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FIELD WEATHERING TEST DECK FOR REFLECTIVE SHEETING

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U.S. Department of Transportation
Federal Highway Administration

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16. Abstract

Historically the Colorado Department of Highways has approved roadside sign material based on data obtained using the weatherometer. The weatherometer is a piece of equipment used for performing accelerated weather testing. While the weatherometer gives some comparative performance data related to UV stability and exposure to moisture, the true performance is best measured under actual field conditions.

An outdoor exposure deck was constructed to test sign materials for their field performance and expected longevity. Sample materials were split into three pieces, one for the weatherometer testing, one for the outdoor exposure deck, and one to remain in original condition for later comparison. This report describes the construction of the deck, and the sheeting results after three years of exposure to Colorado weather. Sheeting installed on the deck was tested bimonthly for retroreflectance, color retention, and visual defects and compared to the test results of 2,000 hours exposure in the weatherometer.

Implementation

The outdoor exposure deck is impractical for acceptance testing of sheeting materials due to the extreme amount of time the panels must be exposed to sustain sufficient deterioration. Testing with the weatherometer should be continued with the assumption that this test only yields comparative exposure data and is not truly correlated as to time in weatherometer equals a specific time of actual weather.

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I. INTRODUCTION

Colorado has recently changed the materials used to manufacture roadside signs. One of the primary materials used in this new type of sign is reflective sheeting. Historically, the Colorado Department of Highways has approved these materials based on data obtained using a weatherometer. While the weatherometer gives some comparative performance data related to UV stability and exposure to moisture, the true performance is best measured under actual field conditions. Because of numerous new products on the market and changes in several standard products, an outdoor exposure test deck was constructed for rating sign materials as to their field performance and expected longevity.

The objectives of this study are as follows:

a) Establish an outdoor testing method for comparison testing of reflective sheeting.

b) Correlate the results of outdoor tests with weatherometer data.

c) Evaluate the effectiveness of the outdoor test deck method in comparison with weatherometer testing.

II. TEST DECK

The test deck was constructed of aluminum by a metal fabrication company in the spring of 1987. The deck was set in concrete facing south with the main panel adjusted at a 45 degree angle and located at the District 6 maintenance yard in Denver. The 45 degree angle allowed for maximum sun intensity and also allowed the reflective sheeting panels to be self cleaning from rain and snow. ASTM designation G7-83 discusses materials to be used and positioning of the test rack. Photo 1 shows a side view of the deck. The placement of the deck does not allow for true performance of the materials placed within it, since roadway signs do not face at a 45 degree angle and are not all facing south. However, with this setup we can achieve the worst possible weather conditions placed on the deck for the area.

The deck was built to hold 80 - 3"X12" aluminum panels. Spring clips were used to hold the panels in place allowing easy removal of the panels for testing purposes. Photo 2 in appendix D shows the front of the deck containing the panels.

III. WEATHEROMETER

Accelerated testing of reflective sheeting materials is required due to the time required to deteriorate sheeting materials in normal weather conditions. Sheeting materials are warranted by their manufacturer for a period of seven to ten years to be at or above the minimum AASHTO standards. However, deterioration of the material can be seen previous to this. Figure 1 shows AASHTO minimum standards for reflectance of sheeting panels (M268). Ideal condition would be for a weatherometer to resemble a specific factor of actual exposure conditions. If this could be accomplished, testing by weatherometer could be considered an accurate form of testing sheeting materials.

The weatherometer used for the accelerated testing on this study was an Atlas UVCON UV-1 shown in appendix D photo 3. The UVCON uses eight 40-watt fluorescent sunlamps (FS-40) as the source of radiation. The energy from the lamps is concentrated in the wavelength region between 280 and 350 nm. The weatherometer accerlates UV exposure with UV-B lamps, and dew and rain with

FIGURE 1 - AASHTO MINIMUM STANDARDS FOR REFLECTANCE OF SHEETING PANELS M268

TYPE II SHEETING

MINIMUM SIA (CANDELAS PER FOOTCANDLE PER SQUARE FOOT)

OBSERVATION ANGLE ( )	ENTRANCE ANGLE ( )	WHITE	RED	ORANGE	BROWN	YELLOW	GREEN	BLUE
0.2	-4	70	14.5	25.0	1.0	50	9.0	4.0
0.2	30	30	6.0	7.0	0.3	22	3.5	1.7
0.5	-4	30	7.5	13.5	0.3	25	4.5	2.0
0.5	30	15	3.0	4.0	0.2	13	2.2	0.8

TYPE III SHEETING

GLASS BEAD RETROREFLECTIVE ELEMENT MATERIAL

OBSERVATION ANGLE ( )	ENTRANCE ANGLE ( )	WHITE	RED	ORANGE	YELLOW	GREEN	BLUE
0.2	-4	250	45	100	170	45	20
0.2	30	150	25	60	100	25	11
0.5	-4	95	15	30	62	15	7.5
0.5	30	65	10	25	45	10	5.0

TYPE III SHEETING

PRISMATIC RETROREFLECTIVE ELEMENT MATERIAL

OBSERVATION ANGLE ( )	ENTRANCE ANGLE ( )	WHITE	RED	ORANGE	YELLOW	GREEN	BLUE
0.2	-4	250	45.0	100	170	45.0	20.0
0.2	30	95	13.3	26	64	11.4	7.6
0.5	-4	200	28.0	56	136	24.0	18.0
0.5	30	65	10.0	25	45	10.0	5.0

hot condensation (heating water with an electric immersion heater to 50 C.deg. (122 F.deg.). For UV wavelengths this is more sever than sunlight.

Panels used for this study were exposed within the weatherometer for a period of 2,000 hours. The weatherometer was run during this period as follows: UV and condensation cycles were set to 60 C deg. for UV light, and 50 C deg. for condensation. Due to aging of UV lamps, they were rotated every 500 hours and removed after 2,000 hours. A temperature monitor graph was used to record the temperature of each UV and condensation cycle. Water and lamps were checked every day to make sure of proper function during the test period.

IV. MATERIALS

Panels being tested are classified as AASHTO type II medium intensity, (often referred to as engineering grade) type III, high brightness grade sheeting and also vehicle sheeting. A total of 73 reflective sheeting panels were used for testing purposes. Appendix F is a list of all materials used, showing manufacturer, color, and grade. All materials used for this testing had pressure sensitive adhesive. The original sample was mounted on a one foot square aluminum sign stock. These panels were later cut into thirds. The first third was placed in the weatherometer for 2,000 hours, the second third was placed on the outdoor exposure deck for a period of 36 months, and the final third was placed in a protected area free from light and weather.

V. TESTING

Before exposure to the weatherometer or outdoor weather all samples were tested for color and reflectivity. These tests were repeated after every 500 hours of exposure in the weatherometer for a period lasting 2,000 hours.

Visual checks for chalking, fading, cracking, and peeling were also noted. Testing of the 73 reflective sheeting panels on the outdoor exposure deck was performed every three months from June 1987 to July 1990. Testing equipment included two retroreflectometers. Procedures for testing and equipment used are shown below.

A. Retroreflectance Equipment and Testing

Retroreflectivity refers to that light which reflects back to the eye after having contacted a surface. It is measured in terms of specific intensity per unit area (SIA) expressed in candelas per footcandle per square foot (cd/fc/sq.ft.). For the purpose of comparing, two instruments were used to measure this value, one a Model 920 Field Retroreflectometer made by Advanced Retro Technology, Inc. and the other made by United Detector Technology, Inc., photos 4 and 5 in appendix D.

The testing and operating procedure for the 920 begins by separating all the panels into their respective type and color. This is done because each type and color of panel requires its respective calibrating standard. After this, readings are taken at three different locations on the surface of each panel and an average is calculated. The 920 measures in SIA units directly so conversions are unnecessary. Using the United Dector is more cumbersome and must to be used in total darkness except for a flash light for recording numbers. This retroreflectometer also requires more time to set up and calibrate, but on the other hand, gives more information about the panel. For example, the 920 can only emit a light ray from an observation or divergence angle of 0.2 degrees and its sensor can only detect this reflected light at only one incident or entrance angle, that being -4 degrees. On the other hand, the retroreflectometer by United Detector can emit light from 0.2 and 0.5 degrees and it can be observed from -4, 20, 30 and 45 degrees incidence. When using the United Detector retroreflectometer, panels are separated into their respective type and color, as with the 920 this is done because each color requires its own calibrating plate or standard. Readings are recorded from the display meter for the two observation angles and the 4 incident angles for each of the 73 panels. Using these numbers the SIA can be calculated as a ratio of the specific brightness of the standard to that of each respective panel.

The above mentioned angles (observation and entrance) can be described as follows. Observation angle is defined as the angle in which a driver in a vehicle approaching a reflective sign at night sees that object due to the reflectance of his headlamps. The entrance angle is the angle between the direction of the incident light at the sign face and normal (perpendicular) to that reflective face. Figure 2 shows visually the two angles.

B. Visual Inspection

The final step in the testing procedure is a visual inspection of each panel. This involves describing the physical condition of the panel and comparing it to mint sets of panels which are preserved in storage. Each panel is examined for, color fading, cracking, chalking, and delamination. Color fading is a diminished color contrast between the test panel and the mint panel. This condition may be the result of ultraviolet rays in sunlight and often causes a loss in reflectivity. Cracking is a condition which may be a result of thermal expansion from changes in weather which causes the sheeting to separate from the aluminum backing. Chalking is described as a condition whereby the reflective sheeting lacks brilliance or luster, in other

RETRO-REFLECTANCE

DEFINITION OF ENTRANCE AND OBSERVATION ANGLE

OVERHEAD SIGN CONFIGURATION

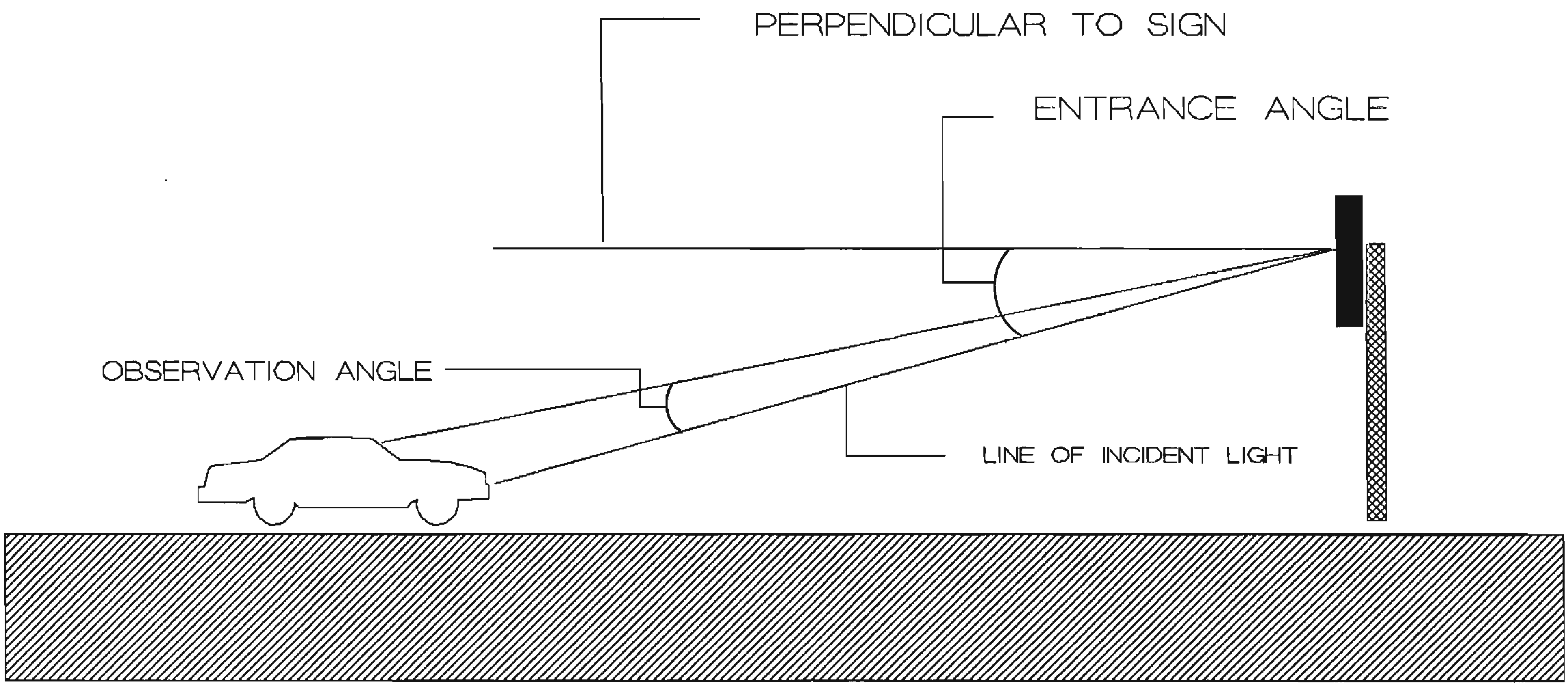


FIGURE 2

words the panel may look dull. This type of deterioration also may result in a loss of reflectivity. Lastly the condition of delamination which describes a sheeting material which has fully separated from the aluminum. This may be caused by insufficient adhesion applied to the sheeting by the manufacturer or by a fabrication problem.

VI. TEST RESULTS

A. Retroreflectance Results

Appendix A and Appendix B show the results of retro-reflectance testing on engineering grade and hi-brightness sheeting, respectively. The results are shown on the graphs by color and overall average of the type of material (Type II or Type III). The materials were not broken down by manufacturer since the purpose of the study is to evaluate the effects of the Weatherometer versus actual weather and not individual sheeting manufacturers.

Appendix A2 shows the results of the following graphs. The initial average retro-reflectance reading in cd/sq.ft./fc is shown for each color, (this includes all manufacturers averaged together) and the final reading after 36 months on the deck and the final reading after 2,000 hours in the Weatherometer is shown. From this a percentage of reflectance loss was calculated for each. This shows that engineering grade material lost, on the average, 9% of its reflectance after 36 months on the outdoor exposure deck. The Weatherometer caused much more severe results with an average of 71% loss of reflectance after 2,000 hours of exposure. The percentages appeared to be fairly consistent for all colors in the engineering grade materials.

The degradation of the material on the outdoor exposure deck appears to be somewhat variable and not necessarily linear. This is caused by the simple fact that weather conditions are not constant. For this purpose, calculations for correlating the time expectancy of the weatherometer versus the actual weather must assume the outdoor exposure deck to be linear and resulting in a correlation that is only an estimate of actual time in the weatherometer to time on the deck. If this is true, it would take 23.6 years in order for a loss of 71% of reflectance on the outdoor deck to occur. Of course this will not happen. At some point the reflectance will drop off the plateau and the rate of deterioration will increase. The deterioration will not be linear. Three years is not enough data to show this. So the determination of time in the weatherometer to the outdoor deck can not be determined on engineering grade sheeting without further testing to determine when the sheeting material will begin to deteriorate at a faster rate.

Appendix B shows the Hi-Brightness (Type III) material reflectance testing results. The results show much more severe deterioration on the type II materials than that on the type III. The fast drop in reflectance seen with the

type II material in the weatherometer toward the end of the test is not seen with the type III. After 36 months on the outdoor deck the average of all type III materials dropped 13% while the weatherometer caused a 24% lose in 2,000 hours. Based on the slope of the reflectance for the deck and the weatherometer, a rough time correlation may be calculated. 2,000 hours in the weatherometer is equivalent to 5.5 years of exposure to actual weather. This can be calculated due to the fact that neither exposure method produced significant reflectance deterioration to the type III material within the period used for testing. Here again, a longer period of time is needed to better evaluated the exposure methods.

Looking at the graphs for both engineering grade material and hi-brightness material there is nothing that appears to be common. Deterioration is different for each type of material, each manufacturer, and each color. This shows that there is no common correlation between the weatherometer and the outdoor exposure deck. A rough estimate can be made on the correlation, however; this time estimate will change with each new factor (manufacturer, color, grade). The weatherometer is a good instrument for accelerated testing of sheeting materials but, it can not be reliably said that a specific time span in the weatherometer is equal to a specific time span of actual Colorado weather.

B. Visual Results

Appendix C show the results of visual inspections of the materials tested in the weaterometer and the outdoor test deck compared to the panels placed in an area away from sunlight and weather. Appendix C top figure shows the color defects which include fading, and visual color change. The panels were rated from 0 to 3. 0 being no change in color and no fading. A rating of 1 was given if there was slight fading or color change. A rating of 2 was given for moderate, and severe color change or fading was given a rating of 3. There is significant color change on most panels placed in the weatherometer. However, again this is manufacturer and color dependent. Some panels had no or very little color change. Using this data, a direct correlation of color change between weatherometer results and outdoor exposure again cannot be determined.

The bottom figure in appendix C shows the visual results of the material defects: cracking, peeling, and delamination of the sheeting. The same type of rating system was used here as that used for color defect. The graph shows very little material defect in the 36 months that the test panels were placed on the deck. However, material placed in the weatherometer did have some severe defects after 2,000 hours. The results do show that relating the weatherometer to the outdoor exposure deck is manufacturer, color, and grade dependent.

