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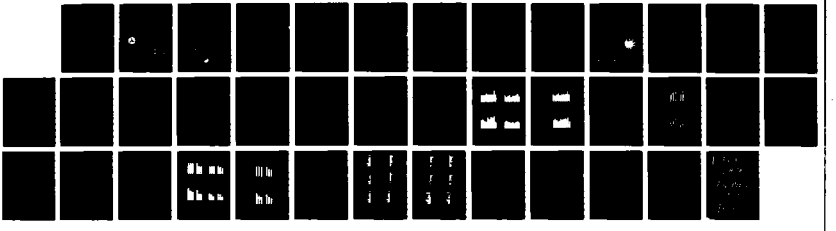

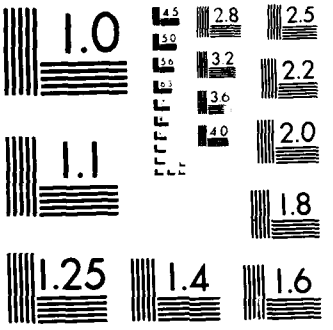

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Report No. CG-D-05-88

DETECTION AND IDENTIFICATION OF FLUORESCENT AND NON-FLUORESCENT DAYMARK MATERIALS

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INTERIM REPORT
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16. Abstract

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Detection and color identification distances of fluorescent and non-fluorescent chromatic materials were measured to compare performance of these two types of materials for use on daymarks. New fluorescent materials had greater detection and identification distances than most non-fluorescent materials due to their ability to convert ultraviolet light to visible light. As fluorescent materials age, they become more difficult to detect and identify. With one exception, non-fluorescent materials could be detected and identified at greater distances than the aged fluorescent materials. This report also examined the relationship between luminance contrast and Munsell notation on detection and identification distances. Detection distance was positively correlated with luminance contrast and Munsell Value. Munsell Chroma was not a good predictor of detection or identification distance. Keywords:

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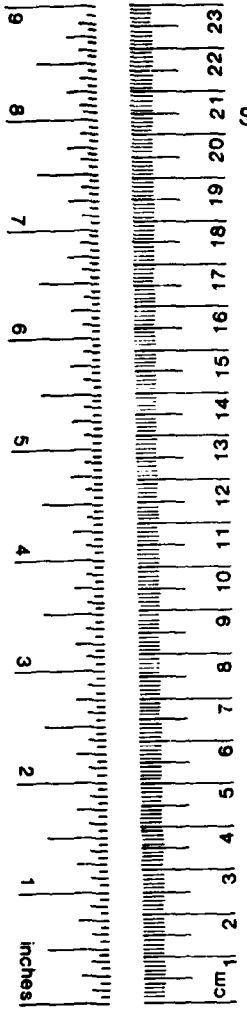
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

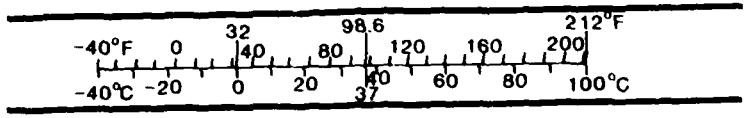
Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
in	inches	* 2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (WEIGHT)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (EXACT)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures. Price $2.25. SD Catalog No. C13.10.286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (WEIGHT)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (EXACT)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1.0 INTRODUCTION

This is the second in a series of reports dealing with selection of materials for daymarks. The first report (Mandler and Scoffone, 1984) examined the effect of environmental exposure of fluorescent materials on detection and color identification distances. The report documented changes in detection and identification distances, providing guidelines for determining the useful life of fluorescent material.

This report is concerned with a comparison of detection and identification distances of non-fluorescent and fluorescent materials to determine if longer life, non-fluorescent materials can provide visual signals equivalent to those of fluorescent materials. If non-fluorescent materials can be used in place of fluorescent materials, substantial savings can be realized in terms of material and maintenance costs. This report will guide the engineer in choosing appropriate daymark materials.

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2.0 BACKGROUND

More than 10,000 daymarks are currently installed and maintained in U.S. waters. Daymarks call attention to hazards, mark edges of channels, or form parallax ranges. They differ in shape, size, color, and type of signaling material comprising the daymark. The visual effectiveness of a daymark is determined by the distance at which it can be detected and identified. The greater the detection and identification distances, the greater the visual effectiveness of a material.

Fluorescent materials convert ultraviolet light to visible light and thus appear brighter than non-fluorescent materials. When viewed against dark backgrounds, fluorescent materials have higher contrast than non-fluorescent materials, yielding greater detection and identification distances. Fluorescent materials, however, degrade with environmental exposure, in most cases losing their fluorescence, and thus their signal advantage,

within two years. Daymarks composed of fluorescent materials must be replaced at regular intervals to maintain the desired detection and identification distances.

In an effort to develop a dayboard with a field life of five years, the Coast Guard is re-evaluating the role of fluorescent materials. Since non-fluorescent materials with field lives of five years can be manufactured (compared to the two year life of fluorescent materials) dayboards composed of non-fluorescent materials will need to be replaced less often. At issue is how detection and identification distances of non-fluorescent materials compare to fluorescent materials. If the difference is small, non-fluorescent materials may prove to be the most cost-effective choice for visual signaling.

This report will compare detection and identification distances of several new non-fluorescent and new and weathered fluorescent materials.

3.0 METHODS

3.1 Laboratory Apparatus

Figure 1 is a schematic of the apparatus used for laboratory measurements. A 150 Watt Xenon arc source, collimated and filtered to approximate the spectrum of daylight (D_{65}), illuminated a wheel on which ten test samples were mounted. The sample wheel was attached to a stepping motor that rotated the wheel to control which test sample was shown the observer. The observer, seated 17.7 feet from the 1.5 x 2.0 ft background field, viewed a test sample through a variable aperture, visible through a 1.0 in diameter hole cut in the background field. The aperture had sixteen circular holes varying in area between 0.1924 in^2 and 0.0005 in^2 in multiples of 0.67.

The background field, shutter, and edges of the variable aperture were painted flat white and illuminated with two 250 Watt tungsten lamps. The lamps were positioned to uniformly illuminate the background field and shutter and to render invisible the inside edges of the background field and variable aperture.

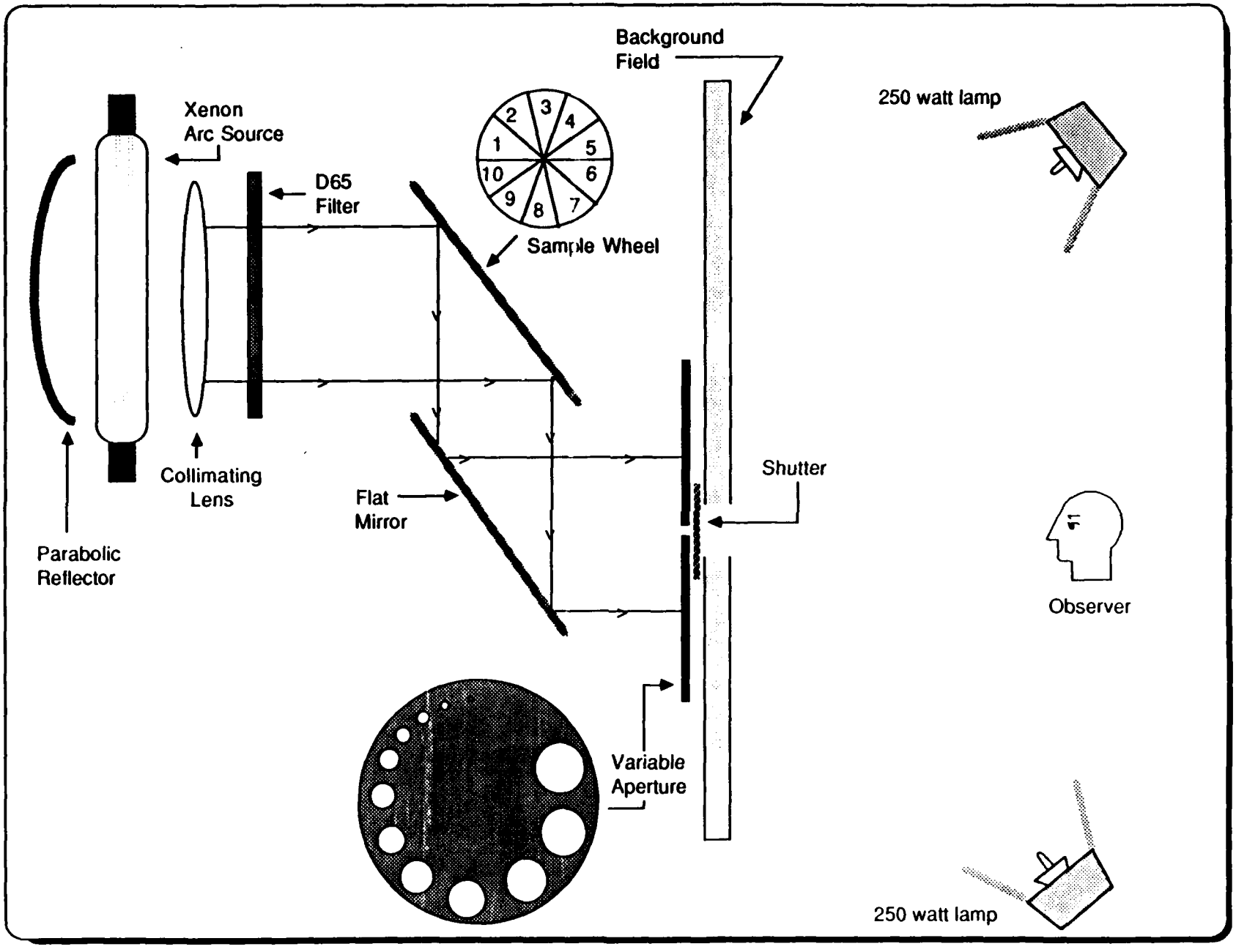

Figure 1. Schematic of Laboratory Apparatus

3.2 Laboratory Materials

Measurements were performed on twenty test samples. Fifteen were glossy Munsell samples, two were fluorescent materials, and the other three were "off-the-shelf" materials for daytime signaling. This subset of materials was selected because of their potential for use in visual signaling. Table I provides a list of the twenty samples and their measured chromaticity coordinates.

