Freight Car Reflectorization

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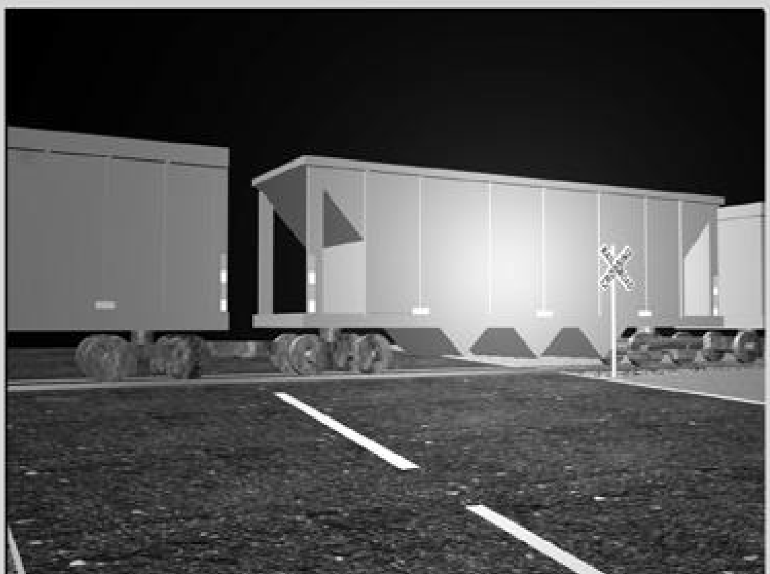
Research and Special Programs Administration
John A. Volpe National Transportation Systems Center
Cambridge, MA 02142



Safety of Highway-Railroad Grade Crossings

DOT/FRA/ORD-98/11
DOT-VNTSC-FRA-97-2

Final Report
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always expect a train

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13. ABSTRACT (Maximum 200 words)

Collisions at highway-railroad grade crossings have posed a significant safety problem. To reduce the number of these collisions at highway-railroad grade crossings where train visibility is a contributing factor, the Federal Railroad Administration (FRA) is investigating measures to enhance the visibility of trains with the use of retroreflectors on freight cars.

A four-phase research program was conducted to determine the feasibility of reflectorization as a train conspicuity device. A literature review provided past and current transportation experiences on the use of retroreflectors. A demonstration test was conducted to establish the durability of a newly developed (microprismatic) material, and to create a retroreflective pattern to test for the next phase of research. A nationwide in-service test was conducted to measure the microprismatic retroreflectors' performance, accident reduction potential, and costs. A human factors test was conducted to evaluate the detectability and recognition of several retroreflective designs.

Results from this research indicate that a uniform, recognizable pattern of reflectorized material can facilitate recognition of a freight car. The durability of the microprismatic material tested indicates that adequate intensity levels can be sustained up to 10 years with maintenance.

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The report was prepared by staff of the US DOT Research and Special Programs Administration (RSPA), John A. Volpe National Transportation Systems Center (Volpe Center). Volpe Center organizational units participating in this research included — within the Office of Safety and Security — the Accident Prevention Division, and the Operator Performance and Safety Analysis Division.

Anya A. Carroll, Principal Investigator for the Volpe Center Highway-Railroad Grade Crossing Safety Research Program, provided overall direction. Melvin A. Yaffee, Volpe Center, provided technical support in the demonstration tests conducted at the US DOT/Association of American Railroads (AAR) Transportation Technology Center (TTC), the nationwide field tests, and targeted railroad field investigations. Irv Golini, Volpe Center retiree, and Robert W. McGuire Jr., Volpe Center, provided technical support in the nationwide field tests conducted with the Norfolk Southern Corporation and the Alaska Railroad. From the Co-Operative Student Program at the Volpe Center, David Hutton, Richard Ow, Robert May, and Janelle Helser provided data collection support. Erica Rhude, Volpe Center, provided insight and realism to this research by producing a Memorandum on Freight Car Reflectorization found in the report's appendix section. Jordan Multer, Volpe Center, directed the controlled laboratory tests conducted at the University of Tennessee. The Report Team Leader was Debra M. Williams Chappell, Volpe Center.

Special acknowledgment is given to the Alaska Railroad Corporation and Norfolk Southern Corporation for their participation in the conduct of the nationwide field tests. The specific individuals listed below are gratefully thanked for their help in the conduct of our research:

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The Volpe Center study team
wishes to dedicate this report
to the memory of

MELVIN A. YAFFEE

PREFACE

Historically, highway-railroad grade crossings have represented a major hazard to motor vehicle drivers and have resulted in numerous motor vehicle-train collisions. The Federal Railroad Administration (FRA) of the U.S. Department of Transportation (US DOT) has initiated a comprehensive research program to develop means of reducing the number of motor vehicle-train collisions. In support of this overall research effort, the John A. Volpe National Transportation Systems Center (Volpe Center) is conducting an investigation of collisions that occur when train visibility is a contributing factor. This study investigates the use of microprismatic retroreflectors to enhance the visibility of freight cars as a means of reducing such collisions. Results of the study are documented in this report, which is one in a series of reports on FRA/Volpe Center highway-railroad grade crossing safety research.

In support of the FRA, the Volpe Center evaluated the feasibility of the latest generation of microprismatic retroreflective materials as a conspicuity device in a four-phase research program. A literature review provided past and current transportation experiences with the use of retroreflectors. A demonstration test was conducted with the assistance of the US DOT/Association of American Railroad's Transportation Technology Center (TTC) to establish the performance of microprismatic material against previously tested materials. The Volpe Center conducted a nationwide test in collaboration with the Norfolk Southern Corporation and the Alaska Railroad Corporation that allowed data collection of retroreflectors' durability, performance, accident reduction potential, and costs under in-service conditions. The Volpe Center also sponsored human factors tests performed by the University of Tennessee to measure the detectability of various patterns and colors of retroreflective materials on freight cars.

Results from this research program indicate that a uniform, recognizable pattern of reflectorized material applied to a freight car can facilitate motor vehicle driver recognition in time to avoid a collision. The results of durability testing of the microprismatic material in a railroad environment indicate that adequate intensity levels can be sustained up to 10 years with routine maintenance.

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EXECUTIVE SUMMARY

Accidents at the approximately 168,000 public highway-railroad grade crossings in the United States have been documented as a significant safety problem. For example, in 1996 there were 4,257 accidents, which resulted in 1,508 injuries and 487 deaths. One factor that contributes to these figures is the difficulty motorists have in seeing a train consist at a crossing, particularly during dawn, dusk, and darkness (i.e., nighttime conditions), thereby causing an accident in which the motorist's vehicle runs into the train (or RIT accident). Of the 4,257 accidents in 1996, 967 (22.72% of the total accidents) were RIT accidents; 473 of these 967 (or 11.11% of the total accidents) occurred in nighttime conditions. The Federal Railroad Administration (FRA) is therefore investigating measures to enhance the visibility of trains in order to reduce the number of accidents/incidents at highway-railroad grade crossings where train visibility is a contributing factor. One such countermeasure involves the use of retroreflectors on freight cars. This report documents the Volpe National Transportation Systems Center's (Volpe Center's) research into the use of reflectorization as a conspicuity device. The results of this research effort will be used to provide technical support for any rulemaking that may be performed by the FRA.

In 1981, the FRA supported a study on the potential use of freight car reflectorization to reduce nighttime accidents/incidents at highway-railroad grade crossings. The study concluded that the use of reflective material had its merits, but the degradation of the materials due to the harsh railroad environment required frequent maintenance and/or replacement to deliver long-term, effective performance. The FRA therefore concluded that rulemaking action was not warranted at that time. Since then, improvements in the brightness, durability, and adhesive properties of reflective materials have been achieved, and a new material, microprismatic corner cube, has been introduced to the market. Additionally, since the initiation of FRA's current studies (1990) on the use of reflectorization, Congress approved the Swift Rail Development Act of 1994, which includes a section on improving freight car visibility through use of reflective material.

The Volpe Center conducted a four-phased research program to investigate the feasibility of freight car reflectorization. These phases consisted of a review of reflectorization experiences in transportation, a demonstration test, an in-service test, and a human factors test.

The first phase, a review of reflectorization experiences in transportation, was conducted to: (1) determine the effectiveness of reflective material used in the past, (2) establish a baseline of reflector performance for comparison in this study, (3) use lessons learned in previous research to help guide this study, and (4) determine the minimum intensity threshold required to attract a motorist's attention. The first phase effort determined that international and domestic experience indicates currently available reflective material used on freight cars in the railroad environment may be successful in reducing nighttime RIT collisions. Specific findings include:

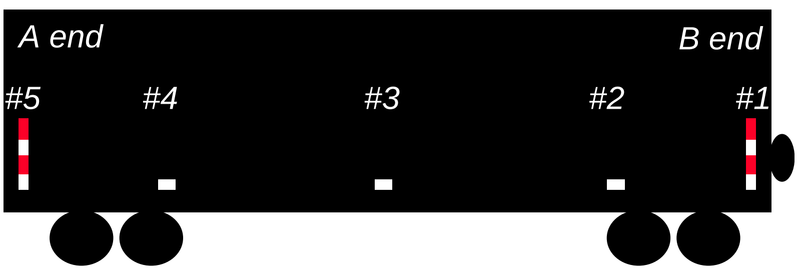
- Reflective materials can enhance motorists' ability to detect the presence of a train in a highway-railroad grade crossing.
- A material with the maximum intensity available should be used (prismatic) to provide the highest level of illuminance to the observer and to reduce maintenance requirements.

- A uniform pattern will enhance the motorist's recognition of a train in time to avoid a collision.
- A favorable placement location for reflectors is 42 inches above top of rail.
- Using visibility assumptions established by previous reflectorization studies, a reflector measuring 4 inches by 8 inches would require a minimum specific intensity per unit area (SIA) of 200 cd/fc/ft^2 to attract a motorist's attention. A reflector measuring 4 inches by 36 inches and using the same conditions would require a minimum threshold of 45 cd/fc/ft^2.
- Several railroads have voluntarily reflectorized their rolling stock.
- The use of reflectors has been successful in other modes of transportation as a means to enhance conspicuity.

The second phase of research, the demonstration test, was conducted at FRA's Transportation Technology Center (TTC) in Pueblo, Colorado. The objectives of the demonstration test were to establish: (1) the performance characteristics of newly developed materials compared to the materials tested in 1982, (2) preliminary costs for material and maintenance, and (3) a preliminary marking design for a nationwide freight car reflectorization test. Various colors and patterns of three materials (bonded, enclosed, and prismatic) were designed and tested over a 1-year period on a train consist that ran 12,941 miles.

The demonstration test resulted in the following conclusions:

- The preferred configuration consisted of three white 4 inches by 8 inches horizontal reflectors spaced 9 ft apart at a height of 42 inches from the top of rail (TOR). Additionally, two alternating red-and-white reflectors measuring 4 inches by 36 inches were placed vertically at the ends of the car for delineation, such that a typical freight car would resemble the following:

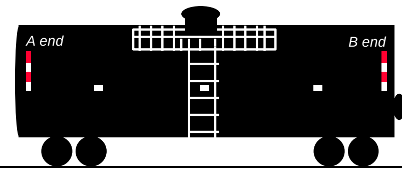
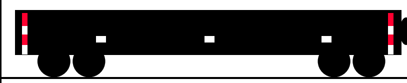
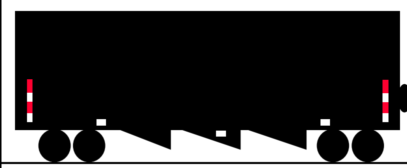
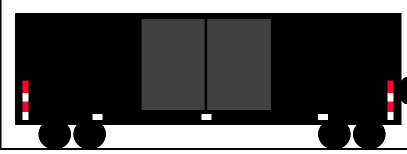


  The installation and material costs for this phase totaled $31.24 per car.

- This configuration would be the "typical" pattern used for the next phase of testing.

The objectives of the third phase of research, the in-service test, were to determine: (1) the performance characteristics of the new material in comparison to an established threshold as well as to the 1982 materials, (2) the reflectors' accident reduction potential, and (3) preliminary costs for reflector material and maintenance. This test provided a real-time study of the reflective material's ability to perform under a variety of harsh railroad environmental conditions. Table ES-1 describes the type and location of the freight cars tested.

Table ES-1.   In-Service Revenue Test Summary

Test Plan	Participating Railroads	Operating Characteristics	Reflector Configuration
A	Alaska Railroad (ARR)	Series DOT-111 Tank Cars carrying various petroleum products from Anchorage to Fairbanks, AK. *Reflector Height*: 72 in TOR	
B	Norfolk Southern (NS)	Intermodal Double Stack Cars carrying containers from Norfolk, VA, to Chicago, IL. *Reflector Height*: Positions 1 and 5: 30 in TOR; all others: 42 in TOR	
C	Norfolk Southern	Steel Open Top Hopper Cars carrying eastern coal from Sheffield, AL, to Wansley, GA. *Reflector Height*: 42 in TOR, except for Position #3 (under sill, 36 in TOR)	
D	Norfolk Southern	Box Cars carrying clay products from Savannah to Gordon, GA. *Reflector Height*: 42 in TOR	

The in-service test resulted in the following conclusions:

- Reflectors in Positions 1 and 5 performed, on average, above the minimum threshold levels for the entire test period, but the reflectors in Positions 2, 3, and 4 varied from 7 months to the entire testing period.
- The performance of the reflectors was not observed to be significantly affected by natural environmental factors. Mechanical washing of the reflectors resulted in their performance rebounding significantly to levels near original SIA values. Periodic washing of reflectors mounted on freight cars can extend their performance to the limits of their life expectancy.

- Railroad operations had a severe effect on the performance of the reflectors; especially the reflectors that were located where loading and unloading of commodities took place. Placement of the reflector under the sill of the freight car has been found to be detrimental to the performance of the reflector. Mid-car locations on many freight car types provide severe operational conditions; therefore, this location should not be considered in any freight car reflectorization rulemaking process.
- For the average freight car involved in this study, it can be estimated that a 12- to 18-month cycle of maintenance would be sufficient to sustain the threshold levels necessary to attract the attention of a motorist. A minimum cleaning time of 15 minutes per car is considered reasonable for these reflectors with no additional cleaning solvents necessary in the process. Periodic washing of the reflectors can extend their acceptable performance to the limits of their life expectancy.
- The hopper car consists, the only fully reflectorized fleet of the in-service test, recorded a reduction of Category 1 RIT accidents along its dedicated route from 6 (occurring in a 33-month period prior to the reflector's installation), to 0 (occurring in a 33-month period after the reflector's installation). This accident reduction potential should reflect the reduction of this type of RIT accident, which occurs when the vehicle strikes the train after the lead unit. This finding, while positive for reflectorization, should be viewed with caution since it is based on very limited accident experience.
- The demonstration test pattern's original cost of \$31.24 has now been reduced by 40% (based on information stated by the manufacturer) for a cost of material per car of approximately \$18.75. Additionally, the 1996 AAR labor rate is approximately \$20.05 per hour. Using the estimates for reflectorizing an older car during the normal maintenance program that may need heavy cleaning (at the 1996 AAR labor rate), and reduced material costs, the resultant maximum material cost per car using the tested pattern would be approximately \$38.80. Heavy cleaning of the reflectors would require 2 persons for 30 minutes to complete the process approximately every 12-18 months, resulting in a cost of approximately \$20.05 per event. The manufacturer specifies this prismatic material's useful life to be 10 years. Therefore, maximum projected total costs of the material and maintenance for a 10-year period would be \$219.25 per car (based on lower material costs, heavy cleaning, two-person annual maintenance, at the 1996 AAR labor rate).

Based on the above observations, a suggested change in design was developed for the in-service test pattern to improve its performance.

The fourth phase, a human factors study conducted at the University of Tennessee (Knoxville), evaluated several proposed retroreflective configurations. The purpose of the study was to determine the perception characteristics of the new material and its accident reduction potential. This study consisted of two parts. In the first part, transportation experts reviewed reflector patterns, then ranked these designs based on the alerting effectiveness of the design. The top eight designs, plus three other designs, which included the design created in the second phase, were used in the second part of the study. The second part used drivers in the Knoxville area and transportation experts to evaluate and rank the designs based on the individual's interpretation of the best "detectable" configuration.

The fourth phase of testing obtained the following findings:

- A reflectorized freight car is significantly more detectable than an unreflectorized freight car.
- A standardized pattern should be used for all types of rail cars to facilitate recognition.
- A pattern of red-and-white will facilitate recognition of the train and convey a sense of warning.
- The design should be sufficiently distinctive so that it is not confused with the retroreflective markings used on trucks and warnings for other roadway hazards.
- The spatial configuration should give some indication of the shape of the rail car to facilitate recognition. This might include some type of outline or modified outline or spatial arrangement in which the material is evenly distributed across the rail car.

The significant findings resulting from this freight car reflectorization research program are summarized as follows:

1. A uniform recognizable pattern of reflective markings can be applied to most freight car types, with a few exceptions.

2. Based on human factors studies, a reflectorized freight car is significantly more detectable than a non-reflectorized freight car.

3. Also, based on the human factors studies, a uniform pattern of reflectorized material can facilitate recognition of the hazard as a freight car. The pattern should indicate the shape of the car, should employ the colors red and white, and be sufficiently distinctive so as not to be confused with large truck markings.

4. A minimum favorable placement location of reflectors is 42 inches above TOR.

5. The large reflectors, measuring 4 inches by 36 inches, maintained, on average, acceptable reflective performance over the entire testing period (2 years) on all freight car types. Placement of the reflector under the sill of the freight car has been found to be detrimental to the performance of the reflector. Due to their smaller size, position below sill level, and location near loading points, the smaller white reflectors did not perform as well under the harsh railroad operating conditions. Mid-car locations on many freight car types provide severe operational conditions; therefore, this location should not be considered in any freight car reflectorization rulemaking process.

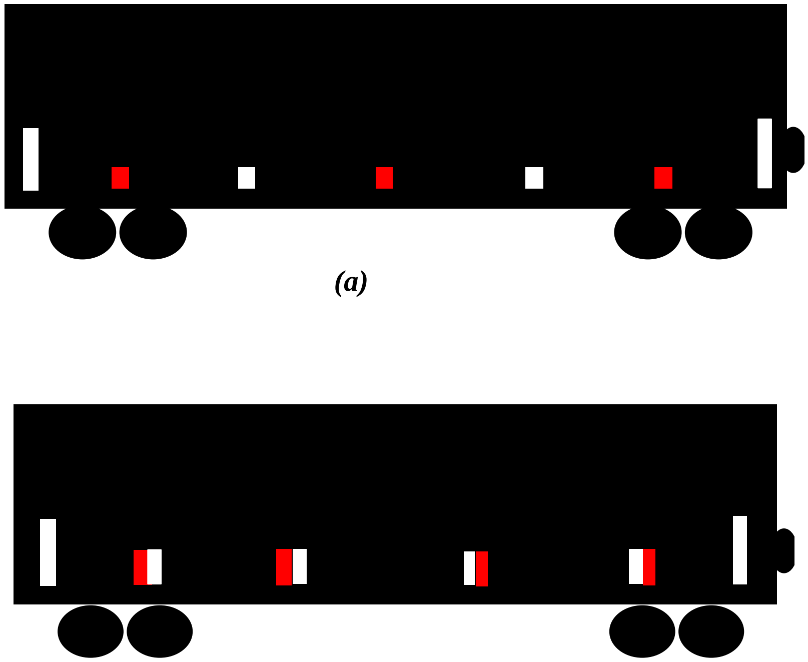
6. The performance of the reflectors was not observed to be significantly affected by natural environmental factors. Mechanical washing of the reflectors resulted in their performance rebounding significantly to levels near original SIA values. Periodic washing of the reflectors mounted on freight cars can extend their performance to the limits of life expectancy. Recently developed prismatic materials' durability and adhesiveness possess the likelihood to perform above threshold levels for up to 10 years with routine maintenance.

7. Based on very limited accident experience, freight car reflectorization was observed to be potentially effective in reducing accidents.

8. The demonstration test pattern's original cost of $31.24 has now been reduced by 40% (based on information stated by the manufacturer) for a cost of material per car of approximately $18.75. Additionally, the 1996 AAR labor rate is approximately $20.05 per hour. Using the estimates for reflectorizing an older car during the normal maintenance program that may need heavy cleaning (at the 1996 AAR labor rate), and reduced material costs, the resultant maximum material cost per car using the tested pattern would be approximately $38.80. Heavy cleaning of the reflectors would require 2 persons for 30 minutes to complete the process approximately every 12-18 months, resulting in a cost of approximately $20.05 per event. The manufacturer specifies this prismatic material's useful life to be 10 years. Therefore, maximum projected total costs of the material and maintenance for a 10-year period would be $219.25 per car (based on lower material costs, heavy cleaning, two-person annual maintenance, at the 1996 AAR labor rate).

9. Based on the results of the in-service and human factors tests, improvements to the second phase pattern are suggested. Two *suggested* reflector designs are shown in Figure ES-1.

   Both designs use red and white reflectors in combination, as suggested by the human factors recommendations, and are mounted vertically to permit an increase in their size. Figure ES-1(a) depicts a more conservative design than Figure ES-1(b) in terms of the amount of material required. Based on the suggested configuration, the cost of material and maintenance will not be significantly increased.



(a)

(b)

Figure ES-1. Suggested Improved Reflector Patterns on a Typical Freight Car

Although these findings are representative of all reflectors tested within this current research study, other operational findings lend themselves to suggest an alternative pattern from the original Volpe Center configuration (used in the in-service test). The human factors studies provide guidance as to the color and pattern necessary to most effectively use freight car reflectorization.

1. INTRODUCTION

Between 1975 and 1996, approximately 176,000 accidents, 16,000 deaths, and 61,500 injuries have occurred at approximately 168,000 public highway-rail grade crossings in the United States. A significant number of these accidents involved the vehicle running into the train (RIT). A contributing factor to this type of accident is the difficulty motorists have in recognizing the train consist in the roadway, especially during dawn, dusk, and darkness.

In 1982, a study was conducted by the Federal Railroad Administration (FRA), with support from the Volpe National Transportation Systems Center (Volpe Center), to determine if retroreflective materials were a feasible option to enhance freight car visibility, and thereby reduce the number of accidents. The National Transportation Safety Board (NTSB) simultaneously published a report and made recommendations on improving train conspicuity in nighttime conditions (i.e., dawn, dusk, and darkness). The FRA study determined that although the use of reflectors enhanced conspicuity, the durability of the reflective material would not withstand the harsh railroad environment. During the 1980s and 1990s, technical advancements were achieved in the brightness, durability, and adhesive properties of retroreflective material, in particular, the creation of prismatic corner cube material.

