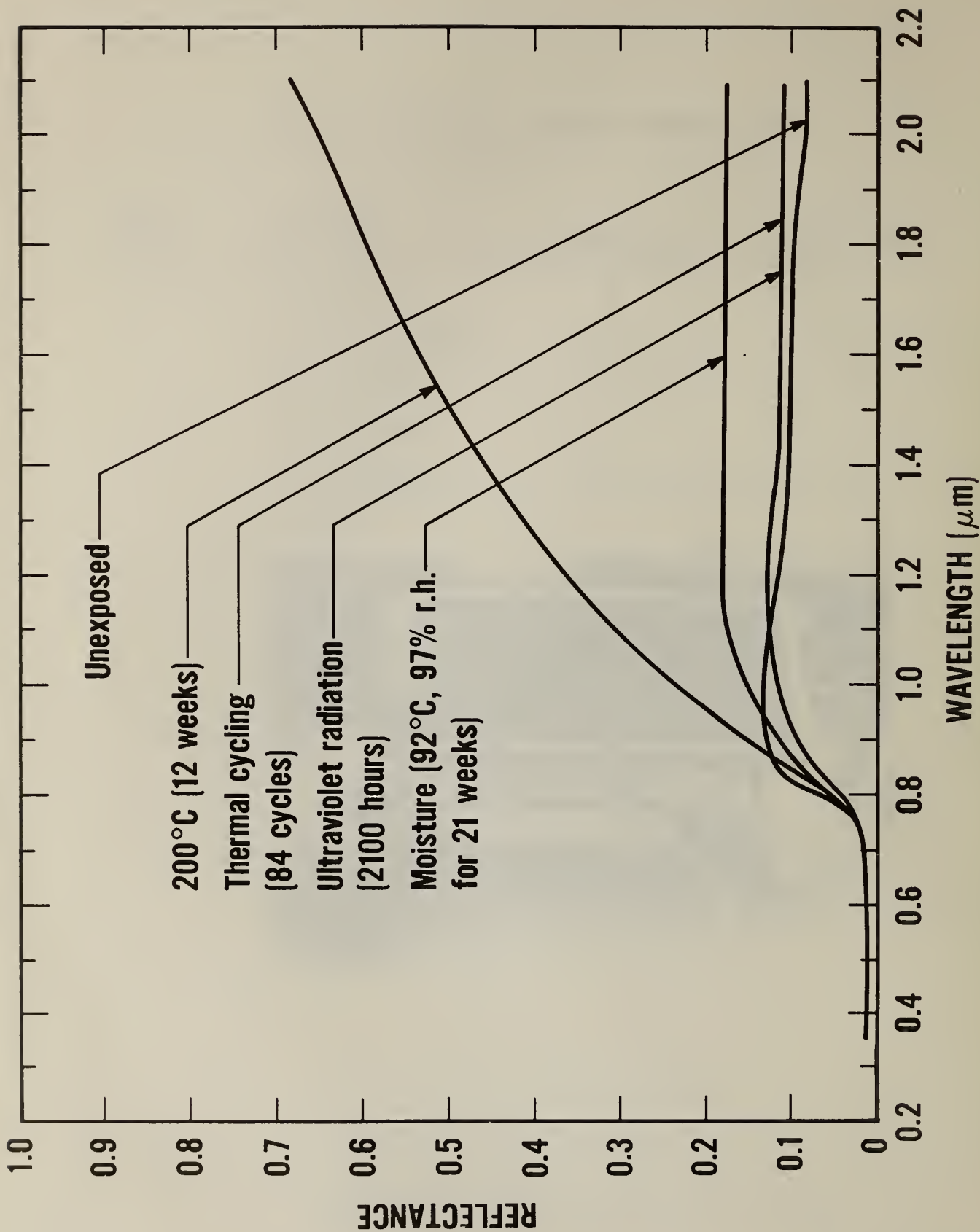


Figure 2. Reflectance of Exposed and Unexposed Copper Oxide

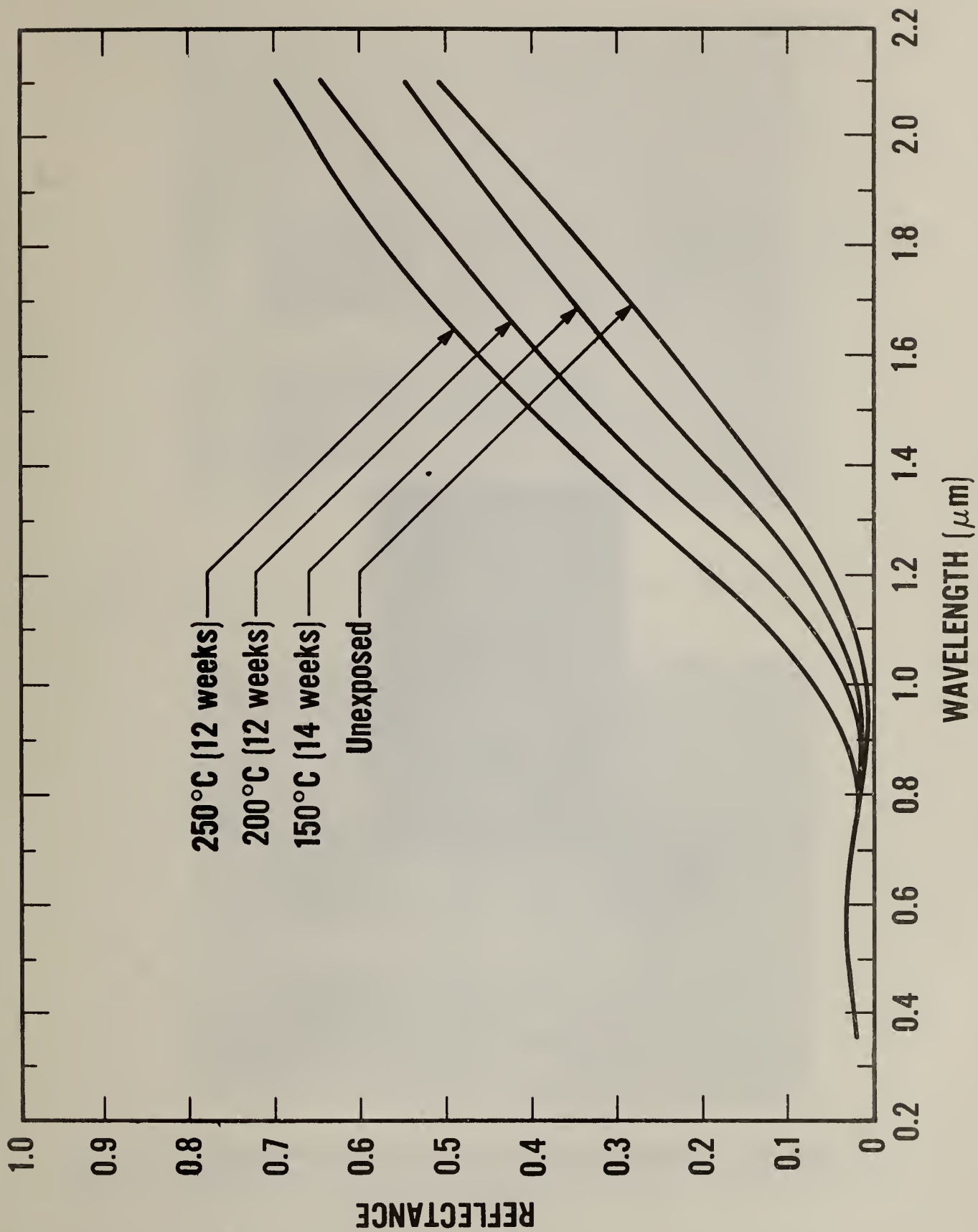


Figure 3. Reflectance of Black Chrome on Copper Before and After Oven Aging

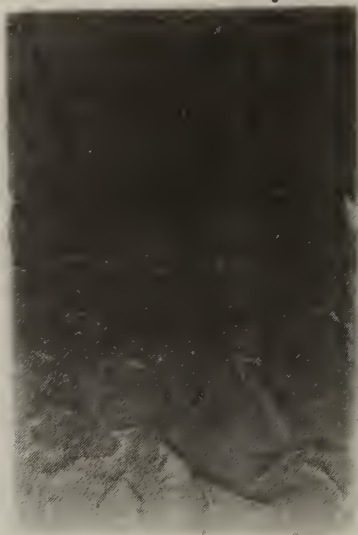


Figure 4. Blistering of Nickel Foil During Oven Aging



Figure 5. Appearance of Copper Oxide Specimens Before and After 250°C Exposure



Figure 6. Appearance of Polyvinylidene Fluoride (G9) on Galvanized Steel Before and After 250°C Exposure