TABLE I
Sample Specifications

Red Samples

Number	Description	Chromaticity Coordinates x	y	Y
1.	10R 5/16	0.611	0.362	0.222
2.	10R 7/10	0.474	0.360	0.485
3.	7.5R 4/16	0.632	0.316	0.130
4.	7.5R 6/16	0.575	0.338	0.316
5.	7.5R 7/10	0.458	0.343	0.482
6.	5R 6/12	0.484	0.322	0.336
7.	5YR 6.6/15.9	0.557	0.417	0.425
8.	Fascal 911 Orange	0.572	0.405	0.339
9.	3M Fluorescent Red	0.670	0.321	0.374
10.	3680-54 Light Orange	0.555	0.412	0.377

Green Samples

Number	Description	Chromaticity Coordinates x	y	Y
1.	7.5G 6/10	0.242	0.434	0.339
2.	5.6G 6.12/13.7	0.221	0.485	0.357
3.	3.5G 5.2/13.1	0.229	0.529	0.242
4.	2.5G 5/12	0.253	0.537	0.210
5.	2.5G 8/8	0.300	0.423	0.653
6.	10GY 6/12	0.311	0.558	0.319
7.	10GY 8/8	0.325	0.451	0.662
8.	7.5GY 6.84/13	0.363	0.562	0.463
9.	3M Fluorescent Green	0.305	0.644	0.663
10.	3680-46 Kelly Green	0.233	0.500	0.191

Figure 2 plots the locations of these samples on the CIE chromaticity diagram. The red samples are those that can be described as either red or orange. Six of the ten "red" samples fall within the red or orange chromaticity regions (IALA, 1980). Seven of ten green samples fall within green chromaticity region (IALA; 1980).

3.3 Laboratory Procedure

3.3.1 Detection Thresholds

As one moves toward or away from a target the size of its image inside the eye increases and decreases. In a laboratory, a change in distance can be simulated simply by a change in size of a target, Thus, to establish detection ranges, the size of a target at detection threshold was established.

A random, double staircase procedure (Cornsweet, 1962) was used to obtain detection thresholds. This procedure provides an efficient method for establishing the size of a material that can be detected 80% of the time[1]. The staircase procedure used an algorithm to choose the size of a target based on observer judgments of whether or not they detected previous presentations of that target. It is called a staircase procedure to reflect the step changes in target that occur from trial to trial.

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[1] In designing aids-to-navigation systems one desires a detection probability between 95% and 99%. The psychometric function relating probability of detection to target size is an "S"shaped function that has a steep slope in the region between approximately 20% and 80% detection. A small change in target size corresponds to a large change in probability of detection. At other probability levels the function has a shallow slope, where a large change in target size results in a small change in probability of detection. The variability in establishing a threshold size at an 80% probability level is much smaller than at higher levels. Extrapolation to higher probability levels can be done by multiplying all data by some constant since all psychometric functions are parallel.

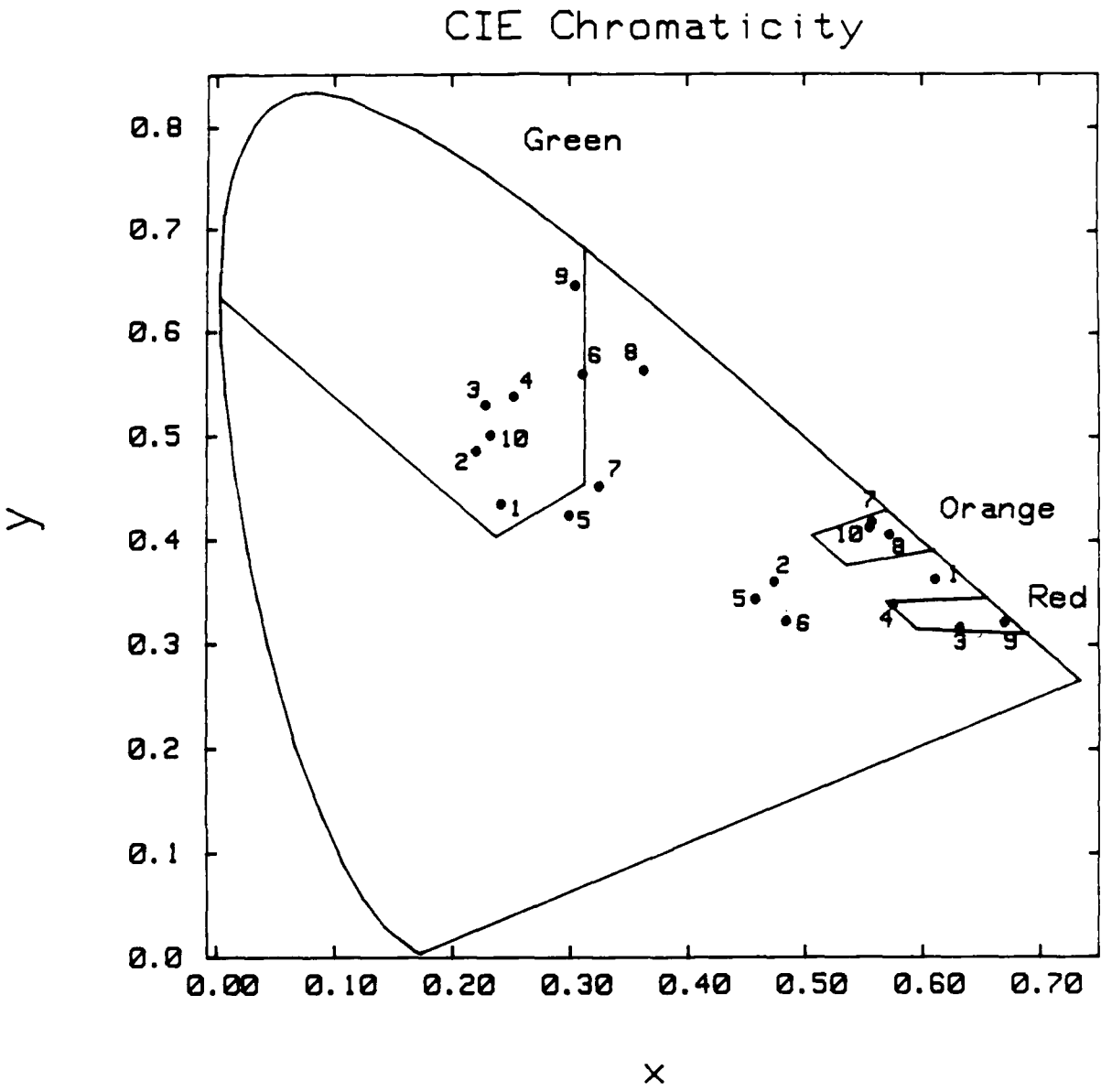

Figure 2. CIE Color Coordinates of 20 Test Samples

On each trial, one of ten randomly chosen test materials was presented to the observer for 0.5 sec by opening a shutter situated between the variable aperture and background field. The observer knew exactly when the shutter opened and precisely where to look for the target. The observer pressed one of two hand-held switches that signaled whether or not the test flash was detected. When the observer responded "yes" three times in succession to a particular test sample, the aperture was reduced 33% in area by rotating the variable aperture disc to the next smaller hole. When the observer reported that the flash was not detected, the aperture was increased in area by 50%[2].

In a given session, two thresholds were obtained for each of ten samples yielding a total of 20 thresholds. A random number generator was used before each trial to determine the sample that was presented. The staircase procedure was used to determine the appropriate size for that target. Catch trials, in which no sample was presented, occurred on an average of 20% of the trials to monitor the number of times the observer was likely to say that a sample was detected when, in fact, no sample was presented. (This is termed a false alarm.) The rate of false alarms was always under 2%.

Thresholds were obtained for samples viewed against a low (106 cd/m^2) and high luminance (414 cd/m^2) background in separate experimental sessions. The background luminances are representative of the luminances of grass and sky, respectively. Each session was repeated twice providing a total of four thresholds per sample per observer for each background.

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[2] On a logarithmic scale, which is appropriate for human vision, these increases and decreases in size correspond to a change in size of 0.175 log units.

3.3.2 Identification Thresholds

Thresholds for identifying the color of each sample were measured with an ascending method of limits (Boynton, 1984). A sample was initially presented at a size well below detection threshold. The size of the sample was increased each time the observer pressed a button until the observer was confident as to whether the material was red or green and correctly identified the color. The aperture size at which identification occurred was considered the identification threshold. In each session, four such thresholds were obtained for each of ten samples. Each session was repeated on a subsequent day to yield a total of eight thresholds per sample on each background.

3.4 Field Procedure

Field measurements were made in Groton, CT on a large open field during the months of July and August. Two 4 x 4 ft background panels were constructed of plywood and painted with specially mixed flat gray paints. The paints (light and dark gray) were mixed so that the luminance contrasts between the test samples and the background were the same as in the laboratory experiment. As the level of illumination varied due to a change in the position of the sun or a change in cloud density, the luminance of the backgrounds also changed. By limiting the measurements to the same period each day, and conditions of low cloud density, the luminance contrast remained constant.

Observers were positioned 600 ft from the background panel and faced the background looking southeast. A 0.5 in diameter circular target was attached to the background. The target was randomly placed in the center of one of four quadrants on the background. The observers walked toward the background until they could correctly identify the location of the target. The distance at which detection occurred was recorded by the experimenter. Observers continued to approach the background until they were certain whether the color was red or green. They

stated the color to the experimenter. (There were no instances where the color was incorrectly judged.) This distance was also noted by the experimenter. The observer returned to the starting point and began another trial with a different test sample.

Because the field measurements were more tedious, time consuming and dependent on weather conditions, only a subset of the samples used in the laboratory experiment could be used for the field measurements. Three red and three green samples listed in Table II were measured.

TABLE II
Test Samples Used in Field Measurements

Sample	Description
Red 2	10R 7/10
Red 4	7.5R 6/16
Red 9	3M Fluorescent Red
Green 2	5.6G 6.12/13.7
Green 5	2.5G 8/8
Green 9	3M Fluorescent Green

In an experimental session four detection and four identification thresholds were obtained for each of six samples on one of two backgrounds. Each of the four observers participated in four experimental sessions. A total of 768 thresholds were obtained.