VII. CONCLUSIONS

Extended testing of materials on the outdoor test deck is impractical due to the rapid changes in material technology. By the time results of testing sheeting materials on the outdoor test deck can be obtained many of the materials tested often will have been upgraded or discontinued by the manufacturer. Comparing reflectivity results between the weatherometer and the outdoor exposure deck does not produce a direct correlation due to the many varying factors. Sheeting materials react differently in the weatherometer depending on manufacturer, color, and grade preventing a correlation between the weatherometer and outdoor conditions.

Reflectance results show that panels that did not perform well in the weatherometer also did not perform well in actual weather. This shows that the weatherometer performance is a relative indicator of actual performance, even though the weatherometer does not directly correlate with actual weather exposure. Panels that perform well or poorly in the weatherometer can be expected to perform generally the same under outdoor conditions.

VIII. IMPLEMENTATION

The outdoor exposure deck is impractical for testing engineering grade and hi-brightness sheeting panels due to the extreme amount of time the panels must be exposed to receive sufficient deterioration. The outdoor deck should be maintained on site and used for materials with a shorter life span than these sheeting materials. The Materials Lab or Staff Traffic may have some use for long term weather exposures. If testing is continued it is recommended that the procedure outlined in Appendix E Outdoor Testing Method be followed.

Testing with the weatherometer should be continued with the assumption that this test only reflects comparative exposure but is not truly correlated as to time of weatherometer exposure equaling a specific time of actual weather exposure.

REFERENCES

1. AASHTO M268-84; Retroreflective Sheeting for Traffic Control

2. ASTM G7-83; Standard Practice for Atmospheric Environmental Exposure Testing of Nonmetallic Materials

3. ASTM E810-81; Standard Test Method for Coefficient of Retroreflection of Retroreflective Sheeting

4. SASHTO Regional Test Facility. Laboratory and Outdoor Exposure Test Data on Sign Sheeting Material: Interim Report 1990.

5. Virginia Highway and Transportation Research Council. Evaluation of High Intensity Sheeting for Overhead Highway Signs: 1974.

6. U.S. Department of Agriculture. Outdoor Testing of Reflective Sign Materials: January 1984.

7. Federal Highway Administration. Retroreflectivity of Roadway Signs for Adequate Visibility: November 1987.

APPENDIX A

RETRO-REFLECTANCE TEST DATA

(ENGINEERING GRADE)

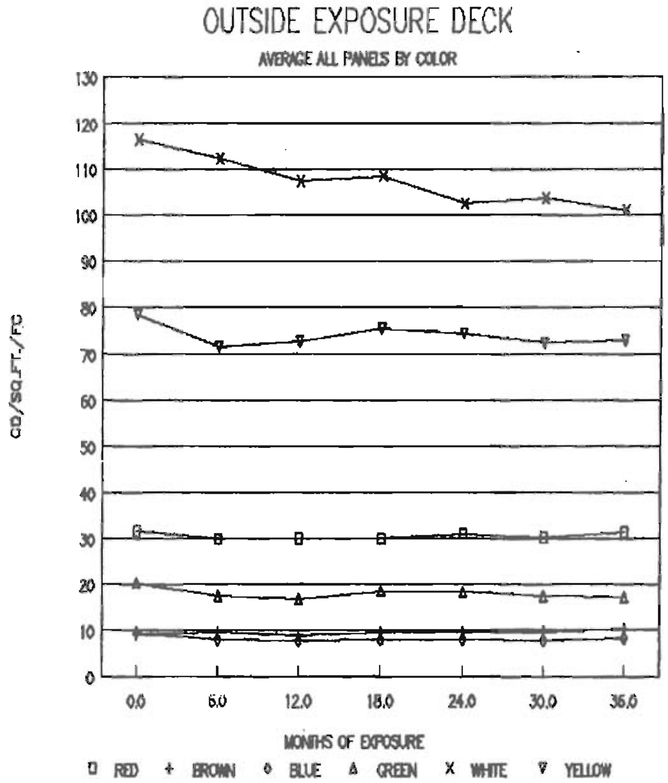
ENGINEERING GRADE

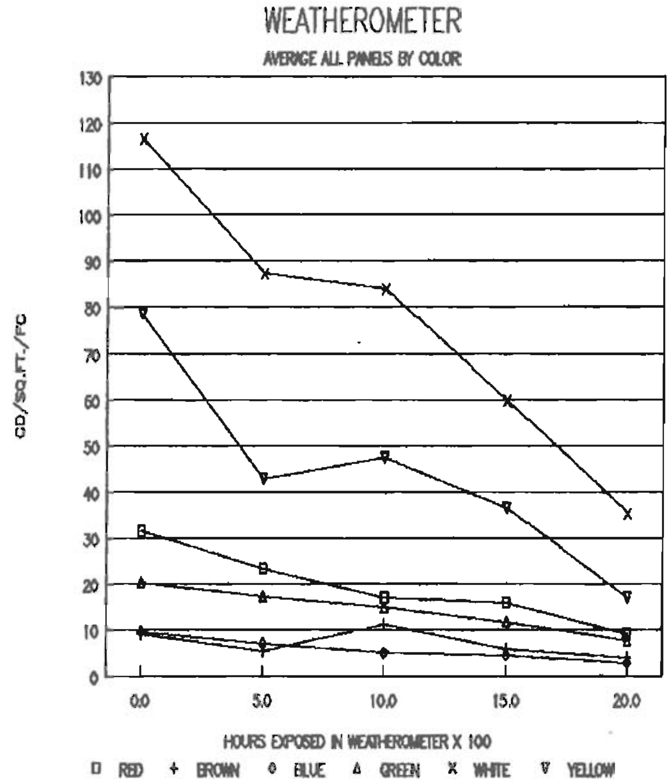
RETRO-REFLECTANCE OUTSIDE EXPOSURE DECK
VS.
WEATHEROMETER

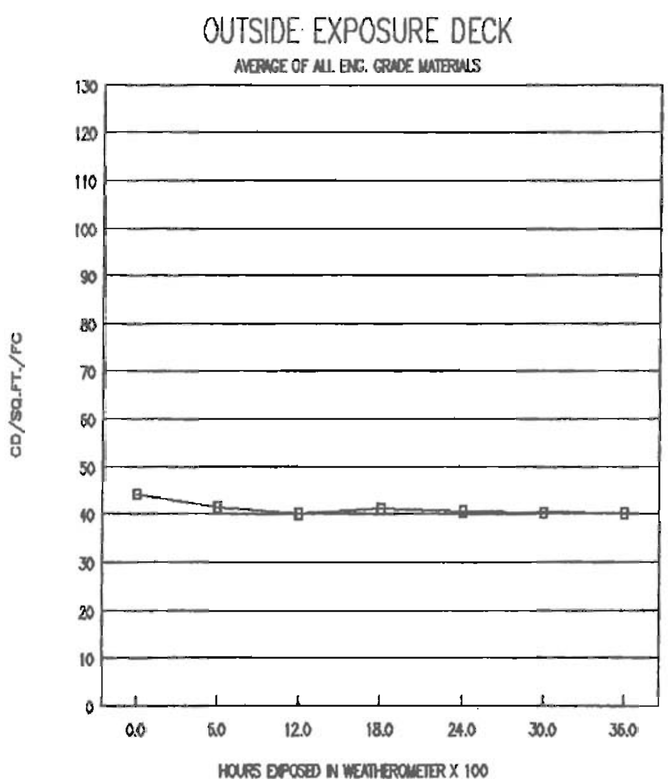
COLOR	AVG. ORIGINAL RETRO-REFLECTANCE (CD/SQ.FT./FC)	36 MONTHS ON DECK (CD/SQ.FT./FC)	2,000 HOURS IN WEATHEROMETER (CD/SQ.FT./FC)
RED	31.6	31.4	9.1
	PERCENT CHANGE –	–1%	–71%
BROWN	9	10.2	4
	PERCENT CHANGE –	+13%	–56%
BLUE	9.7	8.1	2.9
	PERCENT CHANGE –	–16%	–70%
GREEN	20.3	17.1	7.7
	PERCENT CHANGE –	–16%	–62%
WHITE	116.5	101.1	35.2
	PERCENT CHANGE –	–13%	–70%
YELLOW	78.6	72.9	16.9
	PERCENT CHANGE –	–7%	–78%
OVERALL AVERAGE	44.2	40.1	12.6
	PERCENT CHANGE –	–9%	–71%