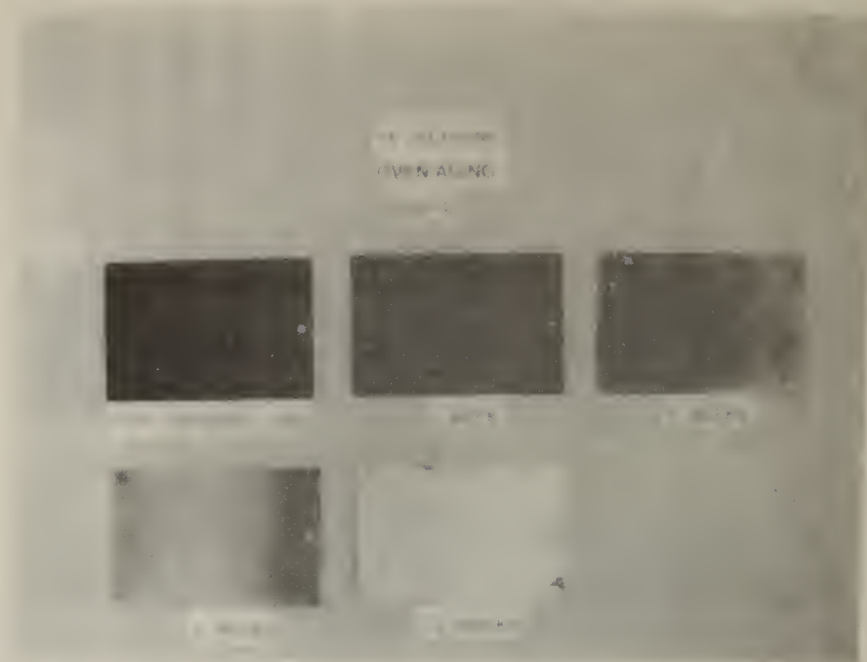


Figure 7. Appearance of Urethane on Copper Before and After 250°C Exposure



Figure 8. Appearance of Urethane on Aluminum Before and After 250°C Exposure

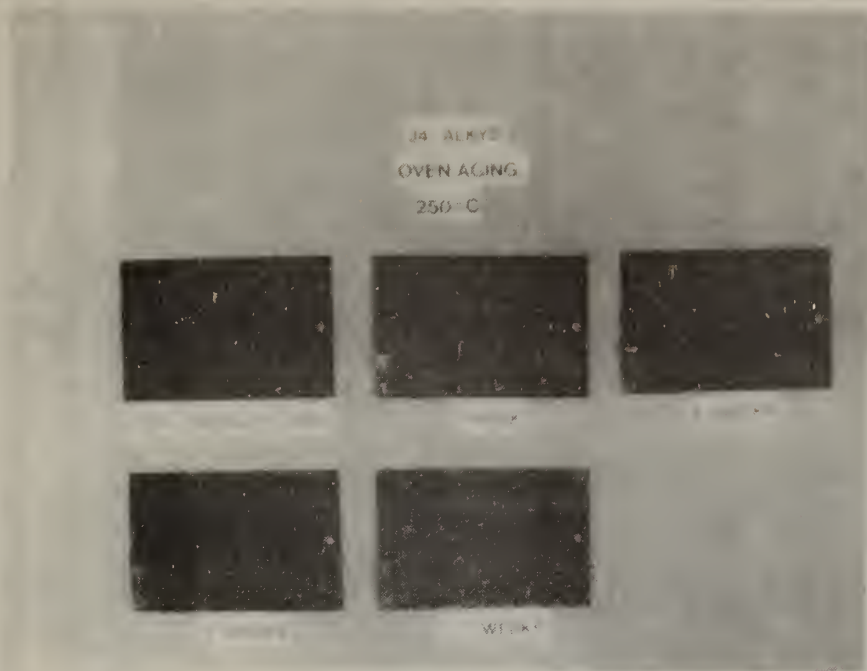


Figure 9. Appearance of Alkyd on Copper Before and After 250°C Exposure



Figure 10. Appearance of Alkyd on Aluminum Before and After 250°C Exposure

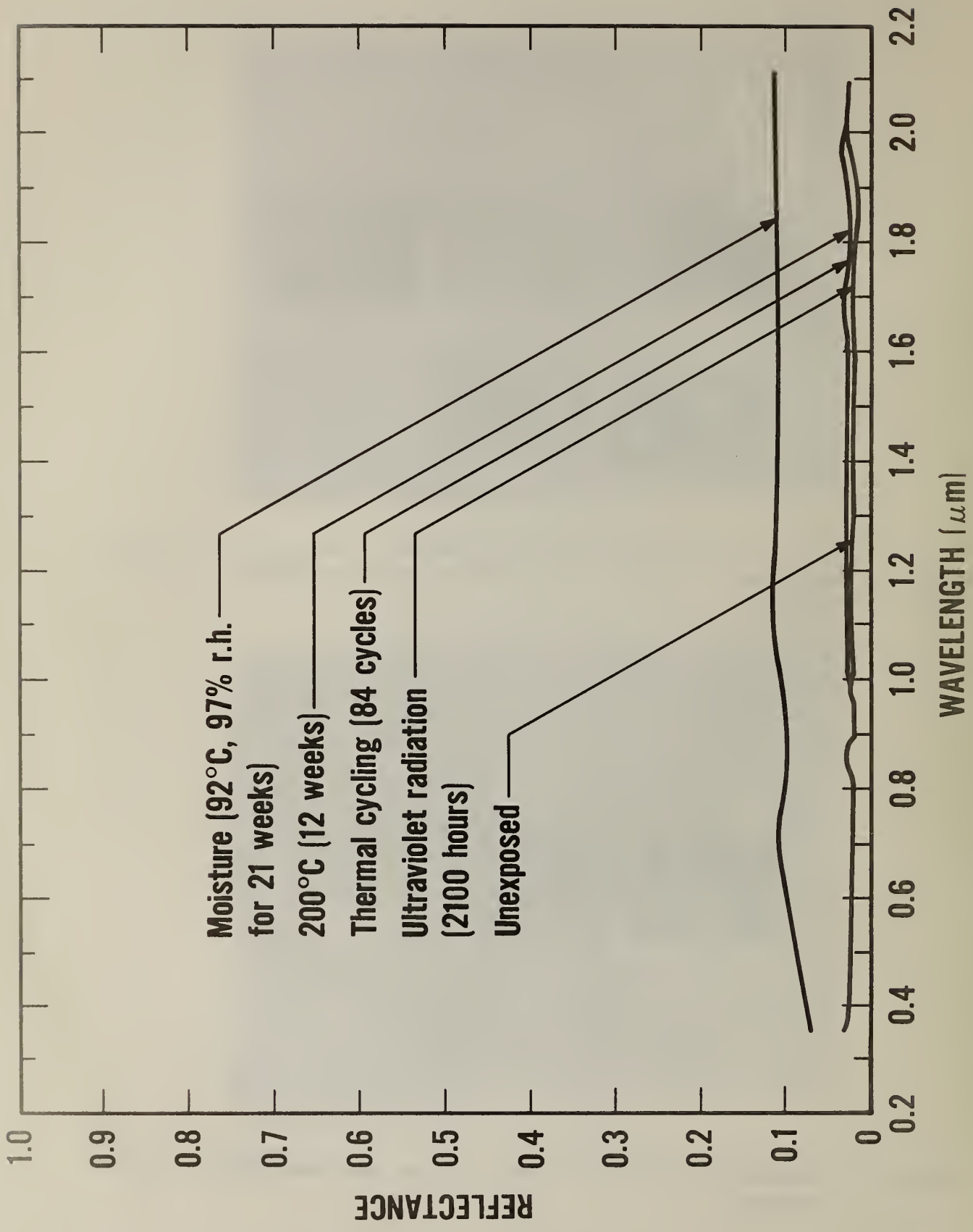


Figure 11. Reflectance of Exposed and Unexposed Alkyd on Steel



Figure 12. Loss of Adhesion of Modified Polyester Coating During Thermal Cycling Exposure

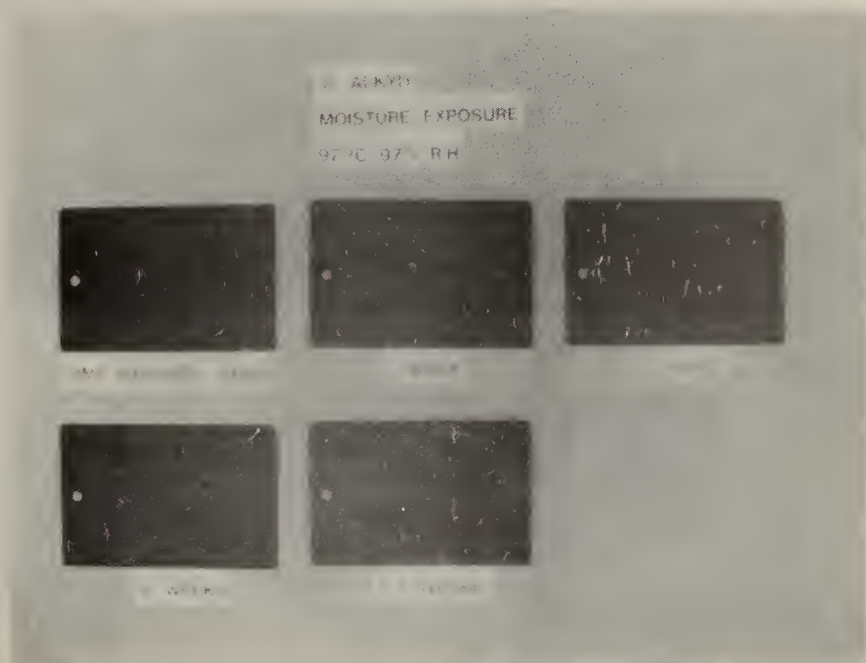


Figure 13. Appearance of Alkyd on Steel Before and After Exposure at 92°C and 97 Percent R. H.