4.0 RESULTS AND DISCUSSION

4.1 Laboratory Data

The luminance contrasts of the ten red and ten green samples against the two backgrounds are given in Table III and plotted in Figures 3a and 3b, respectively. Luminance contrasts against the low and high luminance backgrounds are represented by horizontally-

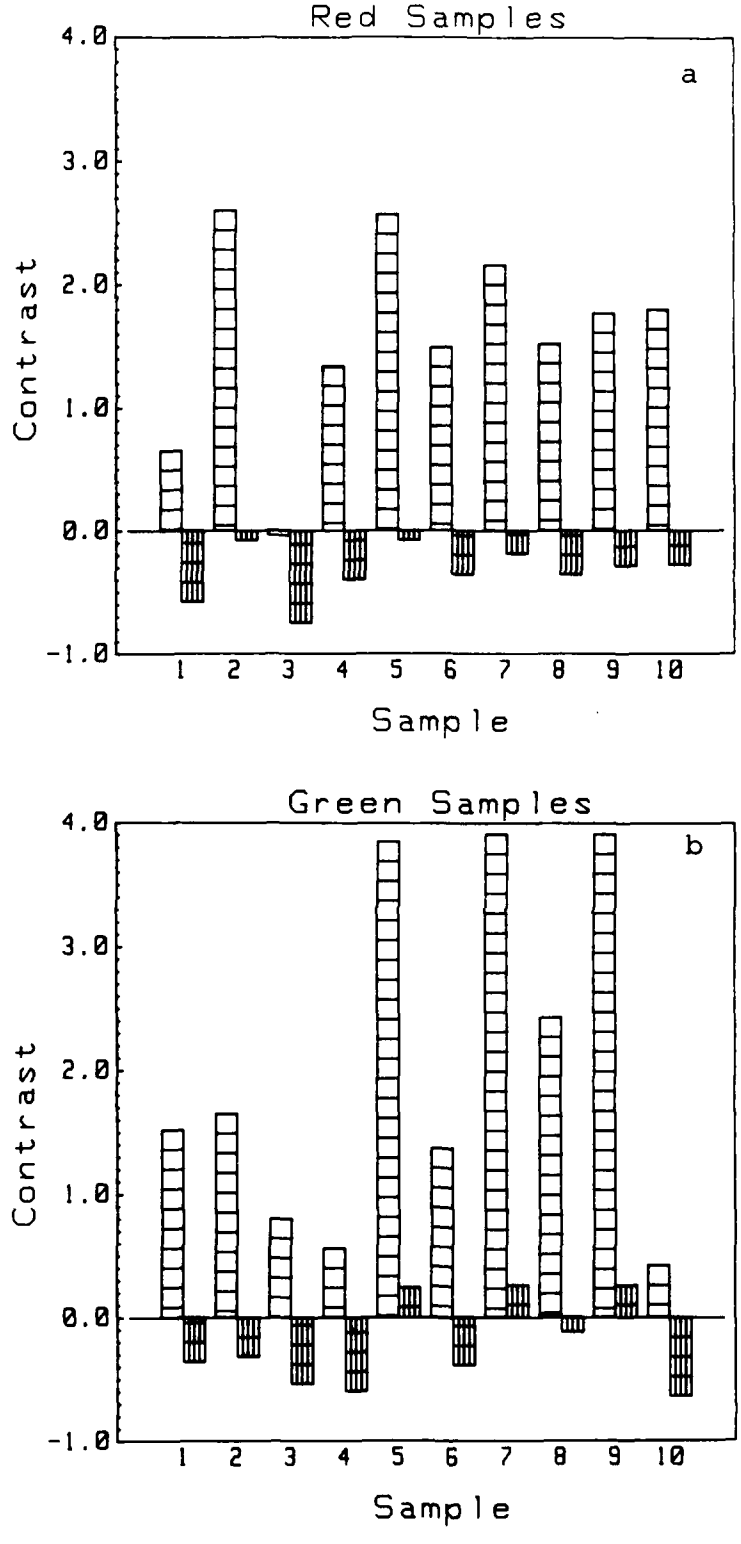

Figure 3. Contrasts of Samples on Dark and Light Backgrounds

Horizontally-hatched bars represent contrasts on dark backgrounds. Cross-hatched bars are contrasts on the light background.

TABLE III
Luminance Contrasts of Test Samples

Number	Sample	Background Low Lum	Background High Lum
1.	10R 5/16	0.65	-0.58
2.	10R 7/10	2.60	-0.08
3.	7.5R 4/16	-0.04	-0.75
4.	7.5R 6/16	1.34	-0.40
5.	7.5R 7/10	2.57	-0.08
6.	5R 6/12	1.49	-0.36
7.	5YR 6.6/15.9	2.16	-0.19
8.	Fascal 911 Orange	1.52	-0.36
9.	3M Fluorescent Red	1.77	-0.29
10.	3680-54 Light Orange	1.80	-0.28
1.	7.5G 6/10	1.52	-0.36
2.	5.6G 6.12/13.7	1.65	-0.32
3.	3.5G 5.2/13.1	0.80	-0.54
4.	2.5G 5/12	0.56	-0.60
5.	2.5G 8/8	3.85	0.24
6.	10GY 6/12	1.37	-0.39
7.	10GY 8/8	3.91	0.26
8.	7.5GY 6.84/13	2.43	-0.12
9.	3M Fluorescent Green	3.91	0.26
10.	3680-46 Kelly Green	0.42	-0.64

hatched and cross-hatched bars, respectively.
Luminance contrast is defined as:

$$\frac{L_T - L_B}{L_B} \qquad (1)$$

where L_T is the luminance of the target and L_B is the luminance of the background. When the target has higher luminance than the background, the contrast is positive. If the background has a higher luminance than target, contrast is negative. The luminance contrasts were chosen to be comparable to what might be obtained in the field for materials viewed against a grass background and sky background (Blackwell, 1960; Blaise, 1971).

Table IV provides mean detection and identification thresholds of five observers. Threshold is defined as the diameter of the target (in minutes of arc) that could be detected 80% of the time. Each value is the mean of 20 thresholds.

The average standard error was 0.028 minutes of arc. The t-ratio required to obtain a significant difference between means at the 0.05 probability level and 19 degrees of freedom is 2.093. Therefore, means that differ by 0.0586 (2.093 x 0.028) are significantly different.

Since angular subtense of a target decreases with increasing distance from the target, these thresholds correspond to measures of detection range for the targets. Assuming a meteorological optical range of infinity[3], the detection distance or color identification distance, D, for each target can be calculated from:

$$D = \frac{0.5W}{\tan(0.5H)} \qquad (2)$$

where W is the diameter of the target, and H is the threshold in degrees of arc. (The thresholds of Table IV can be converted from minutes to degrees by dividing each by 60.0.) For example, Red Sample 1 (henceforth abbreviated as Red-1) has a detection threshold of 0.986 minutes of arc on the dark background. If a

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[3] The meteorological optical range (MOR) is related to atmospheric transmissivity by the equation:

$$MOR = \log_e(0.05)/\log_e(\text{Transmissivity}).$$

For a MOR of infinity, the transmissivity is equal to 1.0. This MOR of infinity is, admittedly, unrealistic. Unfortunately the relationship between size, contrast, atmospheric clarity and detection range is not well understood, and thus this assumed MOR is necessary to solve for detection distance. The effect of other MOR's will be treated in a later section.

TABLE IV
Diameter (minutes of arc) of Samples at Threshold

	Sample	Dark Background		Light Background	
		Detect	Ident.	Detect	Ident.
1.	10R 5/16	0.986	1.229	0.718	1.271
2.	10R 7/10	0.566	1.301	1.295	1.739
3.	7.5R 4/16	1.154	1.311	0.680	1.435
4.	7.5R 6/16	0.729	1.007	0.803	1.237
5.	7.5R 7/10	0.585	1.204	1.073	1.776
6.	5R 6/12	0.754	1.144	0.831	1.354
7.	5YR 6.6/15.9	0.521	1.140	1.029	1.467
8.	Fascal 911 Orange	0.725	1.207	0.856	1.293
9.	3M Fluorescent Red	0.608	0.756	0.858	1.015
10.	3680-54 Light Orange	0.662	1.222	0.909	1.497
1.	7.5G 6/10	0.866	0.999	0.739	1.281
2.	5.6G 6.12/13.7	0.761	0.927	0.750	1.125
3.	3.5G 5.2/13.1	1.020	1.148	0.693	1.238
4.	2.5G 5/12	1.200	1.309	0.672	1.389
5.	2.5G 8/8	0.522	0.768	1.192	1.519
6.	10GY 6/12	0.805	0.976	0.757	1.345
7.	10GY 8/8	0.514	0.723	1.333	1.607
8.	7.5GY 6.84/13	0.642	0.795	0.895	1.305
9.	3M Fluorescent Green	0.496	0.691	1.003	1.181
10.	3680-46 Kelly Green	1.109	1.459	0.679	1.370

daymark of this material with a diameter of 4.0 ft was viewed against a dark background, and the meteorological optical range was infinite, the detection range for such a target would be:

$$D = \frac{(0.5)4.0}{\tan(0.5 * 0.986/60.0)} \qquad (3)$$

$$= 13946 \text{ ft} = 2.29 \text{ nautical miles.}$$

The target with the lowest detection threshold (0.496 minutes) is Green-9 (3M Fluorescent Green) on the dark background. By the above equation, the detection range for this sample is 4.56 n. mi., the maximum of all samples tested. The data for all samples are plotted in Figures 4a-d. The four panels show detection and identification distances of red and green samples on dark and light backgrounds. The diagonally hatched bars are for detection and the cross-hatched bars are for identification. The standard error for the data in units of nautical miles is 0.21. Thus values that differ by 0.43 n. mi. are significantly different.

Figures 5a and 5b show the data averaged across the two backgrounds. Red-9, the 3M fluorescent material was detected and identified at a greater distance than any of the other red samples. Similarly, Green-9, 3M fluorescent material had the greatest detection and identification range of the green materials.

4.2 Laboratory-Field Comparison

Before proceeding with further analysis of the laboratory data, it is necessary to compare the laboratory and field measurements in order to determine if the laboratory approach was valid.