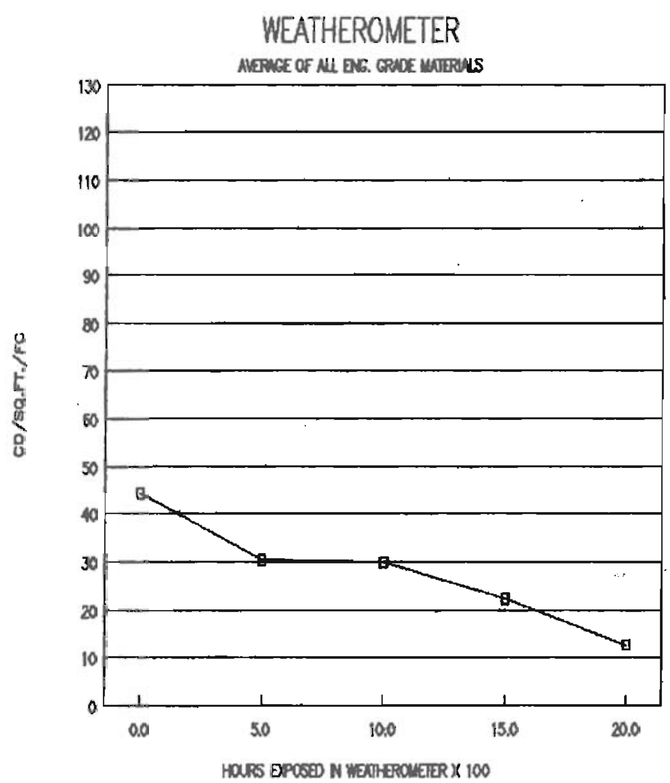
RETRO-REFLECTANCE

AVERAGE ENGINEERING GRADE BY COLOR



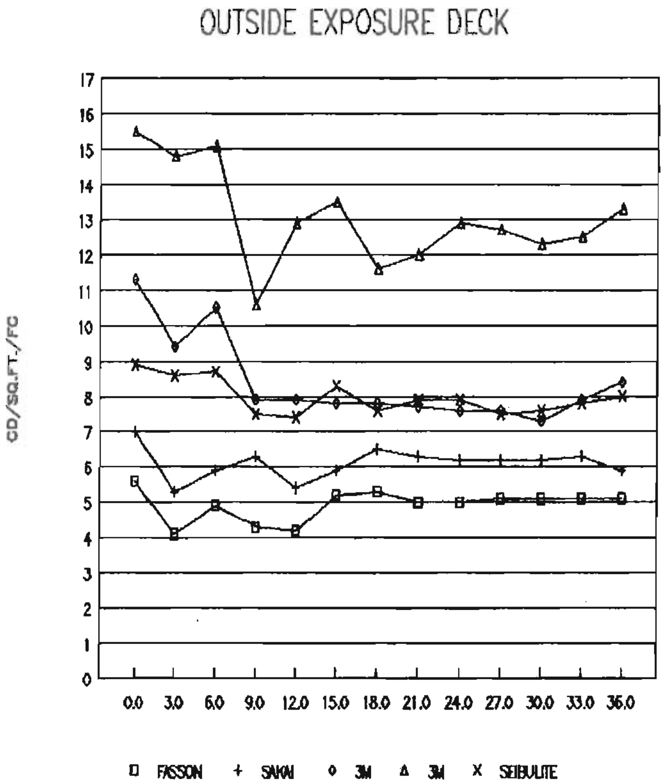


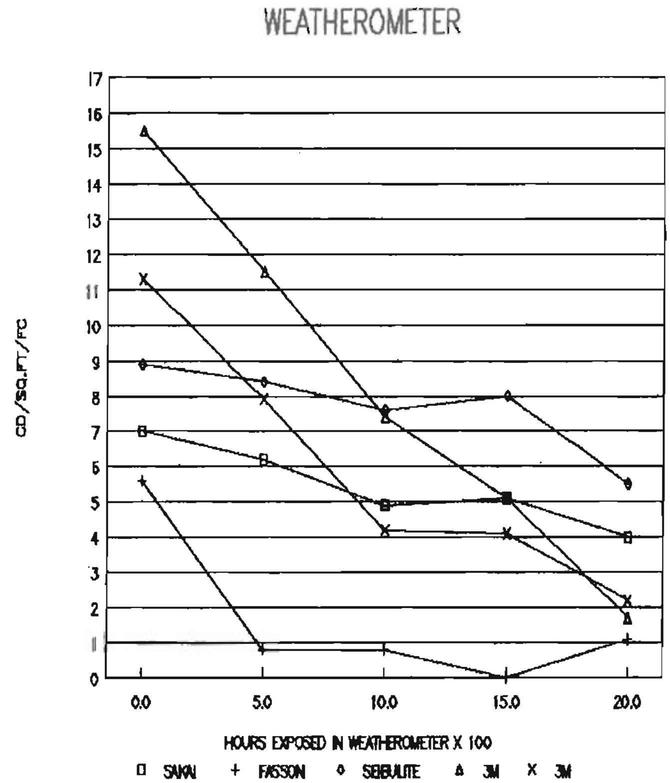


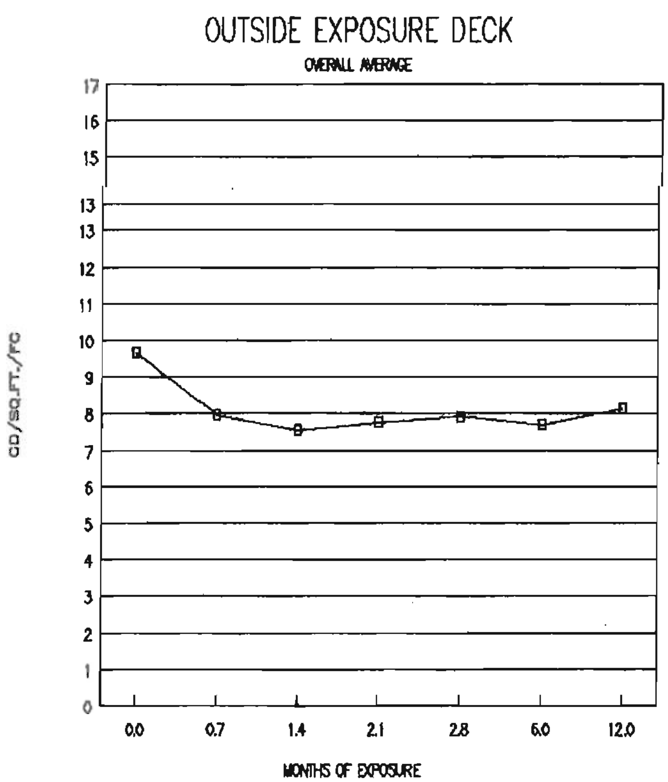


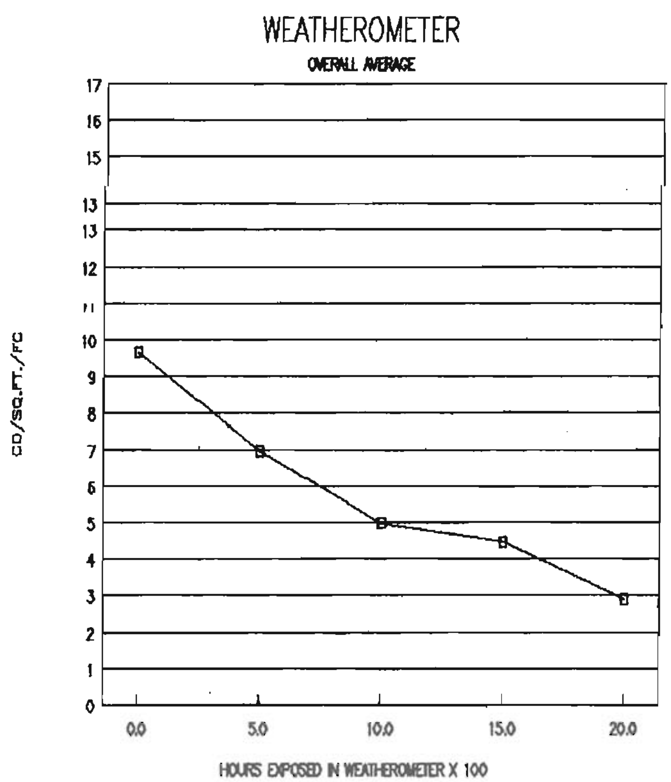
RETRO-REFLECTANCE

BLUE ENGINEERING GRADE



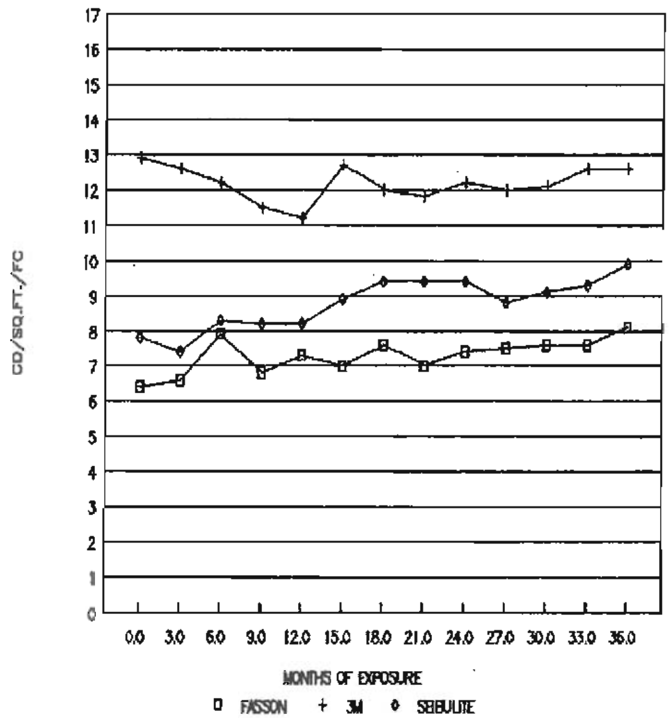




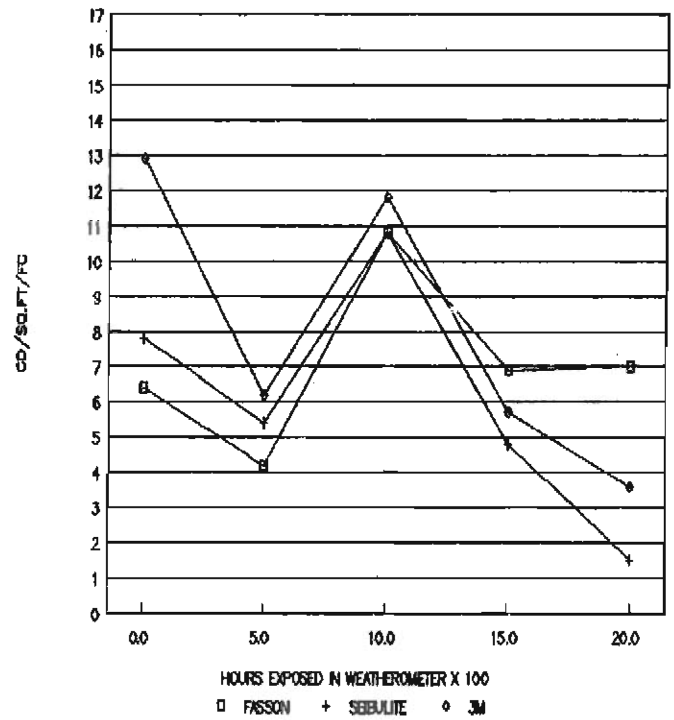


RETRO-REFLECTANCE
BROWN ENGINEERING GRADE

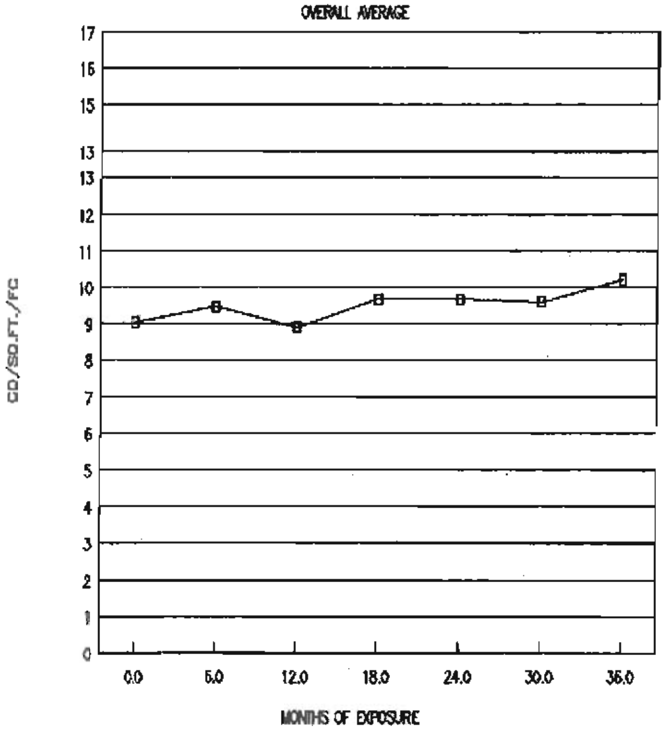
OUTSIDE EXPOSURE DECK



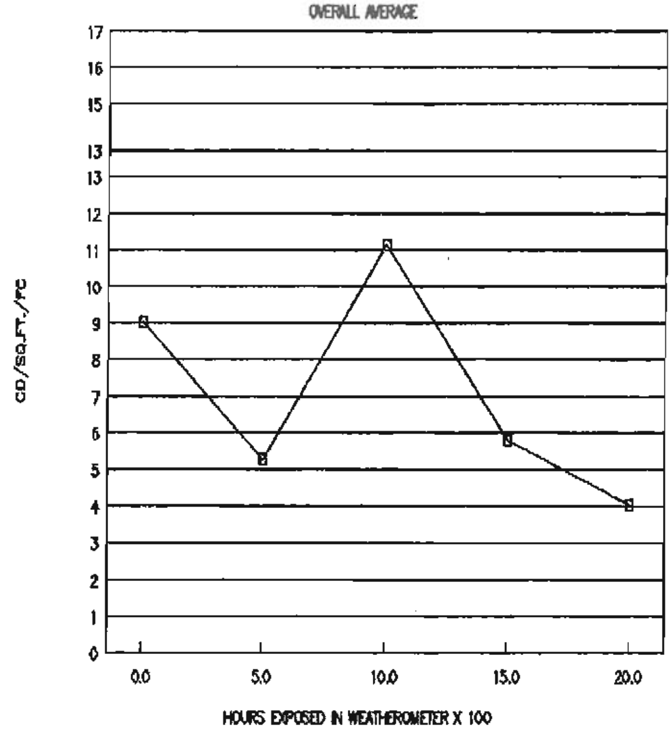
WEATHEROMETER



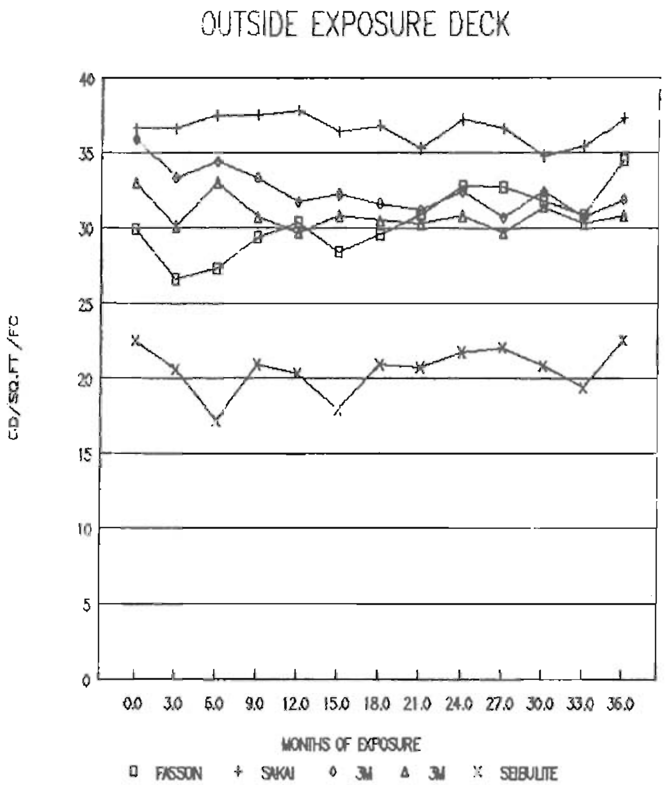
OUTSIDE EXPOSURE DECK
OVERALL AVERAGE

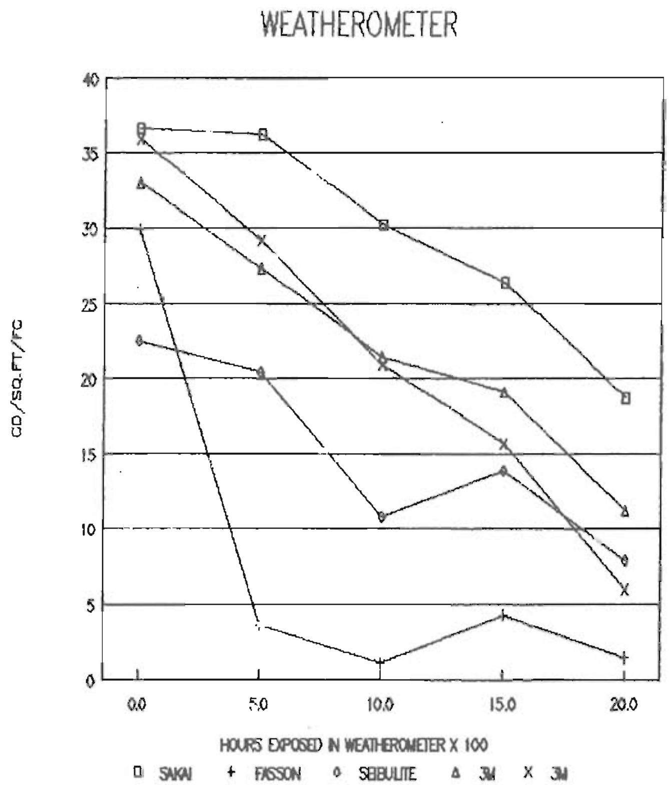


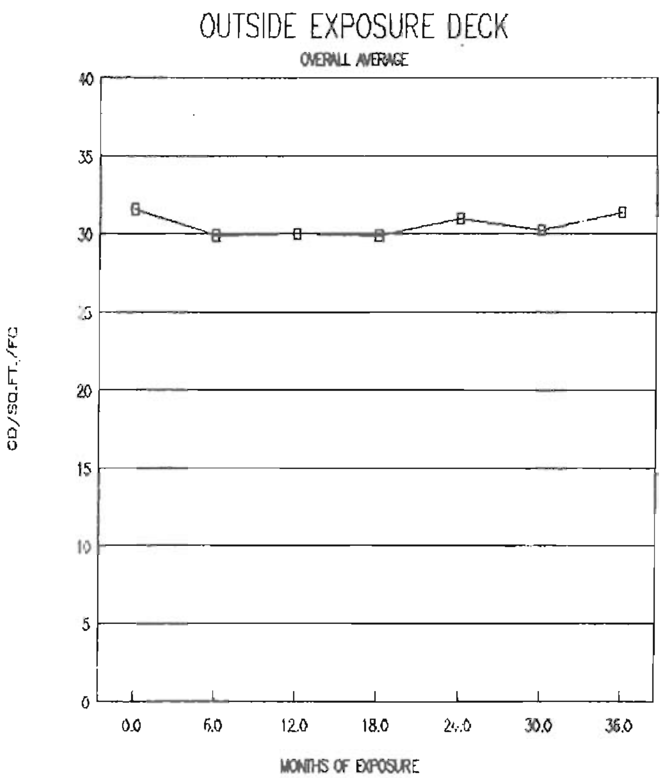
WEATHEROMETER
OVERALL AVERAGE

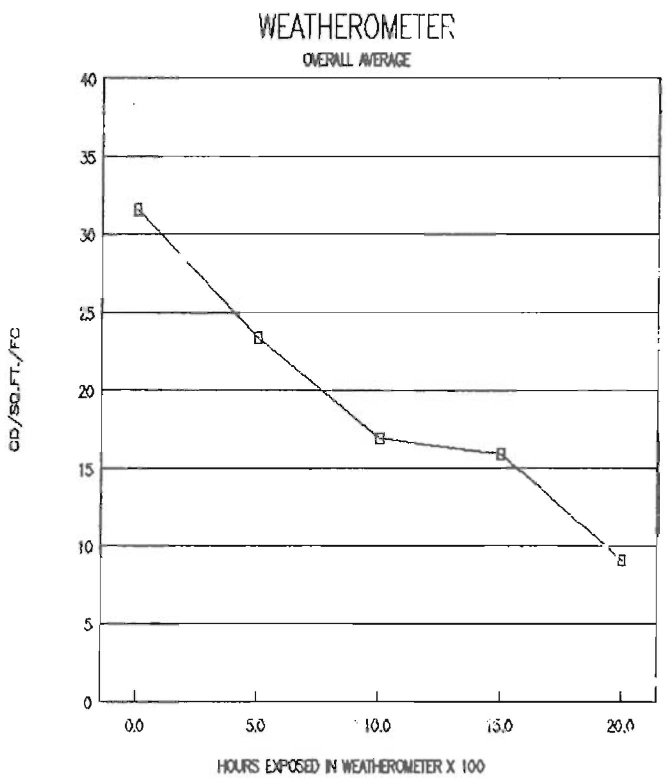