Figure 14. Appearance of Alkyd on Copper Before and After Exposure at 92°C and 97 Percent R. H.



Figure 15. Appearance of Alkyd on Aluminum Before and After Exposure at 92°C and 97 Percent R. H.

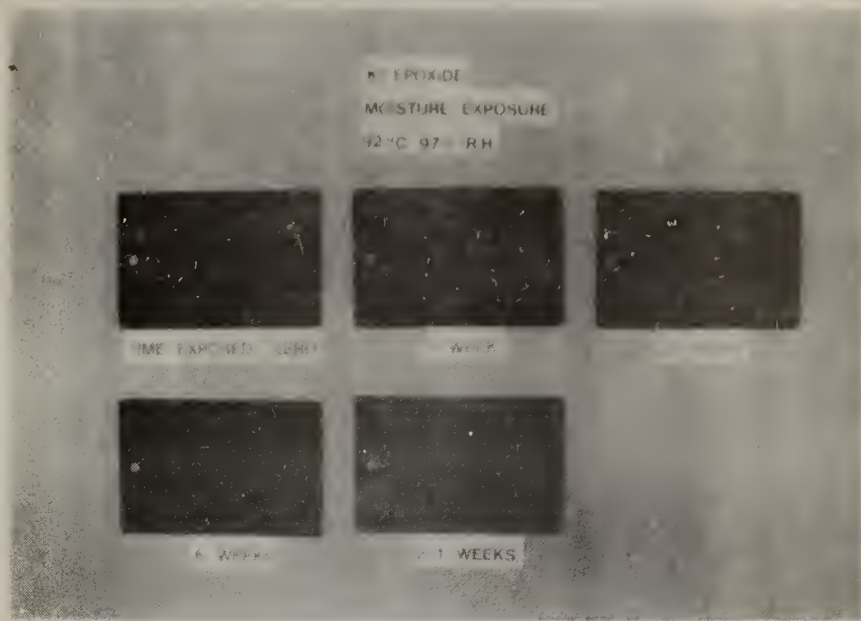


Figure 16. Appearance of Epoxide on Steel Before and After Exposure at 92°C and 97 Percent R. H.

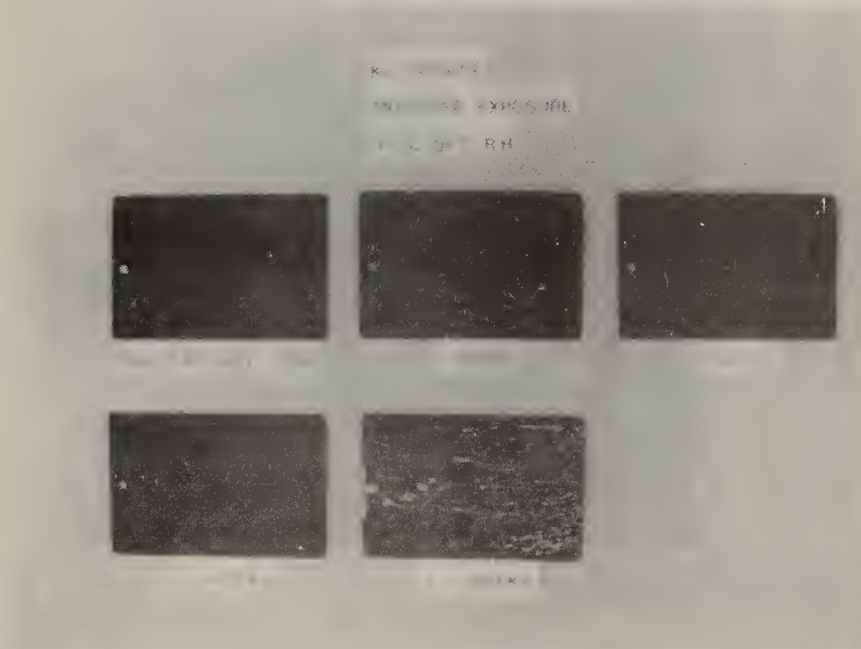


Figure 17. Appearance of Epoxide on Aluminum Before and After Exposure at 92°C and 97 Percent R. H.



Figure 18. Cross-Section of Unexposed Epoxy Coating with Phenolic Butyrate Primer on Aluminum (300 x)

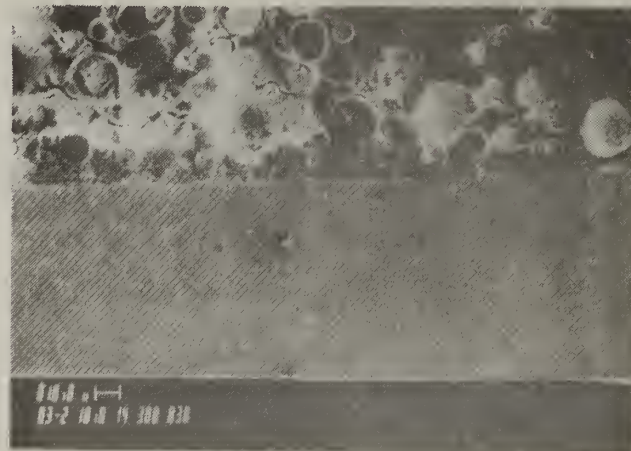


Figure 19. Cross-Section of Epoxy Coating and Primer on Aluminum Following 21 Weeks Exposure at 92°C and 97 Percent R. H.

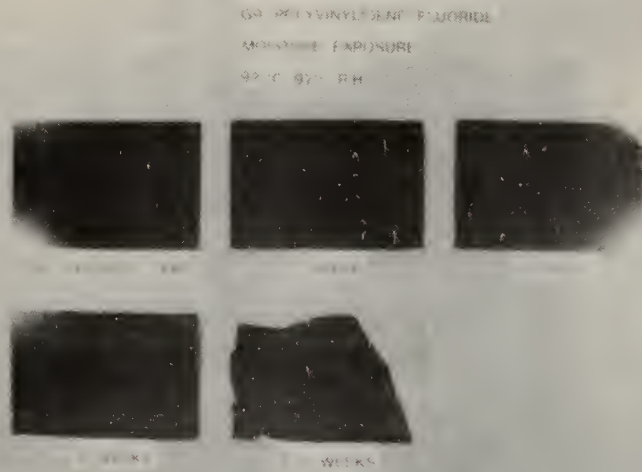


Figure 20. Appearance of Polyvinylidene Fluoride on Galvanized Steel (G9) Before and After Exposure at 92°C and 97 Percent R. H.

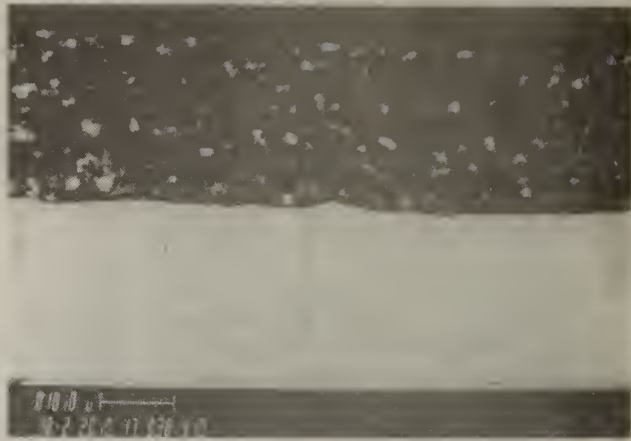


Figure 21. Cross-Section of Unexposed Polyvinylidene Fluoride Coating with Epoxide Primer on Galvanized Steel (G9) (1000 x)

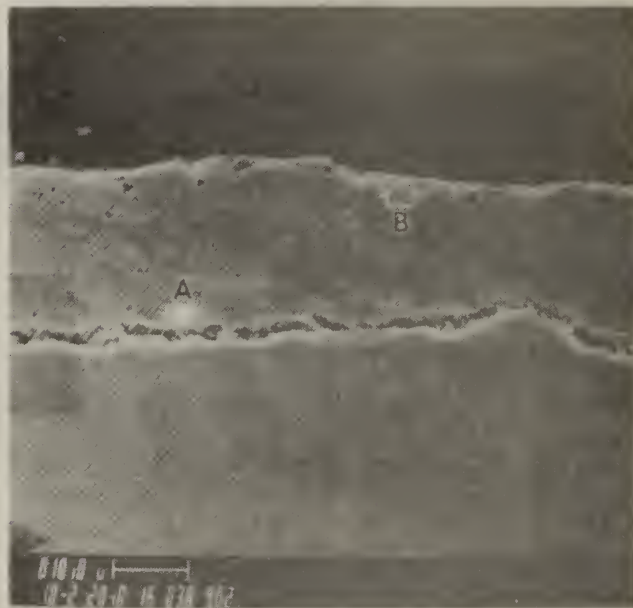


Figure 22. Cross-Section of Polyvinylidene Fluoride with Primer on Galvanized Steel (G9) Following 21 Weeks Exposure at 92°C and 97 Percent R. H.