Due to the continuing number of accidents, as well as improvements in reflective materials, the FRA initiated a second study of freight car reflectorization. After the initiation of this research, Congress enacted the Swift Rail Development Act of 1994 (Swift Rail Act), which includes a section on improving freight car visibility through use of reflective material, if it is deemed cost-beneficial. This report documents the results of the second study, which will be used to provide technical support for FRA rulemaking to improve train visibility in response to Section 212 of the Swift Rail Act.

1.1 PURPOSE

The purpose of this study is to determine if the use of current generation retroreflective materials on freight cars can effectively enhance freight car visibility (in comparison to materials tested in 1982).

1.2 ACCIDENT BACKGROUND

One of the objectives of this research effort was to analyze accident/incident data from the FRA Highway-Rail Accident/Incident Reporting System (RAIRS) database to identify and characterize those accidents that are most likely to be reduced by improvements in freight car visibility. The RAIRS contains accident data for the 22-year period that extends from the inception of the RAIRS database in 1975 to 1996. As will be discussed in Chapter 3, for reflectorization to be effective in reducing RIT accidents, the motorist must be able to see light reflected from the retroreflectors at a distance of 500 feet at night from the grade crossing to allow sufficient distance to stop. For the motorist to see the light reflected off the train, the train must be in the crossing or sufficiently close to it that the headlights will illuminate the train. Under these conditions the train will be in the crossing by the time that the motorist reaches the crossing. It is very unlikely that a motorist, 500 feet prior to the crossing, could see light reflected from an unreflectorized rail car at night in the crossing and pass safely through the crossing before the train arrives (the kinematic relationships between highway vehicles and trains at crossings is described in more detail in Section 3.1). Therefore, only accidents where the highway vehicle runs into the train (RIT accidents) are assumed for purposes of this study to be preventable by the use of reflectors. Figure 1-1 shows the 22-year trend in RIT accidents in relation to total crossing accidents. The 22-year average of RIT accidents as a percentage of total crossing accidents is 26.1%. The aggregate 22-year total of RIT accidents in relation to all crossing accidents as well as RIT accidents by day and night are shown in Figure 1-2.

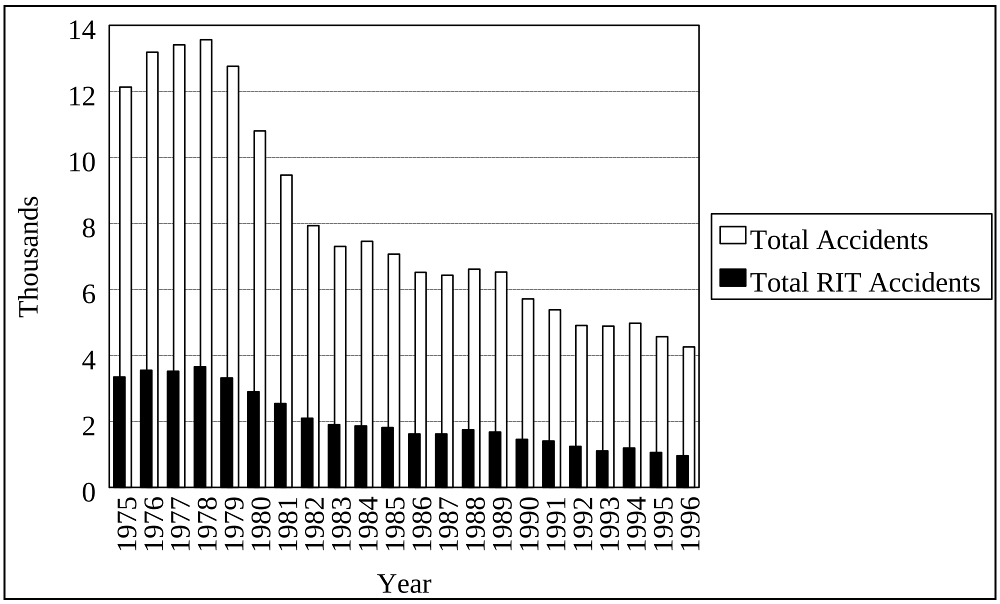


Figure 1-1. Trend in Total Accidents versus Total RIT Accidents (1975–1996)

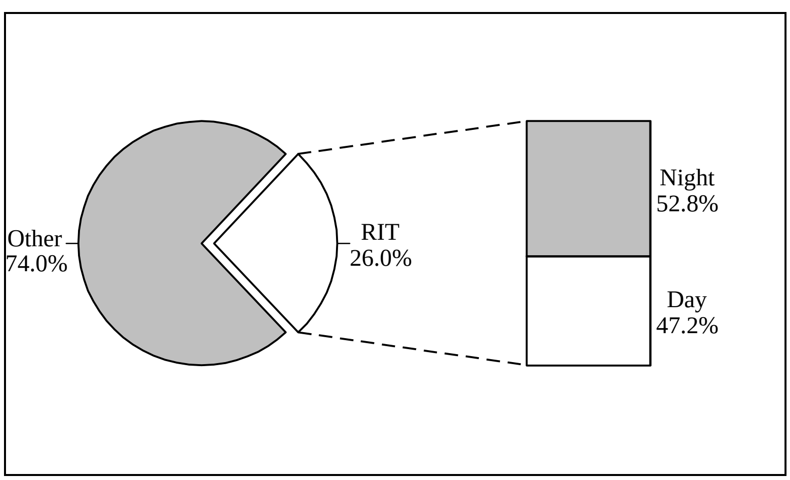


Figure 1-2. Total RIT Accidents versus Total Accidents (1975–1996)

While all RIT accidents are *potentially* affected by reflectorization, those RIT accidents that result from the highway vehicle striking the train after the lead unit has entered the crossing are more likely preventable by reflectorization. Accidents involving the highway vehicle striking the train after the lead unit are referred to as Category 1 RIT accidents. Figure 1-3 shows the trend of Category 1 RIT accidents in relation to total RIT accidents. Category 1 RIT accidents represent an average of 35.4% of total RIT accidents and 9.2% of total crossing accidents.

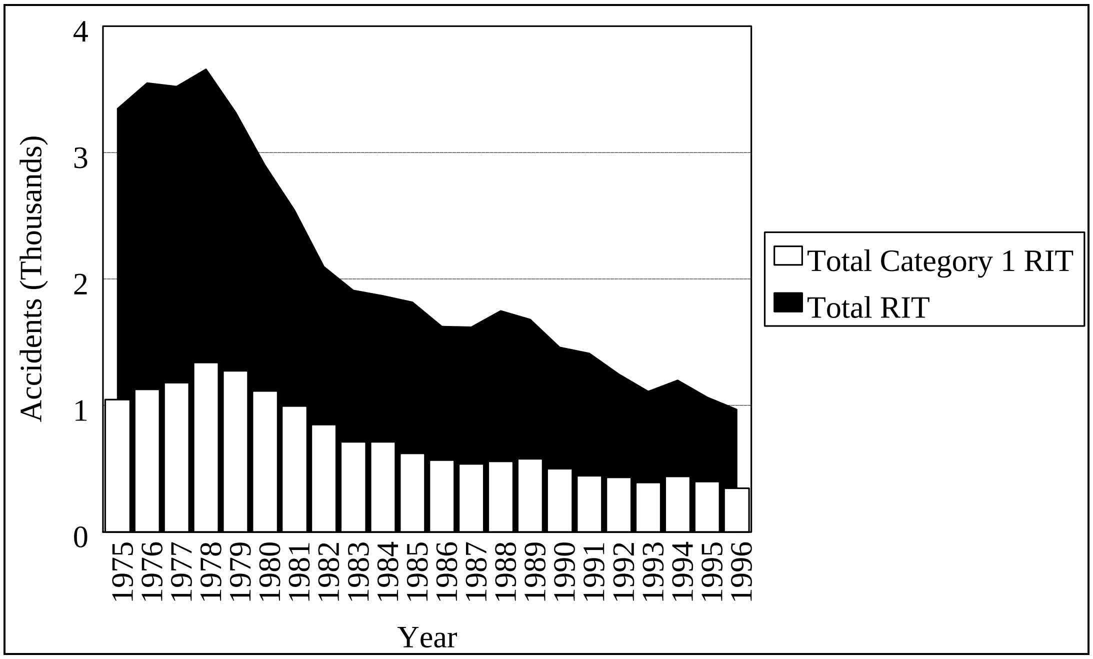


Figure 1-3. Trend in Total Category 1 Accidents versus Total RIT Accidents (1975–1996)

Reflectorization is assumed to be most effective in reducing nighttime Category 1 RIT accidents. Figure 1-4 shows the trend in nighttime versus total Category 1 RIT accidents. Nighttime Category 1 accidents represent an average of 69.7% of Category 1 RIT accidents and 6.4% of total crossing accidents. As can be noted from these statistics, the frequency of nighttime Category 1 RIT accidents is significantly greater than the daytime frequency, in spite of a generally lower volume of highway traffic at night. This strongly supports the assumption that nighttime driving and the resulting diminished visibility of trains is a contributing factor to RIT accidents.

Some daytime RIT accidents may also be reduced by reflectorization. Under conditions of reduced daytime visibility (e.g., inclement weather), reflectors enhance the visibility of freight cars by providing an increased visible contrast with the freight car side wall, especially when the highway vehicle headlights are turned on. During the day, other light sources, particularly the sun, may be at an appropriate orientation to cause reflected light to be seen by the motorist.

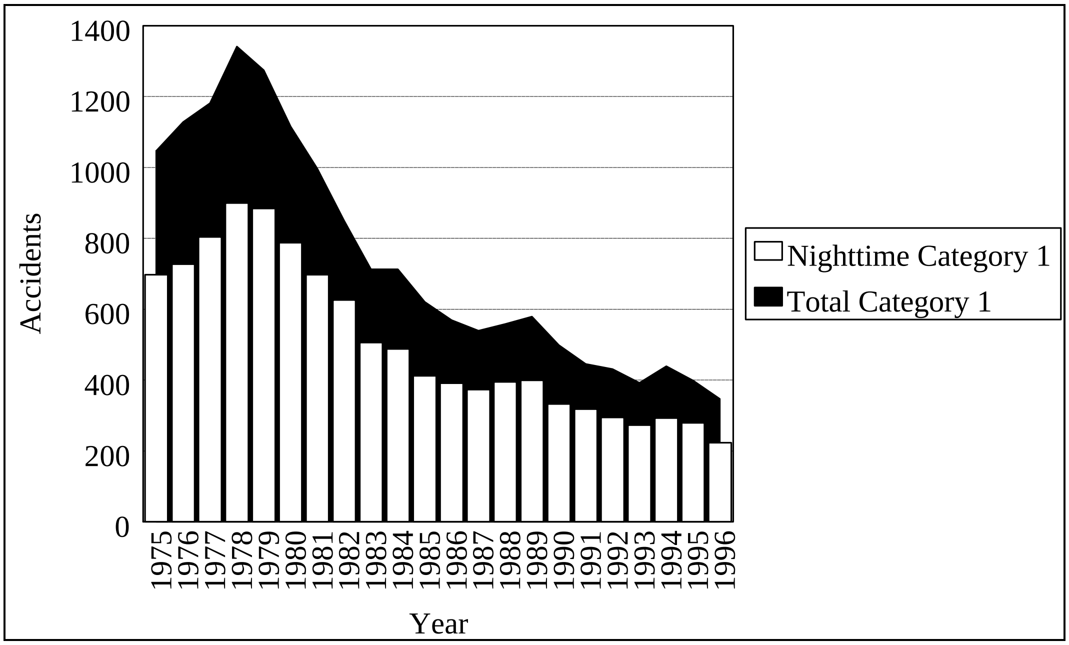


Figure 1-4. Trend in Nighttime Category 1 RIT Accidents versus Total Category 1 RIT Accidents (1975–1996)

The type of warning device at the crossing can also influence the effectiveness of reflectorization. Table 1-1 shows the proportion of Category 1 RIT accidents by warning device. Clearly, the crossings with only passive devices, where 47.1% of all Category 1 RIT accidents occur, will benefit the most from reflectorization. Crossings with flashing lights may also receive some limited benefit from reflectorization. Under conditions of limited visibility, such as darkness and inclement weather, the added, unique visual signal offered by reflectors will augment the visual warning of flashing lights. As Figure 1-5 shows, a significant proportion of Category 1 RIT accidents, 31.8%, occur at crossings with flashing lights. This percentage suggests that these lights are not always sufficient by themselves to provide adequate warning to motorists. This same reasoning applies to crossings with gates, but to a lesser extent. However, it is notable that a significant 13.1% of Category 1 RIT accidents occurred at crossings with gates. Other active warning devices (e.g., wig-wags) account for 8.0% of Category 1 RIT accidents. Table 1-2 details the statistics for various categories of crossing accidents discussed above.

Table 1-1. Total Category 1 RIT Accidents by Warning Device (1975–1996)

Warning Device	Percentage of Category 1 Accidents
Passive	47.1
Flashing Lights	31.8
Gates and Lights	13.1
Other	8.0

Table 1-2. Summary of Accidents Potentially Reducible by Reflectorization

CATEGORY BY ACCIDENT	PERCENTAGE OF TOTAL ACCIDENTS
RIT	24.9
Behind Lead Unit	9.0
Nighttime	6.3
Passive Warning Devices	3.0
Flashing Lights Warning Devices	2.0
Gates and Other Warning Devices	1.3
Daytime	2.7
Passive Warning Devices	1.2
Flashing Lights Warning Devices	1.0
Gates and Other Warning Devices	0.5
Lead Unit	15.9
Nighttime	7.4
Passive Warning Devices	3.3
Flashing Lights Warning Devices	2.4
Gates and Other Warning Devices	1.7
Daytime All Warning Devices	8.5

Note: The percentages given are based on specific warning devices. They do not include other/unknown warning device/visibility accidents. Thus, these percentages may differ slightly from the total RIT accidents based on annual counts.

1.3 RESEARCH METHODOLOGY

Results of the 1983 Volpe Center report (Poage, Pomfret, and Hopkins 1983), the continuing significant number of RIT accidents, and technological advancements in reflective material, provided the incentive for developing this four-phased research program to determine the effectiveness of reflectorization. These phases consisted of a review of reflectorization experiences in transportation, a demonstration test, an in-service test, and a human factors evaluation.

The first phase, a review of reflectorization experiences in transportation, was conducted to: (1) determine the effectiveness of reflective material used in the past, (2) establish a baseline of reflector performance for comparison in this study, (3) use lessons learned in previous research to help guide this study, and (4) determine the minimum intensity threshold (the minimum value to attract the attention of a motorist).

The second phase of research, the demonstration test, was conducted at the FRA’s Transportation Technology Center (TTC) in Pueblo, Colorado. The objectives of the demonstration test were to establish: (1) the performance characteristics of newly developed materials compared to the materials tested in 1982, (2) the preliminary costs for material and maintenance, and (3) the preliminary marking design for a nationwide freight car reflectorization test.

The objectives of the third phase of research, the in-service test, were to determine: (1) the performance characteristics of the new material in comparison to an established threshold as well as to the 1982 materials, (2) the reflectors' accident reduction potential, and (3) preliminary costs for reflector material and maintenance to the railroad industry. This test provided a real-time study of the reflective materials' ability to perform under a variety of harsh railroad environmental conditions.

The fourth phase, a human factors laboratory evaluation conducted at the University of Tennessee (Knoxville), evaluated several proposed retroreflective configurations. This evaluation consisted of two parts. In the first part, transportation experts reviewed reflector patterns, then ranked these designs based on their effectiveness. The top eight designs, plus three other designs (including the design created in the second phase), were used in the second part of the study. The second part used drivers in the Knoxville area and transportation experts to evaluate and rank the designs based on their detectability.

1.4 REPORT LAYOUT

Chapter 2 reviews the fundamental theories and properties of reflective materials and visibility, and establishes the minimum or threshold reflector brightness (or intensity) necessary for freight car reflectorization.

Chapter 3 presents a review of previous studies related to the use of reflectorization within the transportation industry. National and international case studies are presented. Additionally, a section discusses the current use of reflectorization by railroad organizations.

Chapter 4 discusses a controlled demonstration test. The findings of this test provided the basis for the shape, size, color, configuration, and location of the reflector markings to be used in the railroad in-service revenue field test.

Chapter 5 discusses the nationwide in-service revenue field test. The results of this test include degradation of prismatic retroreflectors under varying environmental conditions and provide preliminary results of the potential for accident reductions at highway-railroad grade crossings.

Chapter 6 discusses the human factors laboratory evaluation. This evaluation provides subjective and objective evaluations by experts and laypersons, respectively, of the conspicuity of various marking patterns and colors on the side of a typical open top hopper freight car.

Chapter 7 reports the findings of the study and corresponding recommendations.

2. RETROREFLECTION

2.1 FUNDAMENTAL RETROREFLECTING PROPERTIES

The first condition that affects the amount of illuminance reflected back to an observer of a reflector is the reflective material design characteristics. Materials that have reflective properties can be classified in three general categories: direct reflectors, diffused reflectors, and retroreflectors (see Figure 2-1). Direct reflectors bounce light off the reflector material at an angle equal and opposite to the direction of the light source. An example of a material that has direct reflector properties is a mirror. Diffuse reflectors reflect light off the reflected material at an angular spread of up to 180 degrees. An example of a diffuse reflector is a license plate. License plates use embedded glass beads as diffuse reflectors. Further examples of diffuse reflectors can be found in Chapter 3.

Retroreflectors, as the name implies, direct the reflected light in the general direction of the light source. Retroreflectors are used on items such as trucks, automobiles, bicycles, and roadway signs. The American Society for Testing and Materials (ASTM) defines retroreflection as "reflection in which radiation is returned in directions close to the direction from which it came, this property being maintained over wide variations of the direction of the incident (source) radiation" (ASTM 1981).

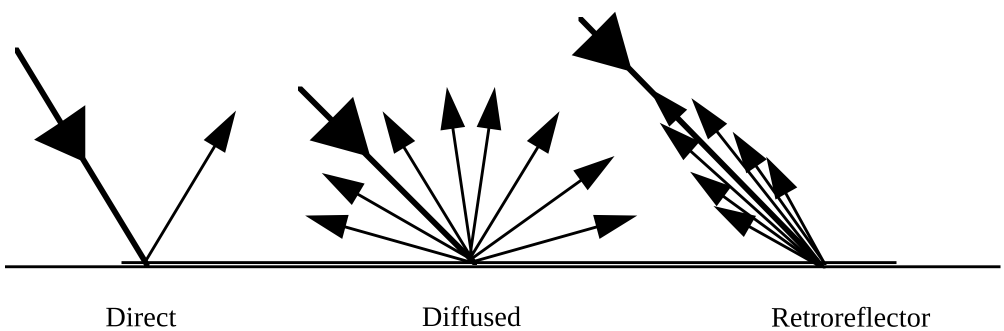


Figure 2-1. Types of Reflectors

The amount of illuminance received by an observer from a retroreflector can be affected by six factors:

1. Reflective intensity of the reflector;
2. Size of the reflector;
3. Intensity of the light source;
4. Atmospheric transmissivity;
5. Windshield transmittance; and
6. Distance of the observer from the retroreflector.

The relationship between these factors and the illuminance received by the observer can be given by the following equation, which is based on *Allard's Law*:

$$E_e = \frac{I_s \; A \; B \; t^{2d} \; W \; H}{d^4} \quad \text{- Eq. 2-1}$$

in which

E_e = Illuminance received by the observer –footcandles, fc
I_s = Intensity of the light beamed toward the reflector – candela, cd
A = Area of the reflector –square feet
B = Reflective intensity of reflector in units of Specific Intensity per unit Area (SIA) – candela/footcandle/ft^2
t = Transmissivity of the atmosphere per foot
d = distance between the observer and the reflector – feet
W = Windshield transmittance – percentage
H = Headlight efficiency – percentage

The above relationship assumes that the incident light from the light source is normal to the surface of the retroreflector. In most typical applications, the incident light will strike the retroreflector at an angle as shown in Figure 2-2. In such cases, the reflected light received by the observer will be reduced. This reduction is a function of three factors: the incidence (or entrance) angle, the divergence (or observation) angle, and the properties of the retroreflecting material. The incidence angle, in terms of retroreflection, is defined as the angle between the light source and a line perpendicular to the surface of the reflector.

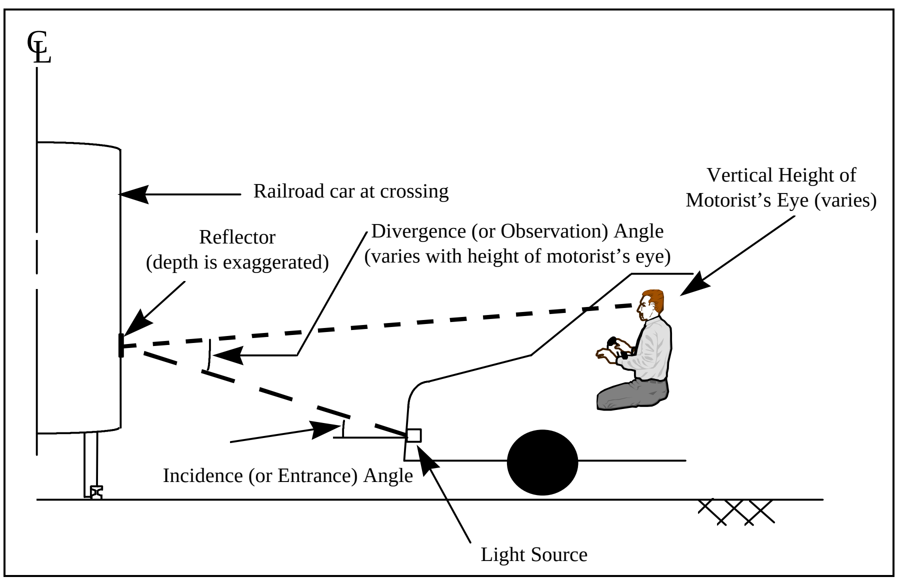


Figure 2-2. Graphical Representation of Incidence and Divergence Angles with Respect to a Railroad Freight Car (Not to Scale)

The divergence angle is the angle formed between the light source and the observer. The reflector will produce maximum reflectivity for the motorist when both the incidence and divergence angles equal zero. This maximum reflectivity will not be achieved for highway-railroad grade crossings, however, due to the fact that the divergence angle increases as the vehicle approaches the reflective material on the train. The reduction in reflectivity can be partly compensated for by using reflective materials with the highest level of performance.

2.2 FUNDAMENTALS OF VISION

For human beings to see in darkness, some light must enter their eyes. Two types of light sources affect the human's ability to see. The primary light source is one that is self-luminous, i.e., a lamp, a campfire, a vehicle's headlights, or a firefly. Secondary light sources are not self-luminous and can be detected in darkness only if light is reflected from their surface. Non-luminous and non-reflecting objects are also visible under low light conditions based on available contrast with a lighter background against which they stand out.

The light that enters the human eye is interpreted by two types of receptor cells that permit vision: (1) the cones, which are predominantly located at the center of the retina (fovea); and (2) the rods, which are more numerous than the cones and are distributed outside the fovea in the retina.