RETRO-REFLECTANCE
RED ENGINEERING GRADE

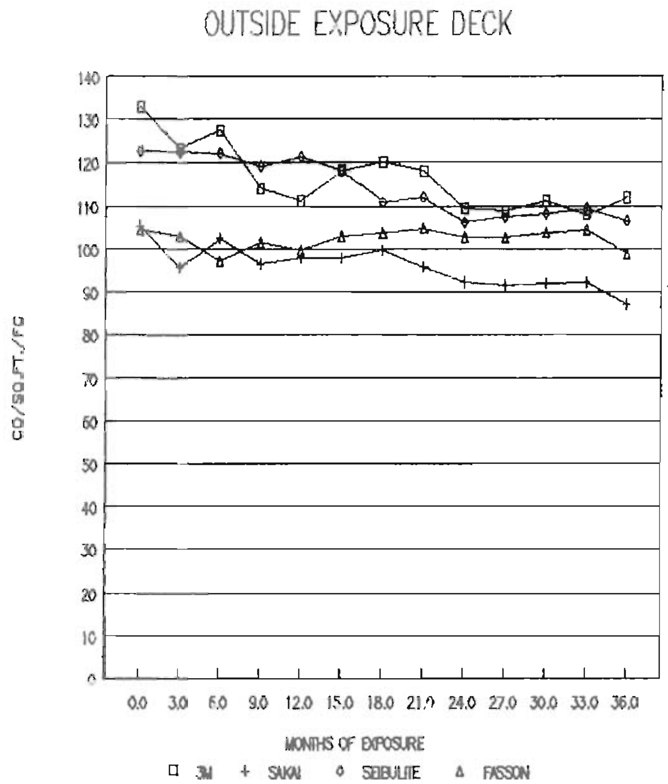


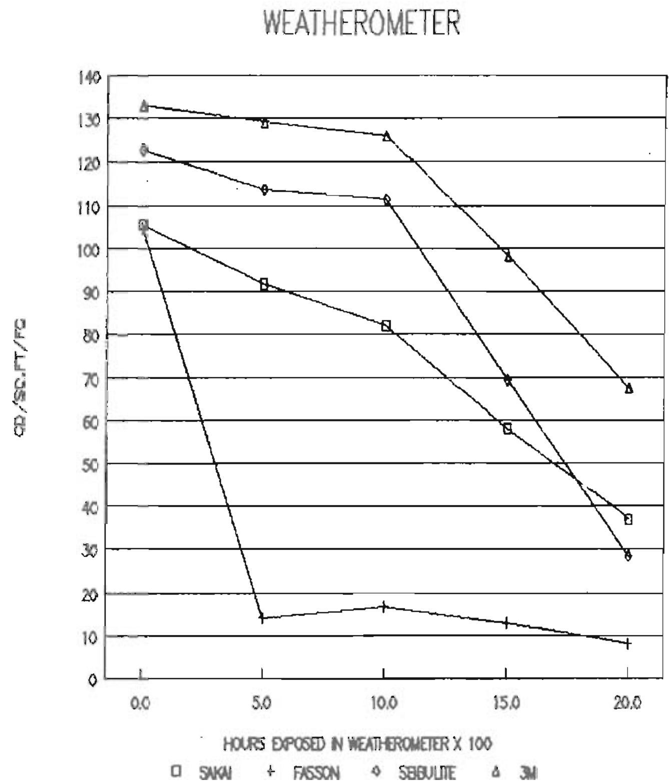


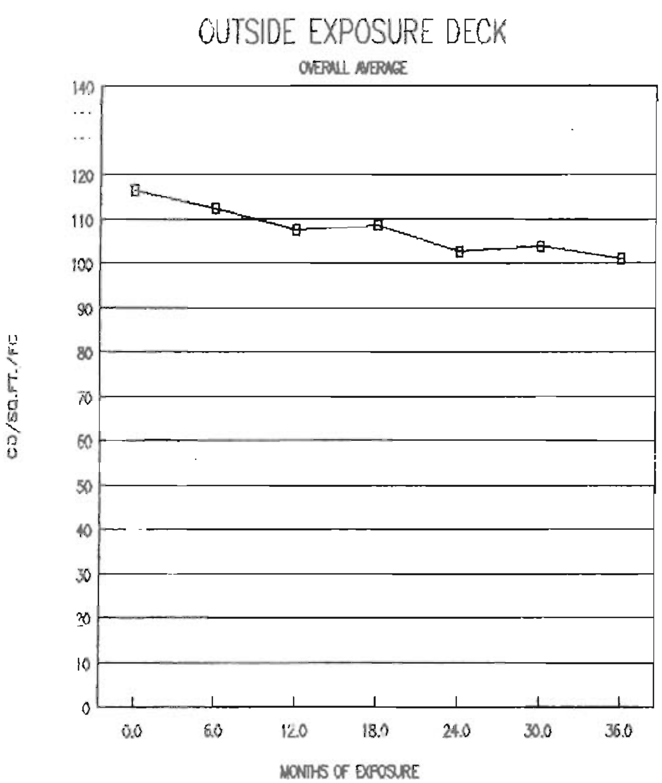


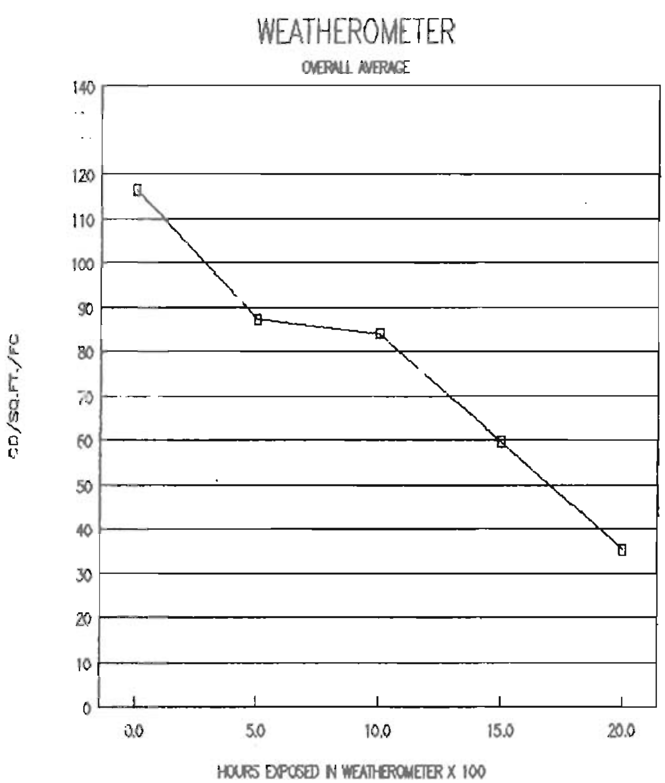


RETRO-REFLECTANCE
WHITE ENGINEERING GRADE



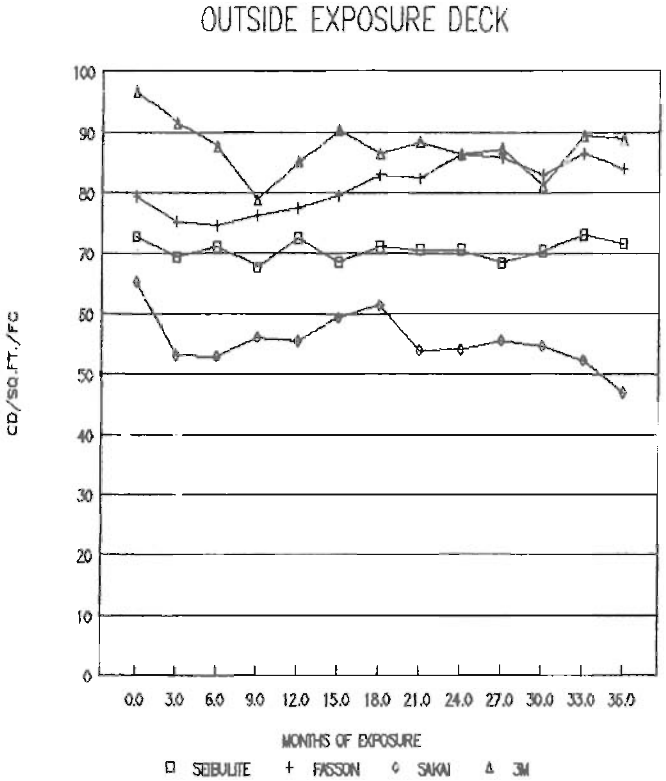


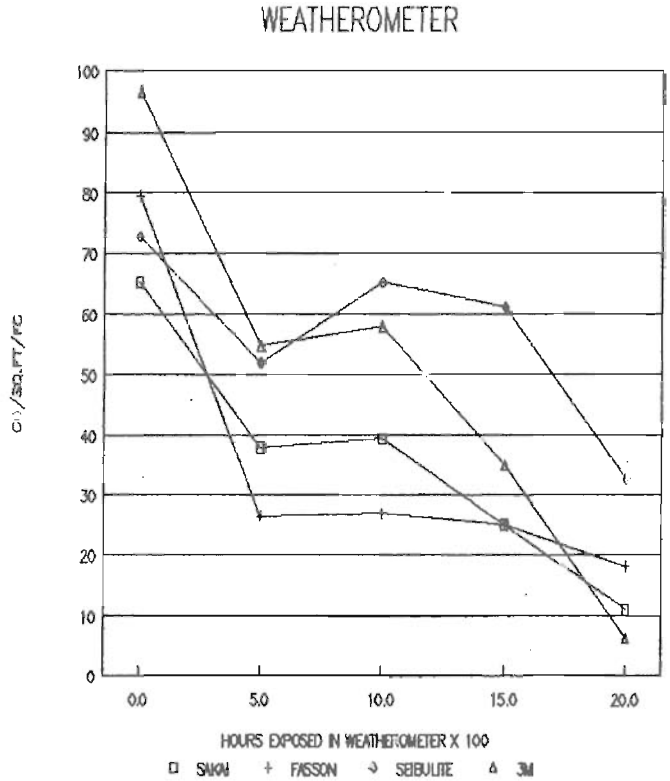


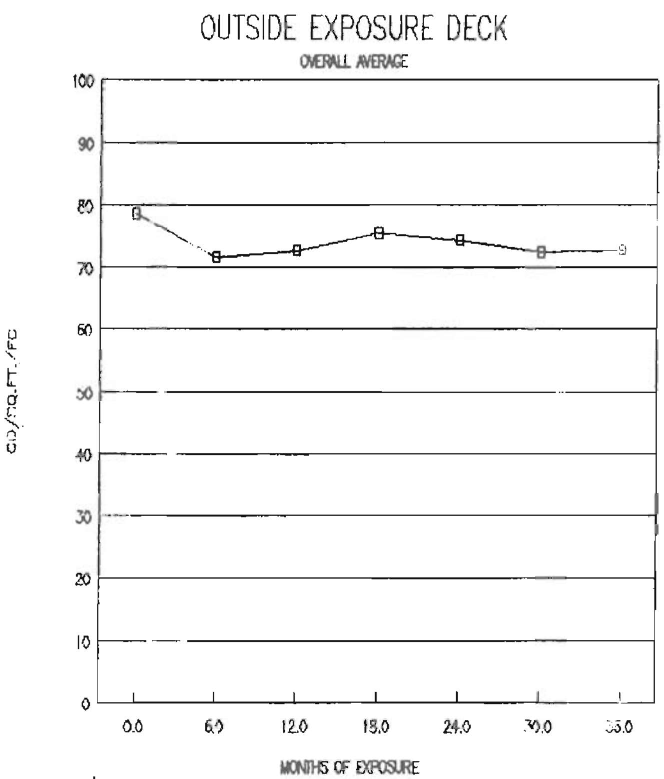


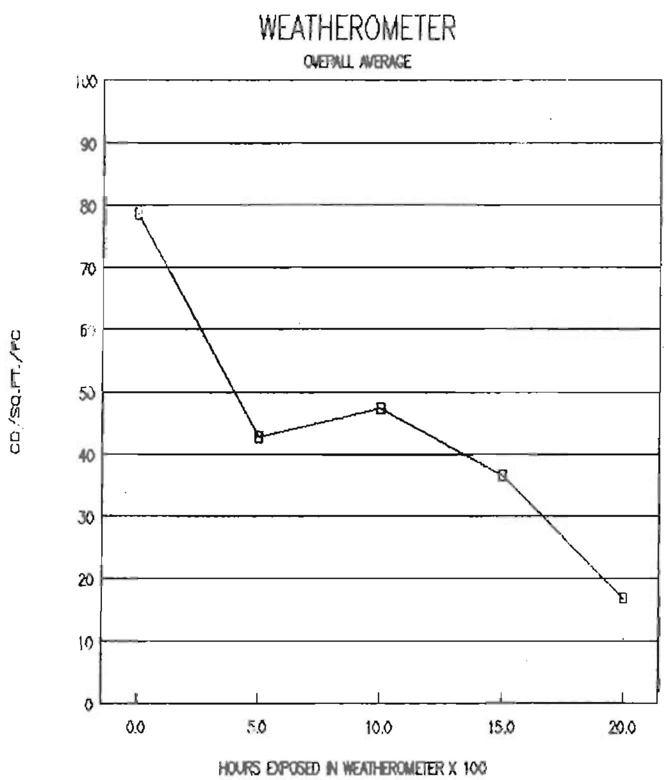
RETRO-REFLECTANCE

YELLOW ENGINEERING GRADE

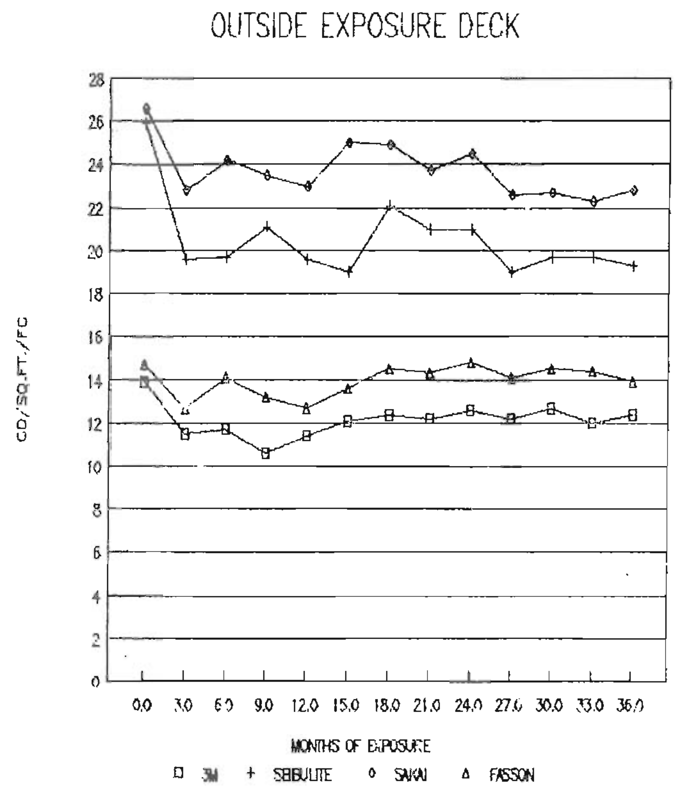


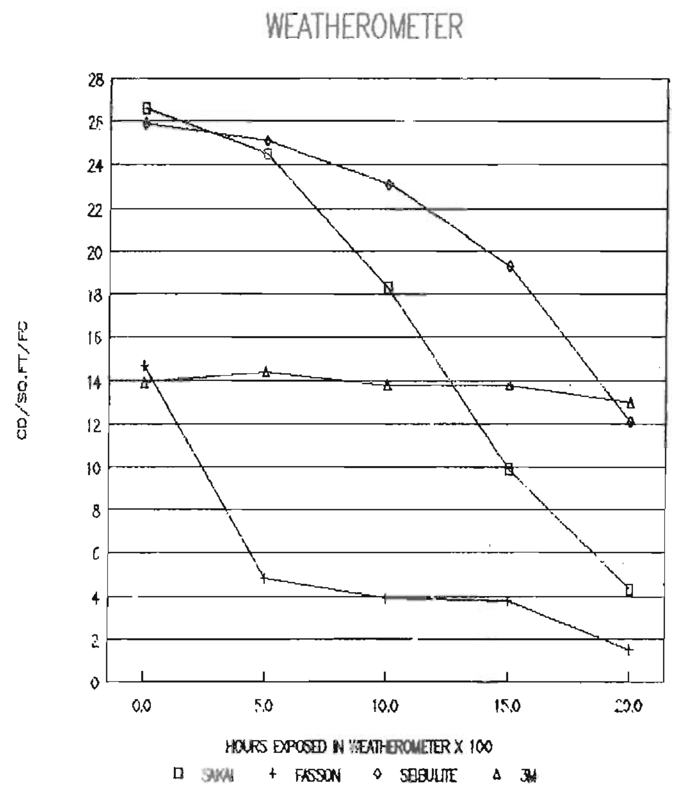


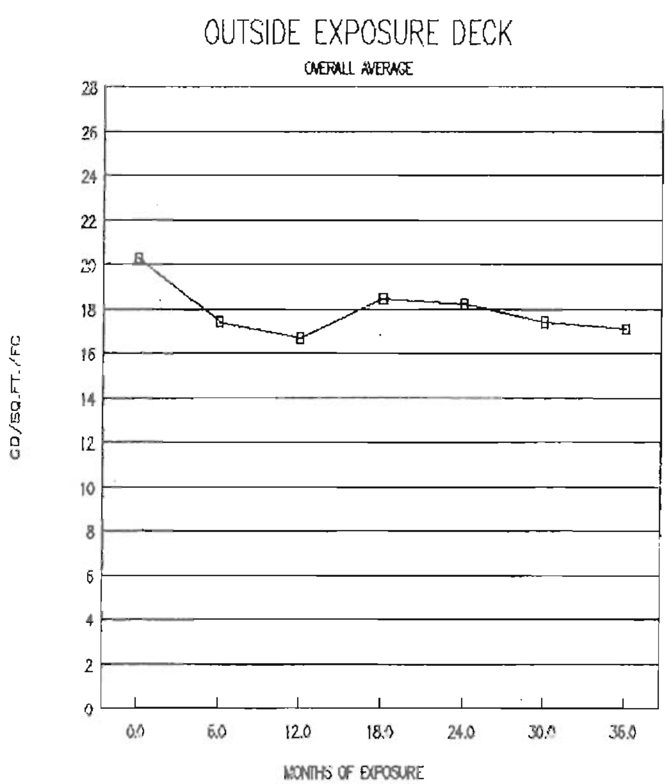


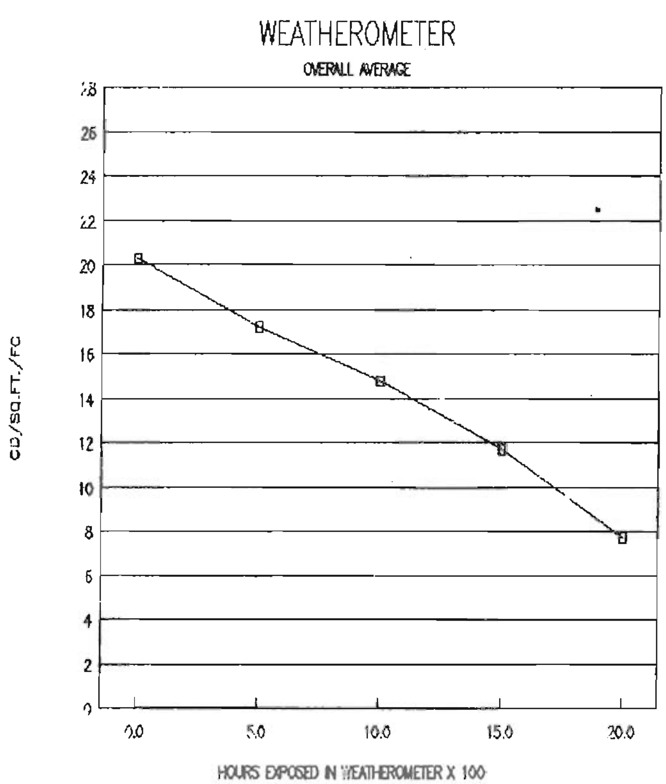


RETRO-REFLECTANCE
GREEN ENGINEERING GRADE









APPENDIX B

RETRO-REFLECTANCE TEST DATA

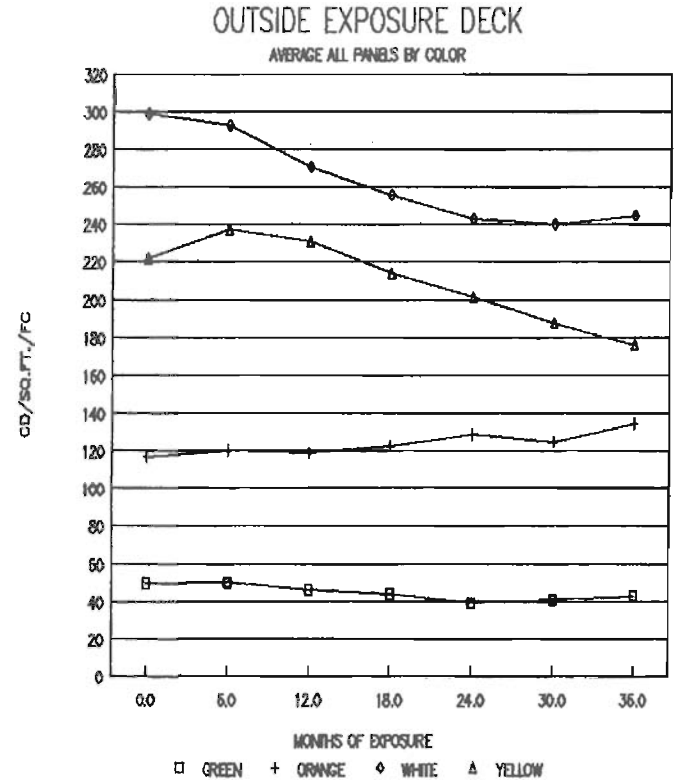
(HI-BRIGHTNESS)