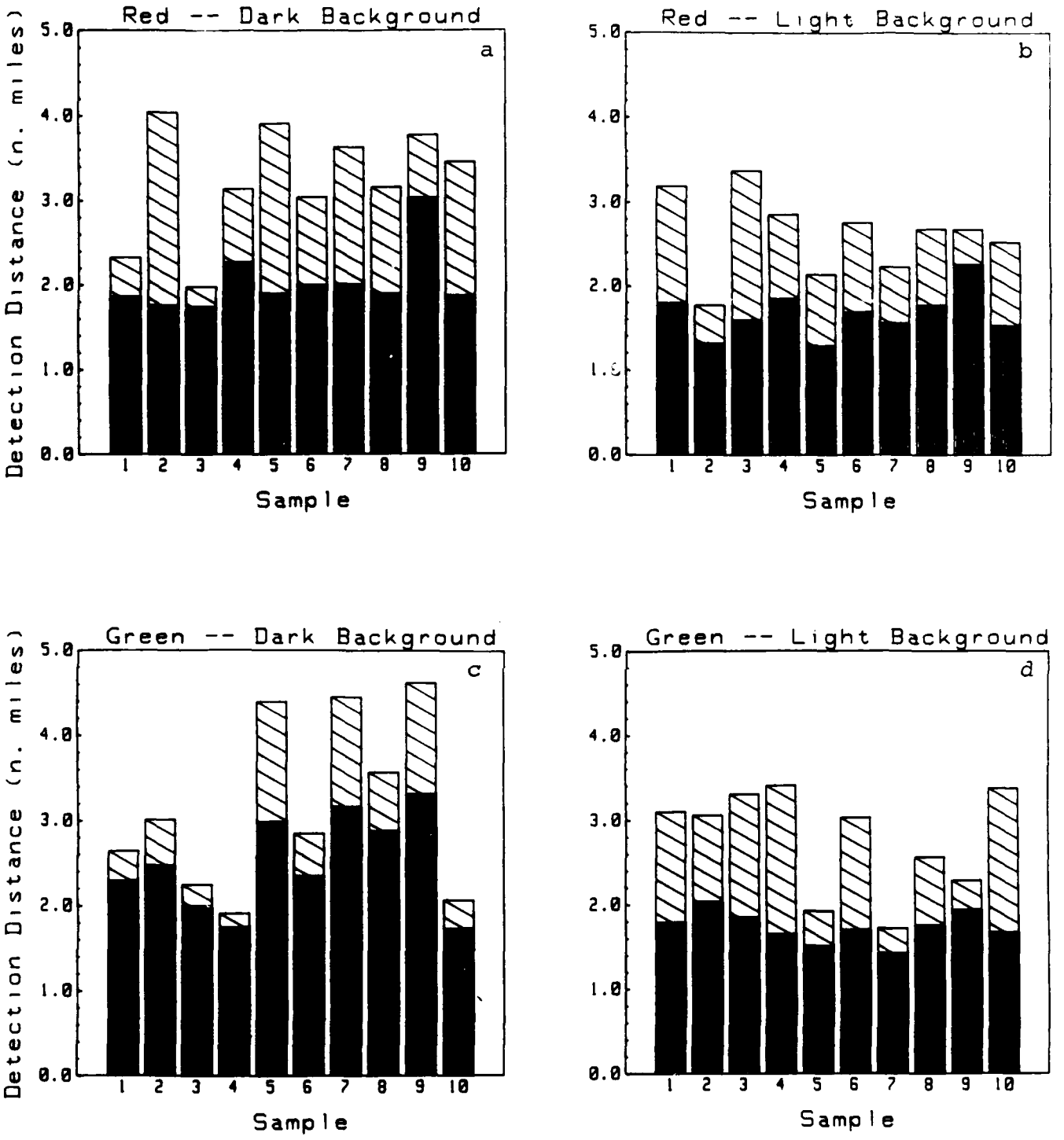

Figure 4. Detection and Identification Distances of 20 Samples

Laboratory measurements. Diagonally-hatched bars represent detection distances and cross-hatched bars represent color identification distances. Sample specifications are given in Table I.

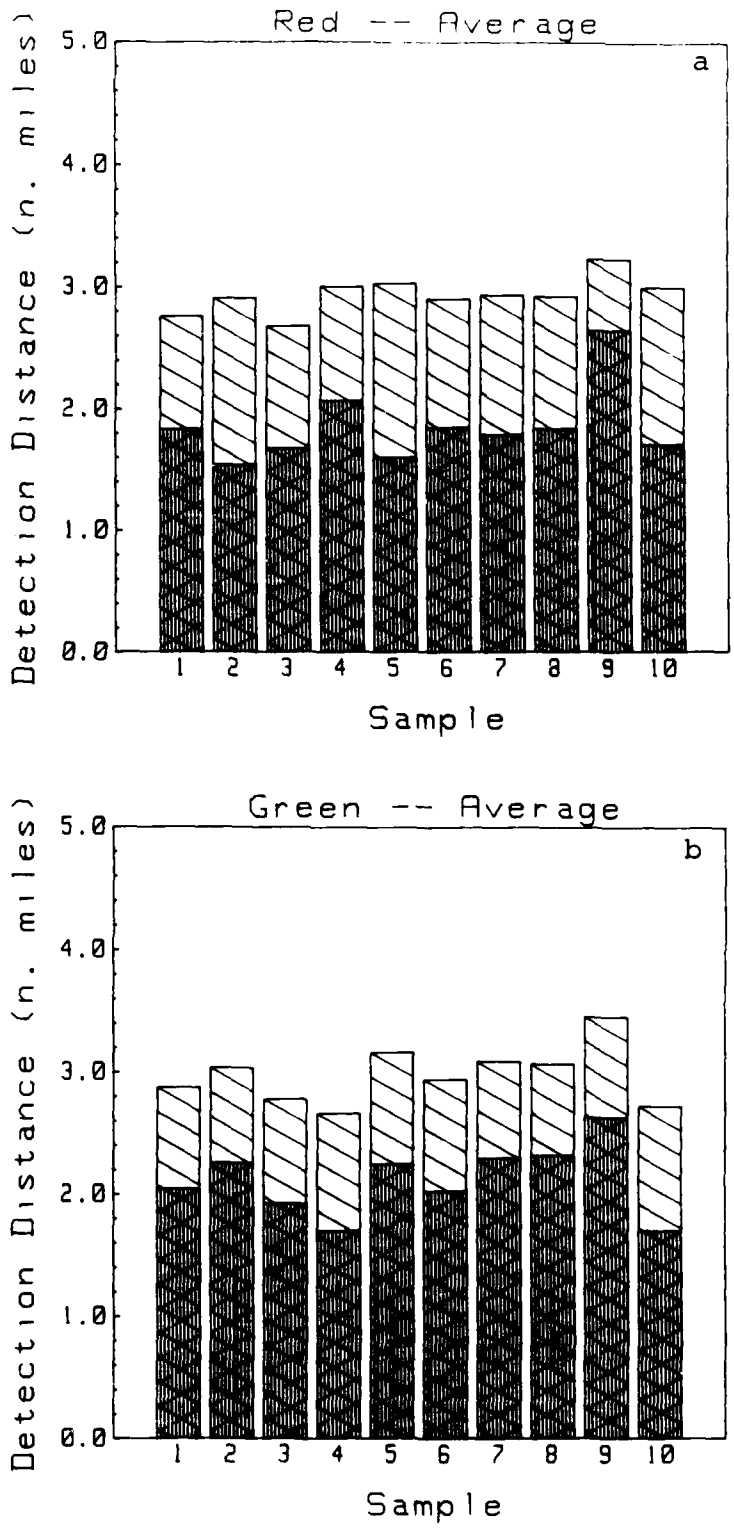

Figure 5. Average Detection and Identification Distances

Data from Figure 4 averaged across the two back-ground conditions. Diagonally-hatched bars represent detection distances and cross-hatched bars represent color identification distances.

If the laboratory experiment is a valid assessment of field performance, there should be good agreement between the two sets of data. Figures 6a and 6b compare laboratory and field data on dark and light backgrounds. The horizontally-hatched bars represent laboratory data and the diagonally-hatched bars represent field data. As before, cross-hatched areas represent identification data.

Major trends present in the laboratory data are also evident in the field data. On the dark background, Red-2 is detected at a greater distance than Red-4 and Red-9, while Red-2 has the shortest identification distance. Green-5 and Green-9 could be detected and identified at distances substantially greater than Green-2. Similar comparisons can be made with data on the light background.

The extent of the differences between the two sets of data were assessed with a t-test. In no case is the difference between lab and field data significant at a probability level of 0.05.

4.3 Luminance Contrast and Detection Distances

Given that distances established in the laboratory are acceptable measures of field performance, it is important to determine how different characteristics of chromatic material affect detection and identification ranges. The relationship between luminance contrast and detection range is shown in Figure 7. The squares are for red samples and circles for green samples. The solid lines are independent least-square fits to the positive and negative contrast data. As expected, these least-square fits intersect near a luminance contrast of 0.0 where detection distance ought to be at a minimum.

The effect of luminance contrast on detection range is the same for the red and green samples, as shown by the overlap among the points. For both positive and negative contrasts, detection distance increases in a nearly linear fashion with contrast.