The cones are mainly activated under normal daylight conditions (photopic vision) and are sensitive to color and achieve a high visual acuity by day. The rods do not have the ability to discern color, but they are activated by small amounts of light. The rods are very sensitive and perform under conditions of low illuminance (scopotic vision). At dusk and dawn both types of receptors are activated (mesopic vision); the cones respond to bright lights and bright retroreflective materials. Cones and rods work to supplement each other, and they play an important role in the determination of retroreflector brightness within this study.

Our visual system has its highest performance characteristics under normal daylight conditions. In low light, the conditions are quite different and the performance of the human eye is greatly reduced. At a low level of ambient illumination, the contrast sensitivity and color discrimination of the eye are drastically lowered, with the result that colors merge into the background. The entire visual field becomes indistinct and details are no longer perceptible. This is a major disadvantage in any human activity during darkness. In addition to basic visual deficiencies during hours of darkness, the eyes of many people are also affected by a great sensitivity to glare (e.g., sudden illumination, oncoming vehicles' headlights) accompanied by a slow re-adaptation process during which vision is impaired. Night myopia (night blindness) is another weakness that can affect people and reduce their vision under low light conditions.

As the discussion above indicates, the human eye has a reduced visual ability during hours of dawn, dusk, and darkness. Under these conditions of low-level illumination, the use of bright retroreflectors mounted on the sides of freight cars may enhance the driver's ability to detect and possibly recognize the presence of a train at a highway-railroad grade crossing, and thus avoid an accident.

2.3 MINIMUM THRESHOLD FOR REFLECTOR BRIGHTNESS

As a basis for evaluating reflector performance resulting from laboratory and field tests conducted under this research program, a minimum threshold for reflector brightness was established. This threshold of intensity (luminous intensity) should be bright enough to attract the attention of a motorist approaching a highway-railroad grade crossing. An assumption of the following analysis is that the motorist may not be actively looking for the presence of a train. This could increase the detectability threshold level by 100 to 1,000 times the necessary luminance if the motorist is actively looking for an object (CIE 1987). An additional assumption is that not only should the driver be able to detect the reflector but also to recognize it as describing the existence of a hazard. The requirement of recognition of a luminous object by an observer can increase the detectability threshold 5 to 10 times (IES 1984). There are several theoretical methods that may be used to establish this threshold. The specific method for this study is the "point source method." Discussion of the point source method provides a basis for development of the minimum thresholds used in the following chapters of this report to evaluate the performance of the reflectors involved in this study.

2.3.1 Point Source Method

There are many organizations worldwide involved in providing guidelines for the use of lighting devices. Some of these organizations also provide guidelines for the use of retroreflective material, which are given in Chapter 3. Three specific organizations are discussed below, namely, the International Commission on Illumination (Commission Internationale de L'Éclairage [CIE]), the Illuminating Engineering Society (IES), and the Federal Aviation Administration (FAA).[1]

Many guidelines for reflector visibility are based on the fact that astronomical observations have determined that a star producing an illuminance of 2.3×10^{-9} footcandles at the eye of the observer against an overcast moon sky luminance, equal to 9.9×10^{-4} footlamberts, can be detected with a 98% probability. This finding results in a threshold illuminance level of 2.3×10^{-9} footcandles, and is required for a point source of light to be detected by an observer who knows precisely where to look for it. All point source methods discussed build upon this basic threshold.

The CIE Guide defines the visual threshold or threshold illuminance as the smallest illuminance (point brilliance) produced at the eye of an observer by a light source seen as a point which renders the source perceptible against a given background luminance (CIE 1987). The CIE Guide also indicates that for visual signaling the light source must be rendered recognizable and, hence, a higher threshold of illuminance is expected. An example is given for retroreflective sea markers. A visual threshold of 1.9×10^{-8} footcandles has been found appropriate for a dark night at sea without background lighting. A ten-fold increase in this threshold to an illuminance of 1.9×10^{-7} footcandles is considered appropriate to ensure recognition of retroreflecting sea markers against a minor background lighting comparable to a populated shore environment. The CIE Guide recommends that the minimum threshold be increased further to 4.6×10^{-7}

[1] The FAA discussion within this report is contained within the IES Lighting Handbook.

footcandles for visibility distances less than 3,281 feet to compensate for back-scattering of the light source.

The IES Lighting Handbook uses the minimum threshold illumination of 2.3×10^{-9} footcandles. This value represents a 98% probability of detection when an observer is looking for the source of light. This minimum must be increased by 5 to 10 times for the light or source to be easily found, resulting in a threshold of 2.3×10^{-8} footcandles. The IES handbook further specifies that these increases in illuminance are applicable only when the observer is looking for the light signal. Much greater increases are required if the light signal is to attract the attention of the observer. Factors of 100 to 1,000 are used instead with a resultant luminance level of 2.3×10^{-6} footcandles (Breckinridge and Douglas 1945). This illuminance level is about five times that of the CIE sea marker example given above. The IES handbook further states that this value is applicable to sources of light which are, in effect, point sources. Most signal lights are considered to behave as point sources.

The FAA uses a threshold level of 7.8 times the basic illumination level of 2.3×10^{-9} footcandles for pilots in approach to airport runways. This level is also increased by a factor of 100 to 1,000 — which is equivalent to 2.3×10^{-6} footcandles — if the source is to attract the attention of the pilot. Of the three organizations discussed, two (FAA and IES) suggest a more conservative value of 2.3×10^{-6} footcandles for a minimum threshold illuminance level. For purposes of this study, therefore, this more conservative value was used. Studies by Poage, et al. (1983), and McGinnis (1979 [Ref. 21]) on freight car reflectorization have also used this threshold level in determining the necessary brightness of reflectors mounted on railroad freight cars to attract the attention of motorists.

In an extension of the point source method, the IES Lighting Handbook discusses and references a report de Boer completed in 1951 entitled *Visibility of Approach and Runway Lights*. Based on de Boer's work on runway lights, approximate thresholds have been established for sources that are too large to be considered point sources. Thresholds for the larger sources are determined by multiplying the point source threshold by a size factor that is related to the ratio of the source diameter to viewing distance. Table 2-1 shows the relationship of the ratio to the size factor multiplier for sources considered other than point sources.

This table is used as a multiplier for the use of the threshold level determined by the point source method. Based on the two diameters of reflectors used in the in-service revenue field study, 4-inch and 8-inch as will be discussed in detail in Chapter 5, and a motorist detection distance of 500 feet, the resultant ratios are determined to be 0.00067 and 0.0013, respectively. Based on de Boer's work, the point source method with no adjustments would be applicable for night conditions, which is the primary focus of this study. Only for larger reflectors under daytime conditions would a minor 20% increase in threshold be suggested.

Further support for use of the point source method is provided by McGinnis's research, which states that if the visual angle subtended is less than a critical angle, the point source method should be used. The critical angle stated by McGinnis, based on the background luminance of an overcast moon, as mentioned above, is 6.8 minutes of arc. A typical reflector of 12-inch diameter would have a visual angle of approximately 6.8 minutes of arc when viewed at a distance of 500 feet. Consistent with this finding, studies in Australia (Fisher and Cole 1974) have determined that the intensity of red traffic signals required to produce optimum recognition in bright daylight conditions are independent of source size subtending a solid angle of up to 16.5 minutes of arc.

Table 2-1. The Effects of Source Diameter and Viewing Distance to Size Factor Implications

Ratio of Source Diameter to Viewing Distance	Size Factor Multiplier	
	Night	Day
0.0005	1	1
0.001	1	1.2
0.003	1.1	2.5
0.005	1.4	4.9
0.01	2.5	20

2.3.2 Determination of Threshold Intensity for Tested Reflectors

Based on the previous discussions, the threshold luminance and resultant SIAs used in the following chapters of this report are based on the point source method. Accordingly, an illumination level of 2.3×10^{-6} footcandles is assumed to be sufficient for detectability and recognition. If a level approach grade, a 2.5-second driver reaction time, wet pavement, and a vehicle speed of 50 mph are assumed, the motorist must be aware of a train's presence when the vehicle is 500 feet from the crossing so that the vehicle can be brought to a safe stop. The required reflector intensity is the reflector area, A, multiplied by the specific intensity per unit area (commonly referred to as SIA or the reflective brightness), B, and can be determined from Equation 2-1, using the following assumed values:

E_e	= Required Level of Illuminance	2.3×10^{-6} footcandles
d	= Required Detection Distance	500 feet
W	= Windshield Transmittance	0.70
H	= Headlight Efficiency	0.85
I_s	= Headlight Intensity	3000 cd (per headlight)
t^{2d}	= Atmospheric Transmittance	0.945

The results indicate that the reflector brightness must have an overall reflective intensity of approximately 45 cd/footcandles.

Two sizes of reflectors are used in the in-service revenue field test. Their minimum SIA values are shown below:

- A reflector measuring 4 inches by 8 inches requires a minimum SIA of approximately 200 $cd/fc/ft^2$
- A reflector measuring 4 inches by 36 inches requires a minimum SIA of approximately 45 $cd/fc/ft^2$

This SIA value represents the minimum detection levels used in the third phase of this study, the nationwide in-service demonstration test, which is discussed in Chapter 5.

3. REVIEW OF REFLECTORIZATION EXPERIENCE IN TRANSPORTATION

3.1 REVIEW OF PREVIOUS STUDIES

Research has been conducted on railcar conspicuity materials such as luminous sources (lights on the cars), self-luminous sources (phosphorescent), and reflective sources (mirrors). It was the general consensus of this historical research that reflectorization is the most cost-effective means to alert motorists of an approaching train and/or highway-railroad crossing (Russell, et al. 1994).

Stalder and Lauer (1954) studied the human response to reflectorized railroad cars in a controlled laboratory study. This research measured detectability in a controlled laboratory setting. The subjects observed miniature railroad box cars painted on a thin belt. These miniatures consisted of three designs: (1) unreflectorized box car images; (2) box car images with eleven .09-inch square reflectors, spaced 1 inch at sill level; and (3) box car images with the railroad logos and car numbers reflectorized. The laboratory study used two types of lighting: a Ferree-Rand acuity meter with an adjustable diaphragm, and a Viewmaster Model S-1 projector with a Variac control. The research results indicated three findings pertaining to the use of bright-contrasting reflective material on freight cars at night:

1. The use of materials giving the greatest brightness contrast at night significantly decreases: (a) the amount of luminance needed; and (b) the difficulty of discriminating movement of the box cars crossing the line of vision at night.

2. The larger the patches of material, the lower the level of luminance needed.

3. The extent of the visual angle reflectorized determines effectiveness up to a certain size.

Stalder and Lauer’s analysis also converted their resulting visibility distances (of the unreflectorized, small reflector, and fully reflectorized lettering and numbering) for high beam headlight intensities. This comparison demonstrated that for high beam conditions, box car conspicuity could be obtained for rail cars with “small” reflectors or reflective lettering and numbering. It was also concluded that the results for low beam headlights and/or poor weather conditions at night would be “proportionally lower.”

Lepkowski and Mullis (1973) analyzed rail car reflectorization in detail. Because the number of daytime RIT accidents was significantly fewer than nighttime, this report concentrated on the conspicuity of trains at night. Lepkowski and Mullis studied the use of reflecting fluorescent (paints), luminous (electric power), self-luminous (irradiated), and reflective sources on trains. The results indicated that luminous and reflective sources proved to be effective, however, reflective sources were found to be the most cost-effective. Reflectors also provided conspicuity at a greater distance and field of vision than the other sources studied. In conclusion, it was determined that conspicuity is essential to give an indication of a train’s presence and permit an effective vehicular maneuver to avoid a collision. The study strongly encouraged a voluntary reflectorization program by the railroad industry.

McGinnis (1979) conducted a study that determined the type of railroad crossing accident that would benefit from reflectorization. McGinnis obtained his data from the 1975 FRA Grade Crossing Accident file (now called the RAIRS database). These 12,000 reports were categorized relative to a "critical point." McGinnis provided a relationship between vehicle stopping distance and a critical point on the train. The determination of the "critical point" is based on variables such as the speed of the train, the speed of the vehicle, and the pavement conditions (see Figure 3-1). In summary, the critical point is the location on the train where a vehicle strikes it, and indicates the accident could have been avoided had its presence been detected. The McGinnis research assigned the accidents to four categories. Category 1 accidents occur when the motor vehicle runs into the side of the train after a "critical point" beyond the lead unit. Category 2 accidents occur when the motor vehicle hits the side of the lead unit of the train. Category 3 accidents occur when the motor vehicle hits the side of the train before the critical point of the train is reached. Category 4 accidents occur when the motor vehicle is hit by the train. Many accidents classified as Category 1 were those that could have been avoided if the driver could have stopped safely, having visually detected the train's presence.

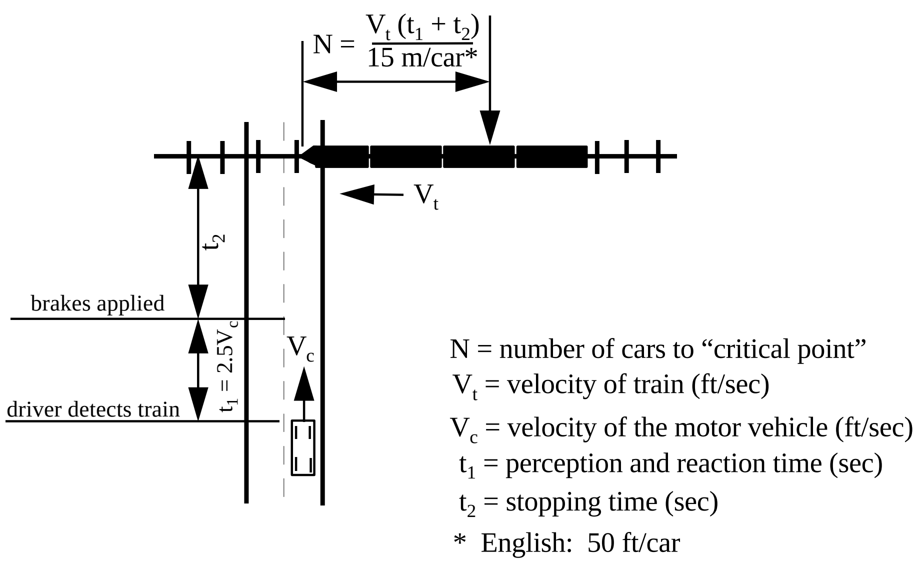


Figure 3-1. Relationship between "Critical Point" on Train and Perception/Reaction and Stopping

In the early 1980s, Poage, et al. (1983), conducted tests in the United States and Canada that examined eight factors affecting the safety impact and costs associated with the application of reflective material on railroad freight cars: (1) material, (2) location and number, (3) color, (4) brightness, (5) shape, (6) size, (7) washing cycle, and (8) degradation. The factor that Poage, et al., studied which pertains to the current research program is degradation of the reflectors in the railroad environment. It was discovered that this environment causes dirt to accumulate on the reflector to an extent that it loses its effectiveness. Washing the reflector will cause a significant rebound towards its original intensity, however, the intensity will continue to decrease with aging. Poage, et al., determined that reflectors should: (1) have an area of 2.75 ft^2, with dimensions of 12 inches by 33 inches; (2) be washed every 20 months; and (3) be replaced every 10 years to achieve “the required visibility under the expected conditions of dirt accumulation.”

One of the studies in Poage, et al., involved 33 Boston and Maine Railroad sand and gravel cars in 1981. High intensity grade sheeting was applied to these cars. These reflectors measured 4 inches by 12 inches, were placed above the sill, and were orange and white in color. After 6 months, the average reflective intensity of 19 of the cars declined to 8% of its initial intensity. It should be noted that there were no long-term studies on these cars.

The second study measured the reflective intensity of 208 freight cars belonging to the Canadian National and Canadian Pacific Railways. This study investigated the use of the 3M Scotchbrand Silver Reflective Sheeting (Engineer Grade). The material is categorized as diffuse and consists of embedded glass beads. The Canadian National Railways used 4-inch discs, while the Canadian Pacific Railways used 4-inch squares. The results indicated that after 2 years of service, the average reflective intensity was reduced to 5% of its initial value. Additionally, night observations (human response) indicated that 61% of these cars were judged to be in poor condition. Poage, et al., concluded that the use of reflective material available at the time was not cost-effective in the railroad environment.

3.2 PREVIOUS EXPERIENCES WITH FREIGHT CAR REFLECTORIZATION

3.2.1 Australia

Uber (1994) discussed three retroreflective degradation studies in Australia. One of the studies was conducted (via in-service field tests) in Victoria and began in 1991. The field test in Victoria tested three types of reflective material sheeting (high intensity, prismatic, and glass beads) provided by five manufacturers. These reflectors consisted of different colors, and two types of coatings (plain and anti-graffiti). Three reflector sizes, which measured 10 inches by 40 inches, 10 inches by 20 inches, and 10 inches by 10 inches, were placed on a captive fleet of quarry hoppers (hopper cars that carry stone products), approximately 55 inches above the TOR. The results of this test indicated that after 2 years of service: (1) the reflectors achieved a maximum performance of 14.5% of their initial reflective intensity; (2) after washing, the diamond prismatic grade rebounded to only 40.2% of its original reflective intensity; and (3) the high intensity grade was inferior to the diamond prismatic grade. The report recommended a “Fix and Forget” approach where the reflectors are replaced when the freight car is maintained. According to Uber, the usage of two Class 1A (diamond grade) sheetings should “provide a minimum retroreflectivity of 45 cd-fc^{-1} ft^{-2} for a period of 4.4 years without washing.”

Ford (1998) and Uber (1994) cited two reports that presented results of a field test on the Queensland Railways’ rolling stock in 1984, and New South Wales Railways’ bulk grain wagons (U.S. hopper cars) in 1989. High intensity white sheeting measuring 5 inches by 15 inches and 30 inches by 48 inches, respectively, was placed on freight cars. The Queensland Railways used four reflectors per side, while New South Wales Railways used only one per side. An empirical investigation was conducted, and both railways reported the reflectors “are very effective” based solely on visual inspection.

3.2.2 Canada

Since May 1959, the Canadian Transport Commission (CTC) and the Board of Transport Commissioners (BTC) have issued Order Number 097788, which required all Canadian freight cars to be reflectorized. Transport Canada Order No. 123336, dated 1/26/67, required that all freight cars measuring 50 feet or less in length have four reflectors per side, and that cars measuring greater than 50 feet have six reflectors per side (see Appendix A). Eighty percent of the cost for this program was funded by the CTC via an amended Railway Act for a number of years. This program was discontinued a number of years ago.

An article in the April 1995 issue of *Traffic Safety News*, stated that new Canadian National Railroad freight cars, built at either the Trenton works or at National Steel Car in Toronto, use the microprismatic material attached for night visibility.

3.2.3 Southern Company

The Georgia Power Company's Plant Bowen was visited by Volpe Center employees in July 1991 to measure the reflectivity of retroreflective decals used on the open top coal hopper cars. These cars belong to the Southern Company and are maintained annually, including the washing of the decals. These decals consisted of yellow high-intensity sheeting measuring 3 inches by 36 inches and 3 inches by 12 inches. Twelve coal hopper cars having a revenue service ranging from 1 to 10 years were tested. Three decals were placed on each side of the hopper car at a height of 42 inches above TOR.

The investigation revealed that: (1) after 5 to 10 years of service, the reflectors maintained 63 to 74% of the estimated original coefficient of retroreflectorization (260 cd/fc/ft^2); (2) after washing with water, the intensity coefficient rebounded to as much as 87% of the estimated original intensity; and (3) improper washing (the use of chemical solvents) can degrade the performance of the material drastically below suitable values in less than 1 year. This report concludes that proper maintenance of decals can create a useful life beyond 10 years.

3.2.4 Burlington Northern

In 1990, Burlington Northern[1] (BN) acquired new covered grain hoppers and aluminum coal hoppers and equipped them with prismatic reflectors. BN coal-carrying open top hopper cars were reflectorized and have been operating along the northern coal corridor for several years.

In a separate investigation during July 1992, Volpe Center employees traveled to Mandan, North Dakota, to locate reflectorized coal hopper cars and measure their reflectivity after several years of service. Most of these cars were between 16 and 17 years old, and were reflectorized by paint and decals as markings. A total of 104 cars were tested in a 3-day period, and included over 600 decals made from white high-intensity material. An analysis determined that the majority of the decals were "unreadable," and the decals that could be measured had average SIA values that ranged between 1.6 to 199.67. One decal had an exceptionally high SIA of 294.67.

[1] Burlington Northern and Santa Fe merged in 1995 to form the Burlington Northern Santa Fe Railway.

3.2.5 Other Railroad Organizations

Wisconsin Central Railroad applies orange and white micro-prismatic reflectors 42 inches above TOR. These decals measure approximately 2 inches by 16 inches, and are applied at the ends of the cars, in a pattern resembling that used on the rear of large trucks, such that locomotive engineers can see the cars in the yards. Freight car reflectorization is limited to box cars, hoppers, gondolas, and intermodal double stack cars. This program is in response to Wisconsin's legislative Statute §192.267, which states:

> "Luminous markings on engines and cars. Every railroad engine and railroad box car, flat car, gondola, and tank car, which is built or rebuilt in this state, shall have luminous tape or reflectors affixed to each side. The tape shall be at least 2 inches wide and shall form a continuous horizontal strip. The reflectors shall be not less than 2 inches in diameter and shall be placed not more than 6 inches apart in a horizontal line."

The Santa Fe Railway[2] has applied 6-inch by 6-inch reflective panels every 8 feet on new and rebuilt equipment. The number of Santa Fe units with retroreflective material was estimated at 20,000. Also, the Soo Line has applied reflective material to its equipment for advertisement purposes, improvement of nighttime yard operations, and safety.

3.3 TRUCK REFLECTORIZATION

In 1979, Sivak published a report entitled *A Review of Literature on Nighttime Conspicuity and Effects of Reflectorization*. Sivak's report was concerned with the results of Minahan and O'Day (1977) that found fatal truck-car accidents frequently occur at night and with frequent car underride. The report dealt primarily with the theoretical analysis of the nighttime conspicuity problem and with empirical data on the effect of retroreflectorization. The findings concluded the following:

1. A treatment resulting in an increased visible size or increased contrast (luminance) is likely to be conspicuity enhancing and therefore,

2. Retroreflectorization of parts of vehicles would likely be beneficial for highway safety.

In the late 1970s and early 1980s, Burger, et al. (1985), conducted a study of vehicle-into-large-truck accidents that produced a disproportionately large number of fatalities. The study used approximately 2,000 trailer trucks over a 2-year field study. Red-and-white 2-inch retroreflective material was used during this study. The back of the trailer trucks was fully outlined whereas the sides only had a red-and-white strip along the side rail. The results of the 23-month long study indicated an 18% overall reduction of collisions in which other vehicles struck reflectorized tractor-trailer units. The daylight and dawn, dusk and darkness reductions were found to be 16.3% and 21.2%, respectively. These reductions were found to be statistically

[2] See note 1 on preceding page.

significant. This study indicated the need to determine whether: (1) the perimeter outline of trailer sides or the use of 4-inch versus 2-inch material would result in an even greater collision reduction; (2) other colors would result in equivalent effectiveness; (3) other reflective angular light dispersion characteristics are more or less effective; and (4) whether logos can be integrated into reflectorization requirements to provide similar effectiveness (Burger, et al.).