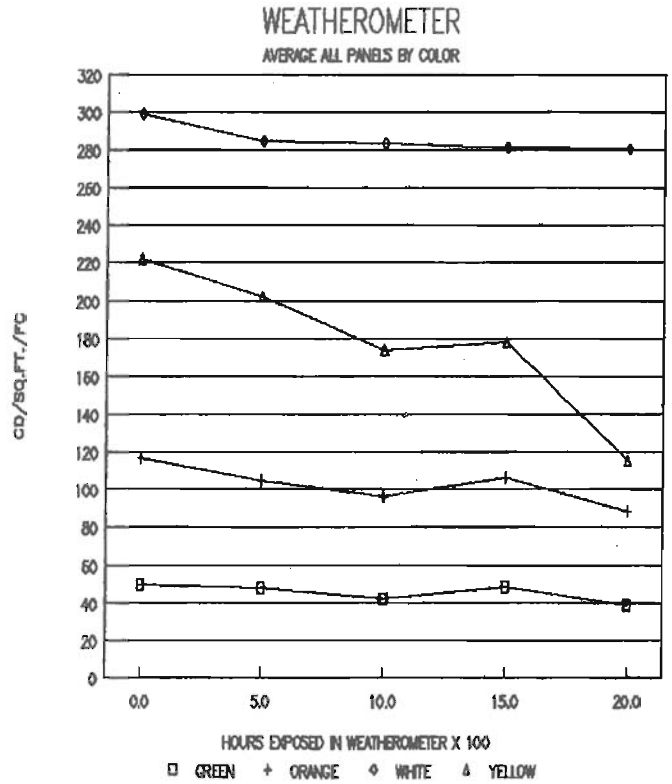
HI-BRIGHTNESS

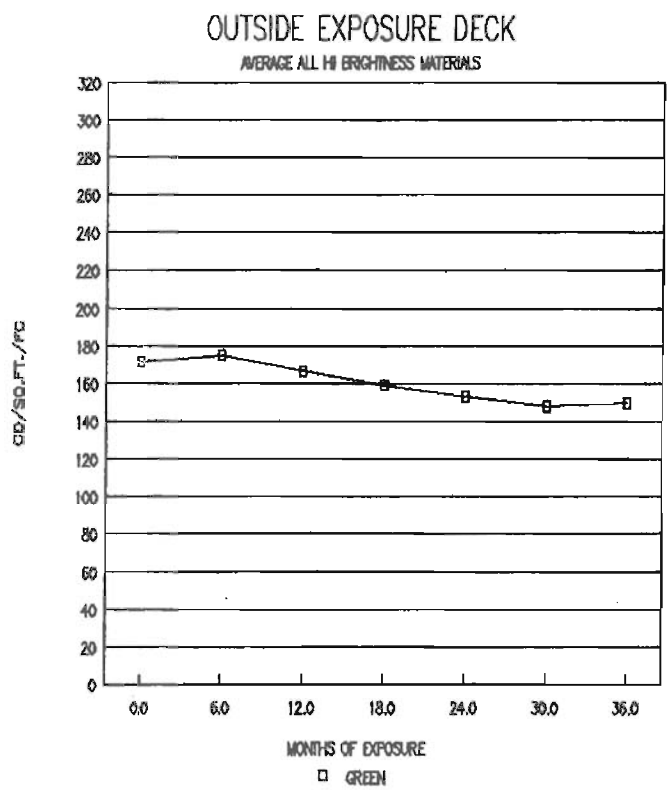
RETRO-REFLECTANCE OUTSIDE EXPOSURE DECK
VS.
WEATHEROMETER

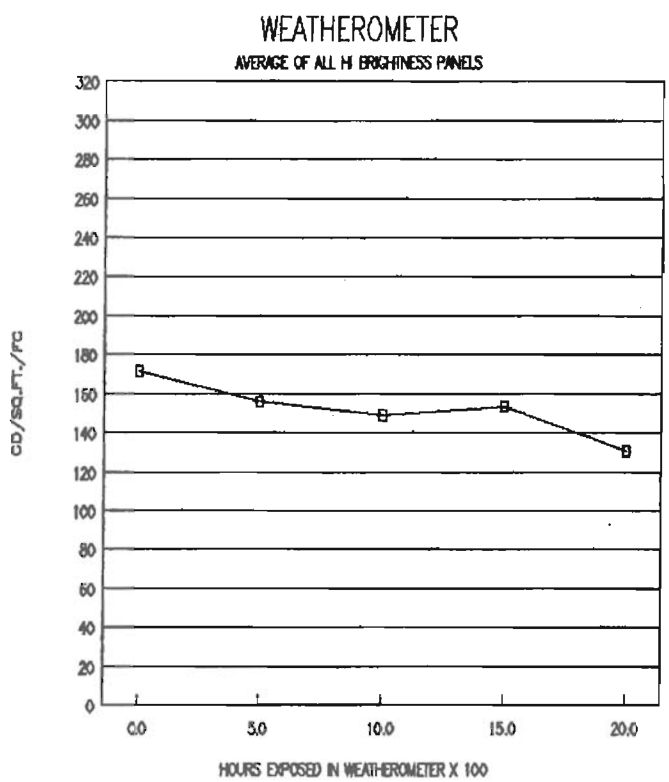
COLOR	AVG. ORIGINAL RETRO-REFLECTANCE (CD/SQ.FT./FC)	36 MONTHS ON DECK (CD/SQ.FT./FC)	2,000 HOURS IN WEATHEROMETER (CD/SQ.FT./FC)
GREEN	49.3	43	38.5
	PERCENT CHANGE –	–13%	–22%
ORANGE	116.4	134.2	88.5
	PERCENT CHANGE –	+15%	–24%
WHITE	298.7	244.9	280.4
	PERCENT CHANGE –	–18%	–6%
YELLOW	221.7	176.1	115.1
	PERCENT CHANGE –	–21%	–48%
OVERALL AVERAGE	171.5	149.5	130.6
	PERCENT CHANGE –	–13%	–24%