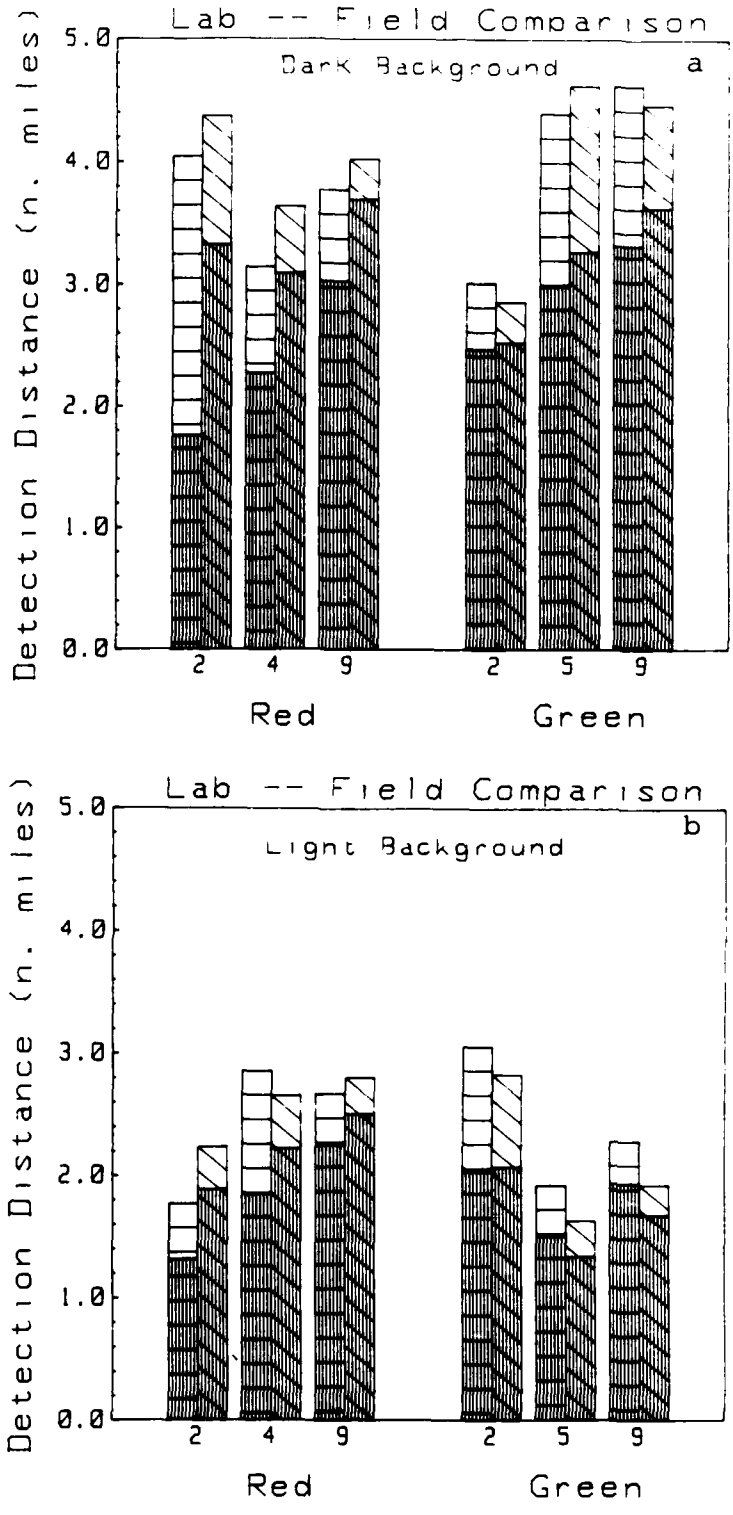

Figure 6. Comparison of Laboratory and Field Data

Sample specifications given in Table 2. Horizontally hatched bars are detection distances from laboratory measurements and redrawn from Figure 4. Diagonally-hatched bars are detection distances from field measurements. Cross-hatched bars are identificaton distances.

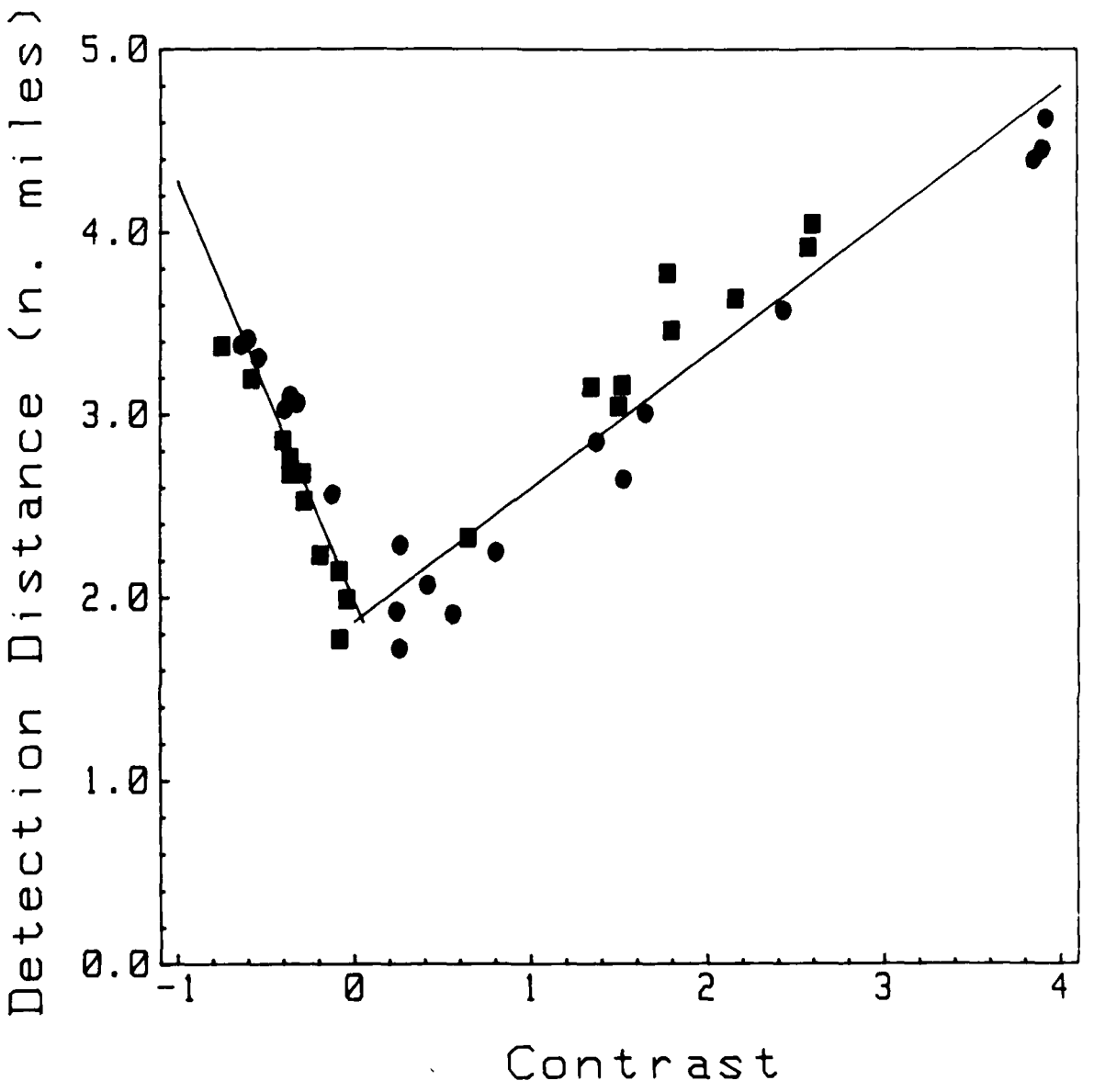

Figure 7. Detection Distance Versus Luminance Contrast

Squares are for red samples and circles for green samples. Lines are least-square fits to positive and negative contrasts.

4.4 Munsell Notation and Detection and Identification Distances

The Munsell Color System (Wyszecki and Stiles, 1982) provides one convenient classification system for chromatic materials. Each material can be identified with a three-part code corresponding to its Munsell hue, Munsell value and Munsell chroma. Munsell hue is a descriptor of the color, value relates to the lightness of the material and chroma is the "colorfulness." The descriptions of many of the test samples used in this study are provided in Table I as Munsell notations. It is interesting to determine if there is a relationship between detection range or color identification range of different materials and its Munsell notation. If such a relationship existed it would simplify the process of choosing daymark materials, as the visual effectiveness of materials could be predicted from knowledge of the material's hue, value and chroma.

4.4.1 Munsell Value

On dark backgrounds, materials of high Munsell value should have greater detection ranges than materials of low Munsell value, since Munsell value corresponds to lightness, and thus is related to contrast. That Munsell value is highly correlated with detection range can be seen in Figures 8a and 8b where detection ranges for red and green samples on both dark and light backgrounds are plotted. Squares are for red samples and circles for green. The lines are least-square fits to the combined set of data.

4.4.2 Munsell Chroma

Since materials of high Munsell chroma are perceived to be more "colorful", the distance between detection distance and identification distance might be less for materials of high chroma than materials of low chroma. Figures 9a-d show the relationship between chroma and identification distance on dark and light backgrounds. The ordinate shows the ratio of identification to detection distances since this ratio reflects

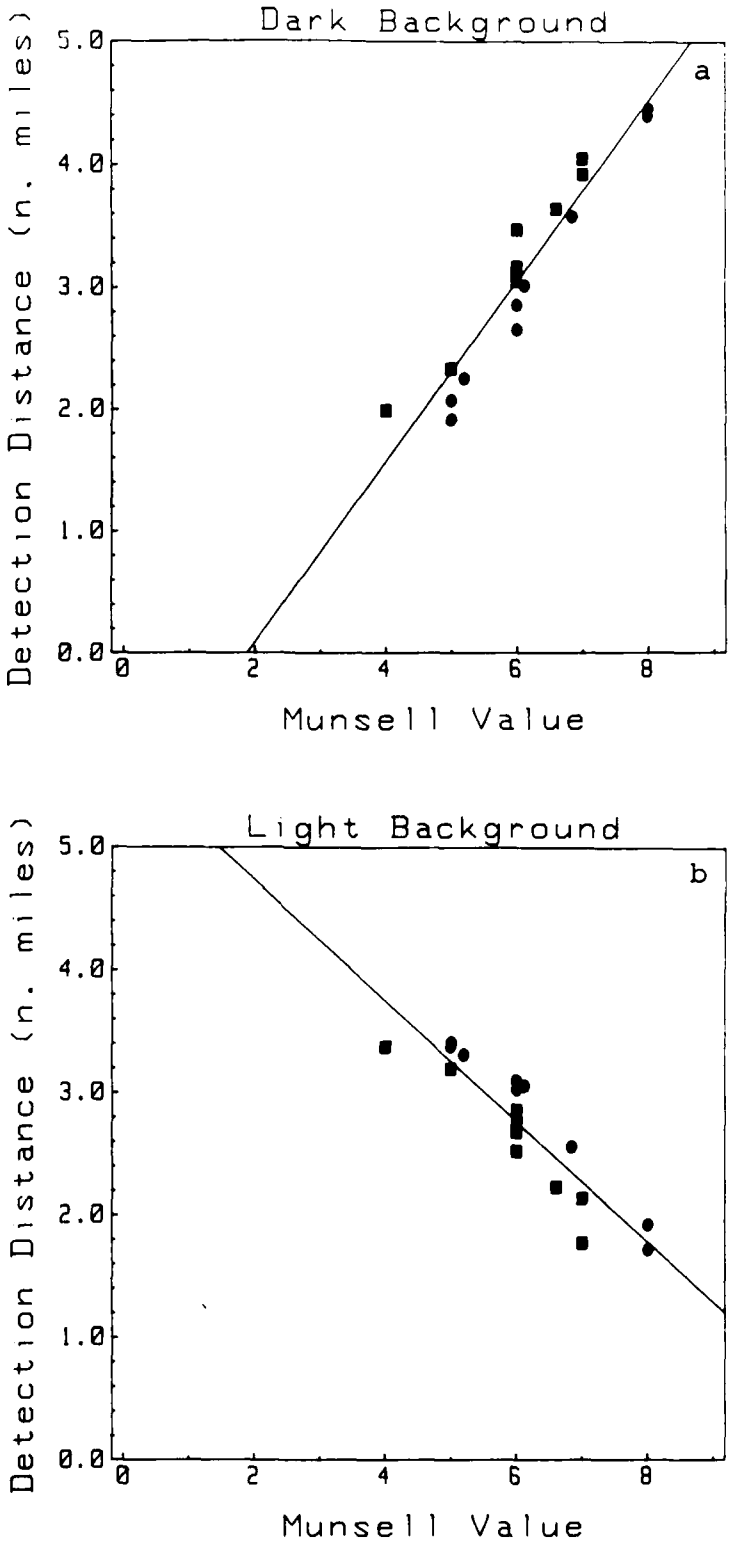

Figure 8. Detection Distance Versus Munsell Value

Squares are for red samples and circles are for green samples. Lines are least-square fits.