In the early 1990s, NHTSA was tasked to develop a set of specific recommendations for setting minimum performance specifications for reflectorizing large tractor truck trailers. A 1992 report entitled *Performance Requirements for Large Truck Conspicuity Enhancements* indicated that collisions of motor vehicles with trucks are caused by the motorist’s inability to detect the truck in time. The report’s purpose was to indicate an effective way to increase truck conspicuity. The report determines the desirability and feasibility of improving nighttime detection and recognition of large trucks at night.

Reflector placement during the NHTSA study conducted by the University of Michigan Transportation Research Institute (UMTRI) resulted in reduced collisions among vehicles of the Greyhound Corporation, the U.S. Postal Service, and the Toronto Transit Commission. The study data suggested that trucks with reduced conspicuity are a particular hazard for alcohol-involved drivers.

The report suggested that material should be as uniform as possible within the constraints imposed by the variety of truck types. The use of a distinctive marking should be a significant aid in recognition of an object such as a truck at night. This would reduce the motorist’s confusion and reduce the response time needed to avoid a collision.

The report recommends an alternating red-and-white bar as the best conspicuity pattern over a solid white bar, which gave the best recognition (detection) performance, for three reasons: (1) the solid white bar might be too bright a stimulus under some operating conditions (provides undue glare to the motorist); (2) a conspicuity marking should have a distinctive pattern (enhances recognition capabilities); and (3) a color contrast effect is required for daytime conspicuity. The final recommendation was for a minimum pattern in which 8 inches of white prismatic material alternates with 12 inches of red prismatic material. The white prismatic material can be as long as 12 inches. It was also recommended that the vehicles should use reflectorized tape (either continuous or broken strips) on the truck trailer sides along the bottom, continuous tape on the rear along the bottom, and white tape at the top corners (on units that will allow an upper configuration). A minimum SIA value of 127 and 32 for the white and red, respectively, along the sides of the trailer, and a minimum SIA value of 254 and 64 for the white and red, respectively, at the rear of the trailer, were calculated. This recommendation was established based on controlled field and subject tests, and will aid in estimates of distance and closing speed, as well as marking a potential hazard.

This report led to the subsequent development of rulemaking by NHTSA for large truck conspicuity that was mandated in January 1995. This rulemaking is located in 49 CFR §571.108.

3.4 OTHER MODES OF TRANSPORTATION

Since transportation of people and goods is not restricted to daytime hours and pristine weather conditions, reflectorization has become a necessary tool for enhancing visibility for certain modes. Reflective material is used in airports and highways, on maritime equipment, and by pedestrians. The everyday use of reflectors indicates its acceptance to delineate potential hazards and obstructions to a vehicle's path of travel.

Historically, air and ground transportation operators have used reflectorization. Microprismatic corner cube retroreflectors are typically used on roadway signs that warn of construction, obstructions, or hazardous conditions. High intensity reflective sheeting is used on informational and directional roadway signs for easy long-distance viewing at night. Diffuse reflectors are used on airport taxiways, tarmacs, and runways. Various types of diffuse reflectors are used on other roadway appurtenances, such as delineators, striping, and pavement markings.

Vehicles are required to display reflective features on their exterior. Airplanes and motor vehicles (e.g., buses, cars, trucks, and vans) are equipped with high brightness retroreflective material, microprismatic corner cube retroreflectors, at key locations on the exterior surfaces to increase their conspicuity. Bicycle safety is a mode of transportation that has specific regulations on the use (16 CFR §1512.16) and testing (16 CFR §1512.18) of diffuse reflectors.

Lifesaving marine equipment, such as life vests, rings, and rafts, requires reflectorization. This type of reflective material is called "Safety Of Life At Sea" (SOLAS) (CIE 1987). This material is a wide-angle enclosed lens reflector that has a wide observation (incidence) angle, and performs well under wet or fully immersed conditions. Signs, buoys, bridge pillars, and sluices typically use high brightness retroreflective material, non-SOLAS sheeting, and microprismatic corner cube retroreflectors.

The safety of the pedestrian is incorporated within various state laws. To enhance the conspicuity of pedestrians, especially at night, high brightness retroreflective material, microprismatic corner cube retroreflectors, have been incorporated into clothing and items such as vests, Halloween costumes, shoes, and skating equipment.

3.5 SUMMARY OF FINDINGS

International and domestic historical literature and experience indicates that the use of currently available reflective material on freight cars in a railroad environment may be successful in reducing nighttime motor vehicle run-into-train (RIT) collisions. Specific findings include:

- Reflective materials can enhance motorists' ability to detect the presence of a train in a highway-railroad grade crossing.
- A material with the maximum intensity available should be used (prismatic) to provide the highest level of illuminance to the observer and to reduce maintenance requirements.
- A uniform pattern will enhance the motorist's recognition of a train in time to avoid a collision.
- A favorable placement location for reflectors is 42 inches above top of rail.
- Using visibility assumptions established by previous reflectorization studies, a reflector measuring 4 inches by 8 inches would require a minimum specific intensity per unit area (SIA) of 200 $cd/fc/ft^2$ to attract a motorist's attention. A reflector measuring 4 inches by 36 inches and using the same conditions would require a minimum threshold of 45 $cd/fc/ft^2$.
- Several railroads have voluntarily reflectorized their rolling stock.
- The use of reflectors has been successful in other modes of transportation as a means to enhance conspicuity.

4. DEMONSTRATION TEST

4.1 DEMONSTRATION TEST METHODOLOGY

The purpose of the demonstration test was to evaluate the degradation of different reflective materials applied to freight cars under controlled conditions. During the test, 3 types of reflective materials were applied to 14 open top hopper cars. Based on the results of the demonstration test, the most suitable material, color, design, placement location, and configuration were defined for further testing in the third phase of this research. The initial phase of testing was designed to demonstrate advances made in materials related to reflectorization of freight cars, over the last 10 years. The test was conducted at the FRA's Transportation Technology Center (TTC) in Pueblo, Colorado, between March 1991 and March 1992. The following objectives were established for the demonstration test:

1. Establish the performance characteristics of newly developed materials compared to the materials tested in 1982.
2. Establish a preliminary marking design for the in-service freight car reflectorization test.
3. Determine preliminary costs for material and maintenance.

4.1.1 Description of Reflectors Tested

The Volpe Center placed an advertisement in the *Commerce Business Daily* in November 1990, asking for companies to participate in a study on reflective materials. Two companies responded and provided three types of retroreflective materials for the demonstration test. One company provided both the enclosed lens (engineering grade) and a prismatic retroreflective material (diamond grade) while the other provided the bonded reflective material (diffuse reflector).

Types of Materials Tested. The bonded reflector consists of small reflective exposed beads attached to the backing material of the reflector. Light entering these beads is focused at or near the rear of the bead and is reflected back to the observer in a diffuse beam pattern. This material is normally used for pavement marking applications and is categorized as a diffuse material.

The enclosed lens reflector consists of microscopic beads that are encapsulated and bonded within the material. Light striking these beads is reflected back toward the observer in a narrower beam pattern than the bonded type but still in a diffuse beam pattern. This material is generally called "engineering grade" and was tested in 1982 by the Volpe Center.

The prismatic (corner cube) type retroreflector is made up of microscopic prisms or corner cubes. Each of these corner cubes contains 3 surfaces oriented at 90 degrees of each other. The entering rays of light are reflected from each of the surfaces and are returned to the observer in a more concentrated and focused beam than either of the other two materials tested. This material is generally called "diamond grade" and is the newest material available within the industry.

Size and Location of Reflectors. The train consist used for the demonstration test comprised 80 open top hopper cars with reflective decals applied to 14 cars. Eight freight cars had 4-inch by 4-inch decals placed on the side sill; five cars had 4-inch by 2-inch decals placed on the wheel plates, and one car had a 4-inch by 96.5-inch decal placed vertically along the corner brace of the car.

4.1.2 Reflector Color and Pattern

Various colors and patterns of the three materials were used during the demonstration test. The 4-inch by 4-inch and the 4-inch by 2-inch decals were either all red, all white, or a combination of both colors (which consisted of half red/half white, red-and-white stripes, or diamonds).

Figure 4-1 shows one of the two reference freight cars that have four groupings of three decals. Each group of three decals included one each of the three materials acquired. These four groups are placed 108 inches apart, 54 inches above the top of rail (TOR), along both side sills. These two freight cars represent the washed and unwashed reference cars.

With the exception of the cars with wheel plate decals and the delineator strip, all cars mentioned in this section had decals located 42 inches above the TOR.

The second reference freight car shown in Figure 4-2 has four groupings, each with two decals, placed 108 inches apart, comparing the enclosed lens material with the prismatic material. The remaining decals tested in this phase were made of prismatic material.

Figure 4-1. Full and Close-Up Views of Reference Car with Bonded, Prismatic, and Enclosed Materials

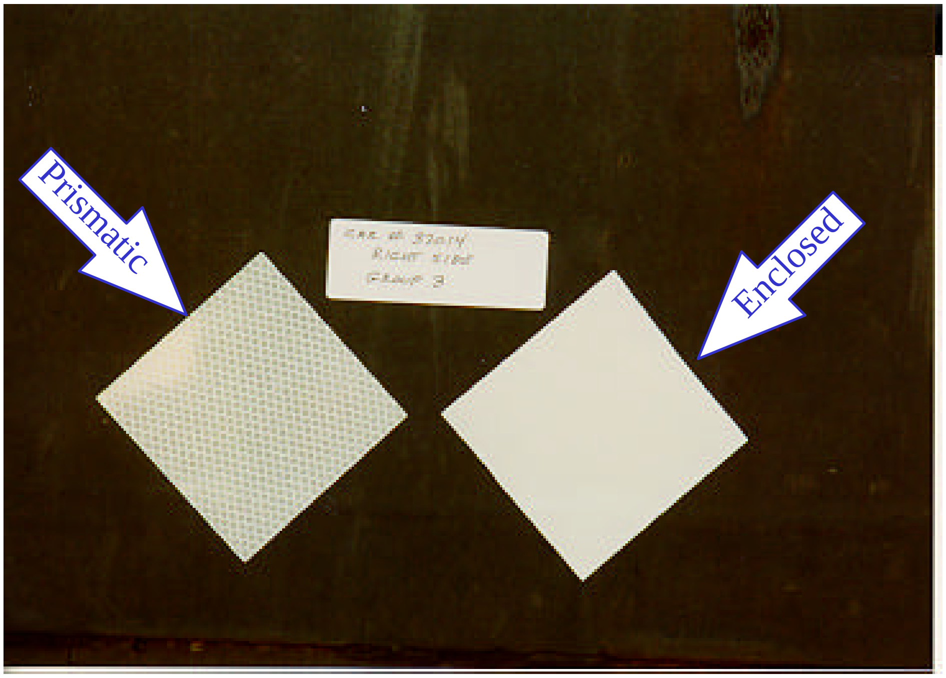


Figure 4-2. Full and Close-Up Views of Prismatic and Enclosed Lens Materials

Figure 4-3 shows the freight car that has a 4-inch by 96.5-in vertical alternating red-and-white prismatic material decal located on the corner bracing of the hopper car.

Figure 4-3. Full and Close-Up Views of Red-and-White Vertical Reflector

Five of the freight cars had prismatic material decals, either red or red-and-white, with various patterns. Figures 4-4 through 4-8 show the various patterns and colors for each design.

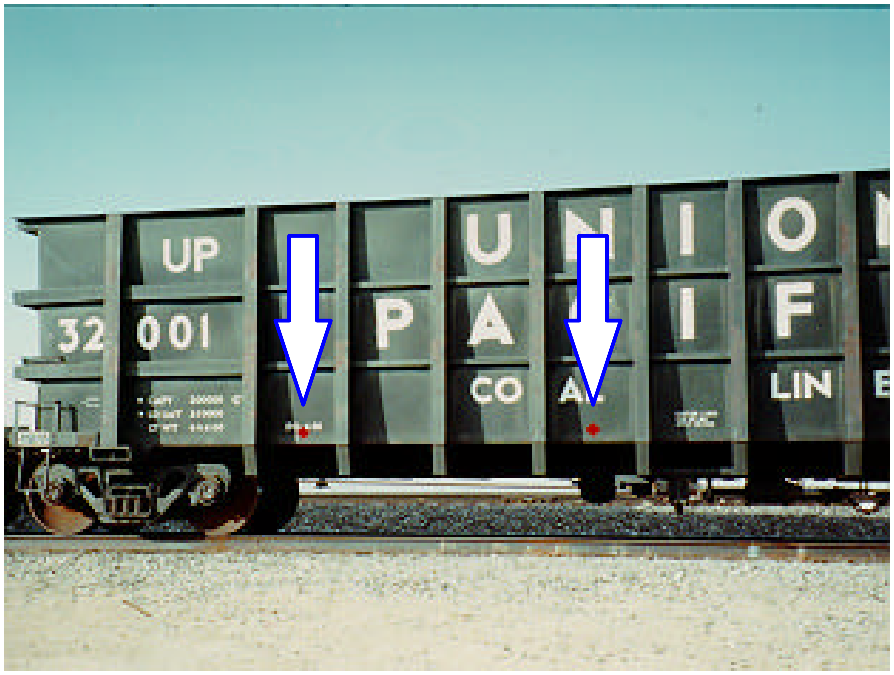


Figure 4-4. Full and Close-Up Views of Solid Red Decal

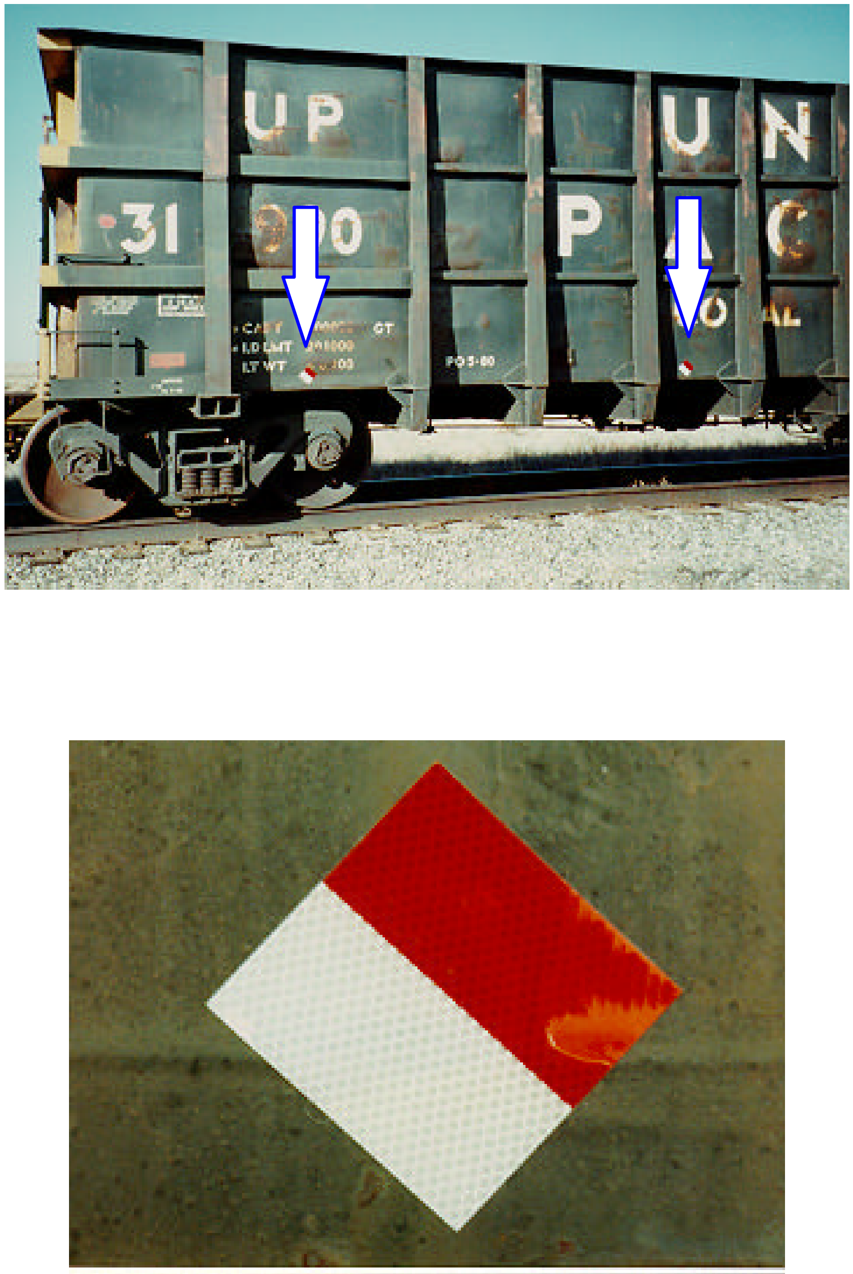


Figure 4-5. Full and Close-Up Views of Half-Red/Half-White Decal

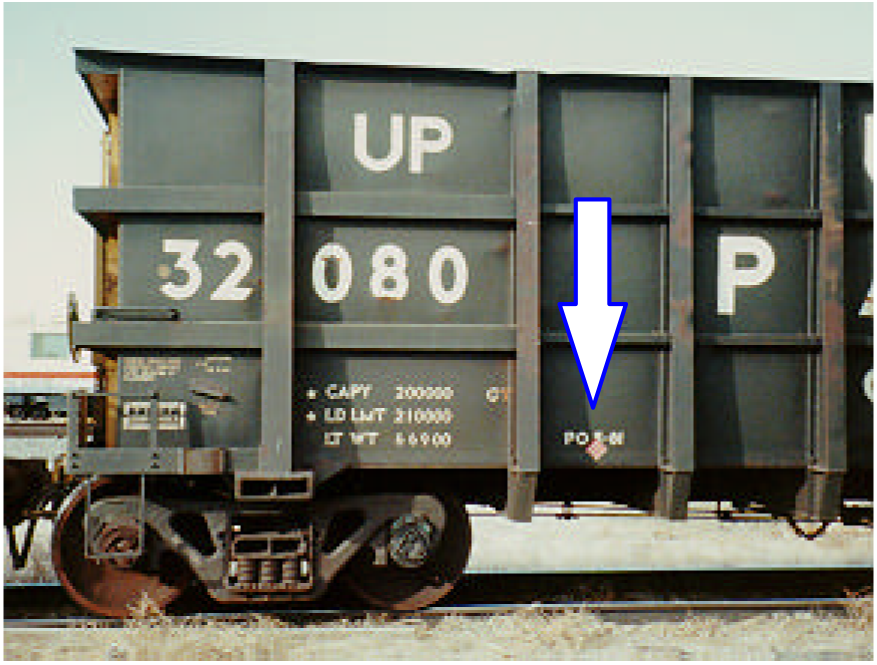


Figure 4-6. Full and Close-Up Views of Alternating Red and White Stripes

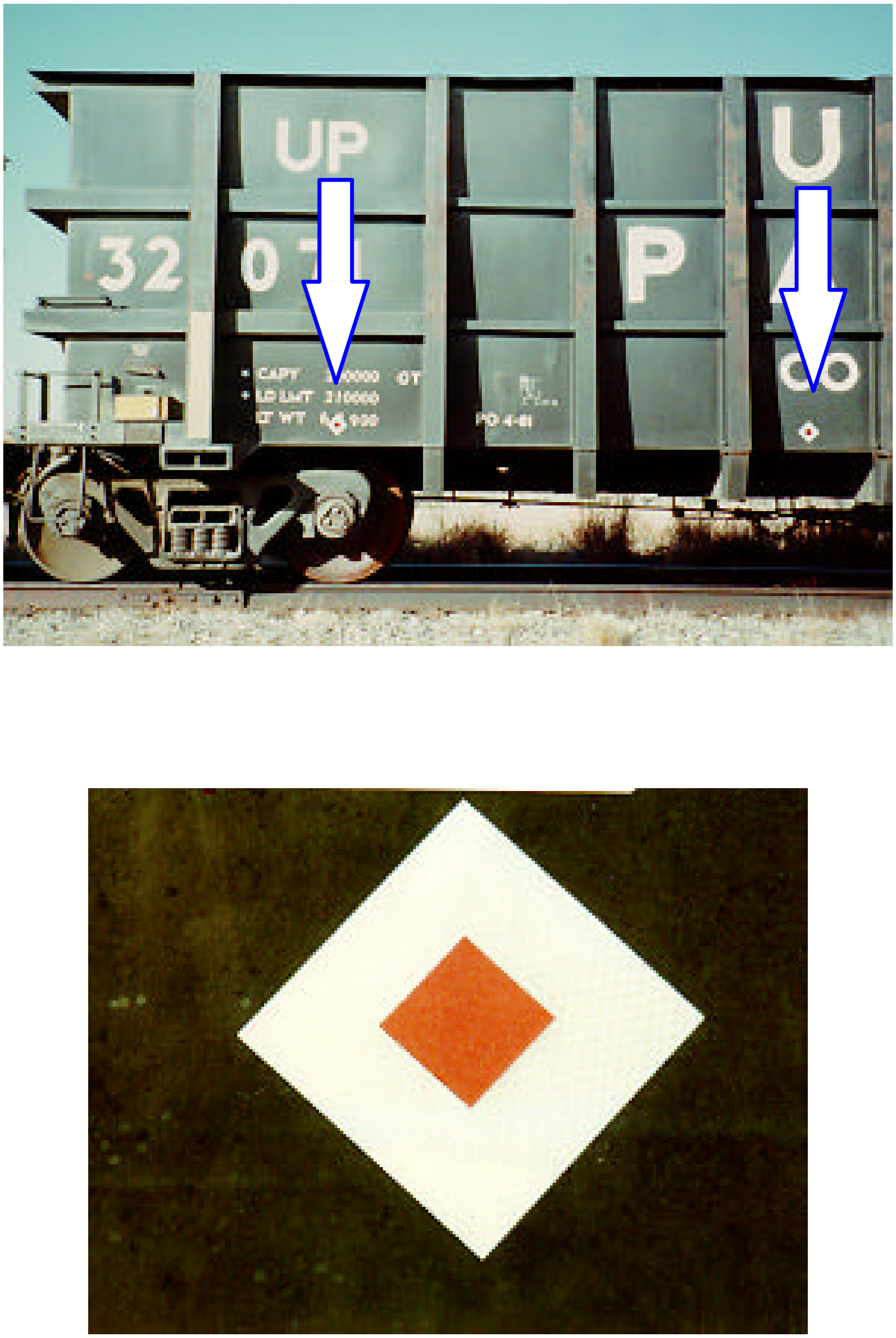


Figure 4-7. Full and Close-Up Views of Red-on-White Diamonds

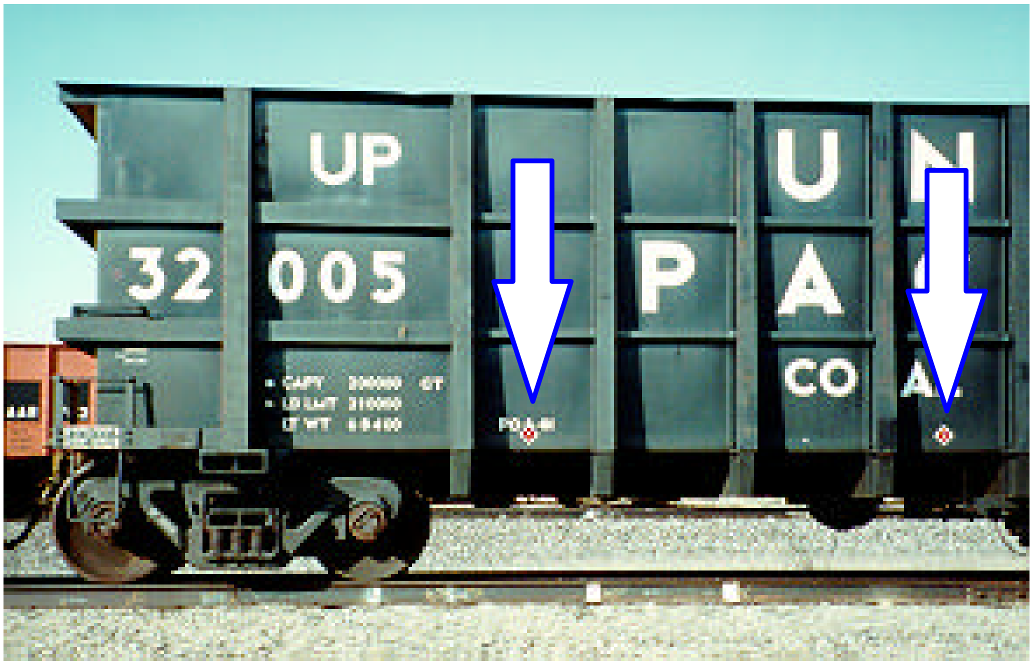


Figure 4-8. Full and Close-Up Views of White-Red-White Diamonds

Five of the freight cars had 2 or 3 prismatic type decals, each 4 inches by 2 inches, located on each wheel plate at either a 90-, 120- (see Figure 4-9), or 180-degree separation. The decals were white, red, or a combination of both.