Figure 23. Appearance of Alkyd on Aluminum Before and After Cumulative Exposure (12 Weeks at 200°C Followed by 28 Temperature Cycles from 200°C to -10°C)

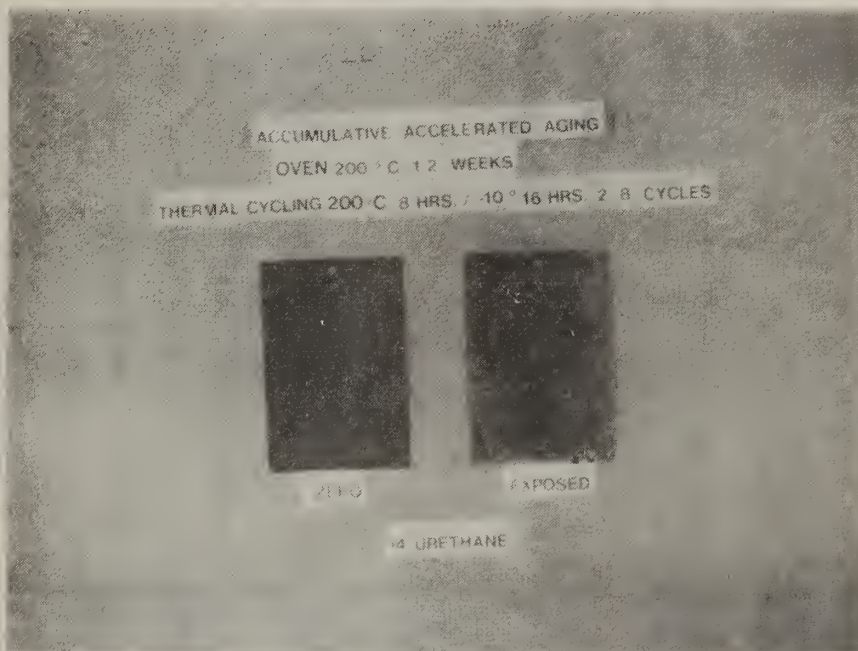


Figure 24. Appearance of Urethane on Copper Before and After Cumulative Exposure (12 Weeks at 200°C Followed by 28 Temperature Cycles from 200°C to -10°C)

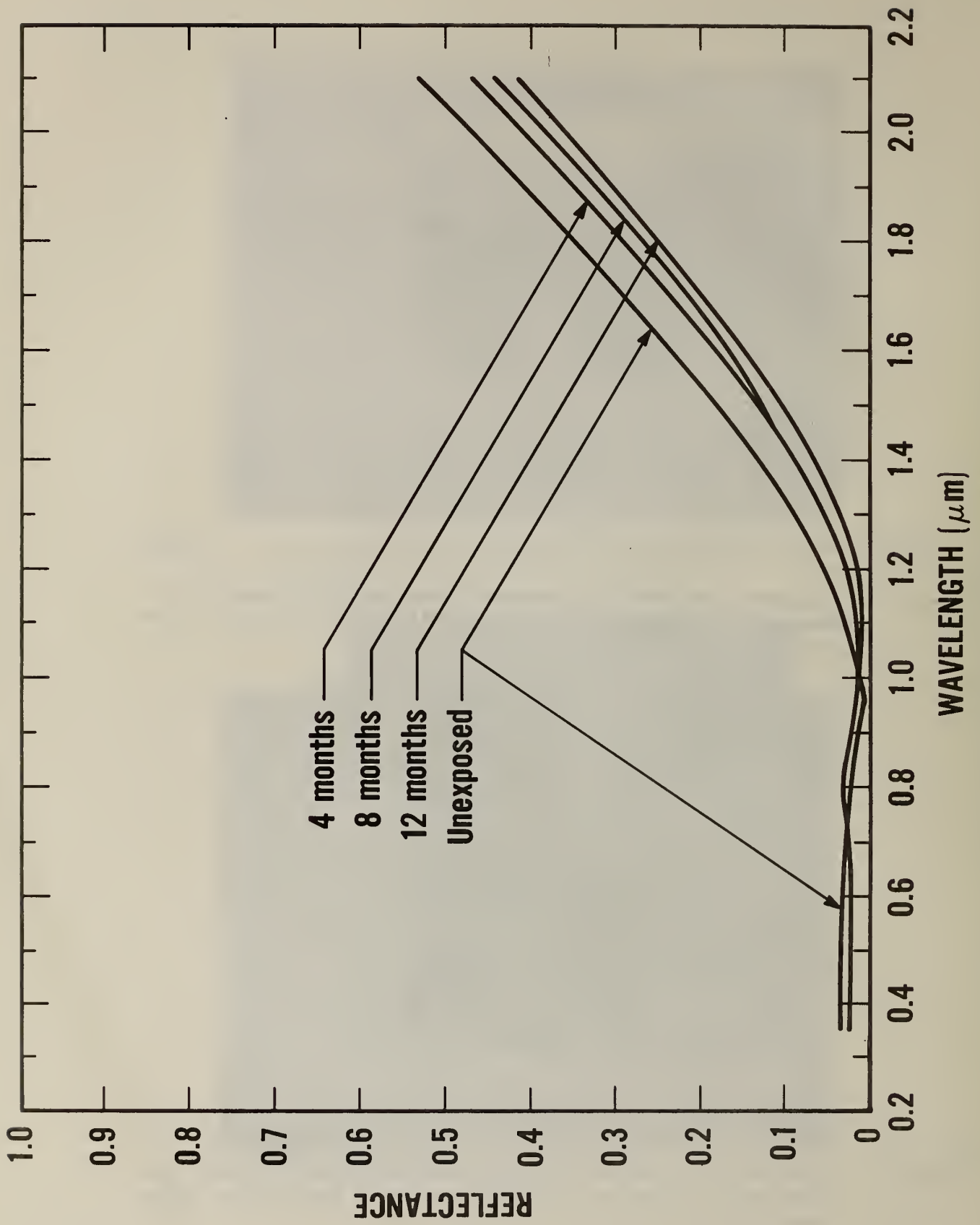


Figure 25. Reflectance Curves of Black Chrome on Steel Before and After Outdoor Exposure at Gaithersburg, Maryland