RETRO-REFLECTANCE
AVERAGE HI-BRIGHTNESS

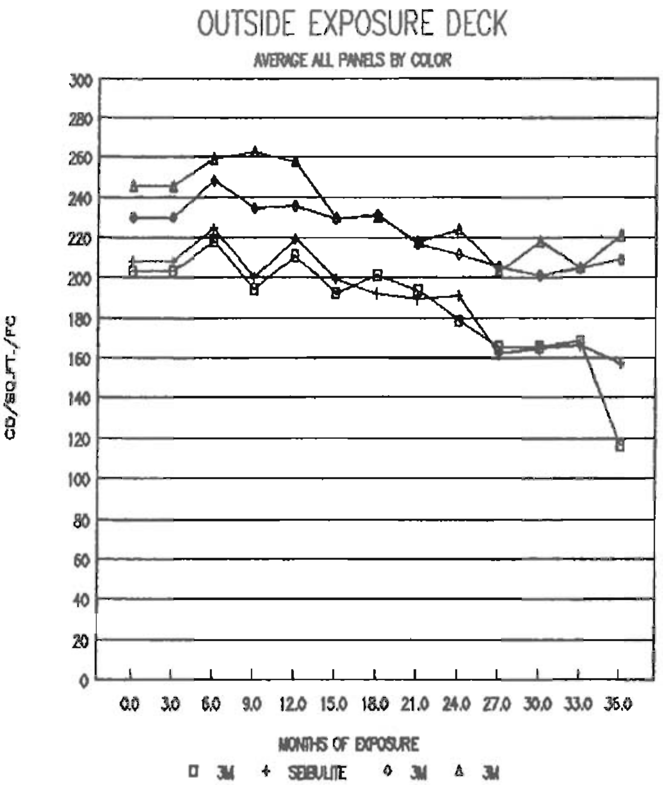


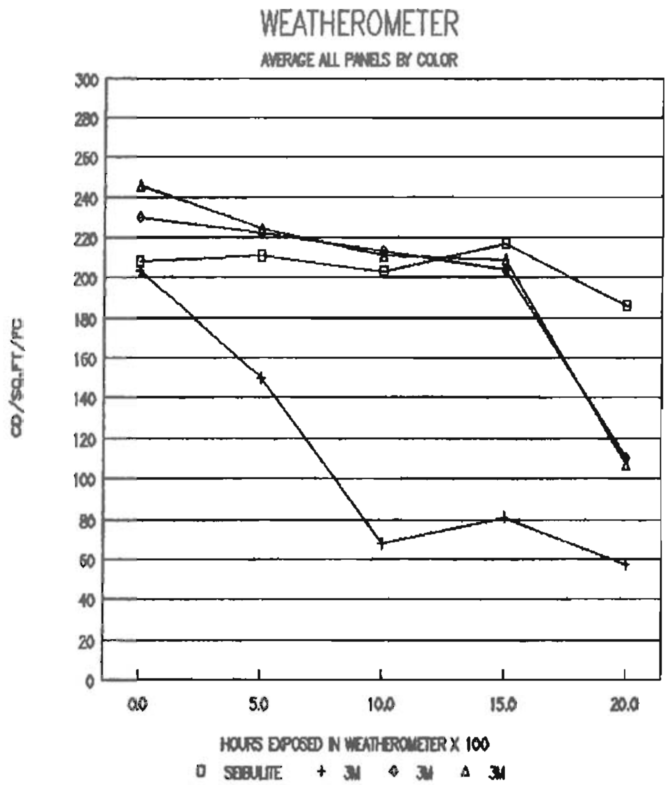


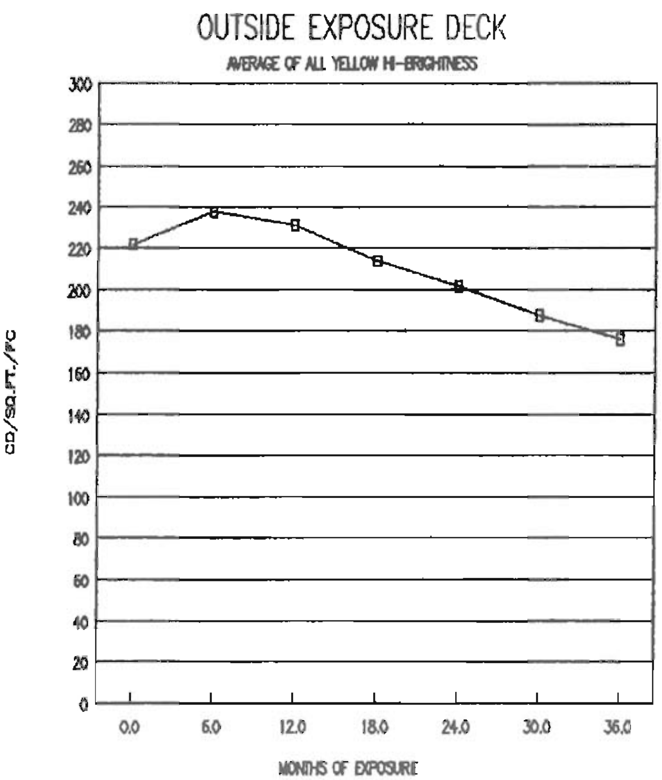


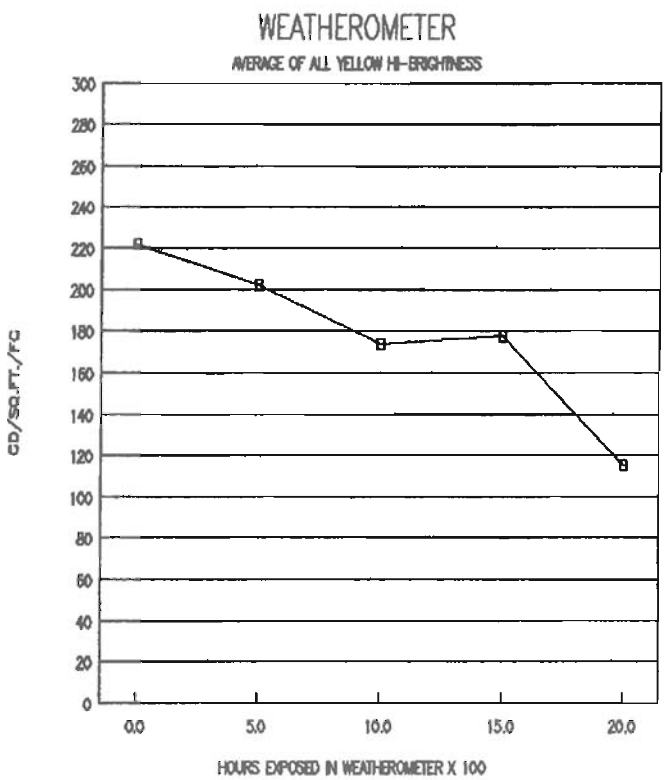


RETRO-REFLECTANCE
YELLOW HI-BRIGHTNESS

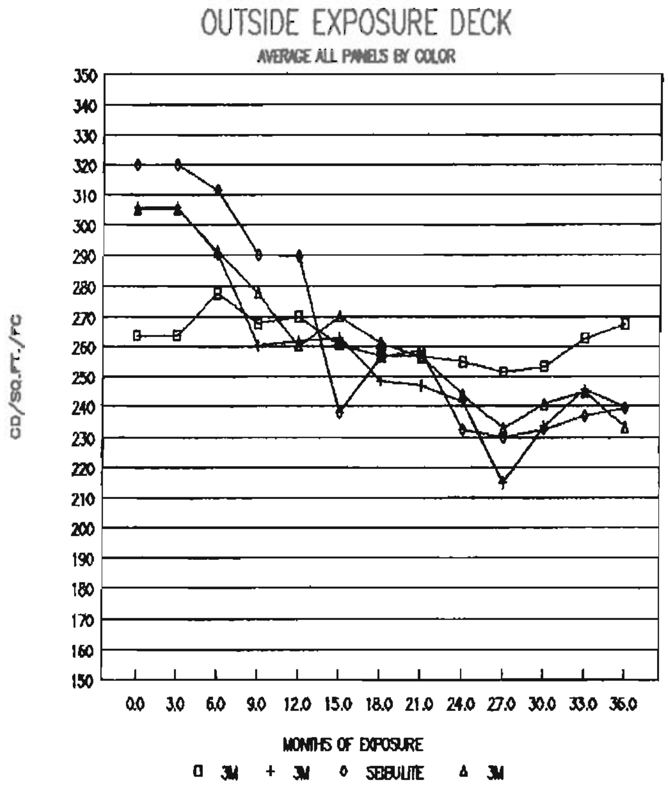


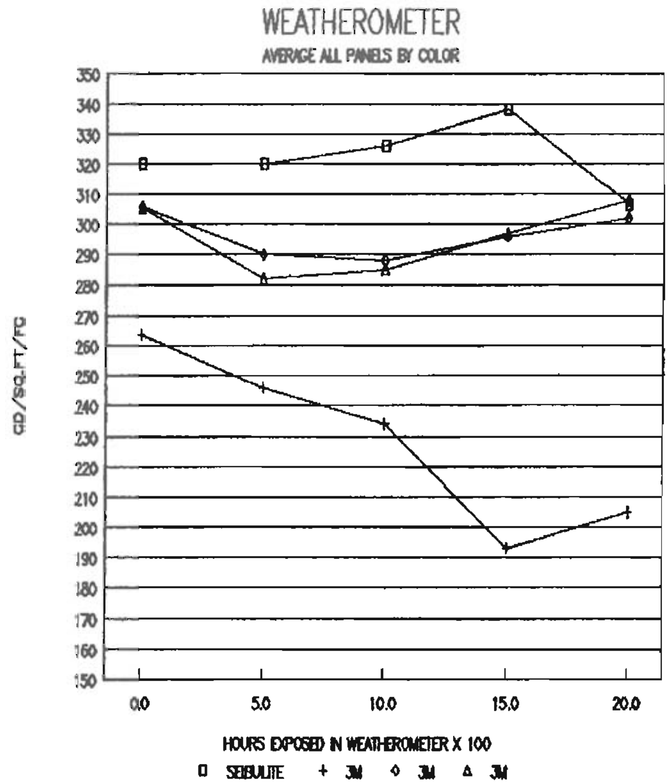


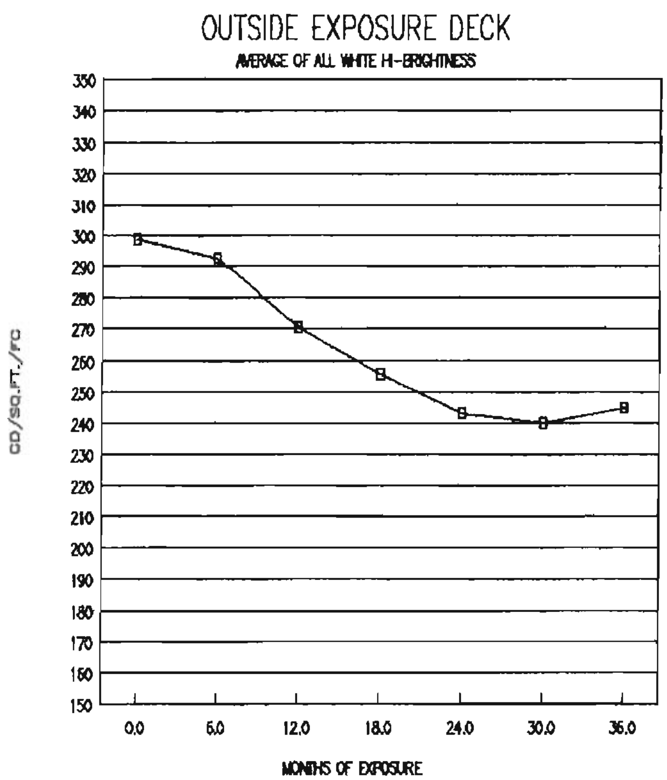


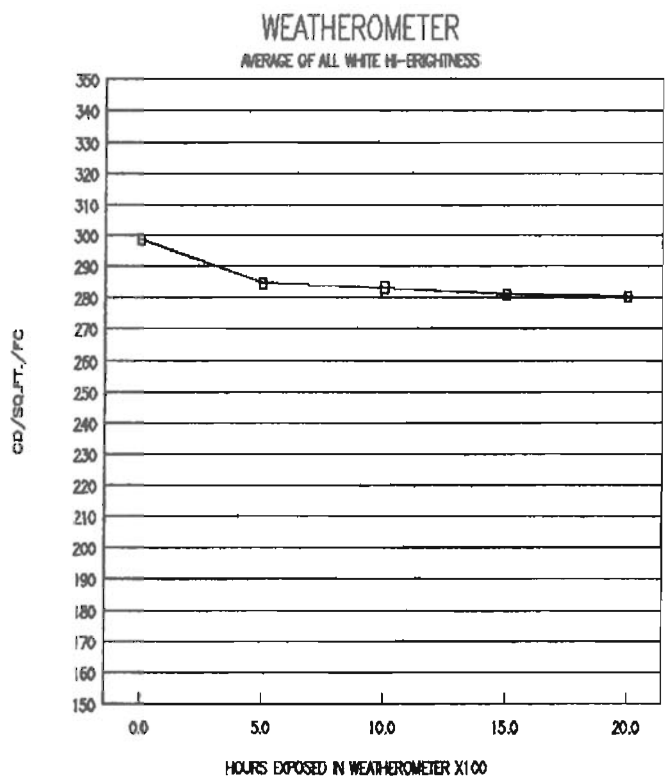


RETRO-REFLECTANCE
WHITE HI-BRIGHTNESS

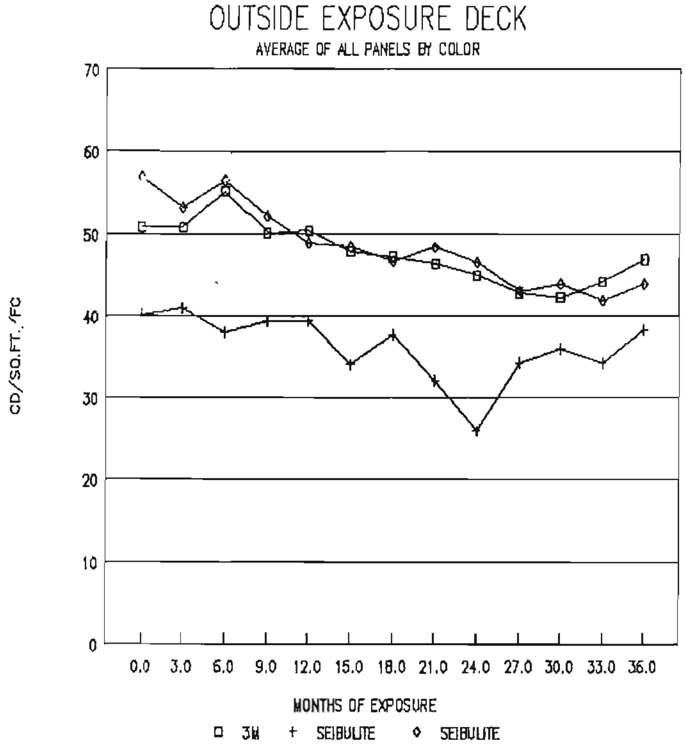


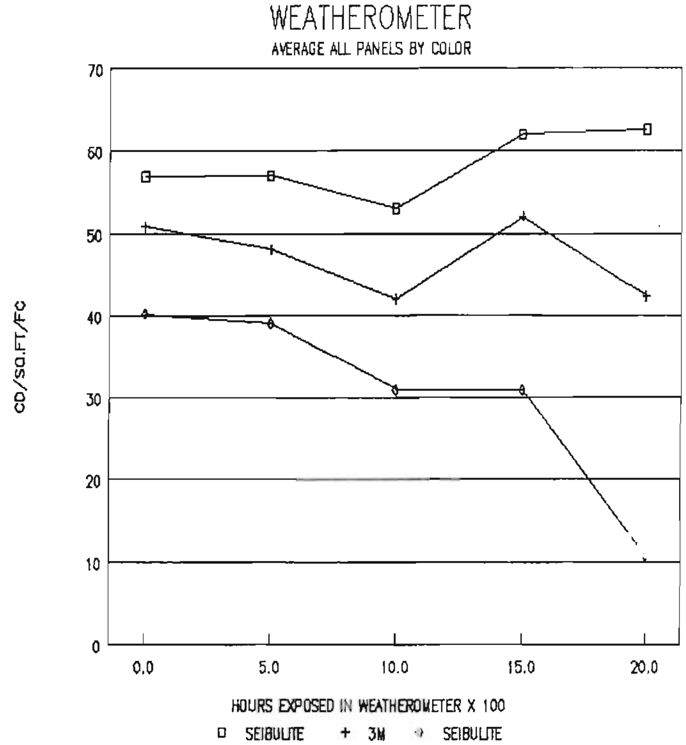


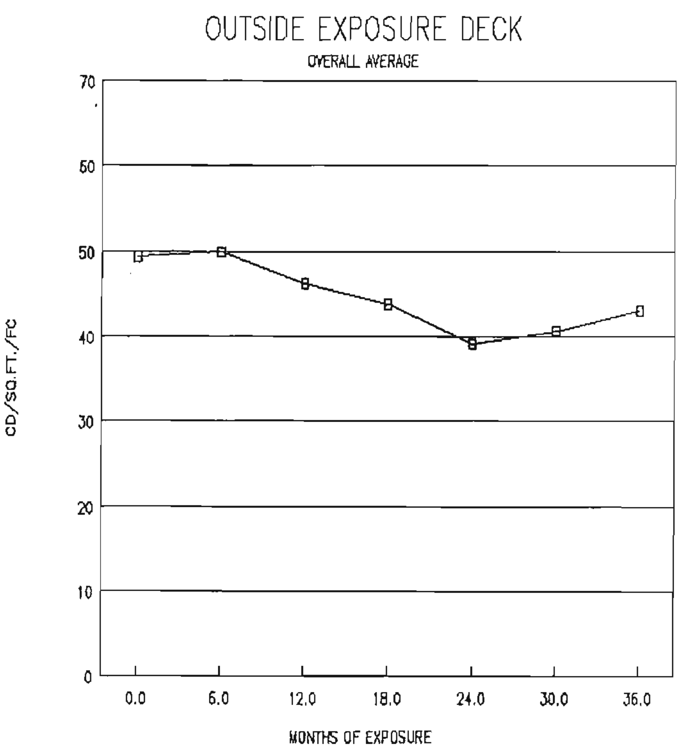


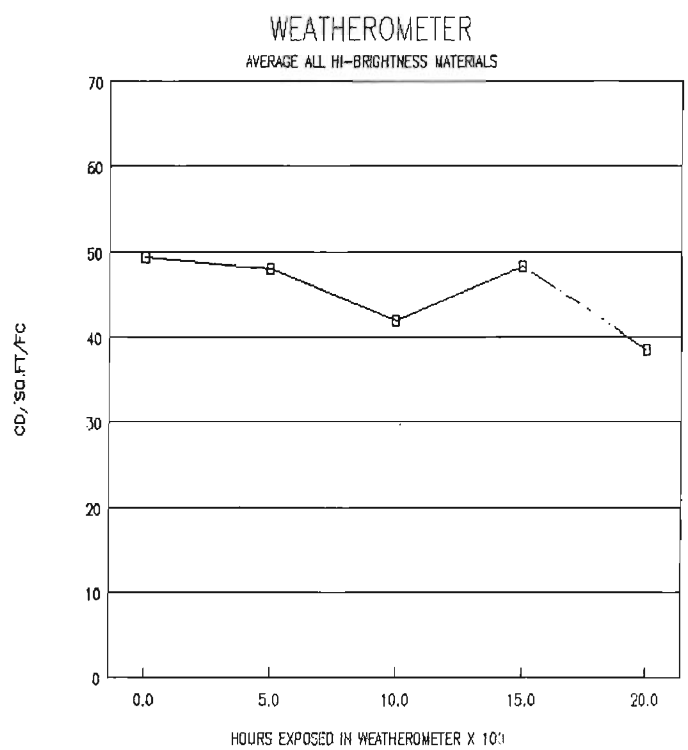


RETRO-REFLECTANCE
GREEN HI-BRIGHTNESS



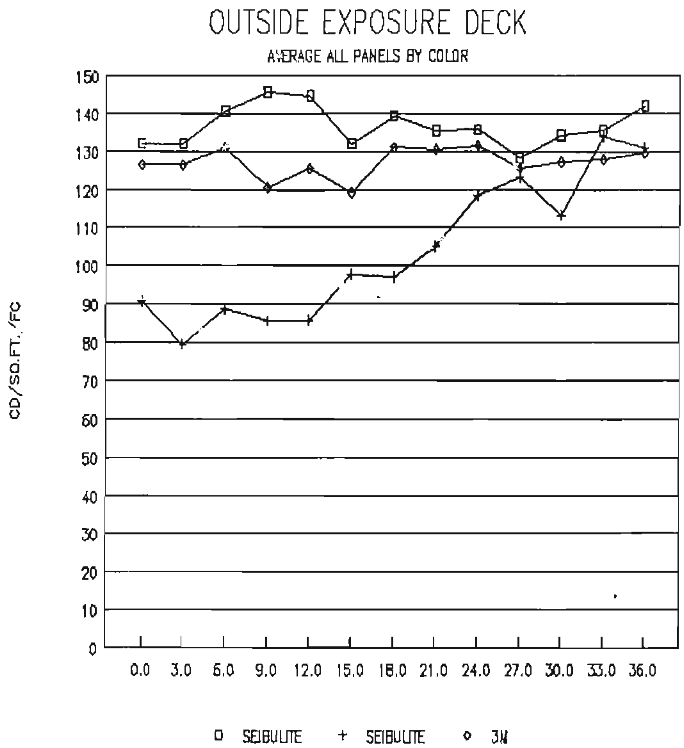


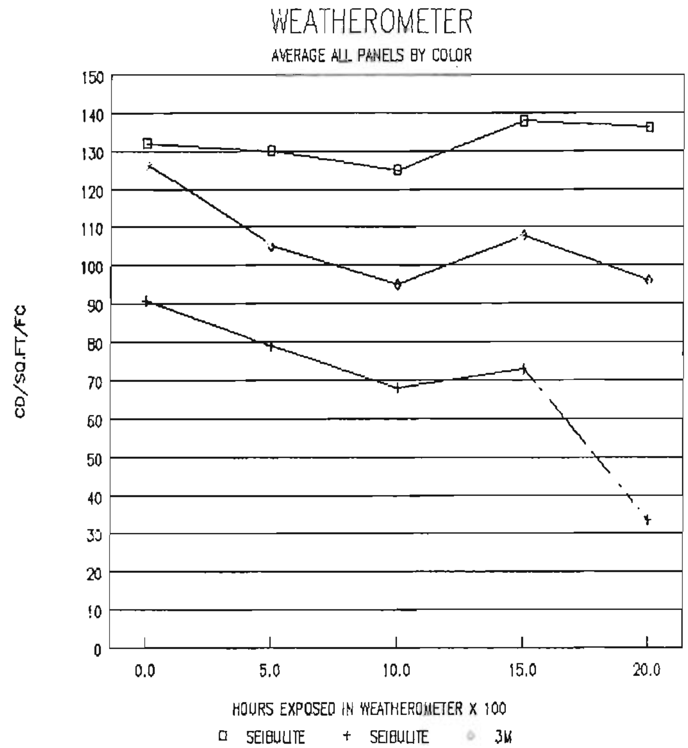


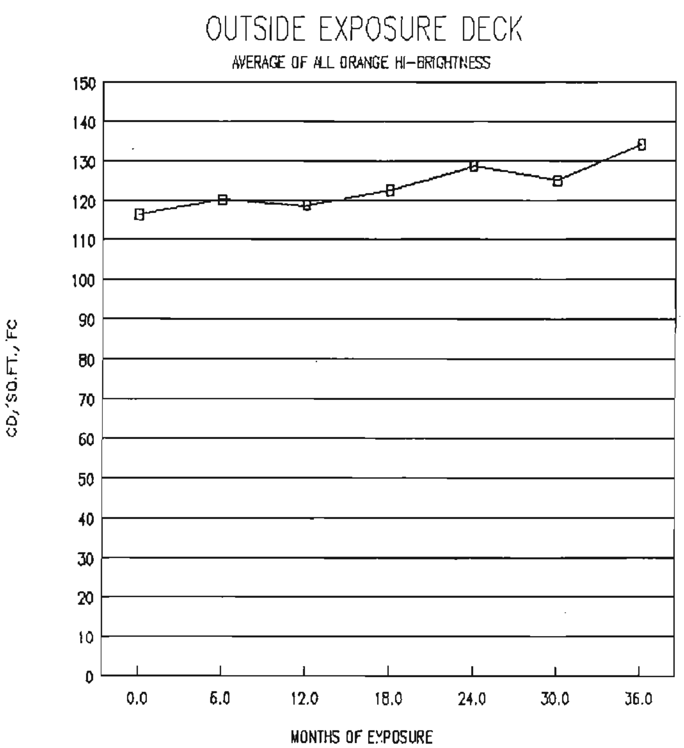


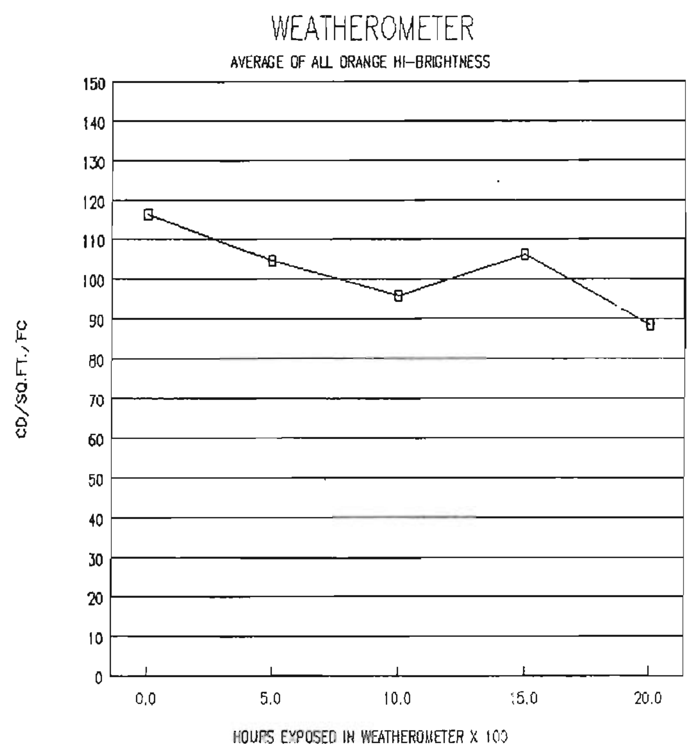
RETRO-REFLECTANCE

ORANGE HI-BRIGHTNESS





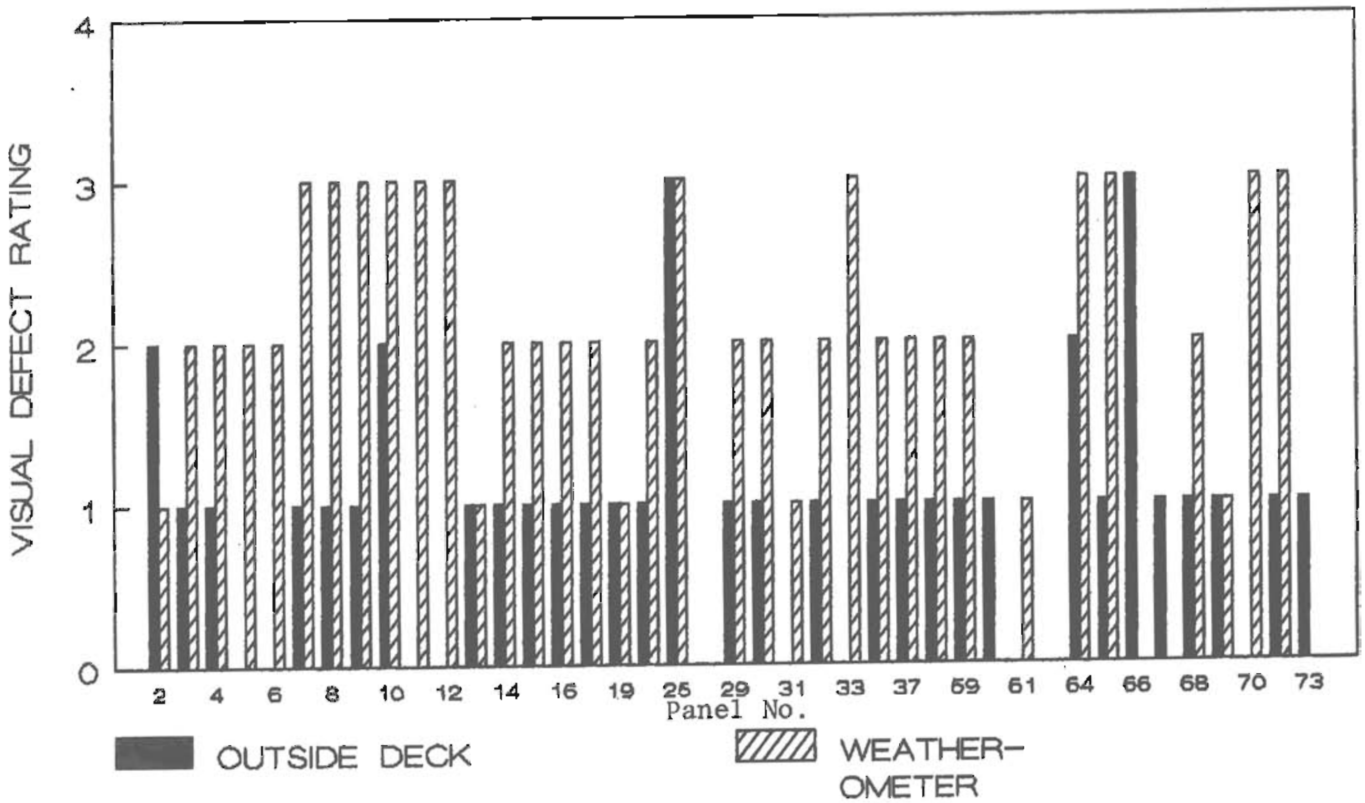




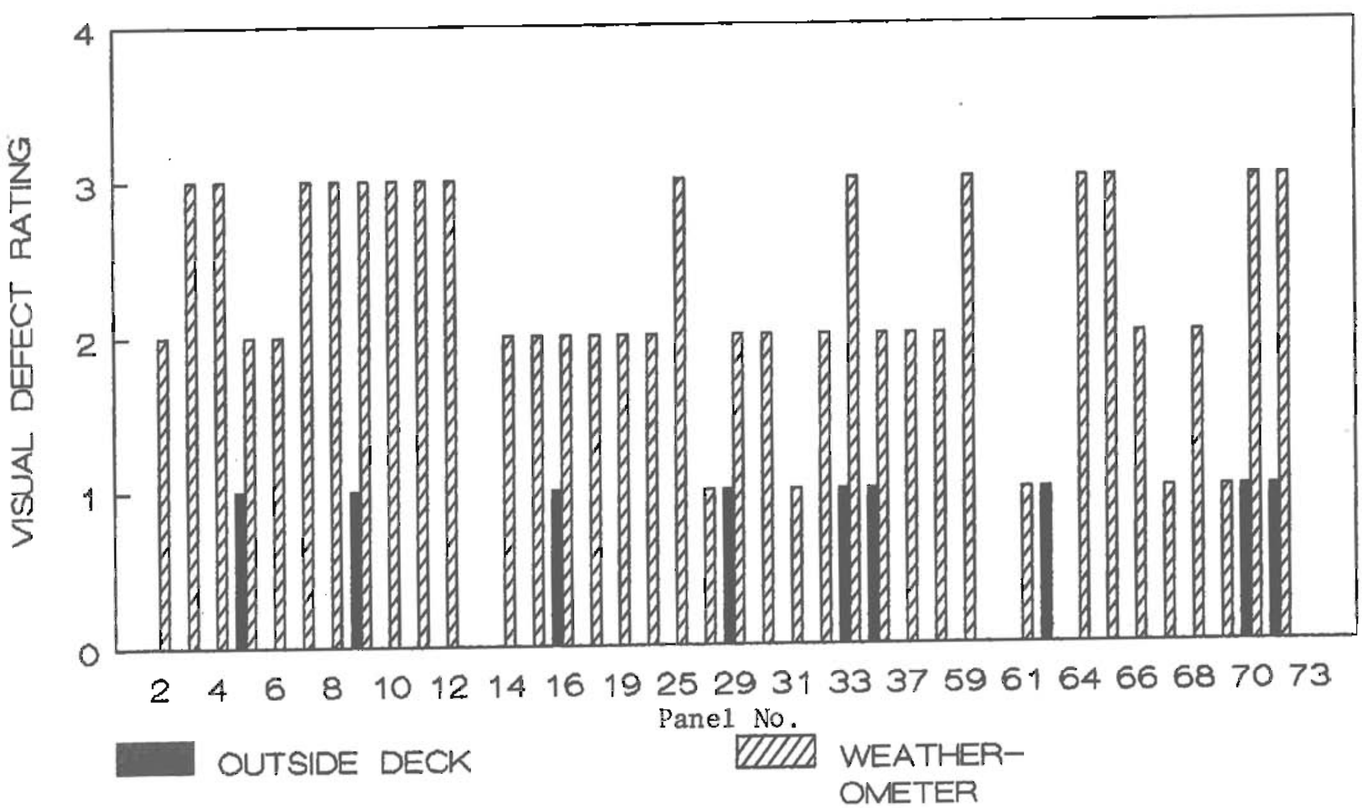
APPENDIX C

VISUAL DEFECTS

REFLECTIVE SHEETING - VISUAL DEFECTS
COLOR DEFECT (FADING, COLOR CHANGE)



REFLECTIVE SHEETING - VISUAL DEFECTS
MATERIAL DEFECT (CRACKING, PEELING)



APPENDIX D

PHOTOGRAPHS

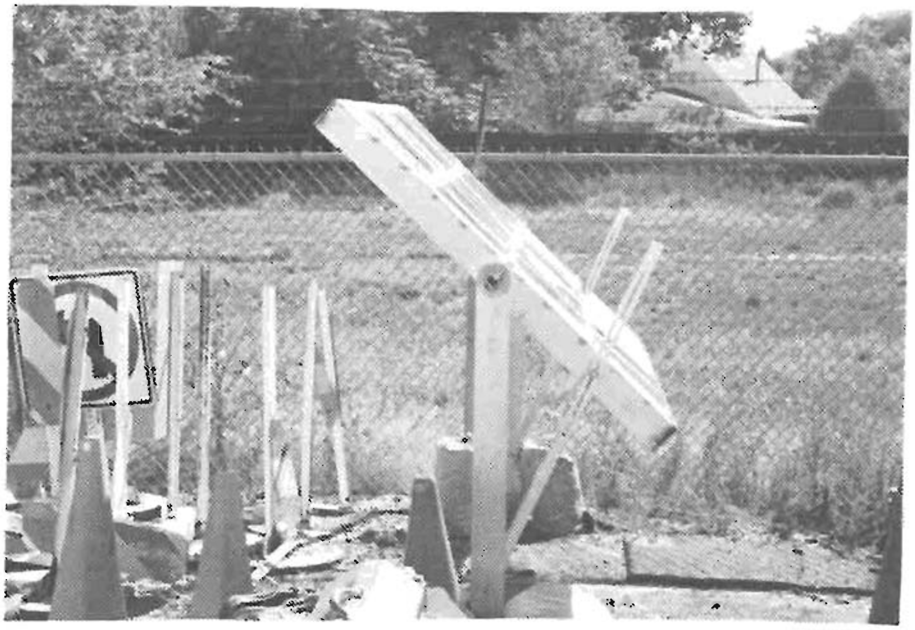


Photo 1 - Side view of outside exposure deck.

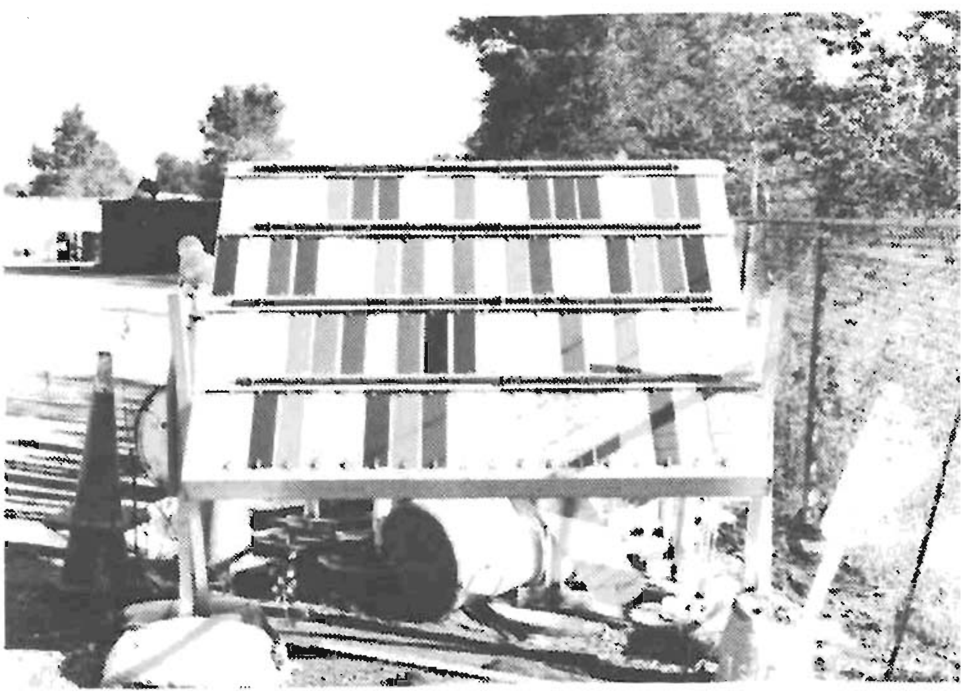


Photo 2 - The outside exposure deck holds 80 4-inch by 12-inch samples. The deck is placed facing north at a 45 degree angle to the ground.

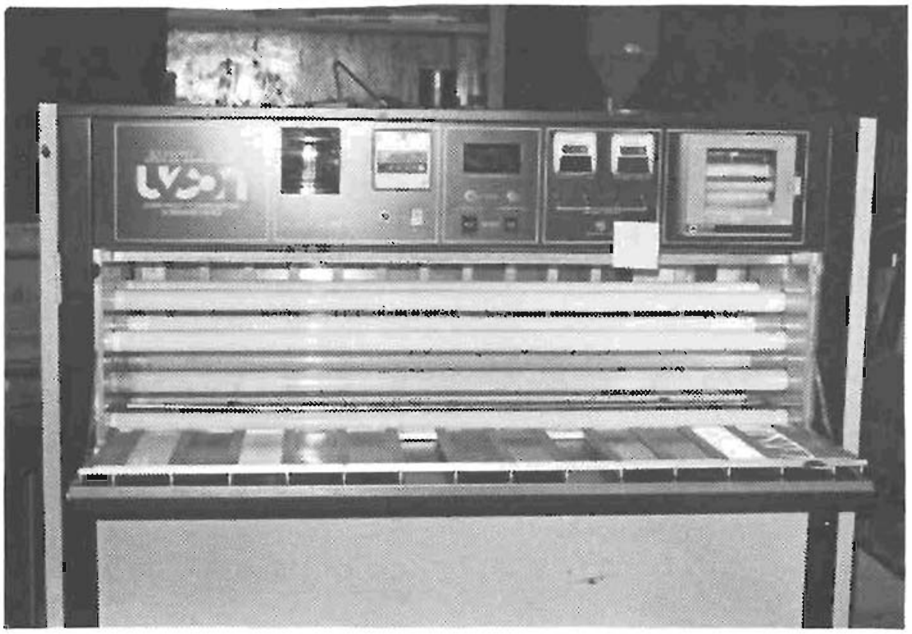