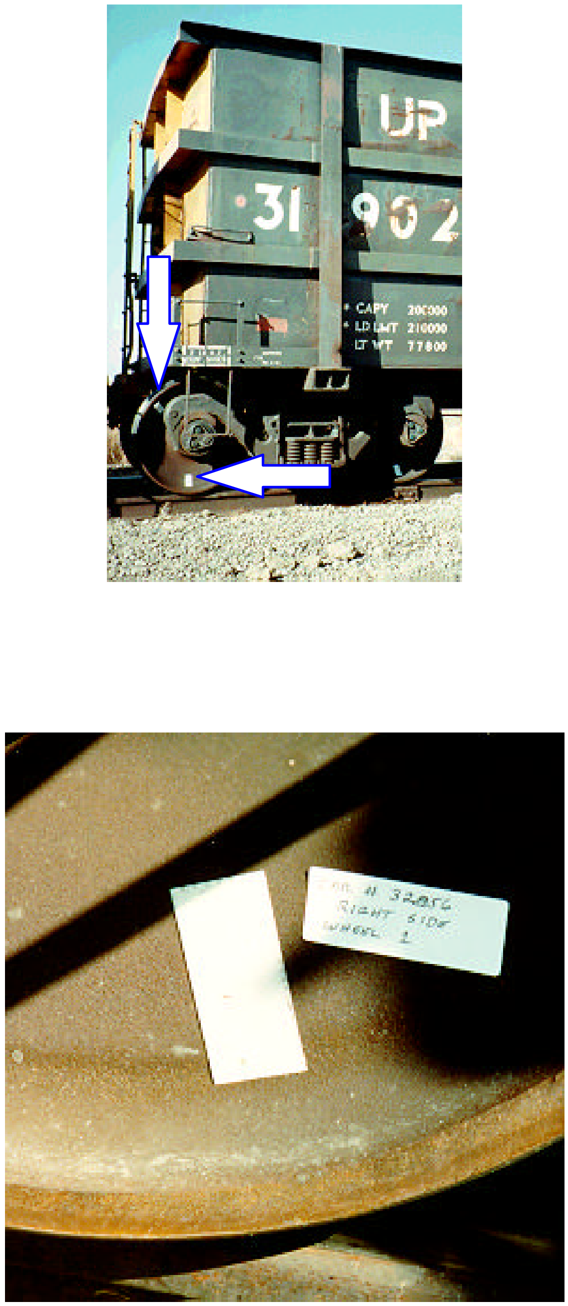


Figure 4-9. Full and Close-Up Views of White Wheel Plate Decals at 120-Degree Spacing

4.1.3 Demonstration Test Site Conditions

The TTC is situated 4,663 feet above sea level and has a relatively flat terrain. The climate is semi-arid and marked by large daily temperature variations. Temperatures in excess of 90° are not uncommon during the summer months while dropping to 0° during the winter. Summer precipitation is usually in the form of afternoon thunderstorms. Blowing dust frequently develops during the spring months, especially in an abnormally dry year.

The TTC demonstration test was initiated during the week of March 18, 1991. The consist was marked with the reflective decals described in Section 4.1.2. Initial car documentation as well as initial brightness and other parameters were logged. (See Appendix B for information on the instrumentation and measurement procedure.) A nighttime video was taken at a simulated grade crossing at several distances and angles to evaluate shape recognition, color definition, and sight distances. The specific characteristics of the demonstration test can be found on a video produced by the Volpe Center and available from the National Audiovisual Center Library in Capital Heights, Maryland, entitled, *Freight Car Reflectorization – Demonstration Test* (Volpe Center 1992).

Nine monthly sets of measurements were taken through December 1991. In March 1992, the final measurements of the one-year test were completed. Environmental conditions and accumulated mileage were logged. Both natural and scheduled washing effects were noted. The test results are shown in Section 4.2. An analysis of those results and the subsequent findings can be found in Section 4.3 of this chapter.

4.2 DEMONSTRATION TEST RESULTS

4.2.1 Reflectivity Measurements

The data and findings presented encompass a 1-year test span in which the test consist accumulated 12,941 miles in a climate offering a full mix of weather conditions and seasons. The data in Figure 4-10 shows the comparison of the three types of white material used — prismatic, enclosed lens, and bonded — after 1 year of testing.

The data presented in Figure 4-10 was obtained from the unwashed reference car that comprised four groups of the three types of decals on each side of the train. Each monthly measurement was the average of 24 individual measurements taken on each type of material (each reflector was measured three times).

It is evident from the data that the prismatic material has a much higher initial SIA value than the other two materials tested. The prismatic material, after 1 year of service, maintained an SIA value that is 87% of the original measurement.

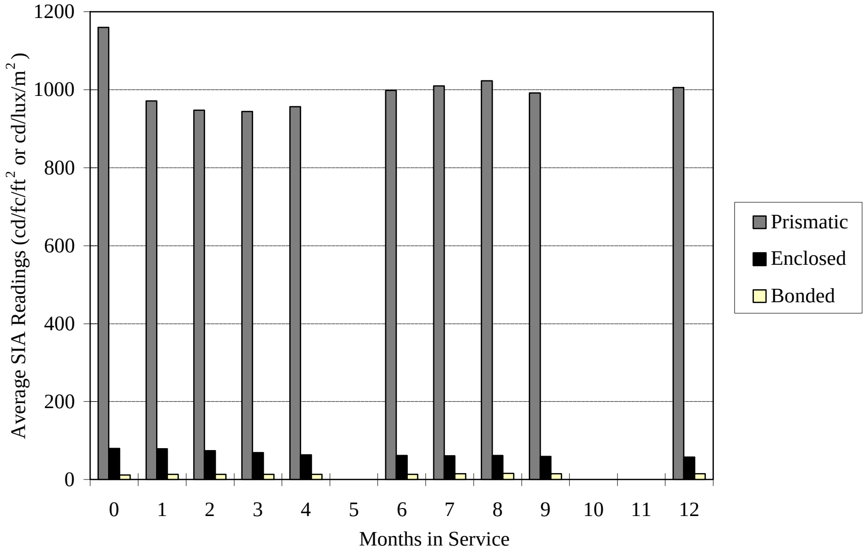


Figure 4-10. Comparison of All Reflective Materials Tested (Unwashed Reference)

The following comparative sets of data are presented using the mean and one standard deviation for each set of monthly measurements. In Figure 4-11, the unwashed white prismatic material and unwashed white enclosed lens material results are shown. The enclosed lens material is the same material used in the 1982 Freight Car Reflection report. The sample population for these graphs includes the unwashed reference car data and the old (materials investigated in the 1982 study) versus new (materials developed since the 1982 study) car data. Each monthly data point is the average of 3 readings on each of the 16 decals, or 48 individual data points.

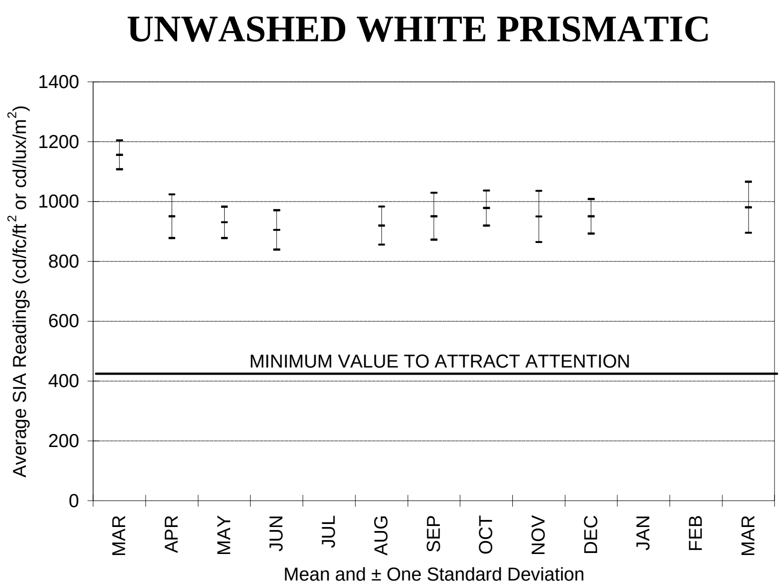
Since these decals are 4 inches by 4 inches, the minimum SIA value of 405 is needed to attract the attention of a motorist (see Section 2.3). It is evident from the data in these graphs that the prismatic material lies far above the minimum value, while the enclosed lens falls far below it.

It should be noted that the bonded lens material SIA values were initially so low that the data was omitted for the rest of this report.

For the purpose of choosing the material for the nationwide in-service field test, a more practical method of viewing data is expressed in the form of percentile distributions using the 85th percentile as a reference. The choice of percentile is somewhat arbitrary. In highway design it has been traditional to set standards to exclude no more than 15% of the relevant population. Hence, the 85th percentile was used as a performance criterion.

This method was used in Figure 4-12 in comparing the percentile distributions for the white prismatic and white enclosed lens material. The white prismatic SIA value at the 85th percentile was 861 compared to 59.5 for the enclosed lens type. The sample population for these graphs includes the unwashed reference car data and the old versus new car data. The percentile distribution graph comprises 480 individual data points.

From the data presented in Figures 4-11 and 4-12, it is obvious that the white prismatic material has a much higher SIA value or coefficient of retroreflection than the older encapsulated lens type, which was used in the 1982 tests.



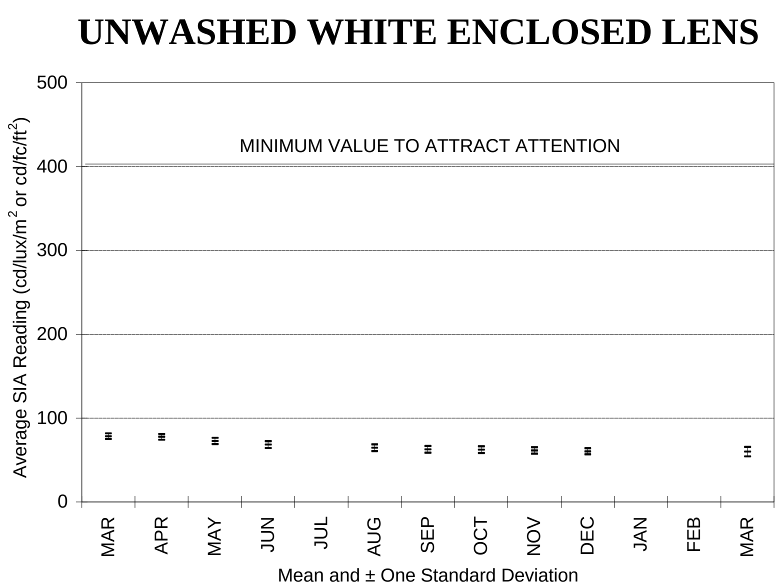
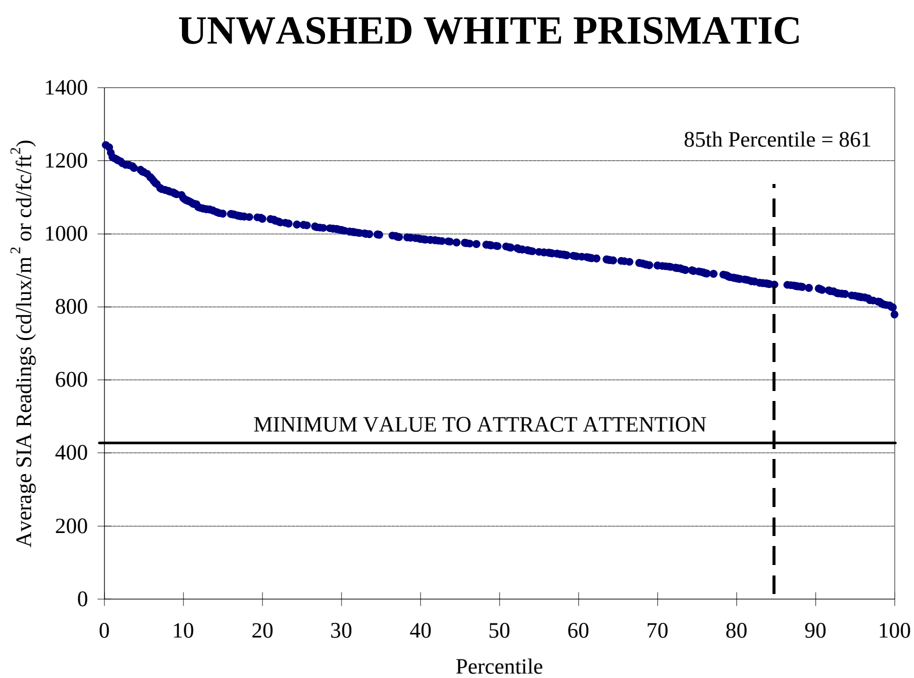


Figure 4-11. Unwashed Prismatic vs. Unwashed Enclosed Lens (Mean and One Standard Deviation)



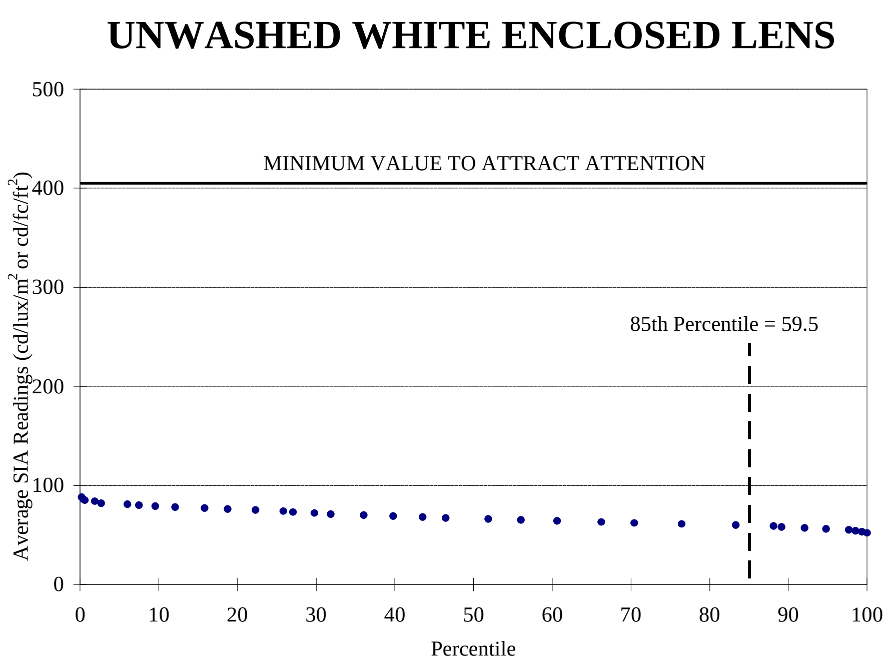


Figure 4-12. Unwashed Prismatic vs. Unwashed Enclosed Lens (Percentiles)

Red Prismatic Material. The mean and percentile data shown in Figure 4-13 are for the solid red prismatic material. These decals are 4 inches by 4 inches and again the minimum SIA value needed to attract the attention of a motorist is 405. The sample population for these graphs consisted of eight decals mounted on one car. Each monthly mean was the average of 24 individual measurements. The percentile distribution comprises 240 individual data points.

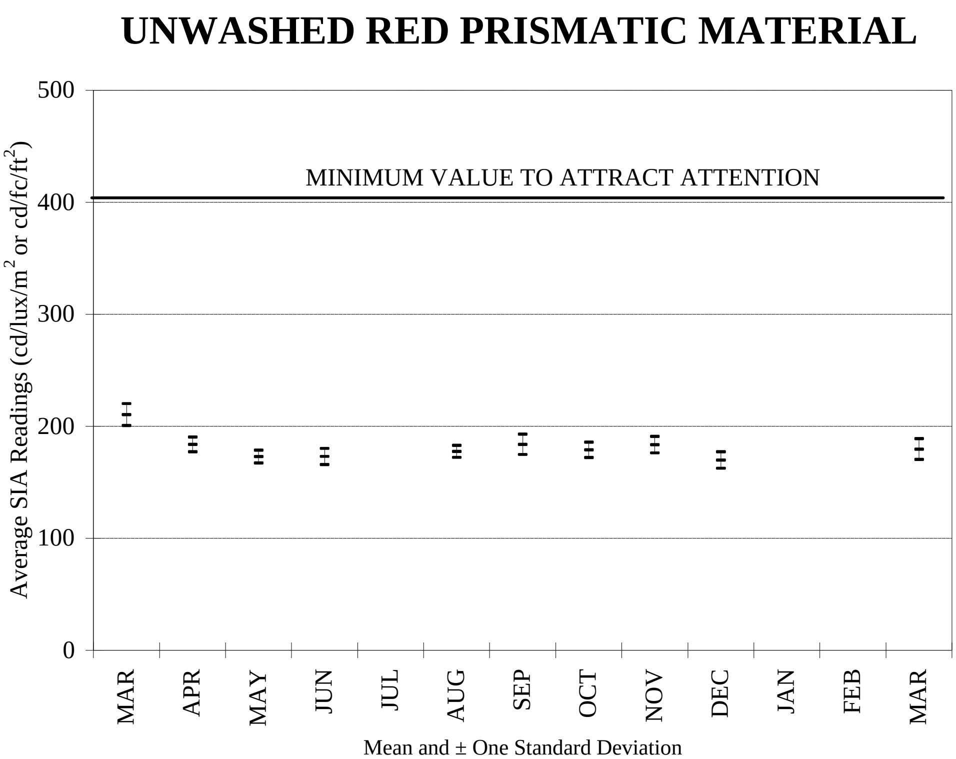
Although the values are below the minimum value needed to attract attention, the additional implication of red being associated with danger might warrant further investigation of using red or a combination of red and white material. In a 1988 report, P. L. Olson states that "the apparent brightness of a color depends to some extent on its saturation. The reds employed in retroreflective materials are highly saturated, appear brighter, and are detected at greater distances than would be suggested by their SIA. This effect was noted more for reds than for any other color in a field test of sign conspicuity."

Red-and-White Delineating Stripe. It is important for motorists when approaching a darkened highway-rail grade crossing to be aware of a train's presence within the crossing. The improved visibility of trains offered by decals placed on the train sill can be further enhanced by placing long vertical decals that delineate the ends of freight cars. The data presented in Figure 4-14 is for a 4-inch by 96.5-inch prismatic material, alternating red and white pattern decal that was placed vertically at the end of the car. The SIA values presented are an average of the red and white readings. The large area of these decals lowers the minimum SIA value to 17. The population sample was limited to one car with one delineating strip on each side. Each month's average consisted of 10 individual measurements. The averages and percentile distributions of the alternating red and white are far above the minimum detection level.

Wheel Plate Decals. For decals located on the wheel plate, the motion of the wheels improved their visibility and increased the conspicuity of the freight car. However, the decals accumulated dirt and grease very quickly, due to their low placement and proximity to the track and roadbed. These decals became ineffective after only a few months. No results are shown.

4.2.2 Washing Effects on Prismatic Materials

One of the test parameters was to monitor the results of washing various decals at specific intervals. Only the prismatic material results are shown in the next series of figures. One freight car of the consist was equipped on each side with four sets of the three types of materials. Each of these sets was washed at intervals of 1, 2, 4, and 6 months, respectively. The data shown in Figure 4-15 depicts the results of the 1- and 2-month washing cycles of the prismatic material. In both instances, the SIA value returns to or very close to its initial value. This seems to indicate that the degradation process is only due to the accumulation of dirt on the surface, and does not destroy the retroreflective properties of the material itself. The 4- and 6-month cycle charts are shown in Figure 4-16 and again demonstrate that the SIA value returns close to the original value even after a 6-month period.