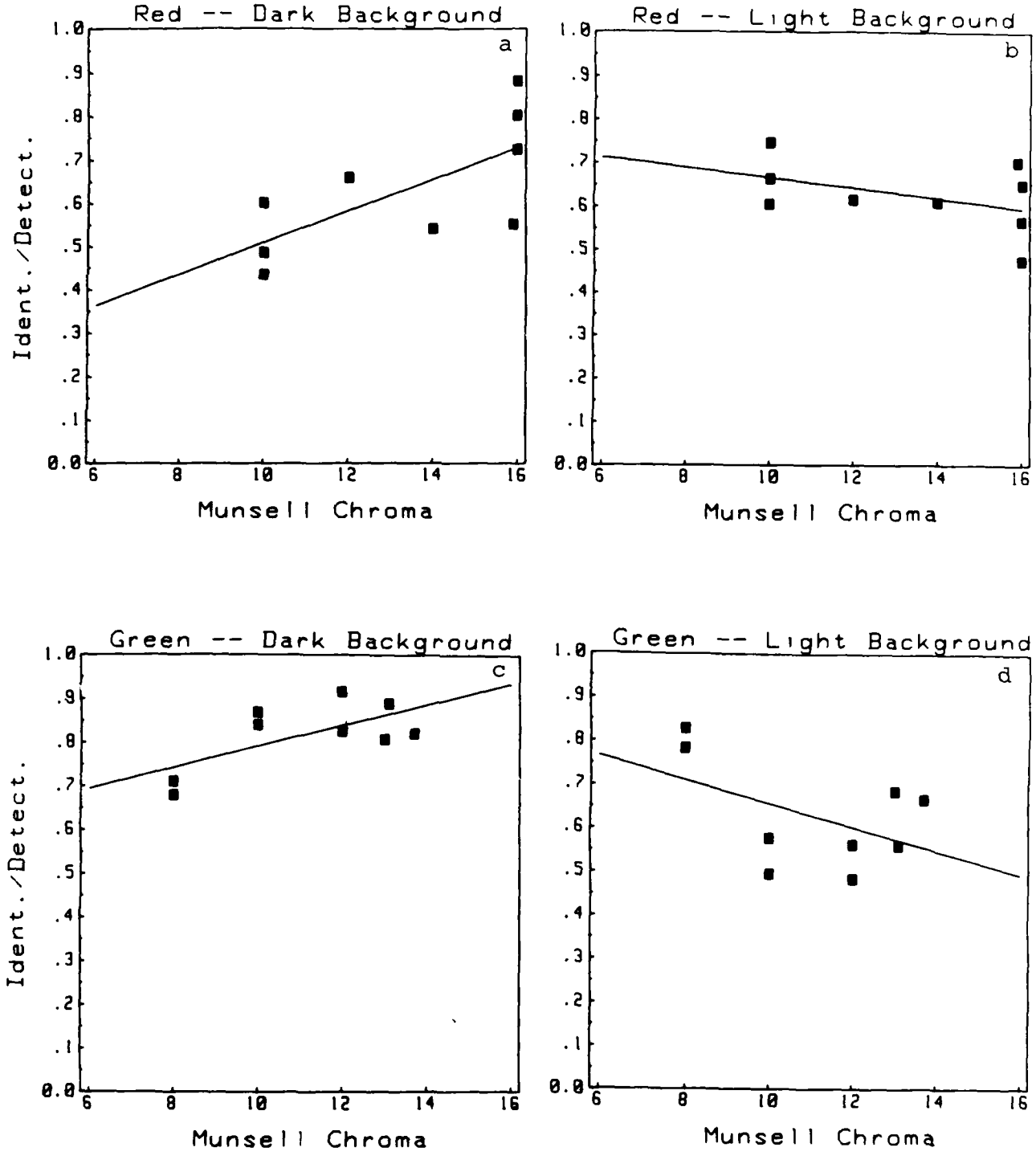

Figure 9. Identification-Detection Ratio Versus Munsell Chroma

the proportion of the detection distance in which color is perceived. A ratio of 1.0 means that the color could be identified at the same distance it could be detected.

For dark backgrounds, the identification/detection ratios were positively correlated (red and green: r=0.70) with chroma for both the red and green samples. Note that for a particular chroma on the dark background the identification/detection ratio is higher for green samples, meaning that green samples can be identified nearer the detection distance than red samples.

On light backgrounds the correlation coefficients were small and not statistically significant (red: r=-0.43, green: r=-0.39). Thus on light backgrounds color identification distance cannot be predicted from chroma.

4.4.3 Munsell Hue

The effect of Munsell hue cannot be unambiguously evaluated since materials that differ in Munsell hue also differ in Munsell value and chroma. To adequately evaluate the effect of hue it is necessary to choose samples of equal value and chroma, but different hue.

4.5 Comparison of Fluorescent and Non-Fluorescent Material

The purpose of this experiment was to evaluate various materials as potential daymark signals. Materials with the greatest detection and color identification ranges are materials that provide the best signal to the mariner. The data (Figure 5) show fluorescent red (Red-9) and fluorescent green (Green-9) have better average detection and identification ranges than other materials tested. When fluorescent materials are exposed to the environment, the chromaticity coordinates and amount of fluorescence change dramatically with exposure time (Winslow and Stachon, 1983), and detection and color identification distances also change (Mandler and Scoffone, 1984). Figures 10a-d show detection and identification distances of several weathered fluorescent materials on dark and light backgrounds from the Mandler and Scoffone (1984) study. Figures 11a-b show the data

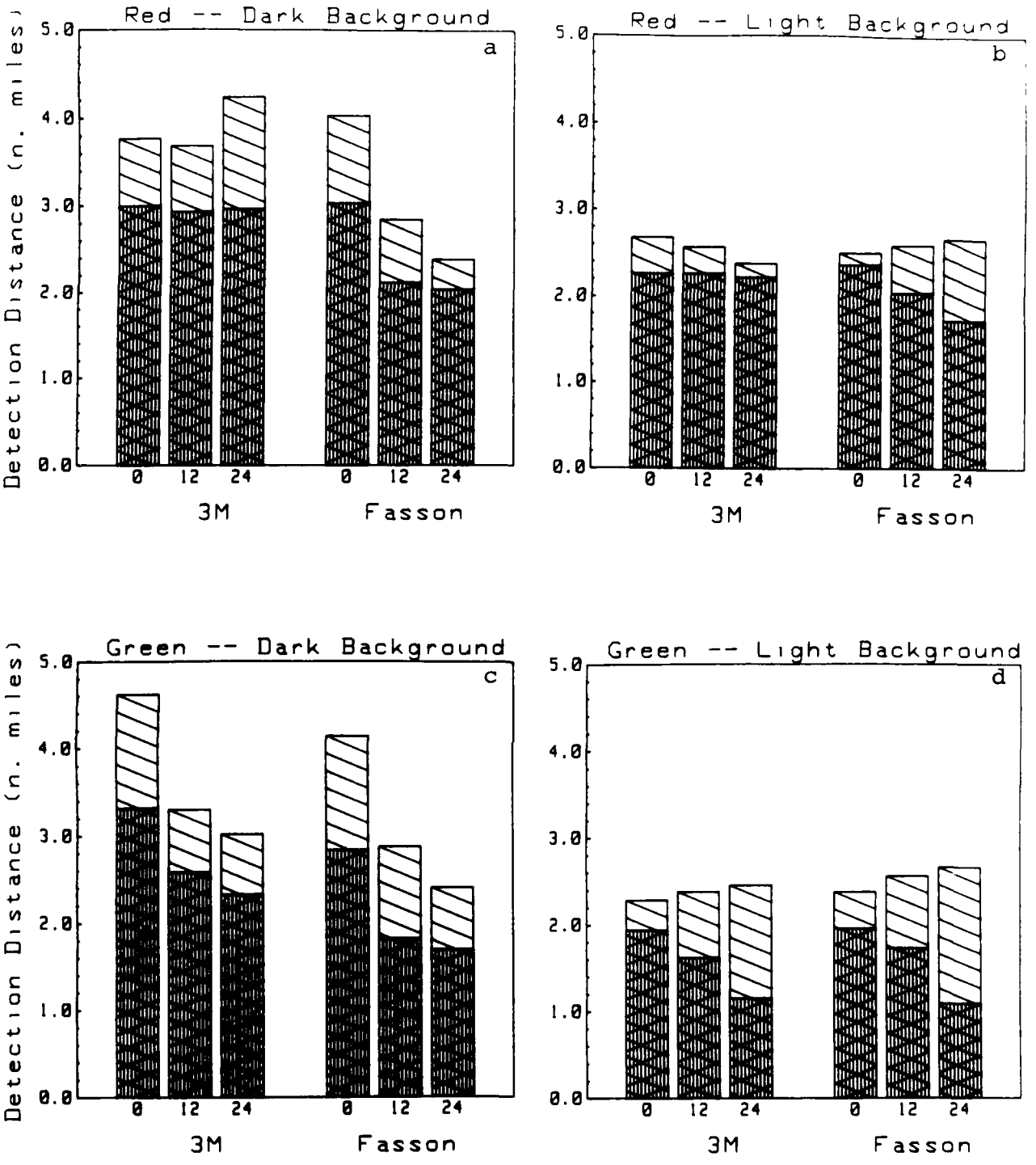

Figure 10. Detection and Identification Distances of Weathered Fluorescent Samples

Data from Mandler and Scoffone (1984) on dark and light backgrounds.