Photo 3 - The Weatherometer used for this study was an Atlas UVCON UV-1. Eight fluorescent sunlamps were used as a source of radiation.

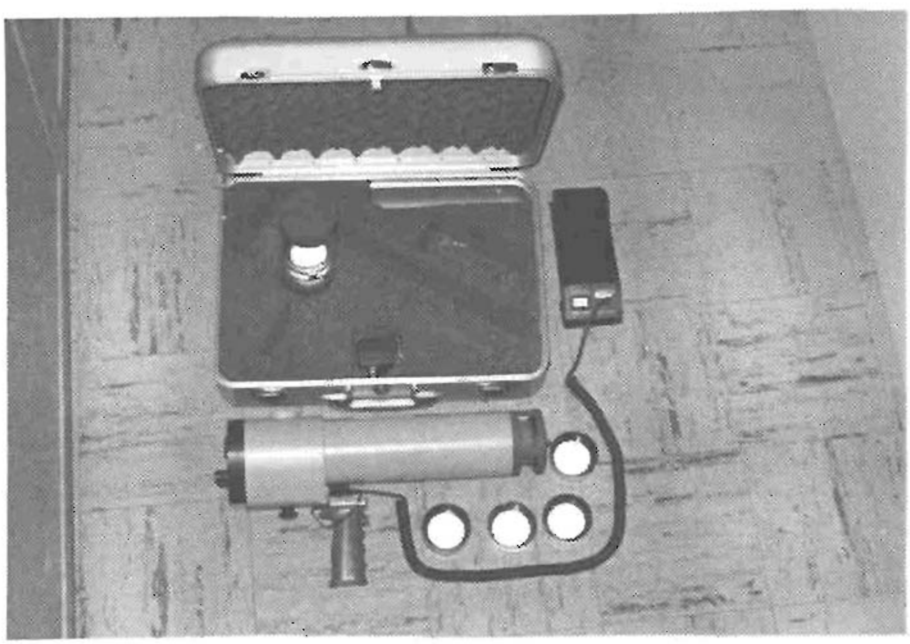


Photo 4 - Retro-reflectivity was measured using the Advanced Retro Technology, Inc. field retro-refectometer model 920.

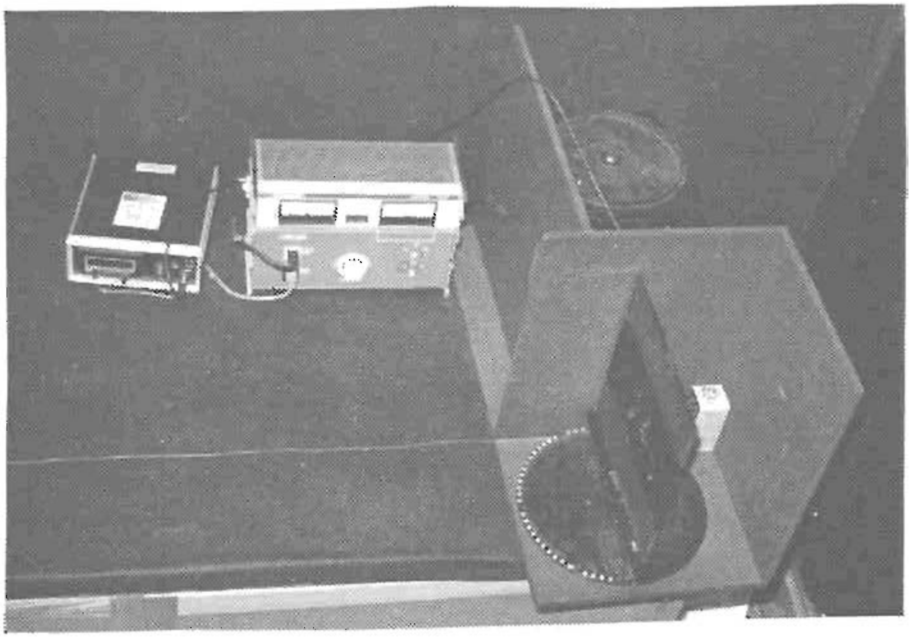


Photo 5 - Some reflectance testing was performed by the United Detector Technology retro-reflectometer. The data taken with this unit did not appear to be as reliable or reproduceable as that with the ART retro-reflectometer seen in photo 4.

APPENDIX E

OUTDOOR TESTING METHOD

VII. OUTDOOR TESTING METHOD

Part of this study was to establish an outdoor testing method for reflective sheeting. The Southeastern Association of State Highway and Transportation Officials (SASHTO) is presently conducting research on sheeting materials placed on an outdoor exposure deck. There procedures for deck testing fit into what Colorado's procedures should be. The following is the SASHTO test deck procedure with some minor modifications tc fit Colorado's needs.

1. Sheeting samples will be mounted to 1 foot square aluminum sign stock. Each panel will be than cut into thirds.

2. Each panel received for use on the test deck will be examined closely. Any flaws or damage will be recorded.

3. Initial retro-reflectance values will be taken with the Art 920 retro-reflectometer for each sample using an observation angle of 0.2 degrees and an entrance angle of -4 degrees.