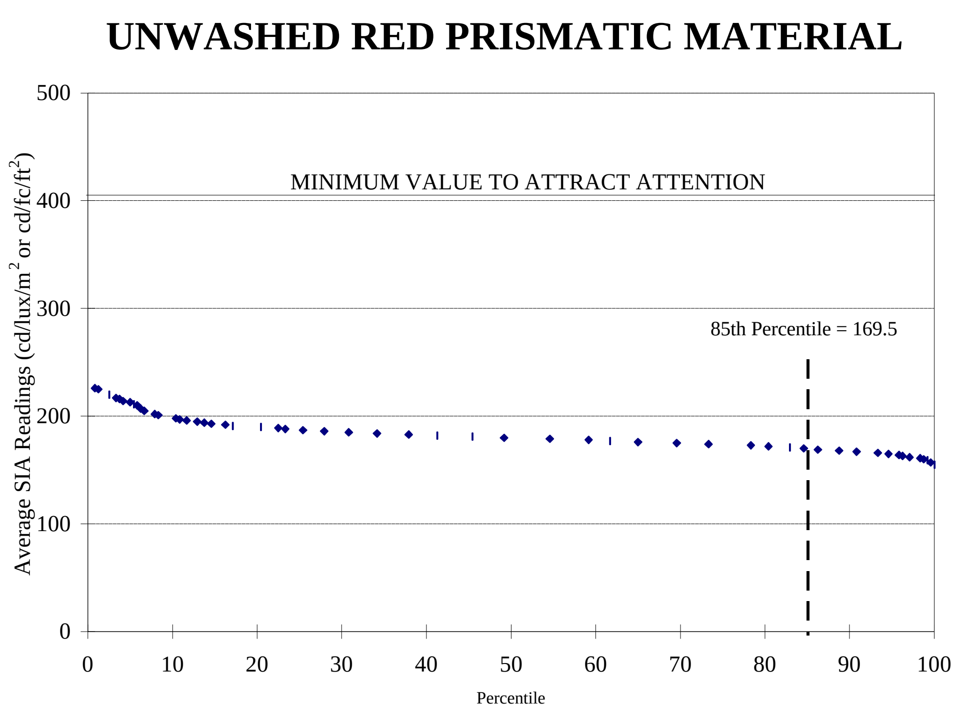
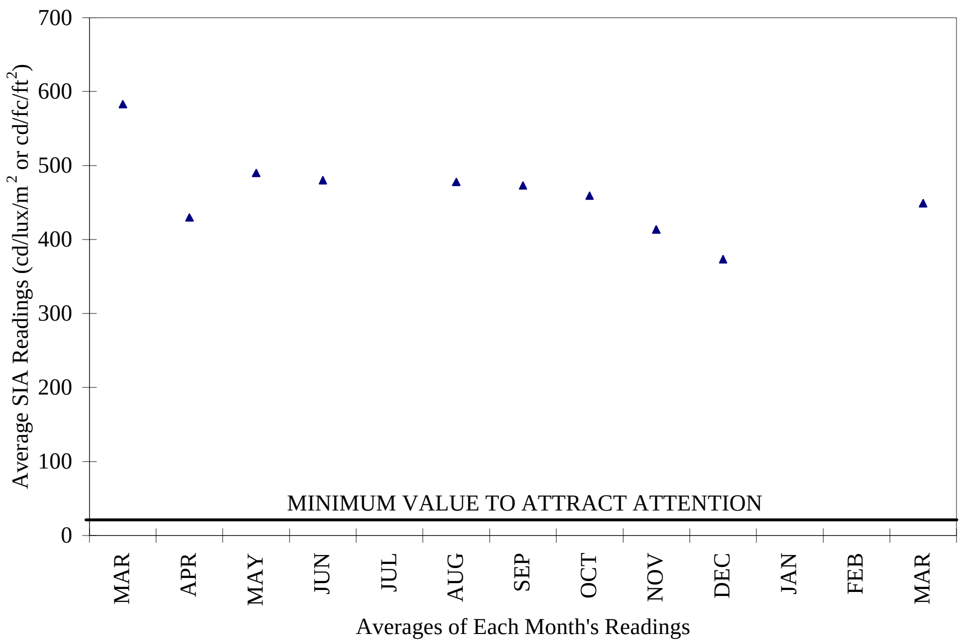


Figure 4-13. Unwashed Red Prismatic (Mean and One Standard Deviation and Percentiles)

UNWASHED RED-AND-WHITE PRISMATIC MATERIAL



UNWASHED RED-AND-WHITE PRISMATIC MATERIAL

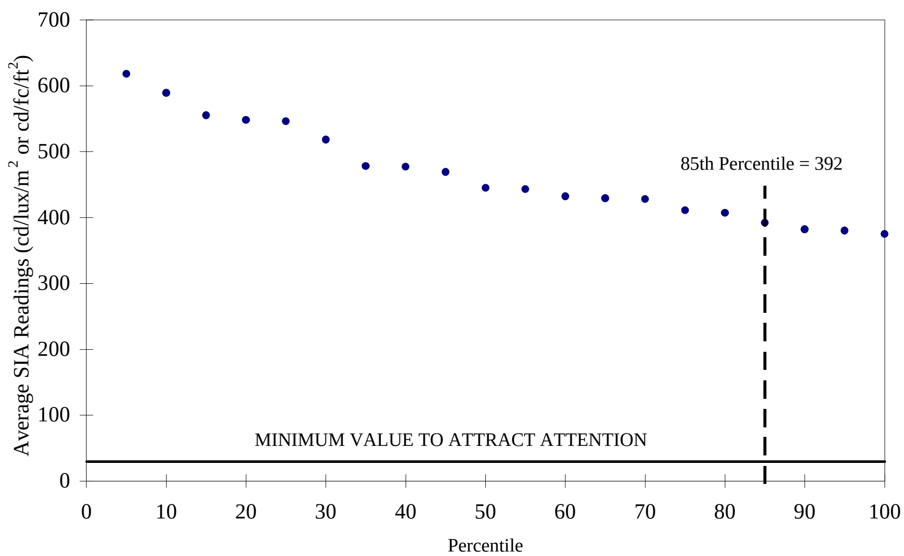
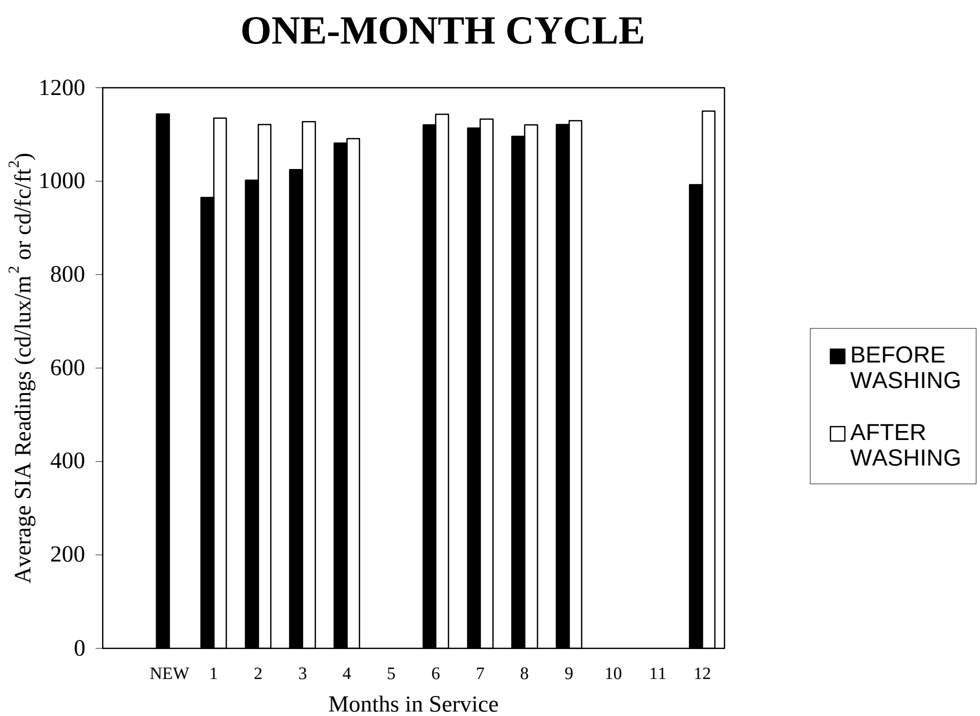


Figure 4-14. Unwashed Red-and-White Prismatic Delineating Stripe (Monthly Averages and Percentiles)



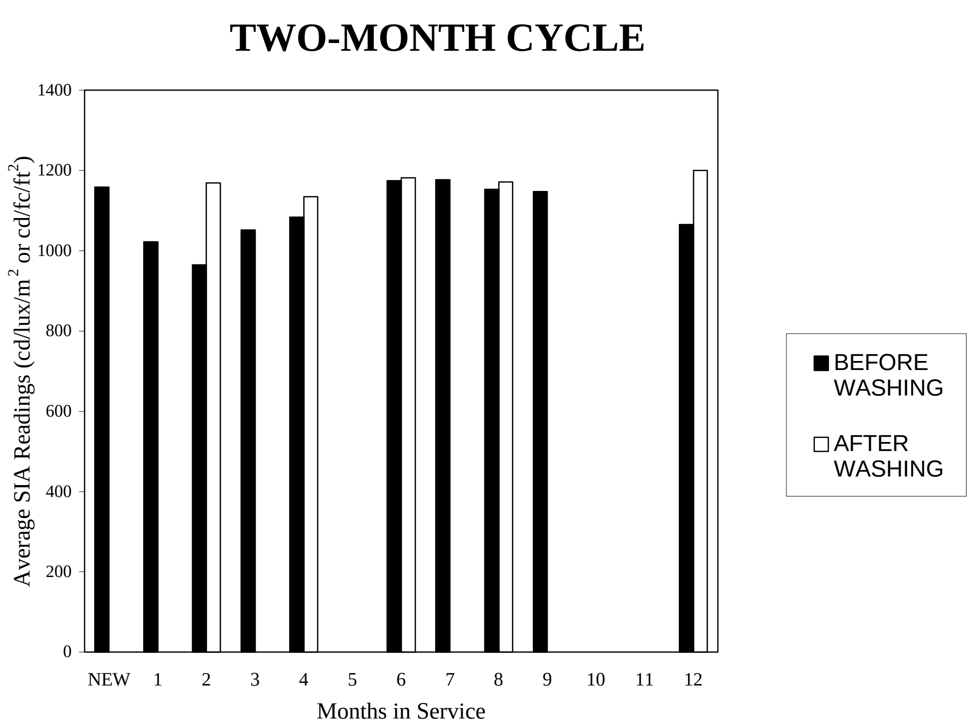
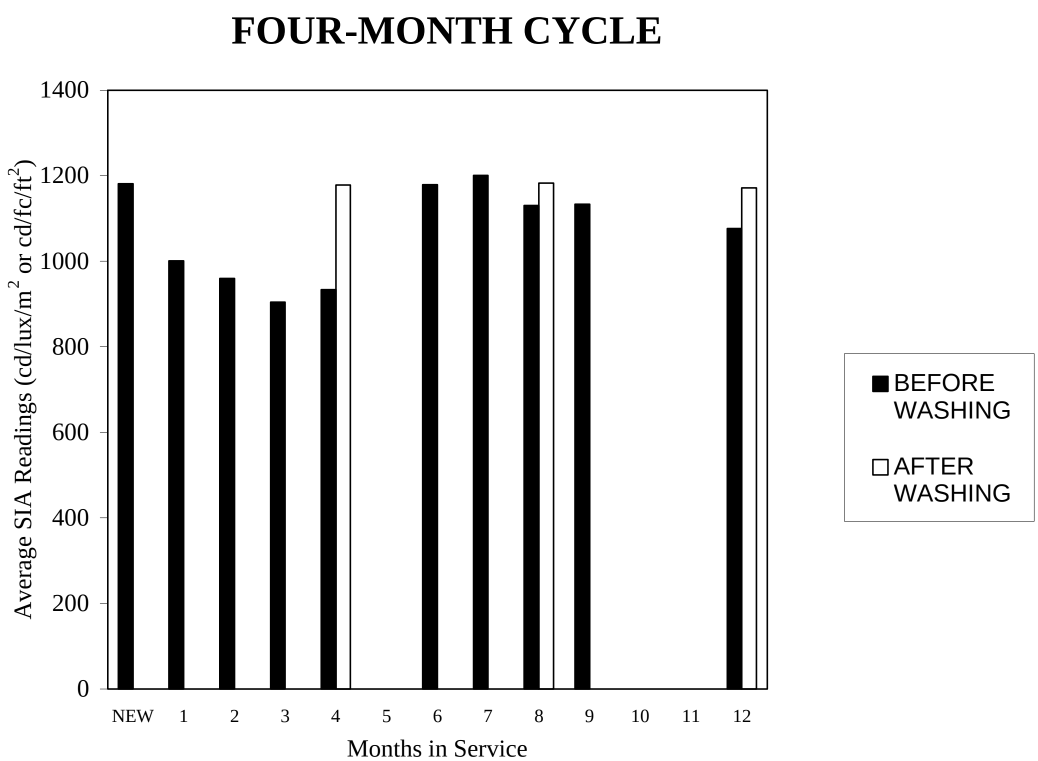


Figure 4-15. SIA of Prismatic Decals with One- and Two-Month Washing Cycles



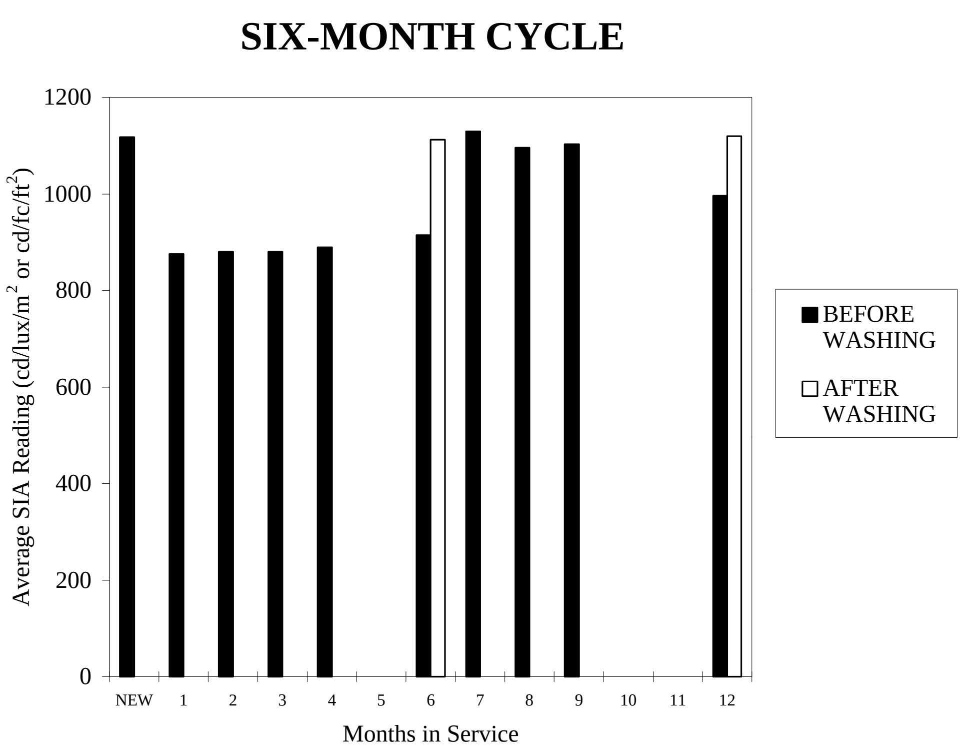


Figure 4-16. SIA of Decals with Four- and Six-Month Washing Cycles

4.2.3 Accumulated Mileage

The accumulated mileage and climatic conditions were closely monitored over the 1-year test period. As shown in Figure 4-17 the test consist was idle most of August through November due to a major rebuild and modification on part of the track structure. The total accumulated mileage for the 1-year period was slightly less than 13,000 miles. A comparison of the cumulative mileage data with the average SIA values by month (Figure 4-11) through November is consistent with the hypothesis that movement of the cars contributes to degradation of the reflectors. However, the last data point, in March 1992, appears inconsistent with this hypothesis.

4.2.4 Environmental Effects

The overall climatic conditions for the 1-year test period are shown in Figure 4-18, which presents both the rainfall and snowfall during the testing period along with the 30-year monthly averages. The total rainfall for the first 3 months of the test was below normal, while for the summer months it was above normal. The snowfall for the test period was twice the 30-year average with abnormally high amounts during October and November.

The graphs in Figure 4-19 show the monthly rainfall and snowfall along with their associated SIA values. The initial drop in the SIA values was due to normal dirt accumulation, however, it might have been accelerated by the less than normal rainfall and blowing dust conditions during the first few months of testing. The slight rise in the SIA values might also be due to the above average rainfall during July, August, and September. During the months of October and November, the total precipitation in the form of rain and snow remained relatively high and the SIA values also continued to remain at stable values. These results are consistent with the hypothesis that precipitation contributed to a natural washing of the reflectors. However, the last SIA reading, in March 1992, is relatively high, after 3 months of little precipitation, and seems to contradict this hypothesis.

4.3 ANALYSIS OF DEMONSTRATION TEST RESULTS

Using the methodology used in Section 2.3.2 of this report, the following minimum threshold levels for reflector brightness were established:

- The 4-inch by 2-inch reflector's SIA should at a minimum be 810.
- The 4-inch by 4-inch reflector's SIA should at a minimum be 405.
- The 4-inch by 108-inch reflector's SIA should at a minimum be 15.

The first objective of the demonstration test was to determine the durability of new materials in comparison to the 1982 materials tested. The 4-inch by 4-inch reflector size allowed a direct comparison of SIA with the 1982 material tested. The three demonstration test materials were measured in the laboratory before placement on the freight cars. The bonded lens material had initial SIA readings that were often lower than 10. The enclosed lens material had initial SIA readings of about 100, similar to the 1982 study. The prismatic material had initial SIA readings of about 1,000.

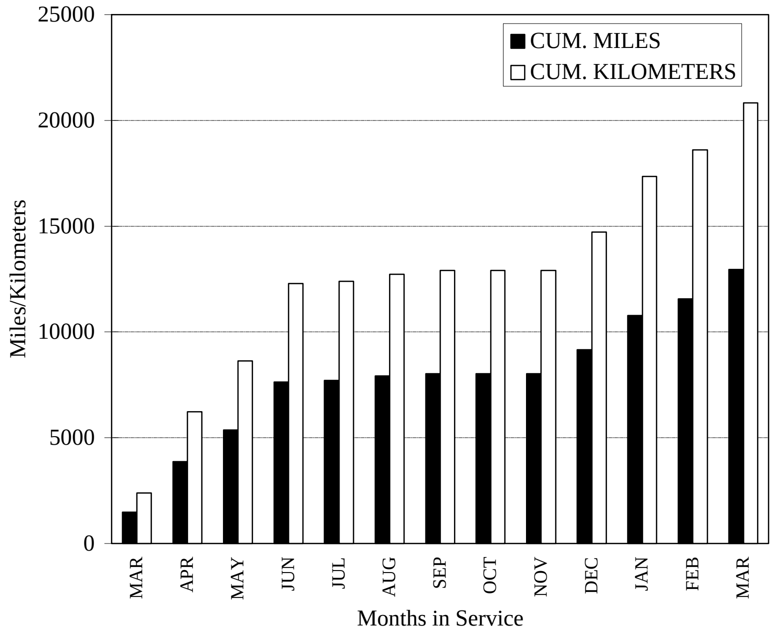
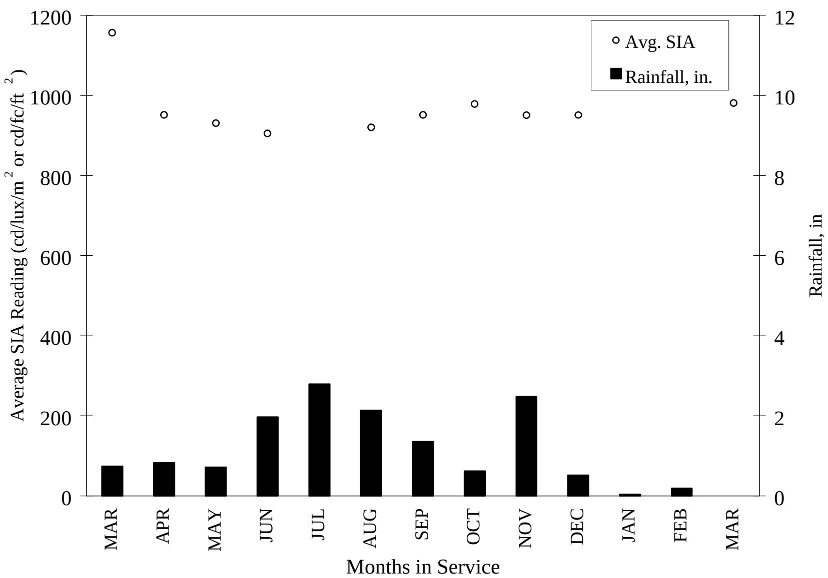


Figure 4-17. Cumulative Mileage

DATE	RAIN (in)	SNOW (in)	30 YEAR MONTHLY AVG. RAIN (in)	30 YEAR MONTHLY AVG. SNOW (in)
MARCH 1991	0.74	10.5	0.7	7.4
APRIL	0.83	2	1.25	3.2
MAY	0.72	0	1.59	0.5
JUNE	1.97	0	1.24	0
JULY	2.79	0	1.93	0
AUGUST	2.14	0	1.8	0
SEPTEMBER	1.36	0	0.79	0.6
OCTOBER	0.62	16.3	0.74	1.1
NOVEMBER	2.48	25.6	0.43	4.3
DECEMBER	0.52	4	0.42	4.9
JANUARY 1992	0.04	1.1	0.32	5.4
FEBRUARY	0.19	0.5	0.41	4.1
TOTAL	14.4	60	11.62	31.5

Figure 4-18. Precipitation

AVERAGE MONTHLY SIA - PRISMATIC MATERIAL WITH ASSOCIATED MONTHLY RAINFALL



AVERAGE MONTHLY SIA - PRISMATIC MATERIAL WITH ASSOCIATED MONTHLY SNOWFALL

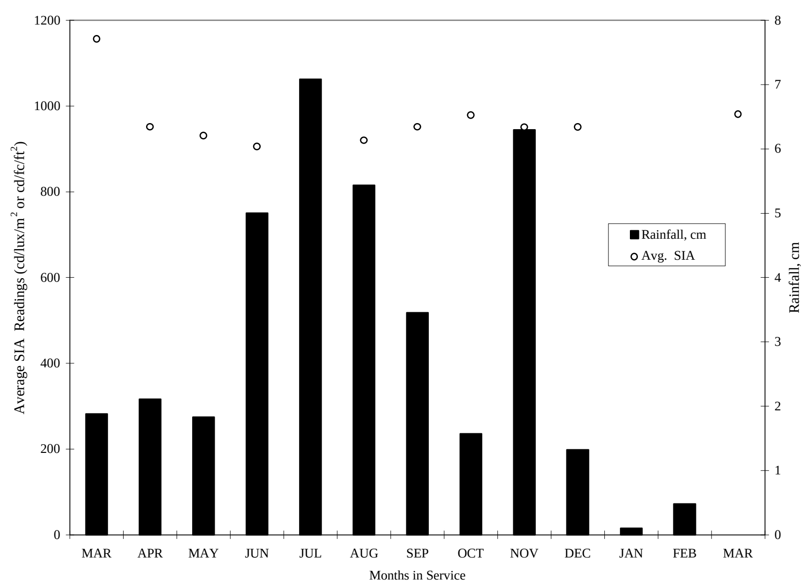


Figure 4-19. SIA vs. Rainfall and Snowfall[1]

[1] Based on ASTM E810-81, the metric and foot-pound units for SIA values are numerically equal.