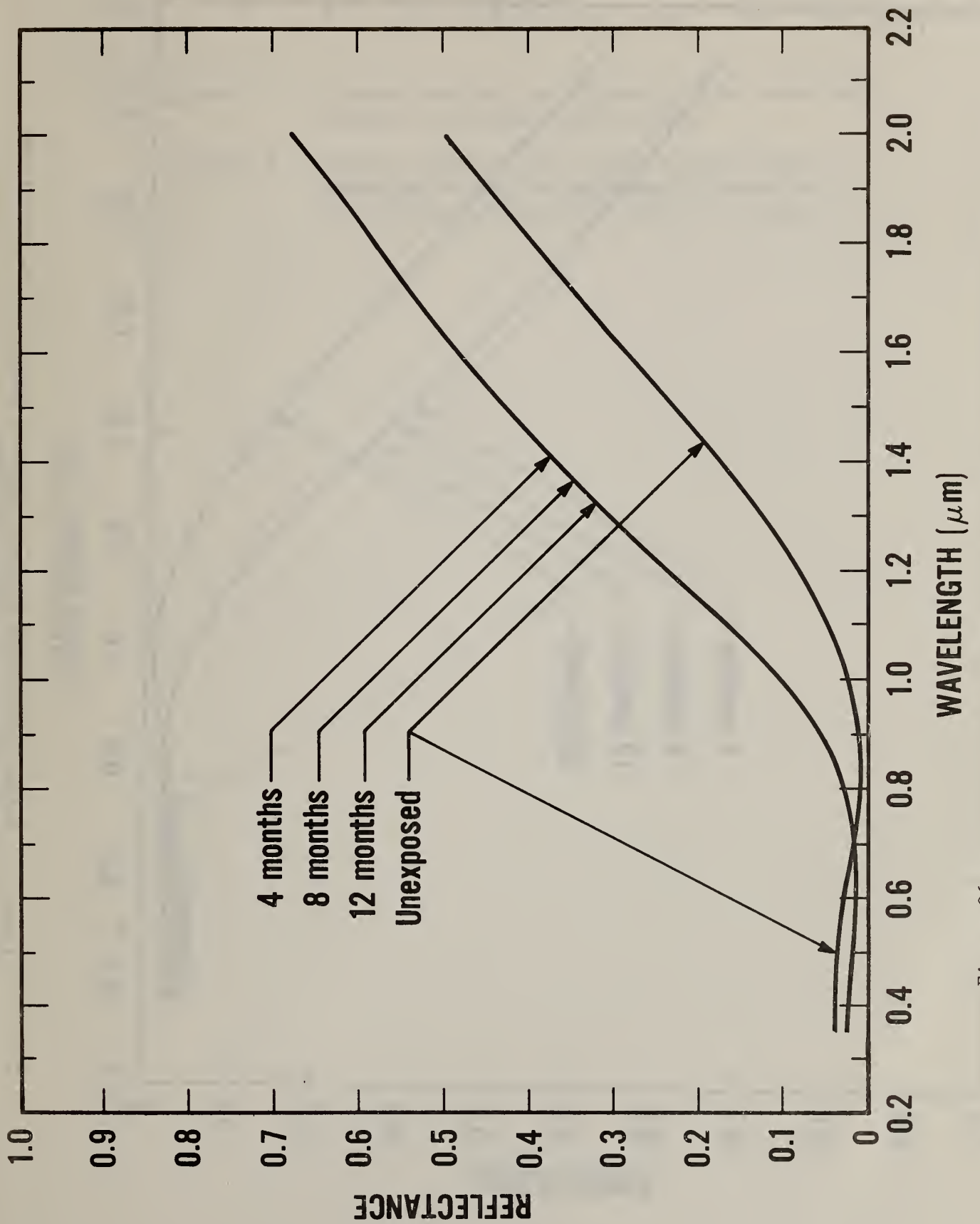


Figure 26. Reflectance Curves of Black Chrome on Copper Before and After Outdoor Exposure at Gaithersburg, Maryland

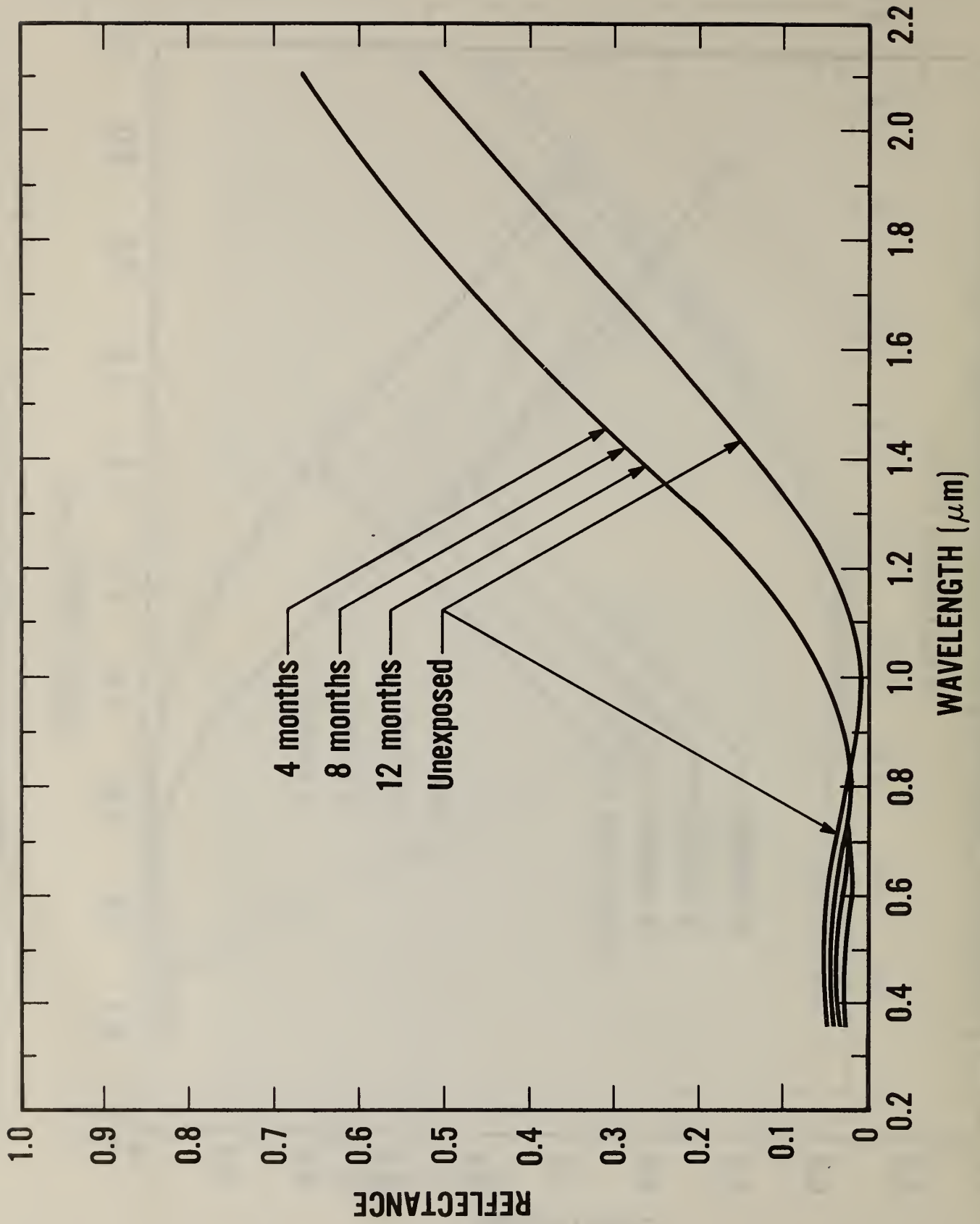


Figure 27. Reflectance Curves of Black Chromeon Copper Before and After Outdoor Exposure at Miami, Florida

APPENDICES

Appendix A - Standard Practice for Evaluating Solar Absorptance
Materials for Thermal Applications

Appendix B - Standard Practice for Determining The Effect of
Outgassing on the Transmittance of Glass Test
Plates Which Simulate Solar Collector Covers

APPENDIX A

STANDARD PRACTICE FOR EVALUATING SOLAR ABSORPTIVE MATERIALS FOR THERMAL APPLICATIONS

1. SCOPE

1.1 This practice provides a testing methodology for evaluating absorptive materials used in flat plate or concentrating collectors, with concentrating ratios not to exceed 5, for solar thermal applications. This practice is not intended to be used for the evaluation of absorptive surfaces that are 1) used in direct contact with, or suspended in, a heat transfer liquid (i.e., trickle collectors, direct absorption fluids, etc.), 2) used in evacuated collectors or 3) used in collectors without cover plate(s).

1.2 Test methods included in this practice are property measurement tests and aging tests. Property measurement tests provide for determination of various properties of absorptive materials, e.g., absorptance, emittance and appearance. Aging tests provide for exposure of absorptive materials to environments that may induce changes in the properties of test specimens. Measuring properties before and after an aging test provides a means of determining the effect of the exposure.

1.3 The assumption is made that solar radiation, elevated temperature, temperature cycles and moisture are the primary factors that cause degradation of absorptive materials. Aging tests are described for exposure of specimens to these factors. For some geographic locations, other factors such as salt spray and dust erosion, may be important.

2. SIGNIFICANCE AND USE

2.1 The methods in this practice are intended to aid the assessment of long-term performance by comparative testing of absorptive materials. The results of the methods, however, have not been shown to correlate to actual in-service performance.

2.2 The testing methodology in this practice provides two testing methods (See Figure A-1). Method 1, which aims at decreasing the time required for evaluation, uses a series of individual tests to simulate various exposure conditions. Method 2 utilizes a single test of actual outdoor exposure under conditions simulating thermal stagnation. Equivalency of the two methods has not yet been established.