4. One-third of the original 1 foot square panel will be placed on the outdoor exposure deck. The second third of the original panel will be used for weatherometer testing, while the final third is stored in a safe place protected from sunlight and weather.

5. Readings will be taken at 6 month intervals with the portable ART 920 retroreflectometer. Before taking the reflectance measurements the panels will be wiped with a damp soft cloth, and allowed to dry.

6. Readings should also be taken on the samples that were placed in storage. This will show any calibration problems that might occur with the portable retroreflectometer.

7. Visual comparison with the control sample will also be made at 6 month intervals. The visual comparison should include colorfastness, shrinkage, expansion, blistering, and cracking.

8. A minimum of 3 years may be required to see any significant changes for most materials.

APPENDIX F

LIST OF MATERIALS

LIST OF MATERIALS USED
ON OUTSIDE EXPOSURE DECK AND WEATHEROMETER

LAB NO	COLOR	TYPE	MANUFACTURER
C/142	YELLOW	ENGINEERING GRADE	SAKAI TRADING/KIWALITE
C/155	YELLOW	ENGINEERING GRADE	FASSON/AVERY INT.
C/169	YELLOW	ENGINEERING GRADE	SEIBULITE INT.
C/182	YELLOW	SUPER ENGINEERING GRADE	SEIBULITE INT.
C/200	YELLOW	ENGINEERING GRADE	3M
C/214	YELLOW	ENGINEERING GRADE	3M
C/221	YELLOW	VEHICLE MARKING	3M
C/236	YELLOW	ENGINEERING GRADE	3M
C/194	YELLOW	HIGH BRIGHTNESS	SEIBULITE INT.
C/238	YELLOW	HIGH BRIGHTNESS	3M
C/244	YELLOW	HIGH BRIGHTNESS	3M
C/255	YELLOW	HIGH BRIGHTNESS	3M
C/223	BLACK	VEHICLE MARKING	3M
C/228	GOLD	VEHICLE MARKING	3M
C/146	GREEN	ENGINEERING GRADE	SAKAI TRADING/KIAWALITE
C/159	GREEN	ENGINEERING GRADE	FASSON/AVERY INT.
C/173	GREEN	ENGINEERING GRADE	SEIBULITE INT.
C/203	GREEN	ENGINEERING GRADE	3M
C/220	GREEN	ENGINEERING GRADE	3M
C/224	GREEN	VEHICLE MARKING	3M
C/186	GREEN	SUPER ENGINEERING GRADE	SEIBULITE INT.
C/198	GREEN	HIGH BRIGHTNESS	SEIBULITE INT.
C/242	GREEN	HIGH BRIGHTNESS	3M
C/145	BLUE	ENGINEERING GRADE	SAKAI TRADING/KIWALITE
C/158	BLUE	ENGINEERING GRADE	FASSON/AVERY INT.
C/171	BLUE	ENGINEERING GRADE	SEIBULITE INT.
C/184	BLUE	SUPER ENGINEERING GRADE	SEIBULITE INT.
C/207	BLUE	ENGINEERING GRADE	3M
C/218	BLUE	ENGINEERING GRADE	3M
C/222	BLUE	VEHICLE MARKING	3M
C/196	BLUE	HIGH BRIGHTNESS	SEIBULITE INT.
C/241	BLUE	HIGH BRIGHTNESS	3M
C/258	BLUE	HIGH BRIGHTNESS	3M
C/144	RED	ENGINEERING GRADE	SAKAI TRADING/KIWALITE
C/156	RED	ENGINEERING GRADE	FASSON/AVERY INT.
C/170	RED	ENGINEERING GRADE	SEIBULITE INT.
C/183	RED	SUPER ENGINEERING GRADE	SEIBULITE INT.
C/205	RED	ENGINEERING GRADE	3M
C/216	RED	ENGINEERING GRADE	3M
C/227	RED	VEHICLE MARKING	3M
C/229	RED	VEHICLE MARKING	3M
C/195	RED	HIGH BRIGHTNESS	SEIBULITE INT.
C/240	RED	HIGH BRIGHTNESS	3M
C/256	RED	HIGH BRIGHTNESS	3M
C/143	WHITE	ENGINEERING GRADE	SAKAI TRADING/KIWALITE

C/154	WHITE	ENGINEERING GRADE	FASSON/AVERY INT.
C/168	WHITE	ENGINEERING GRADE	SEIBULITE INT.
C/202	WHITE	ENGINEERING GRADE	3M
C/212	WHITE	ENGINEERING GRADE	3M
C/230	WHITE	VEHICLE MARKING	3M
C/181	WHITE	SUPER ENGINEERING GRADE	SEIBULITE INT.
C/234	WHITE	ENGINEERING GRADE	3M
C/193	WHITE	HIGH BRIGHTNESS	SEIBULITE INT.
C/239	WHITE	HIGH BRIGHTNESS	3M
C/243	WHITE	HIGH BRIGHTNESS	3M
C/251	WHITE	HIGH BRIGHTNESS	3M
C/257	WHITE	HIGH BRIGHTNESS	3M
C/160	BROWN	ENGINEERING GRADE	FASSON/AVERY INT.
C/174	BROWN	ENGINEERING GRADE	SEIBULITE INT.
C/210	BROWN	ENGINEERING GRADE	3M
C/592	BROWN	HIGH BRIGHTNESS	3M
C/141	ORANGE	ENGINEERING GRADE	SAKAI TRADING/KIWALITE
C/157	ORANGE	ENGINEERING GRADE	FASSON/AVERY INT.
C/226	ORANGE	VEHICLE MARKING	3M
C/172	ORANGE	ENGINEERING GRADE	SEIBULITE INT.
C/185	ORANGE	SUPER ENGINEERING GRADE	SEIBULITE INT.
C/197	ORANGE	HIGH BRIGHTNESS	SEIBULITE INT.
C/237	ORANGE	HIGH BRIGHTNESS	3M
C/252	ORANGE	HIGH BRIGHTNESS	3M
C/253	ORANGE/SILVER	HIGH BRIGHTNESS	3M
C/254	ORANGE/WHITE	ENGINEERING GRADE	3M

APPENDIX G

RETROREFLECTANCE TEST DATA

OUTDOOR EXPOSURE DECK

TEST DATA

REFLECTIVE SHEETING TEST DECK
RETROREFLECTOMETER READINGS OF PANELS
ART MODEL 920 FIELD RETROREFLECTOMETER
READINGS ARE IN (CD/SQ.FT./FC)

					0.0	3.0	6.0	9.0	12.0	15.0	18.0	21.0	24.0	27.0	30.0	33.0	36.0
					1987		1988					1989			1990		
PNL/	LAB #	COLOR	GRADE	CALIB	INITIAL	9/8	1/6	2/26	5/31	8/31	12/6	3/20	6/27	10/2	1/12	4/9	7/24
11	C/158-1	BLUE	ENG	GREEN	5.6	4.1	4.9	4.3	4.2	5.2	5.3	5.0	5.0	5.1	5.1	5.1	5.1
5	C/145-1	BLUE	ENG	GREEN	7.0	5.3	5.9	6.3	5.4	5.9	6.5	6.3	6.2	6.2	6.2	6.3	5.9
38	C/218-1	BLUE	ENG	GREEN	11.3	9.4	10.5	7.9	7.9	7.8	7.8	7.7	7.6	7.6	7.3	7.9	8.4
33	C/207-1	BLUE	ENG	GREEN	15.5	14.8	15.1	10.6	12.9	13.5	11.6	12.0	12.9	12.7	12.3	12.5	13.3
17	C/171-1	BLUE	ENG	GREEN	8.9	8.6	8.7	7.5	7.4	8.3	7.6	7.9	7.9	7.5	7.6	7.8	8.0
13	C/160-1	BROWN	ENG	RED	6.4	6.6	7.9	6.8	7.3	7.0	7.6	7.0	7.4	7.5	7.6	7.6	8.1
34	C/210-1	BROWN	ENG	RED	12.9	12.6	12.2	11.5	11.2	12.7	12.0	11.8	12.2	12.0	12.1	12.6	12.6
20	C/174-1	BROWN	ENG	RED	7.8	7.4	8.3	8.2	8.2	8.9	9.4	9.4	9.4	8.8	9.1	9.3	9.9
66	C/242-1B	GREEN	ENG*	GREEN*	50.8	50.8	55.1	50.1	50.3	47.8	47.1	46.3	44.9	42.8	42.2	44.1	46.8
59	C/186-1B	GREEN	ENG*	GREEN*	40.2	40.9	38.0	39.3	39.3	34.0	37.6	32.0	25.9	34.2	35.9	34.2	38.3
28	C/198-2	GREEN	ENG*	GREEN*	56.9	53.2	56.5	52.1	48.8	48.4	46.6	48.3	46.5	43.0	43.8	41.8	43.8
31	C/203-1	GREEN	ENG	GREEN	13.9	11.5	11.7	10.6	11.4	12.1	12.4	12.2	12.6	12.2	12.7	12.0	12.4
19	C/173-1	GREEN	ENG	GREEN	25.9	19.6	19.7	21.1	19.6	19.0	22.1	21.0	21.0	19.0	19.7	19.7	19.3
6	C/146-1	GREEN	ENG	GREEN	26.6	22.8	24.2	23.5	23.0	25.0	24.9	23.7	24.5	22.6	22.7	22.3	22.8
12	C/159-1	GREEN	ENG	GREEN	14.7	12.7	14.1	13.2	12.7	13.6	14.5	14.3	14.8	14.1	14.5	14.4	13.9
62	C/197-1B	ORANGE	ENG*	YELLOW*	132.0	132.0	140.6	145.7	144.7	132.0	139.4	135.5	135.8	128.3	134.2	135.7	142.0
25	C/185-1	ORANGE	ENG*	YELLOW*	90.7	79.5	88.7	85.6	85.8	97.8	97.0	105.1	118.6	123.2	113.3	133.9	131.0
63	C/237-1B	ORANGE	ENG*	YELLOW*	126.4	126.4	131.0	120.5	125.6	119.2	131.1	130.5	131.7	125.7	127.2	128.0	129.6
9	C/156-1	RED	ENG	RED	29.9	26.6	27.3	29.4	30.4	28.4	29.6	30.9	32.8	32.7	31.8	30.9	34.5
4	C/144-1	RED	ENG	RED	36.6	36.6	37.5	37.5	37.8	36.4	36.8	35.3	37.2	36.6	34.8	35.4	37.3
37	C/216-1	RED	ENG	RED	35.9	33.3	34.4	33.3	31.7	32.2	31.6	31.2	32.4	30.7	32.4	30.7	31.9
32	C/205-1	RED	ENG	RED	33.0	30.1	33.0	30.7	29.7	30.8	30.5	30.3	30.8	29.7	31.4	30.3	30.8
16	C/170-1	RED	ENG	RED	22.5	20.6	17.2	20.9	20.3	17.9	20.9	20.7	21.7	22.0	20.8	19.4	22.5
65	C/239-1B	WHITE	ENG*	WHITE*	263.7	263.7	277.3	267.6	270.0	260.4	256.7	256.7	254.9	251.4	253.4	262.6	267.4
69	C/251-1B	WHITE	ENG*	WHITE*	305.7	305.7	290.4	260.2	261.9	262.8	248.5	246.9	241.5	214.9	233.5	245.3	239.7
60	C/193-1B	WHITE	ENG*	WHITE*	319.9	319.9	311.6	290.2	289.8	238.1	256.6	258.6	232.4	229.7	232.5	237.0	239.4
72	C/257-1B	WHITE	ENG*	WHITE*	305.4	305.4	291.2	277.5	260.1	270.1	261.0	256.3	243.8	232.7	240.7	244.7	233.0
30	C/202-1	WHITE	ENG	WHITE	133.1	123.2	127.5	114.0	111.1	118.2	120.1	118.0	109.4	108.8	111.2	108.0	111.9
3	C/143-1	WHITE	ENG	WHITE	105.5	95.8	102.5	96.5	97.9	97.9	99.6	95.8	92.2	91.5	92.0	92.3	87.0
14	C/168-1	WHITE	ENG	WHITE	122.8	122.5	122.2	119.1	121.3	118.1	110.8	112.0	106.1	107.3	108.2	109.5	106.5
7	C/154-1	WHITE	ENG	WHITE	104.7	103.1	97.2	101.4	99.6	102.9	103.7	104.8	102.7	102.6	103.8	104.5	98.9
64	C/238-1B	YELLOW	ENG*	YELLOW*	203.3	203.3	218.3	194.2	210.9	192.3	201.3	193.9	178.6	165.5	165.5	168.4	116.4
61	C/194-1B	YELLOW	ENG*	YELLOW*	208.0	208.0	224.1	200.0	219.3	199.3	192.2	189.5	191.1	162.0	164.7	166.4	157.7
68	C/244-1B	YELLOW	ENG*	YELLOW*	229.8	229.8	248.1	234.3	235.5	229.2	231.0	216.6	211.7	205.8	201.3	204.8	209.1
71	C/255-1B	YELLOW	ENG*	YELLOW*	245.8	245.8	258.9	262.6	257.7	229.8	230.0	217.9	223.9	203.5	218.1	205.3	221.0
15	C/169-1	YELLOW	ENG	YELLOW	72.8	69.5	71.2	67.7	72.5	68.6	71.1	70.7	70.7	68.4	70.4	73.1	71.6
8	C/155-1	YELLOW	ENG	YELLOW	79.5	75.3	74.6	76.3	77.5	79.6	83.0	82.4	86.4	85.9	83.1	86.6	84.0
2	C/142-1	YELLOW	ENG	YELLOW	65.3	53.2	53.1	56.1	55.5	59.4	61.5	54.0	54.1	55.6	54.7	52.4	47.0
29	C/200-1	YELLOW	ENG	YELLOW	96.7	91.5	87.7	78.9	85.2	90.4	86.5	88.4	86.4	87.3	81.3	89.4	88.8

WEATHEROMETER TEST DATA

LEGEND: ENG = ENGINEERING GRADE
ENG* = ENGINEERING GRADE'S HIGH INTENSITY
NA = NOT AVAILABLE
++ = SUPER ENG. GRADE

LAB	PANEL #	COLOR	INITI	500HRS	1000HRS	1500HR	2000HR
5	C/145	BLUE	7.0	6.2	4.9	5.1	4.0
11	C/158	BLUE	5.6	0.8	0.8	0.0	1.1
17	C/171	BLUE	8.9	8.4	7.6	8.0	5.5
33	C/207	BLUE	15.5	11.5	7.4	5.1	1.7
38	C/218	BLUE	11.3	7.9	4.2	4.1	2.2
13	C/160	BROWN	6.4	4.2	10.8	6.9	7.0
20	C/174	BROWN	7.8	5.4	10.8	4.8	1.5
34	C/210	BROWN	12.9	6.2	11.8	5.7	3.6
6	C/146	GREEN	26.6	24.5	18.3	9.9	4.3
12	C/159	GREEN	14.7	4.8	3.9	3.8	1.5
19	C/173	GREEN	25.9	25.1	23.1	19.3	12.1
31	C/203	GREEN	13.9	14.4	13.8	13.8	13.0
28	C/198	GREEN	*56.9	57.0	53.0	62.0	62.5
66	C/242	GREEN	*50.8	48.0	42.0	52.0	42.3
59	C/186	GREEN	+40.2	39.0	31.0	31.0	10.7
63	C/237	ORANGE	*****	105.0	95.0	108.0	96.0
62	C/197	ORANGE	*****	130.0	125.0	138.0	136.1
25	C/185	ORANGE	90.7	79.0	68.0	73.0	33.5
4	C/144	RED	36.6	36.2	30.2	26.4	18.7
9	C/156	RED	29.9	3.6	1.1	4.3	1.5
16	C/170	RED	22.5	20.4	10.8	13.9	7.9
32	C/205	RED	33.0	27.3	21.4	19.1	11.2
37	C/216	RED	35.9	29.2	20.9	15.7	6.0
3	C/143	WHITE	*****	91.7	82.0	58.0	36.9
7	C/154	WHITE	*****	14.2	16.6	13.0	8.1
14	C/168	WHITE	*****	113.7	111.3	69.3	28.4
30	C/202	WHITE	*****	129.2	126.0	98.3	67.5
60	C/193	WHITE	*****	320.0	326.0	338.0	306.5
65	C/239	WHITE	C*****	246.0	234.0	193.0	204.9
69	C/251	WHITE	C*****	290.0	288.0	296.0	302.0
72	C/257	WHITE	******	282.0	285.0	297.0	308.0
2	C/142	YELLOW	65.3	37.8	39.3	25.0	10.8
8	C/155	YELLOW	79.5	26.5	26.9	25.0	18.1
15	C/169	YELLOW	72.8	52.0	65.2	61.1	32.6
29	C/200	YELLOW	96.7	54.8	58.0	34.9	6.1
61	C/194	YELLOW	*****	211.0	203.0	217.0	186.0
64	C/238	YELLOW	*****	150.0	68.0	81.0	57.3
68	C/244	YELLOW	*****	222.0	213.0	204.0	110.0
71	C/255	YELLOW	*****	224.0	211.0	209.0	107.0