All three materials were placed on the freight cars to determine degradation rates. The bonded material did not degrade significantly but initial intensities did not meet the minimum SIA requirement. As a result, this material was not investigated further. The enclosed lens material's (engineering grade) initial intensities also did not meet the minimum SIA requirement. This material's degradation rate was found to be lower than the 1982 study; the enclosed lens material retained approximately 73% of its original intensity over the 1-year test. However, this result may be due in part to the demonstration test being less severe than true railroad operations and was a major factor in deciding not to investigate this material beyond the demonstration test. The prismatic material's initial intensities far exceeded the minimum SIA requirements established. The material was found to be 10 times brighter than the material tested in 1982. This material sustained 87% of its original intensity after 1 year of testing. Also, after two 6-month washing cycles, the prismatic material rebounded to approximately its original intensity.

The laboratory tests showed a significant increase in brightness of the prismatic material over the enclosed lens material used in the 1982 study. The prismatic material was placed in many color combinations, designs, and placement locations for the conduct of the demonstration test. As the results discussed earlier show, the prismatic material placed below the sill level (<42 in TOR) on the wheel plates degraded significantly within the first few months of testing. Even in the relatively pristine environment of the TTC, these results indicate that placement of any material for the second phase of testing should be at or above sill level ($\geq$42 inches TOR). A 6.0% difference in brightness was found between the placement of the material at 42 inches TOR and 54 inches TOR during this phase of testing. The population tested was very small (16 reflectors) and, therefore, this result should be used only as an indication that there may be a sensitivity of the reflector performance based on placement location above TOR. This result correlates with previous studies mentioned.

The initial measurements and the results of the degradation of the red prismatic material indicate that a sole red placard does not meet the SIA requirements established with the use of a 4-inch by 4-inch) reflector. The observer's association of "red means danger" might warrant further investigation of this color in combination with the white prismatic material. This condition was tested during this phase. The use of the red-and-white delineating strip, due to its size, met and remained over the threshold level established during the 1-year test. This favorable result indicates the possibility of the use of a red-and-white delineating strip.

The third objective met was to establish a preliminary marking design for the nationwide freight car reflectorization test. The preliminary results from the NHTSA tractor trailer truck study indicated the delineation of a large transportation vehicle was favorable in an attempt to reduce collisions. Secondly, the red-and-white combination was found to be appropriate to warn a motorist of an approaching hazard. Using these results, as well as the results from the demonstration test, a single configuration was developed for the in-service phase of testing.

Results indicated that decals larger than 4 inches by 4 inches should be used in the in-service test and that a combination of a large strip of red-and-white material would delineate each individual freight car and would offer the driver some indication of the presence and nature of the hazard. With these results in mind, the Volpe Center developed a configuration using three 4-inch by 8-inch white prismatic decals mounted horizontally along the sill level and two 4-inch by 36-inch red-and-white strips mounted vertically at each end of the freight car. This configuration was selected to optimize the amount of material used but also to allow reflectorization of a variety of freight car types.

The analysis provided the following results:

1. Initial laboratory tests and the controlled demonstration test of all materials determined that the prismatic (corner cube) material was the best off-the-shelf material for the in-service revenue field test.

2. Cyclical washing can recover the intensity of the prismatic material to nearly its original intensity.

3. Environmental effects show a minor correlation on the performance of the materials tested.

4. Degradation rates indicate a sensitivity to vertical placement above top of rail (i.e., lower placement results in higher degradation rates).

5. Selection of the color and pattern configuration was based on current freight car and tractor trailer truck reflectorization research.

4.4 SUMMARY OF FINDINGS

4.4.1 Reflector Performance

The prismatic material used throughout this phase performed consistently better than the materials tested in 1982. The unwashed prismatic reflectors maintained the highest SIA values of the materials tested throughout the test period. The prismatic materials also showed an after-wash SIA rebound close to original values. The red prismatic reflectors did not attain the minimum threshold.

4.4.2 Optimum Configuration

Three 4-inch by 8-inch decals were chosen to be applied horizontally, spaced approximately 9 feet apart, along with two 4-inch by 36-inch red-and-white delineators applied vertically at the ends of the car. Figure 4-20 shows the arrangement of the decals on a “typical” freight car for use in the in-service field test.

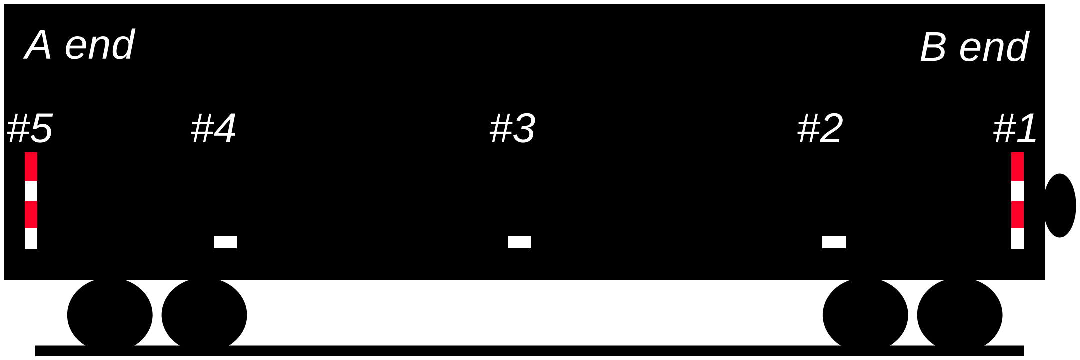


Figure 4-20. Arrangement of Decals on a Typical Freight Car

5. IN-SERVICE REVENUE REFLECTORIZATION TEST

5.1 IN-SERVICE TEST METHODOLOGY

The Volpe Center conducted a survey in 1991 to determine which railroads would participate in an in-service revenue test of freight car reflectorization. The Alaska Railroad Corporation (ARR) and Norfolk Southern Corporation (NS) agreed to participate in the evaluation with the Center.

Although only two railroads agreed to participate, four captive fleets were selected for testing. Each fleet had a different type of freight car carrying specific commodities associated with it and also had differing environmental conditions associated with the test. Once fleet selection was completed, retroreflective material was purchased to equip all the freight cars available for testing. The configuration established by the demonstration test determined the amount of white prismatic and red-and-white prismatic material needed for the entire test. Laboratory measurements of the purchased material, recording of initial measurements and assignment of reflector set numbers were performed (as field measurement availability permitted) to accurately document the environmental effects. Volpe Center employees applied the initial material to a large number of freight cars nationwide. Support from Norfolk Southern Corporation was established to complete the remaining application requirements on two of their test fleets. Accident data were obtained via the RAIRS database to analyze potential accident reductions, which is discussed later in the chapter.

5.1.1 In-Service Test Cars

Table 5-1 is a general description of the captive fleets and freight car types utilized in the in-service revenue test:

Table 5-1. In-Service Revenue Test Summary

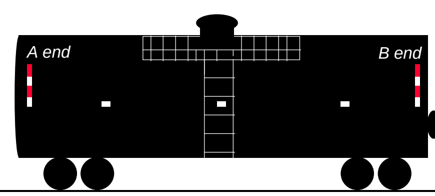
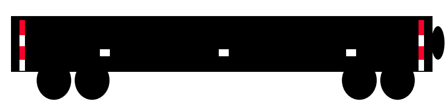
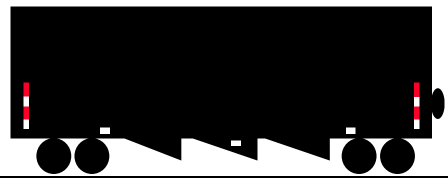
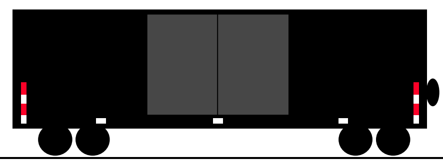
Test Plan	Participating Railroad	Operating Characteristics	Reflector Configuration
A	Alaska Railroad (ARR)	Series DOT-111 Tank Cars carrying various petroleum products from Anchorage to Fairbanks, AK *Reflector Height*: 72 in TOR	
B	Norfolk Southern (NS)	Intermodal Double Stack Cars carrying containers from Norfolk, VA, to Chicago, IL. *Reflector Height*: Positions 1 and 5: 30 in TOR; all others: 42 in TOR	

Table 5-1. In-Service Revenue Test Summary (continued)

Test Plan	Participating Railroad	Operating Characteristics	Reflector Configuration
C	Norfolk Southern	Steel Open Top Hopper Cars carrying eastern coal from Sheffield, AL, to Wansley, GA *Reflector Height*: 42 in TOR, except for Position #3, (under sill, 36 in TOR)	
D	Norfolk Southern	Box Cars carrying clay products from Savannah to Gordon, GA *Reflector Height*: 42 in TOR	

__ARR Tank Cars (Test Plan A).__ This in-service tank car field test was initiated in November 1991. The reflector configuration shown in Table 5-1 was applied to both sides of 29 tank cars. Inclusion of tank cars in the test provided an opportunity to study the effects of (1) spillage of petroleum products, (2) steam cleaning of the inside of the tank, and (3) extreme environmental conditions.

Measurements were made on the reflective material prior to its installation. Table 5-2 lists the color, dimension and placement, and initial SIA mean and standard deviation for each position (which is the same used in the demonstration test). Distribution of initial SIA measurements for the reflective materials at Positions 2, 3, and 4 (white) and Positions 1 and 5 (red-and-white delineators), respectively, on the tank cars are shown in Appendix C. These figures indicate the variability within each position as well as distribution of SIA values found on the original 29 tank cars in the population.

Table 5-2. Initial Tank Car Reflector Characteristics

Position	Reflector Characteristics		SIA Measurements	
	Color	Dimensions/TOR Placement	Mean	Standard Deviation
1	red white	4 in by 36 in total; 72 in TOR Pattern: red/white/red/white	241 1076	12 47
2	white	4 in by 8 in; 72 in TOR	1189	51
3	white	4 in by 8 in; 72 in TOR	1187	47
4	white	4 in by 8 in; 72 in TOR	1184	45
5	red white	4 in by 36 in; 72 in TOR Pattern: red/white/red/white	240 1069	10 46

NS Corporation. The Norfolk Southern Corporation (NS) provided three types of freight cars on three separate captive fleets for inclusion in the test. These test cars were to be operated on the same routes as other trains that have either (1) non-reflectorized cars, or (2) other cars that have reflective material applied that is different in physical properties from that which was used in this test. The NS participation was as follows.

NS Double Stack Cars (Test Plan B) – The double stack car in-service field test was initiated in January 1992. The reflector configuration shown in Table 5-1 was applied to both sides of 149 double stack intermodal cars. The NS double stack cars provided the lowest placement of the material above top of rail within this testing program, and provided an opportunity to study the effect of low placement of the retroreflective materials on a freight car.

Initial SIA measurements were made on the reflective material prior to its installation. Table 5-3 provides information regarding color, placement, SIA mean and standard deviation for each reflector position. The initial SIA measurements for the reflective materials at Positions 2, 3, and 4 (white) and Positions 1 and 5 (red-and-white delineators), respectively, on the double stack cars are given in Appendix D.

Table 5-3. Initial Double Stack Reflector Characteristics

Position	**Reflector Characteristics**		**SIA Measurements**	
	Color	**Dimensions/TOR Placement**	**Mean**	**Standard Deviation**
1	red white	4 in by 36 in total; 30 in TOR Pattern: red/white/red/white	220 1031	14 56
2	white	4 in by 8 in; 30 in TOR	1015	117
3	white	4 in by 8 in; 30 in TOR	1015	118
4	white	4 in by 8 in; 30 in TOR	1013	118
5	red white	4 in by 36 in total; 30 in TOR Pattern: red/white/red/white	220 1035	16 56

NS Hopper Cars (Test Plan C) – The hopper car in-service field test was initiated in March 1992. The reflector configuration shown in Table 5-1 was applied to both sides of 336 hopper cars. These cars provided the opportunity to test the effect of a harsh chemical, eastern high-sulfur coal, on the retroreflective material.

Initial SIA measurements were made on the reflective material prior to its installation. Table 5-4 provides information regarding color, placement, SIA means and standard deviations for each reflector position. The initial mean and standard deviations for the SIA values for the reflective materials at Positions 2, 3, and 4 (white) and Positions 1 and 5 (red-and-white delineators), respectively, on the hopper cars are shown in Appendix E.

Table 5-4. Initial Hopper Reflector Characteristics

Position	Reflector Characteristics		SIA Measurements	
	Color	Dimensions/TOR Placement	Mean	Standard Deviation
1	red white	4 in by 36 in total; 42 in TOR Pattern: red/white/red/white	226 1032	26 66
2	white	4 in by 8 in; 42 in TOR	960	89
3	white	4 in by 8 in;36 in TOR	963	87
4	white	4 in by 8 in; 42 in TOR	960	86
5	red white	4 in by 36 in total; 42 in TOR Pattern: red/white/red/white	226 1034	25 68

NS Box Car (Test Plan D) **–** The box car in-service field test was initiated in April 1992. The reflector configuration shown in Table 5-1 was applied to both sides of 74 box cars. The transported cargo, clay products, is covered in large cloth sacks that could prevent some of the clay dust from reaching the decals; however, the cars are subjected to frequent forklift damage during commodity loading and unloading. Damage to the decals could also occur during car repairs.

Initial SIA measurements were made on the reflective material prior to its installation. Table 5-5 provides information regarding color, placement, SIA means and standard deviations for each reflector position. The initial mean and standard deviations for the SIA values for the reflective materials at Positions 2, 3, and 4 (white) and Positions 1 and 5 (red-and-white delineators), respectively, on the box cars are given in Appendix F.

Table 5-5. Initial Box Reflector Characteristics

Position	Reflector Characteristics		SIA Measurements	
	Color	Dimensions/TOR Placement	Mean	Standard Deviation
1	red white	4 in by 36 in total; 42 in TOR Pattern: red/white/red/white	233 1099	37 131
2	white	4 in by 8 in ; 42 in TOR	1009	71
3	white	4 in by 8 in; 42 in TOR	1012	72
4	white	4 in by 8 in; 42 in TOR	1012	71
5	red white	4 in by 36 in total; 42 in TOR Pattern: red/white/red/white	233 1101	39 133

All reflectors used during this test were grouped to determine the mean initial SIA values for all cars tested. The mean SIA values and standard deviations found for Positions 2, 3, and 4 and Positions 1 and 5, are given in Appendix G.

5.2 IN-SERVICE TEST RESULTS

5.2.1 Tank Cars

Degradation of Reflectors. The tank car test period lasted from November 1991 to August 1993. Three sets of measurements were taken over the course of the testing period: 0, 7, and 21 months. Table 5-6 illustrates the number of cars measured during each measurement cycle.

Table 5-6. Total Number of Alaska Cars Tested by Months

Months In-Service	Cars Tested
0	29
7	26
21	25

The reflectorized tank cars were placed with consists that were non-reflectorized, thereby making it difficult to locate cars for follow-up measurements. Subsequent measurements could only capture a maximum of 26 of these cars during the entire test period. The total number of measurements taken for each car was 18 for the white horizontal reflectors and 16 for the red-and-white delineator strips located at the ends of each car. Figure 5-1 shows the individual degradation trends in Positions 2, 3, and 4. Figure 5-2 shows the individual degradation trends for Positions 1 and 5. Figures 5-3 and 5-4 show the mean degradation rates for all white prismatic horizontal markings and all red-and-white delineator strips, 1 and 5, respectively. These graphs indicate that the reflective material remained far above the threshold levels established during the course of this research effort. The relative position of the reflective markings placed on the tank car at 72 inches TOR, may be a significant factor contributing to these results. An analysis of the effects of placement locations can be found in Section 5.3, Analysis of In-Service Field Test Results.

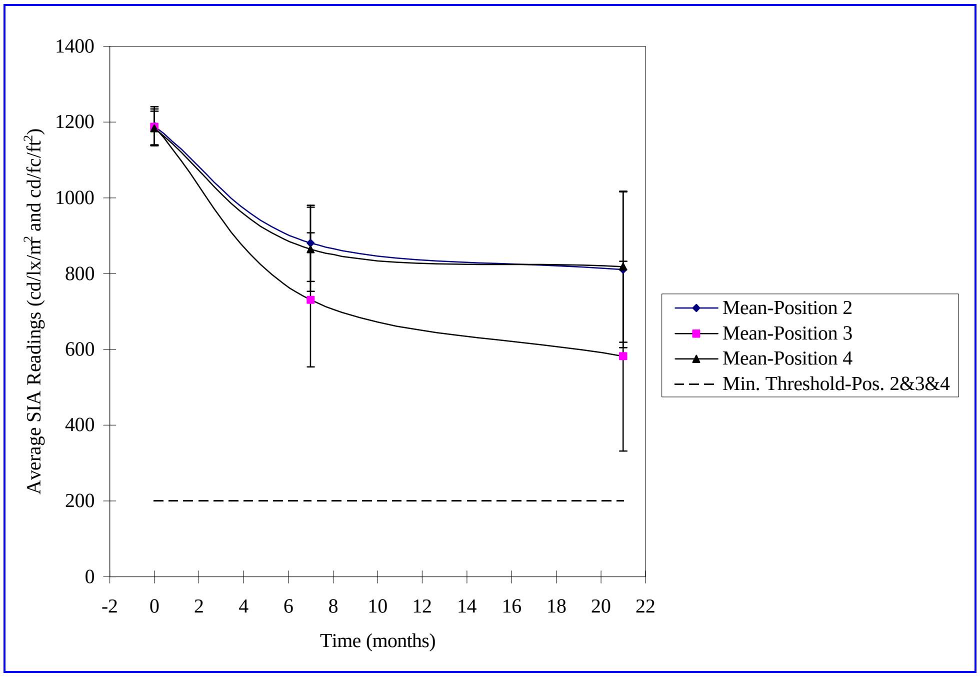


Figure 5-1. Alaska Tank Cars – Degradation of Positions 2, 3, and 4

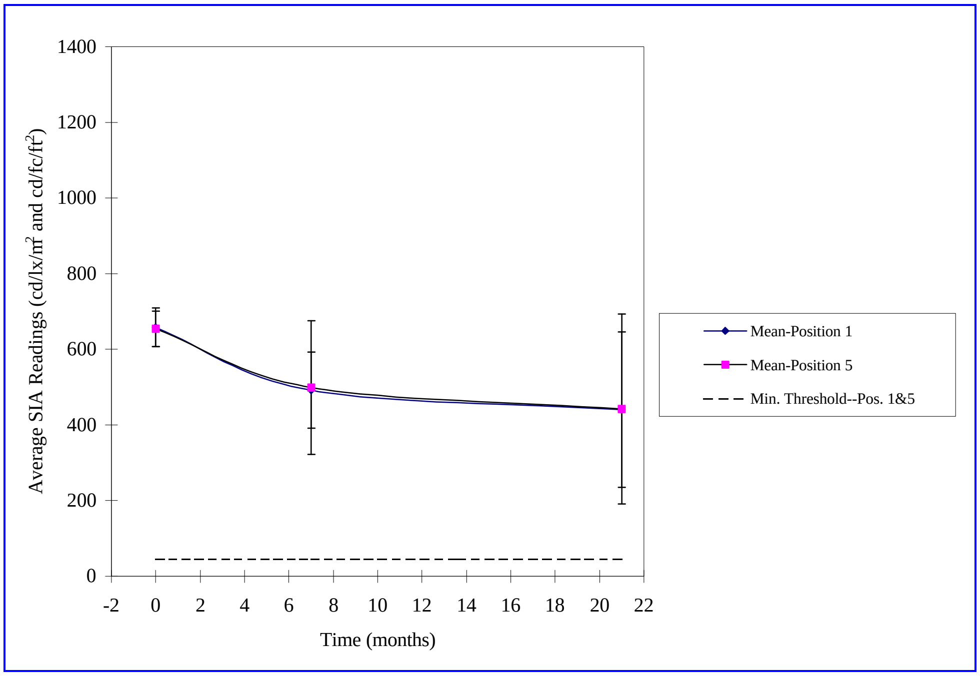


Figure 5-2. Alaska Tank Cars – Degradation of Positions 1 and 5

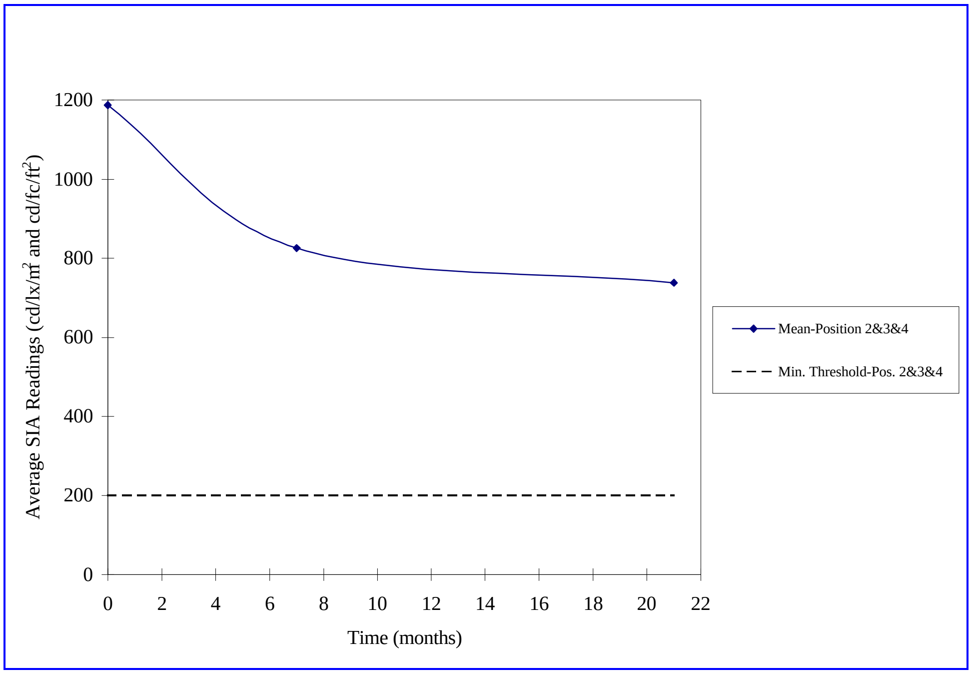


Figure 5-3. Alaska Tank Cars – Mean Degradation Trend for Positions 2, 3, and 4

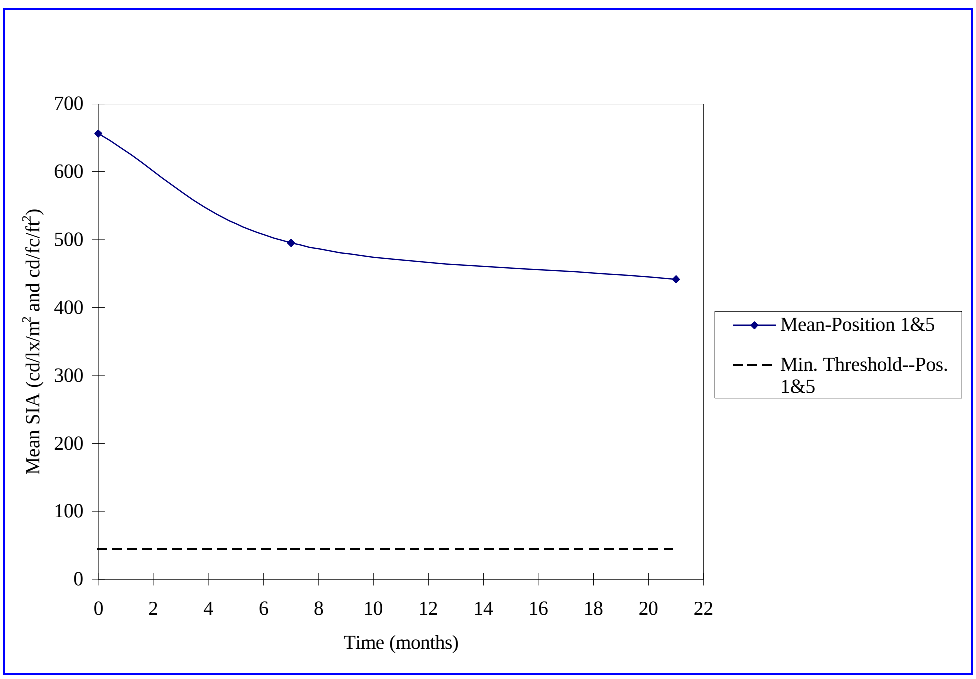


Figure 5-4. Alaska Tank Cars – Mean Degradation Trend for Positions 1 and 5

<u>Natural Environmental and Operational Effects</u>. The natural environmental conditions in the State of Alaska can be severe, but no effects on the reflectors' brightness have been indicated. As noted by the degradation rate figures, the reflectors placed in a position where they may encounter gasoline products (i.e., under the filler cap, which is located at Position 3 in Figure 5-1) degraded more rapidly than the others did. Another effect that has been noted for the Alaska tank cars is the response of the reflectors to internal steam cleaning of the tank cars. Figure 5-5 shows the SIA values for tank cars (initially and after 7 months) that have been steamed cleaned. Figure 5-6 indicates an 8% increase in the reflector intensities after 21 months between tank cars not steamed and tank cars steamed 5 times.