3. APPLICABLE DOCUMENTS (Latest editions shall apply unless otherwise specified)

3.1 ASTM DOCUMENTS^{1/}

^{1/} Available from ASTM, 1916 Race Street, Philadelphia, PA 19103

- B537 - Rec. Practice for Rating of Electroplated Panels Subjected to Atmospheric Exposure
- E408 - Test for Total Normal Emittance of Surfaces Using Inspection-Meter Techniques
- E424 - Test for Solar Energy Transmittance and Reflectance (Terrestrial) of Sheet Materials
- E434 - Test for Calorimetric Determination of Hemispherical Emittance and the Ratio of Solar Absorptance to Hemispherical Emittance Using Solar Simulation
- G23 - Rec. Practice for Operating Light and Water-Exposure Apparatus (Carbon-Arc Type) for Exposure of Nonmetallic Materials
- G26 - Rec. Practice for Operating Light-Exposure Apparatus (Xenon-Arc Type) with and without Water for Exposure of Nonmetallic Materials

3.2 ANSI DOCUMENTS^{2/}

- Z97.1-1975 - Performance Specifications and Methods of Testing for Safety Glazing Material Used in Buildings

4. TEST SPECIMENS

- 4.1 Test specimens shall be either the coating applied to a specific substrate or the absorber material (for materials other than coatings).
- 4.2 The specimens shall be prepared in accordance with procedures and conditions used (or expected to be used) in commercial practice or in accordance with the recommendations of the coatings or material supplier.

5. CONDITIONING

- 5.1 Specimens shall be measured and tested as received without additional processing or pre-conditioning.

6. METHODS OF TEST

6.1 PROPERTY MEASUREMENT TESTS

Perform all property measurement tests at room temperature unless otherwise specified.

^{2/} Available from the American National Standards Institute, Inc., 1430 Broadway, New York, N.Y. 10018

6.1.1 Absorptance

Method E424, Method A, unless otherwise specified.

6.1.2 Emittance

Method E434 or Method E408, unless otherwise specified.

6.1.3 Appearance

Method B537, unless otherwise specified.

6.2 AGING TESTS

6.2.1 Effect of Solar Radiation (Light Fastness)^{3/}

Note 1 - Expose materials with a cover plate between the light source and the test specimen if 6.2.1.1 or 6.2.1.2 are used. The use of a tempered glass cover plate with spectral transmission characteristics approximating those of low iron glass, as shown in Figure A-2, is recommended. Transparent plastics or other types of glass may be used for the cover plates if the absorber material under test is used with these cover plate materials in actual solar collectors.

6.2.1.1 Outdoor Exposure Under Simulated Stagnation Conditions

Expose test specimens for a minimum period of twelve months using ASTM _____, Standard Practice for Evaluating Absorptive Solar Receiver Materials when Exposed to Conditions Simulating Stagnation in Collectors with Cover Plate(s)^{4/}.

Note 2 - It may be desirable to continue exposures of test specimens beyond the time period recommended to obtain additional rate data or to obtain data on mechanisms of degradations.

Note 3 - This method is not applicable to concentrating collectors with a concentration ratio greater than 5.

6.2.1.2 Outdoor Exposure Using Fresnel Concentration

Expose test specimens to direct sunlight reflected from a Fresnel concentrator as referenced in ANSI Z97.1-1975, paragraph 4.3.2, in accordance with the conditions stipulated in Table A-1.

3/ Incident radiation should be monitored using a sensor meeting the requirement of a WMO 2nd class pyranometer.

4/ This test method is currently being developed by ASTM E44.04. It provides for outdoor exposure of absorber specimens in a box which simulates a solar collector.

6.2.1.3 Xenon Arc Exposure

Expose the specimens to radiation from a filtered Xenon arc lamp in accordance with the conditions stipulated in Table A-1.

6.2.1.4 Carbon Arc Exposure

Expose test specimens to radiation from a filtered Carbon arc lamp in accordance with the conditions stipulated in Table A-1.

6.2.2 Effect of Elevated Temperatures

Test specimens shall be exposed to heat aging for a period of 500 hours at the stagnation temperature to which they will be exposed in actual service.

Note 4 - The maximum service temperature will normally be obtained when the collector is receiving its maximum level of solar radiation and the heat transfer fluid is not flowing through the collector. Data on stagnation temperatures are normally available from collector manufacturers. Also, stagnation temperature data for flat plate collectors are included in NBSIR 78-1562, "Interim Performance Criteria for Solar Heating and Cooling Systems in Residential Buildings," National Bureau of Standards, Washington, D.C. 20234.

6.2.3 Effect of Moisture

Test specimens for 30 days at $90 \pm 5^\circ\text{C}$ and 95 ± 5 percent relative humidity.

6.2.4 Effect of Thermal Cycling

Test specimens shall be exposed to 30 cycles of heating and cooling with each cycle consisting of the following steps:

1. Heat for one hour at the stagnation temperature to which they will be exposed in actual service (see Note 4).
2. Cool to room temperature over a 30 minute period.
3. Cool at -10°C and 70 ± 5 percent r.h. for one hour.
4. Warm to room temperature over a 30 minute period.

6.2.5 Outgassing

Release of volatiles from the absorber material, in some cases, may be a significant factor that can affect the transmittance of a cover plate, or the properties of the absorber itself, or both. A generally applicable procedure is not presently available to evaluate effects of outgassing products. It is essential, however, that this factor be recognized.

7. TEST PROCEDURE

7.1 Select either Method 1 (7.2) or Method 2 (7.3).

7.2 Method 1 (Laboratory Exposure)

7.2.1 Select 5 sets of test specimens for each absorber material to be evaluated. Each set shall consist of at least three identical test specimens.

7.2.2 Determine the absorptance and emittance of the specimens in accordance with 6.1.1 and 6.1.2. Also document the appearance of the specimens in accordance with 6.1.3.

7.2.3 Store Set 5 specimens (controls) at ambient laboratory conditions.

7.2.4 Expose Set 1 specimens in accordance with 6.2.2.

7.2.5 Expose Set 2 specimens in accordance with 6.2.4.

7.2.6 Expose Set 3 specimens in accordance with 6.2.3.

7.2.7 Expose Set 4 specimens in accordance with one of the exposures described in 6.2.1.2, 6.2.1.3 and 6.2.1.4.

7.2.8 Determine absorptance and emittance and document appearance as in 7.2.2.

7.3 Method 2 (Outdoor Exposure)

7.3.1 Select 2 sets of test specimens for each absorber material to be evaluated. Each set shall consist of at least three identical test specimens.

7.3.2 Determine the absorptance and emittance of the specimens in accordance with 6.1.1 and 6.1.2. Also document the appearance of the specimens in accordance with 6.1.3.

7.3.3 Store the Set 2 specimens (controls) at ambient laboratory conditions.

7.3.4 Expose Set 1 specimens in accordance with 6.2.1.1.

7.3.5 Determine absorptance and emittance and document appearance as in 7.3.2.

8. REPORT

8.1 The report shall include the following:

8.1.1 Complete identification of the absorber material tested.

8.1.2 Identification of which Method, 1 or 2, was used. If Method 2 was used, the report shall include data required by ASTM EXXXX (see footnote 4).

- 8.1.3 Complete identification of the substrate(s) used for absorber coatings, including composition and thickness.
- 8.1.4 Complete identification of and spectral transmission characteristics of cover plate material used in 6.2.1.1 or 6.2.1.2.
- 8.1.5 Method of preparing test specimens.
- 8.1.6 Location and dates of exposure if 7.3, Method 2 (Outdoor Exposure) is used.
- 8.1.7 Total radiation exposure received by test specimens in 6.2.1.1, length of time of exposure and documentation of instrument and procedure for measuring radiation exposure.
- 8.1.8 Length of time of exposure in 6.2.1.2, 6.2.1.3, or 6.2.1.4 as appropriate.
- 8.1.9 Identification of filters used in 6.2.1.3 or 6.2.1.4
- 8.1.10 Temperatures used in the exposures described in 6.2.1.2, 6.2.1.3, 6.2.1.4, 6.2.2, 6.2.3 and 6.2.4. Also heating and cooling rates and number of cycles used in 6.2.4.
- 8.1.11 Moisture conditions used in the exposure described in 6.2.3.
- 8.1.12 Number of specimens tested.
- 8.1.13 Test results (absorptance, emittance and appearance) before and after aging (mean and range) for exposed specimens and for controls.
- 8.1.14 Documentation from specified procedures/conditions (agreed upon or unintentional).
- 8.1.15 Any readily apparent change in appearance or condition (fading, blistering, rusting, etc.) of individual specimens or groups of specimens.

Table A-1. Exposure Test Conditions

Reference Paragraph	6.2.1.2	6.2.1.3	6.2.1.4
Radiation Source	Concentrated Sunlight	Xenon Arc	Carbon Arc
Standard Practice (ASTM)	-----	G26	G23
Method	-----	A	A
Apparatus Type	Fresnel Mirror (8x)	A, AH, B, BH	E ⁽¹⁾ , EH
Filters	-----	Borosilicate ⁽²⁾	Borosilicate ⁽²⁾
Irradiance at 340nm, W/m ²	-----	.55	-----
Radiant Energy Interval	Uncontrolled	Continuous	Continuous
Black Panel Temperature, °C	90 ± 5	90 ± 5	90 ± 5
Relative Humidity	Uncontrolled	Uncontrolled ⁽³⁾	Uncontrolled ⁽³⁾
Irradiation at 340nm, kJ/m ²	-----	2970	-----
Exposure Interval, hours	1100	1500	1200

(1) Water or air heaters may be required to maintain temperature

(2) Corning 7740 glass for Xenon Arc and 7058 glass for Carbon Arc is satisfactory.