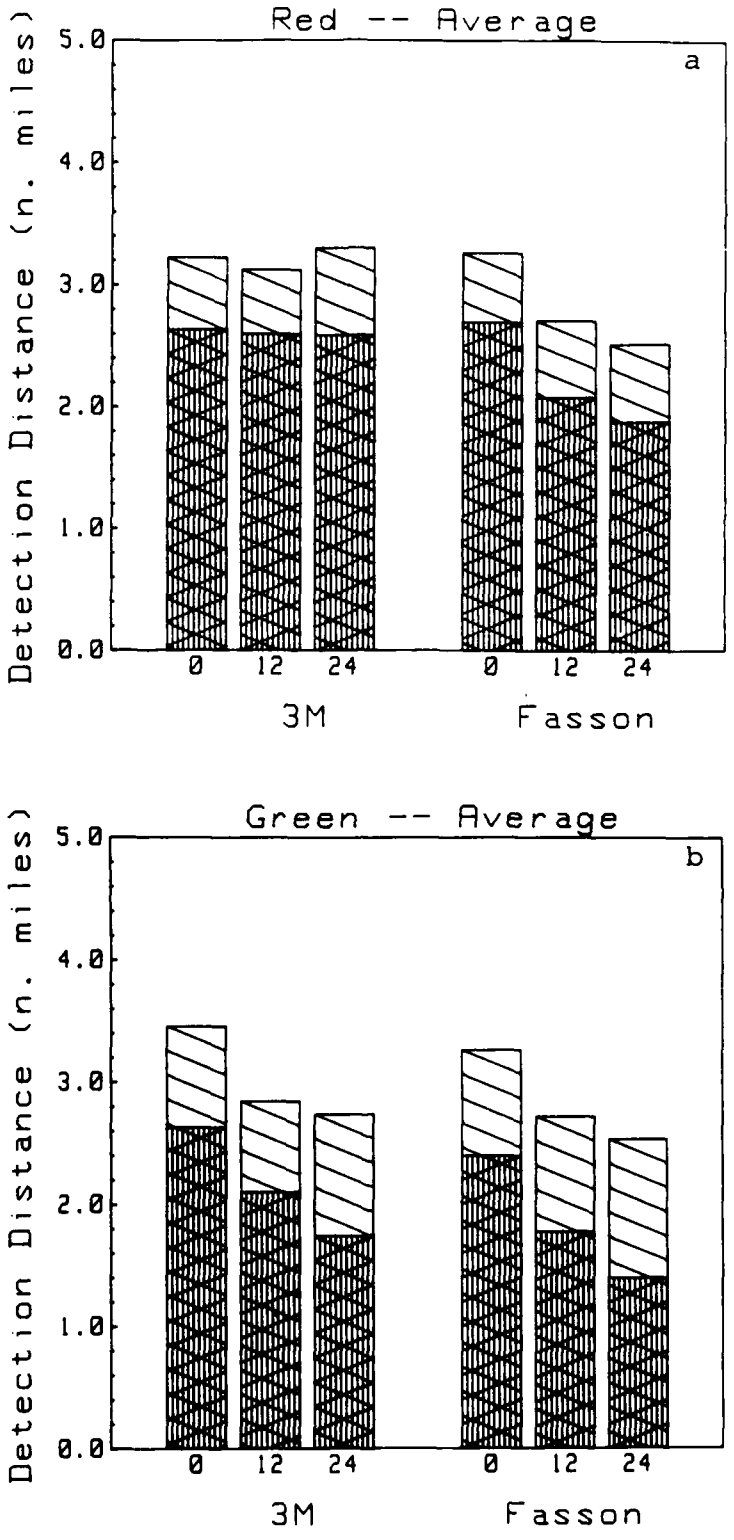

Figure 11. Average Detection and Identification Distances of Weathered Fluorescent Samples

Data of Figure 10 averaged across two background conditions.

averaged across background. The data have been scaled for comparison with the present set of data. The number of months associated with each figure refers to amount of time for which the material was placed outdoors.

With the exception of 3M Red, detection and color identification distances are reduced with exposure. Detection range for 3M Red increases slightly, due to the fact that the color pigment fades, the material appears to have been bleached and thus the amount of light reflected by the material increases.

At issue is how the weathered fluorescent materials compare to non-fluorescent materials. A comparison that can be made is the percentage difference in detection range between a new or weathered fluorescent material and non-fluorescent material. Such comparisons are shown in Figures 12a-12f for red samples and 13a-13f for green samples. The ordinate is the percentage advantage in detection distance of the fluorescent material. Positive values indicate the extent to which the fluorescent material has a longer detection distance than the non-fluorescent, while negative values indicate the extent to which the non-fluorescent material has a longer detection distance than the fluorescent material. In Figure 12a for example, 3M Red that was exposed for 0 months could be detected at a distance 17% greater than Sample 1. (Sample 9 in Figure 12a has an advantage of 0% since it is also 3M Red - 0 Month.)

With the exception of 3M Red, the fluorescent materials degraded within 12 months to the point that they were not better than a majority of the non-fluorescent materials. It must be kept in mind, however, that the non-fluorescent materials were not subjected to the same environmental exposure as fluorescent materials. Manufacturers claim that non-fluorescent materials do not degrade like fluorescent materials. This has not been corroborated by the Coast Guard.

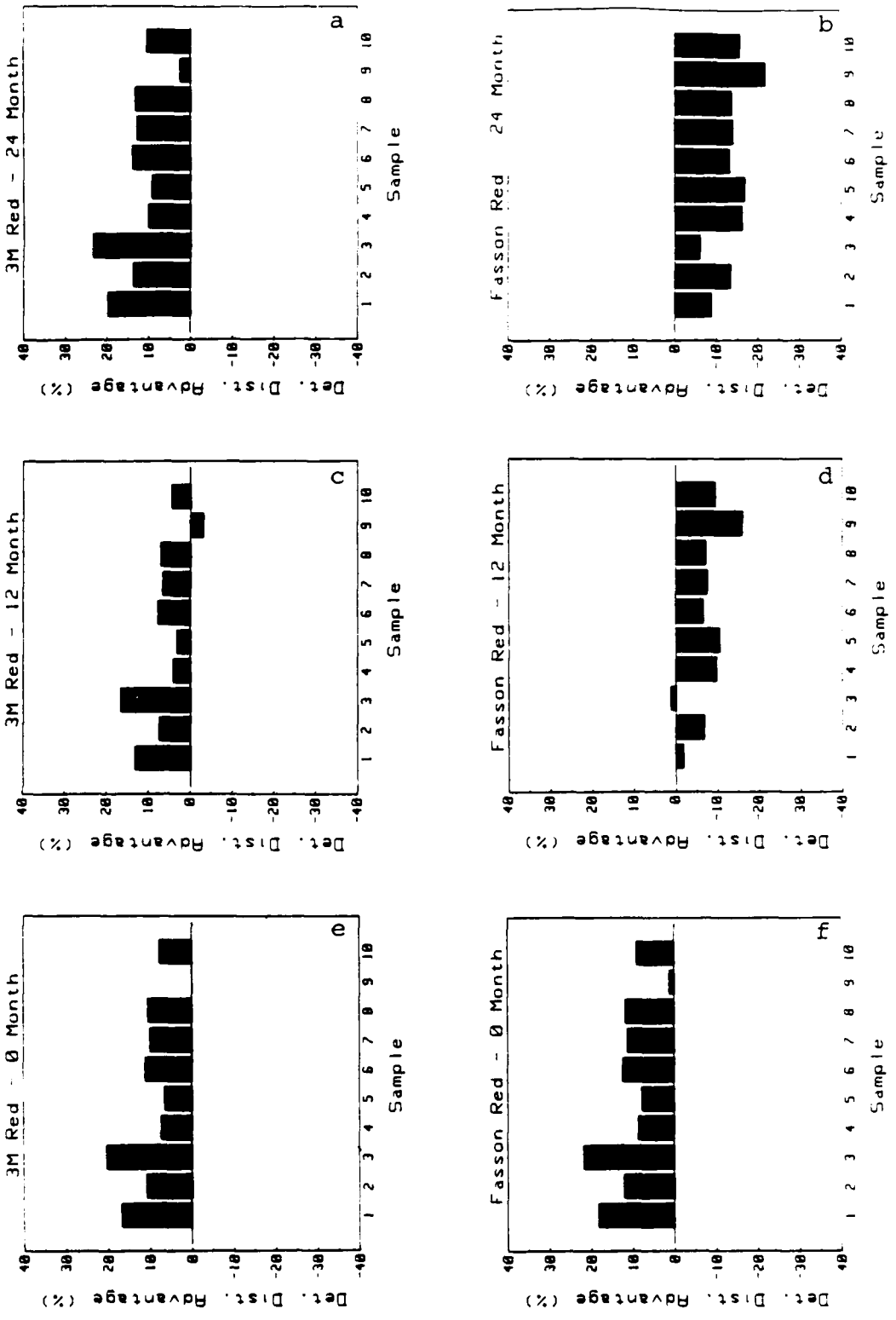

Figure 12. Detection Advantage of Red Fluorescent Samples

Detection distance advantage of fluorescent materials of various ages. Positive values indicate the extent to which the fluorescent material had a greater detection distance than the test samples. Negative values indicate the opposite.