(3) Operate with humidifier turned off.

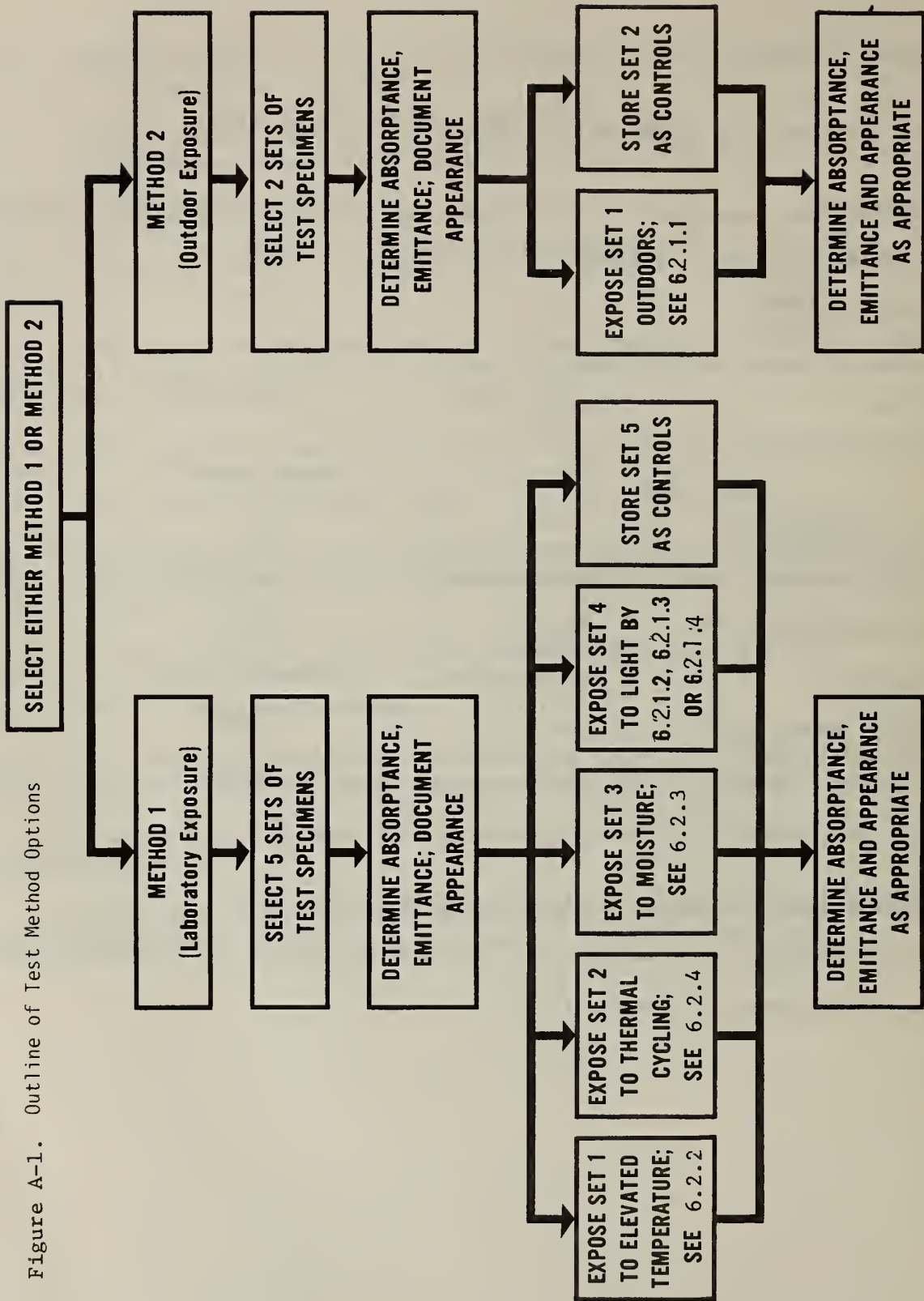


Figure A-1. Outline of Test Method Options

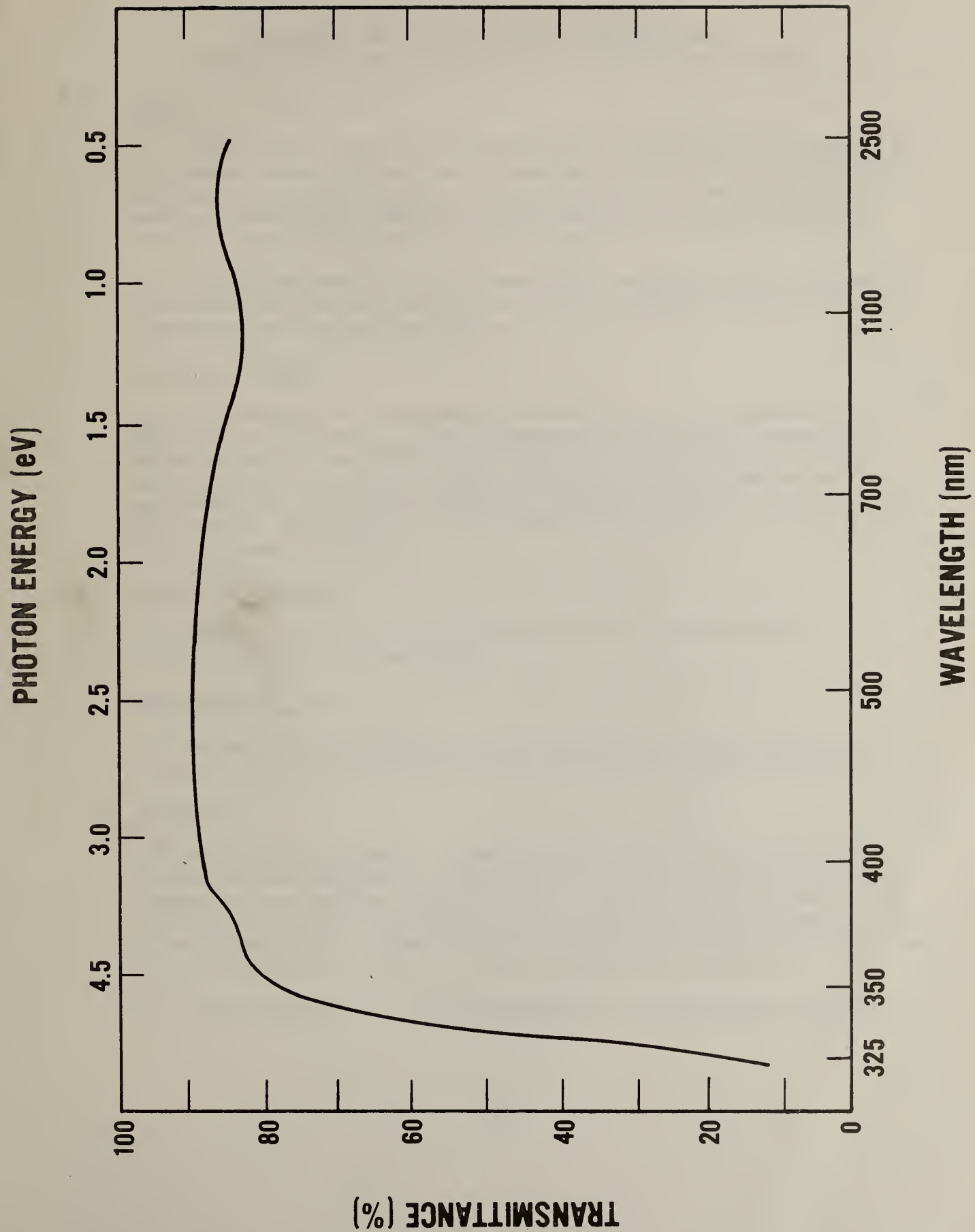


Figure A-2. Transmittance of Single Strength Low Iron Glass

APPENDIX B

STANDARD PRACTICE FOR DETERMINING THE EFFECT OF OUTGASSING ON THE TRANSMITTANCE OF GLASS TEST PLATES WHICH SIMULATE SOLAR COLLECTOR COVERS

1. Scope

1.1 This method covers the determination of the effect of outgassing on the transmittance of glass test plates which simulate cover plates used in solar energy collectors. It is applicable to polymeric materials, such as rubber seals, insulation and absorptive coatings, which may release condensible materials upon heating.

1.2 This method can be used to compare the relative effect of volatile condensible degradation products of specific polymeric materials on the transmittance of glass test plates.