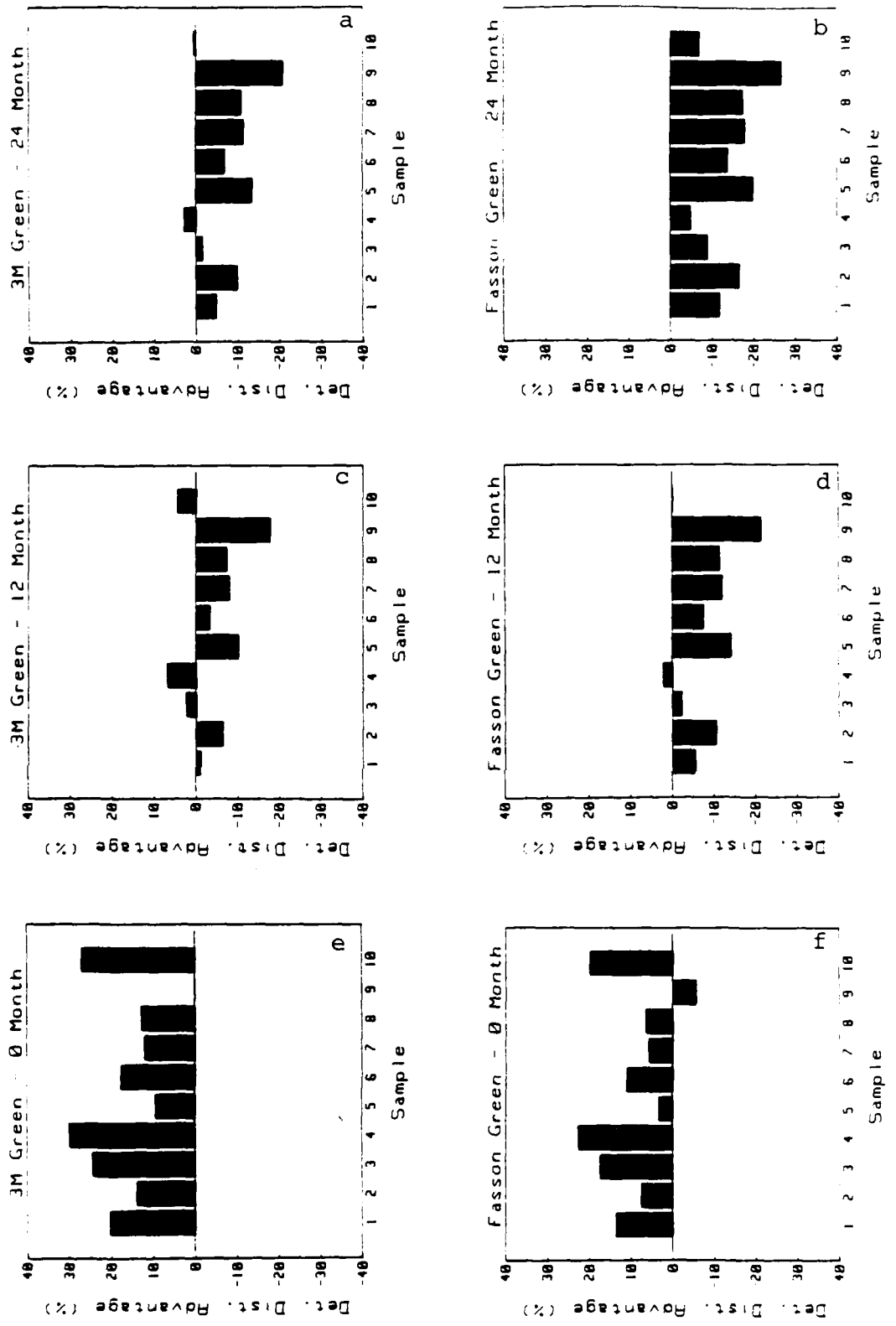

Figure 13. Detection Advantage of Green Fluorescent Samples

Same as Figure 12 for green samples.

4.6 Effects of Reduced Visibility

To this point, computation of detection and identification distances have assumed that measurements were obtained in a perfectly clear atmosphere. Weather conditions, of course, are not often ideal, thus it is important to know how materials compare in less than ideal conditions. When the clarity of the atmosphere is reduced, there is a reduction and spectral shift in the illumination, a change in the hue of the material and background, and a change in contrast (Middleton, 1952). These changes are difficult to implement in a laboratory. Actual field measurements are difficult because of lack of control over experimental conditions and the fact that atmospheric clarity varies significantly over space and time. The effect of the atmosphere on detection and identification can be treated from a theoretical point of view.

The effect of visibility can be determined from nomograms provided by Duntley(1948) for a limited set of conditions. Blaise(1972) reports that detection range of a daymark can be calculated from:

$$C(0.05)^{X/V} (D^2/X^2) = K \qquad (3)$$

where C is luminance contrast of the target at a short distance, X is the distance in kilometers at which the target can be detected, V is the meteorological visibility in kilometers, D is the side of a square in meters having the same area of the target, and K is a constant of 0.38. As this equation does not take chromatic contrast into account, it will not accurately predict detection ranges for chromatic materials. However, it does provide a general framework for comparing detection ranges of targets in different conditions.

Figure 14 shows detection range as a function of luminance contrast as from equation (3) for four different transmissivities, assuming a 1.0 meter daymark. With a clear atmosphere, detection range increases rapidly with increasing luminance contrast. When the visibility is decreased, the

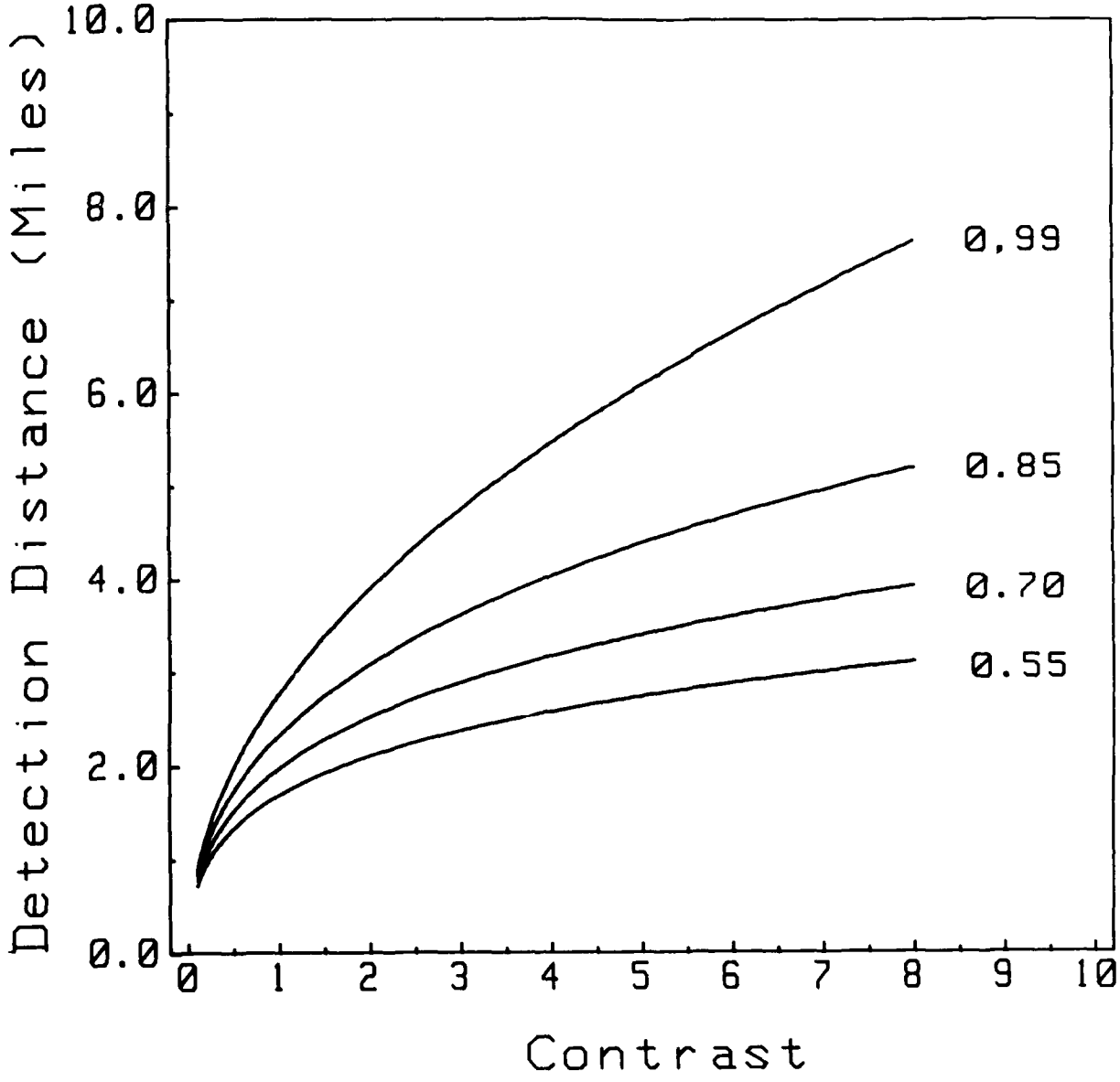

Figure 14. Effect of Transmissivity on Detection Distance

detection ranges for high contrast targets are reduced to a greater extent than those of low contrast targets. This means that differences between materials when the atmosphere is clear will be greatly reduced when haze or fog are present. Since the atmosphere is rarely clear, the reported differences between test materials are smaller than reported. The extent of the differences under different atmospheric conditions cannot be determined since the attenuation of chromatic contrast by the atmosphere has not been studied.

5.0 CONCLUSIONS AND RECOMMENDATIONS

New fluorescent materials can be detected and identified at distances greater than non-fluorescent materials prior to extended environmental exposure. During a single year of exposure, the environment degrades fluorescent materials to a point where they are inferior to new non-fluorescent materials. This trend is found to exist in all cases but 3M Red which fades to white after weathering, and for this reason is not authorized for dayboards.

It must be kept in mind that weathered non-fluorescent materials were not available for this study. Manufacturers argue that non-fluorescent materials degrade very slowly relative to fluorescent materials, and thus performance of weathered non-fluorescent materials should not be significantly different than new materials.

The use of fluorescent materials for daytime signaling should be reconsidered in light of the present results. The performance of fluorescent materials suggests that dayboards should be replaced on a yearly cycle to maintain the detection distance advantage. Since it is unlikely that this replacement cycle be realized, dayboards may provide inferior signals a substantial portion of the time.

It is recommended that a study be conducted to document the weathering characteristics of non-fluorescent materials. Such a

study will determine the useful lifetime of non-fluorescent materials and show how rapidly the detection range of such materials changes with environmental exposure.

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