2. Summary of Method

2.1 The material to be evaluated is heated in a test apparatus as described in Section 5.1. The condensible decomposition products are collected on a glass plate. The transmittance of the glass plate is measured from 0.3 to 2.1 μm before and after testing to determine any change in transmittance resulting from the deposited products. The mass loss of the polymeric test specimen and the mass gain of the glass plate are also determined.

3. Applicable Documents

ASTM E424, Test for Solar Energy Transmittance and Reflectance (Terrestrial) of Sheet Materials.

4. Description of Terms

4.1 Outgassing - The emission of gases by materials and components, usually during exposure to elevated temperature or reduced pressure.

5. Apparatus

5.1 Outgassing apparatus - a test apparatus containing a controlled temperature heating device, a temperature monitor, an enclosed specimen chamber, a test specimen holder, a glass plate upon which volatiles are condensed and a filtered air stream directed toward the external surface of the glass plate. Figure B-1 is a diagram of the individual components of the apparatus and Figure B-2 shows the assembled apparatus.

5.2 Spectrophotometer - a spectrophotometer as described in ASTM E424.

6. Test Specimen

6.1 The test specimen shall consist of a sample of the material.

6.2 Specimens of absorptive coatings, which are applicable to metallic substrates, shall consist of both the coating and the substrate.

6.3 Specimens of absorptive coatings, which are normally applied to polymeric materials for use in solar collectors, should be applied on a metallic substrate as in 6.2

6.4 The size of specimen should be approximately proportional to the ratio of apparatus glass plate area to cover plate area of solar collector.

7. Conditioning

7.1 Test specimen shall be conditioned at room temperature prior to testing.

8. Procedure

8.1 Measure the transmittance of the glass plate from 0.3 to 2.1 μm according to ASTM E424.

8.2 Weigh the test specimen and the glass plate of the test apparatus to the nearest 0.00001 gm.

8.3 Adjust the temperature of the test apparatus to the desired test temperature prior to inserting the test specimen and installing the glass plate.

8.4 Place the test specimen in the specimen holder and install the glass plate over the teflon gasket using the spring clips.

8.5 Turn on the air stream, adjusted to 70 CFH, and direct the flow to the center of the exterior surface of the glass plate.

8.6 Allow the test to proceed for 3 hours or the time mutually agreed upon by the purchaser and the seller.

8.7 Stop the flow of the air stream, turn off the hot plate and remove the glass plate and the test specimen.

8.8 Allow the test specimen and the glass plate to reach room temperature and weigh both.

8.9 Re-measure the transmittance of the glass plate from 0.3 to 2.1 μm according to ASTM E424.

9. Calculations

9.1 Integrate the area under the transmittance curves obtained in 8.1 and 8.9 and calculate the difference between the integrated values.

9.2 Calculate the mass gain of the glass plate and the mass loss of the test specimen.

10. Report

10.1 The report shall include the following:

10.1.1 Identification of the test specimen, including type of material, source or manufacturer, product identification, batch or lot serial number.

10.1.2. Identification of metal used if the test specimen is an absorptive coating applied to a substrate.

10.1.3. Conditioning procedure prior to testing.

10.1.4. Identification of type of glass used as the glass plate, test temperature and test duration.

10.1.5. Test specimen mass before and after test and mass loss.

10.1.6. Glass plate mass before and after test and mass gain.

10.1.7. Integrated transmittance from 0.3 to 2.1 μm of the glass plate before and after testing and the difference between the two values.

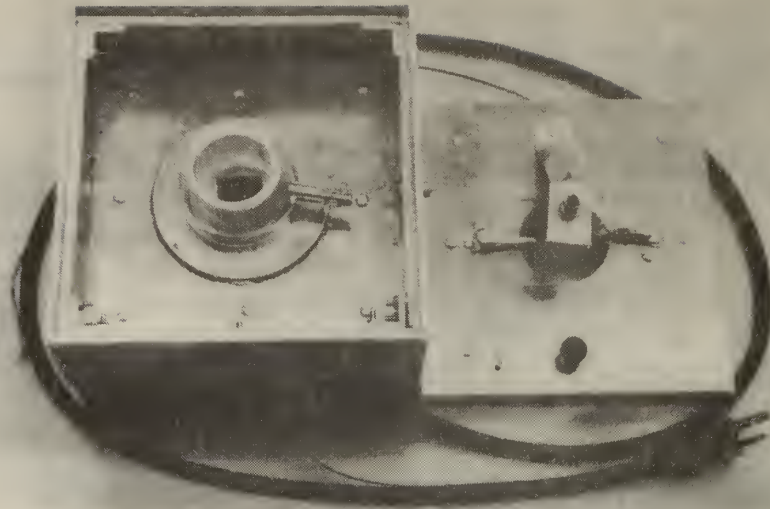


Figure B-1. Components of the Outgassing Test Apparatus.

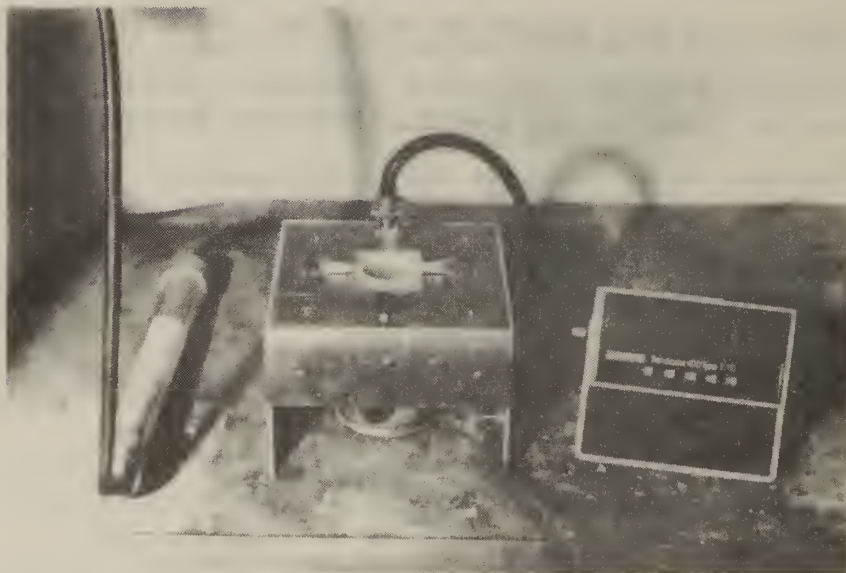


Figure B-2. Assembled Outgassing Test Apparatus.

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET	1. PUBLICATION OR REPORT NO. NBS 81-2232	2. Gov't. Accession No.	3. Recipient's Accession No.
4. TITLE AND SUBTITLE Solar Energy Systems - Standards for Absorber Materials		5. Publication Date January 1981	
7. AUTHOR(S) L.W. Masters, J.F. Seiler, E.J. Embree, W. E. Roberts		6. Performing Organization Code	
9. PERFORMING ORGANIZATION NAME AND ADDRESS NATIONAL BUREAU OF STANDARDS DEPARTMENT OF COMMERCE WASHINGTON, DC 20234		8. Performing Organ. Report No.	
12. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS (Street, City, State, ZIP) Department of Energy Office of the Assistant Secretary Conservation and Solar Applications 20 Massachusetts Avenue - Washington, D. C. 20545		10. Project/Task/Work Unit No.	
15. SUPPLEMENTARY NOTES <input type="checkbox"/> Document describes a computer program; SF-185, FIPS Software Summary, is attached.		11. Contract/Grant No.	
16. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.) Absorber materials used in solar heating and cooling systems absorb energy from the sun and convert it to thermal energy. These materials must perform their intended functions both when first installed and after extended use. However, the environment in which absorber materials are exposed can cause degradation and loss of ability to function. Numerous problems with absorber materials in solar energy systems have demonstrated the need for standards to assess their performance and durability. A study was performed to aid in the development of accelerated test methods needed for the evaluation of absorber materials and to incorporate the methods into draft standards for consideration as consensus standards by the American Society for Testing and Materials (ASTM). After identifying the performance requirements for absorber materials, laboratory and field studies were performed to measure performance according to the requirements. The data obtained, using twelve absorber materials, were used as the technical basis for two draft standards. This report presents the results of the research, including the proposed draft standards.		13. Type of Report & Period Covered Final	
17. KEY WORDS (six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons) Absorber materials; accelerated test methods; durability; solar energy; standards		14. Sponsoring Agency Code	
18. AVAILABILITY <input checked="" type="checkbox"/> Unlimited <input type="checkbox"/> For Official Distribution. Do Not Release to NTIS <input type="checkbox"/> Order From Sup. of Doc., U.S. Government Printing Office, Washington, DC 20402, SD Stock No. SN003-003- <input type="checkbox"/> Order From National Technical Information Service (NTIS), Springfield, VA. 22161	19. SECURITY CLASS (THIS REPORT) UNCLASSIFIED 20. SECURITY CLASS (THIS PAGE) UNCLASSIFIED	21. NO. OF PRINTED PAGES 60 22. Price \$8.00	