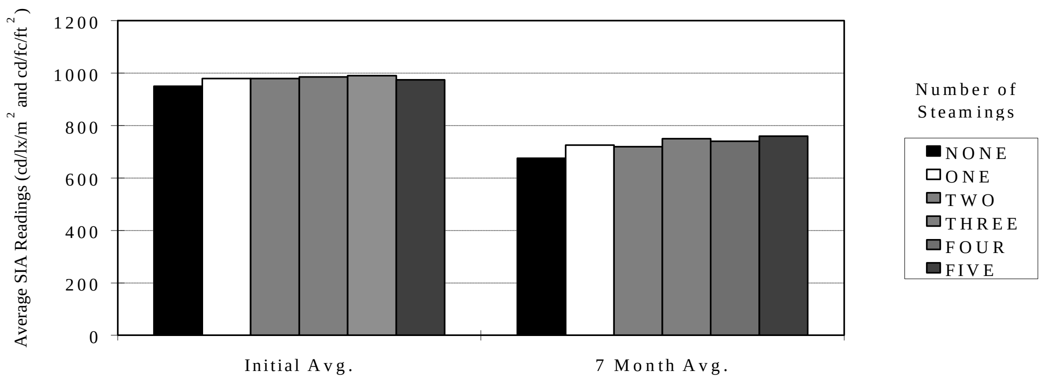


Figure 5-5. Seven-Month SIA Readings for Tank Cars

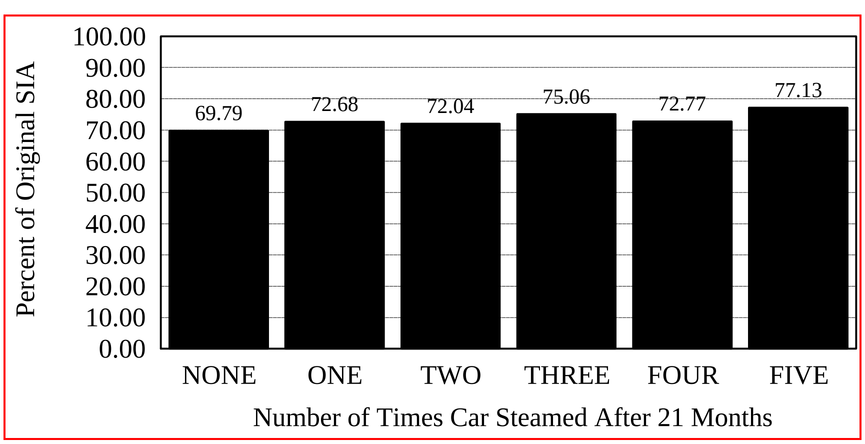


Figure 5-6. Effects on Tank Car Reflectors from Internal Steam Cleaning

This phenomenon should be further investigated by manufacturers of retroreflective materials. The manufacturer rates this material to withstand temperatures up to 190°F, but the outside temperatures reached 220°F after the internal steam cleaning was completed.

One tank was washed with water to determine washing effects on this fleet. After 7 months, the reflector intensity was down to 63% of its original value. After washing, this percentage increased to 88% of the original value.

Accident Reduction Potential. Individual reflectorized tank cars were randomly placed in consists with and without reflectorized cars. Due to this car placement, it was not possible to obtain meaningful statistics on the accident reduction potential of reflectorization for the Alaska Railroad tests.

5.2.2 Double Stack Cars

Degradation of Reflectors. The double stack test was conducted from January 1992 through June 1994. Five sets of measurements were taken over the course of the testing period. These measurements were taken at 0, 3, 7, 20, and 29 months. Table 5-7 illustrates the number of cars measured during each measurement cycle.

Table 5-7. Total Number of NS Double Stack Cars Tested

Months In-Service	Double Stack Car Count
0	149
3	81
7	60
20	23
29	9

The reflectorized double stack cars were placed in one of four unit train consists that were non-reflectorized, thereby making follow-up measurements difficult. Subsequent measurements captured a maximum of 81 cars during the entire test period as shown above. The total number of measurements was 18 for the white horizontal reflectors and 16 for the red-and-white delineator strips located at the ends of each car. Figure 5-7, depicts individual degradation rates on Positions 2, 3, and 4. Figure 5-8 displays individual degradation results in Positions 1 and 5 of the double stack cars. The double stack car's reflectors remained above the threshold levels established during the course of this research effort for Positions 1 and 5, but fell below the threshold level after 18 months for Positions 2, 3, and 4. Figures 5-9 and 5-10 show the mean degradation rates for all white prismatic horizontal markings and all red-and-white delineator strips, 1 and 5, respectively. An analysis of various placement locations can be found in Section 5.3, Analysis of In-Service Field Test Results.

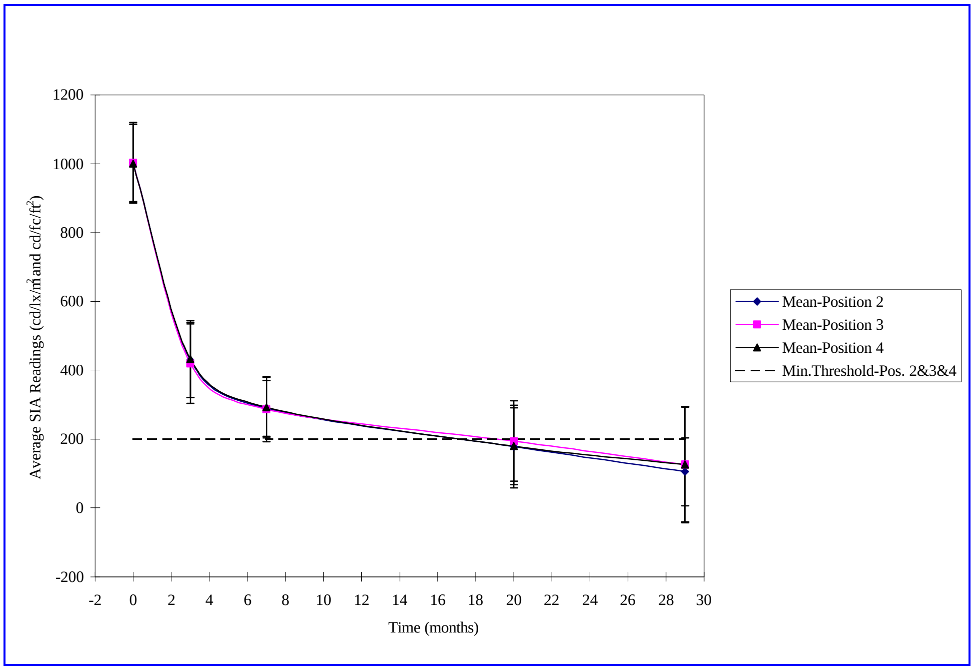


Figure 5-7. NS Double Stack Cars – Degradation of Positions 2, 3, and 4

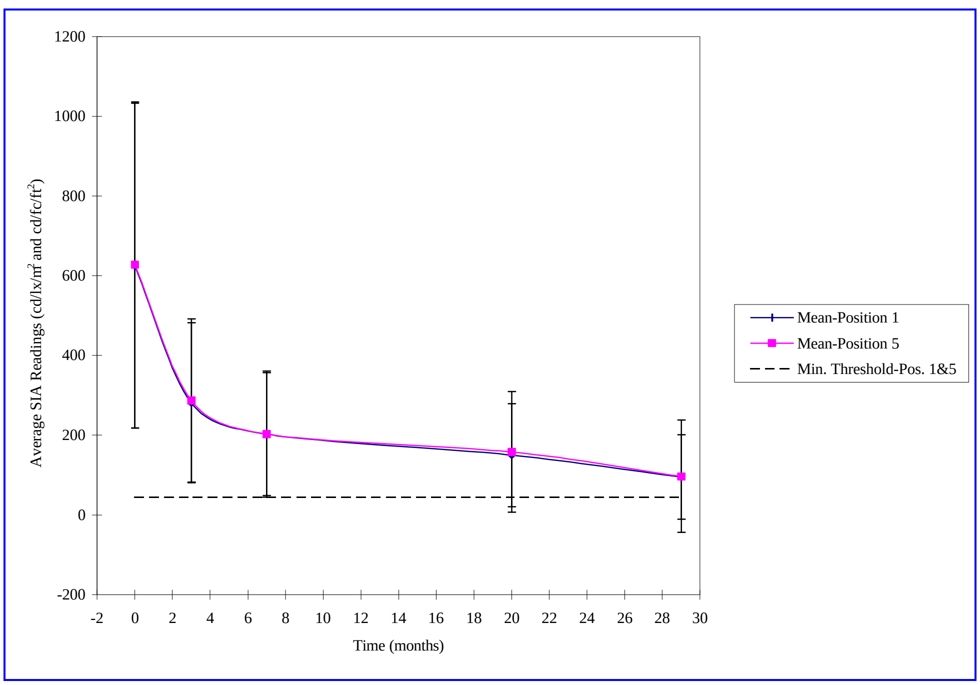


Figure 5-8. NS Double Stack Cars – Degradation of Positions 1 and 5

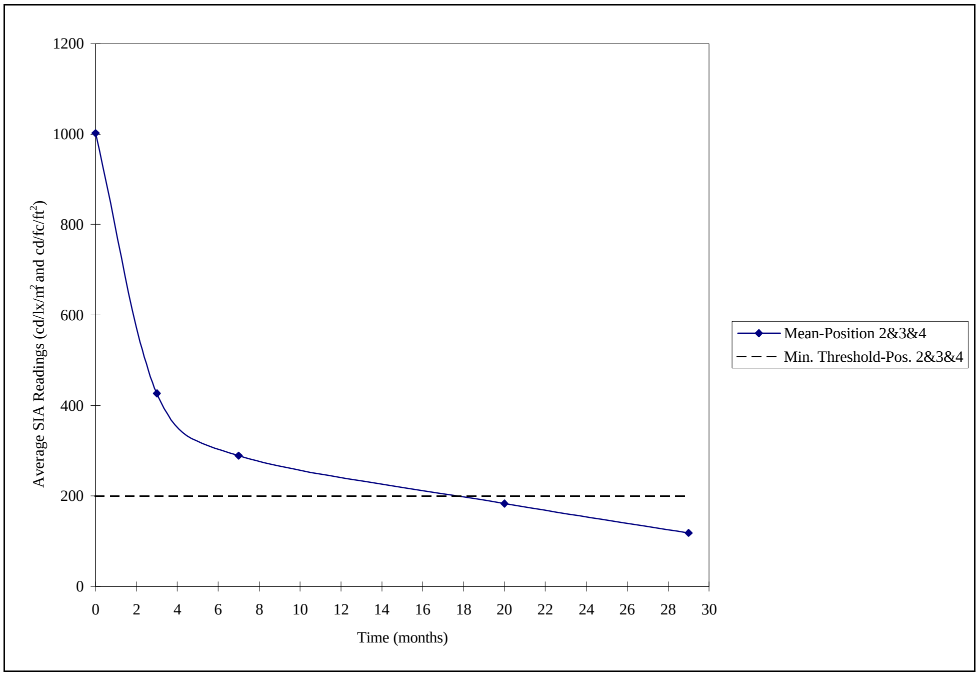


Figure 5-9. NS Double Stack Cars – Mean Degradation Trend for Positions 2, 3, and 4

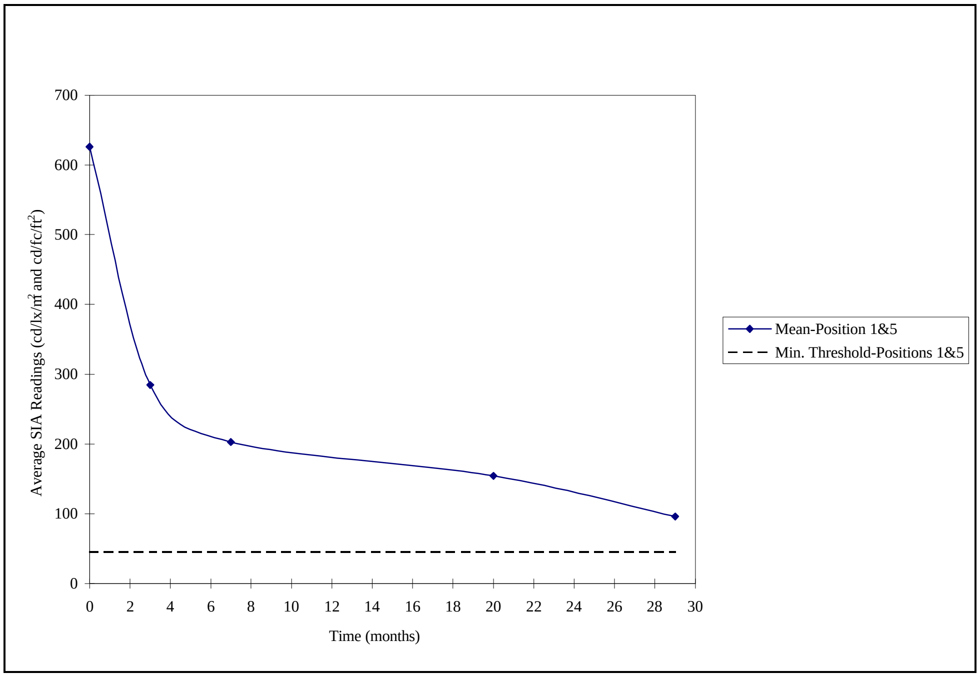


Figure 5-10. NS Double Stack Cars – Mean Degradation Trend for Positions 1 and 5

Natural Environmental and Operational Effects. The natural environmental conditions had no significant effect on the reflectors' brightness. Although the harsh railroad environment contributed to the reflectors' degradation over time, and the reflectors in Positions 1 and 5 were lower to the TOR, the SIA values remained above the threshold over time.

Accident Reduction Potential. Individual reflectorized double stack cars, and not an entire unit train, were randomly placed in consists with and without reflectorized cars. Therefore, very little information could be gathered on accident reduction potential within this captive route.

5.2.3 Hopper Cars

Degradation of Reflectors. This phase of the in-service test was conducted from March 1992 through December 1993. Four sets of measurements were taken over the course of the testing period. These measurements were taken at 0, 3, 7, and 21 months. Table 5-8 illustrates the number of cars measured during each measurement cycle.

Table 5-8. Total Number of NS Hopper Cars Tested

Months In-Service	Hopper Car Count
0	336
3	110
7	99
21	12

The hopper car captive route consisted of four fully reflectorized consists. Measurements were made when the cars were at NS's Refueling Yards in Muscle Shoals, Alabama. Subsequent measurements captured a maximum of 110 cars during the test period. The total number of measurements taken (per car) was 18 for the white horizontal reflectors and 16 for the red-and-white delineator strips located at the ends of each car. As can be found in Figures 5-11, 5-12, 5-13, and 5-14, the hopper cars remained above the threshold levels established during the course of this research effort for Positions 1 and 5, but fell below the threshold level after 7 months for Positions 2, 3, and 4. One finding to be noted in Figure 5-11 is that Position 3 has a slightly higher degradation rate than Positions 2 and 4. An analysis of various placement locations can be found in Section 5.3, Analysis of In-Service Field Test Results. Figure 5-12 displays individual degradation results in Positions 1 and 5 of the hopper cars. As can be seen, the delineator strip still lies above the threshold level after 21 months. Figures 5-13 and 5-14 show general degradation rates for all white prismatic horizontal markings and all red-and-white delineator strips, 1 and 5, respectively.

Natural Environmental and Operational Effects. The natural environmental conditions encountered by this captive fleet within Alabama had no effect on the reflectors' brightness. The harsh operational environment of eastern coal dust from the hopper cars resulted in the most severe degradation rate of all the fleets tested. Based on the sharp decline of Positions 2, 3, and 4 in less than 6 months, it is suggested a reflector should not be placed under the sill level.

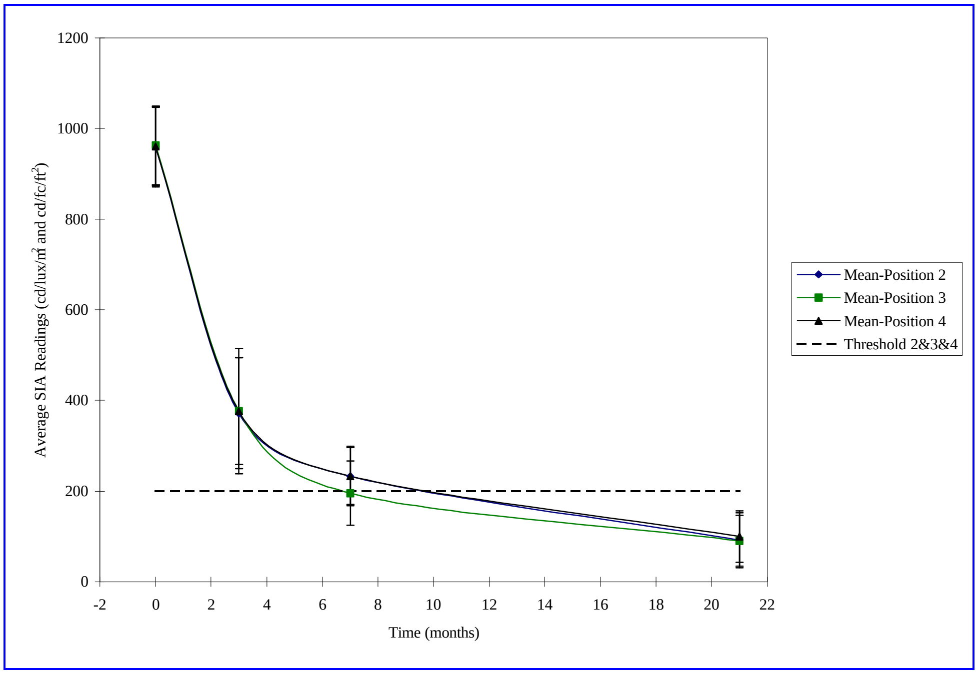


Figure 5-11. NS Hopper Cars – Degradation of Positions 2, 3, and 4

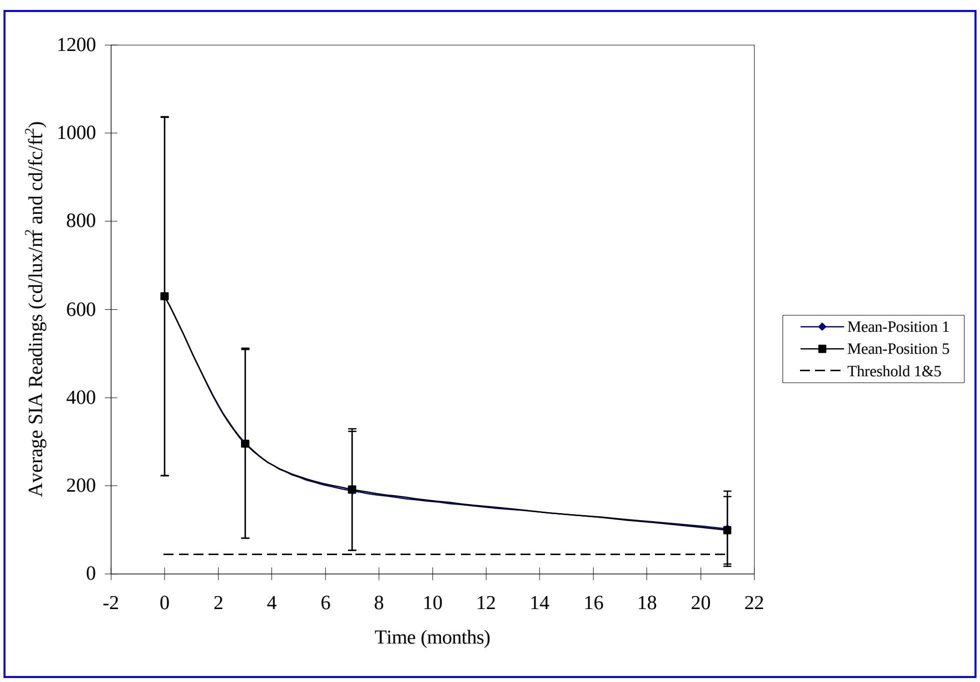


Figure 5-12. NS Hopper Cars – Degradation of Positions 1 and 5

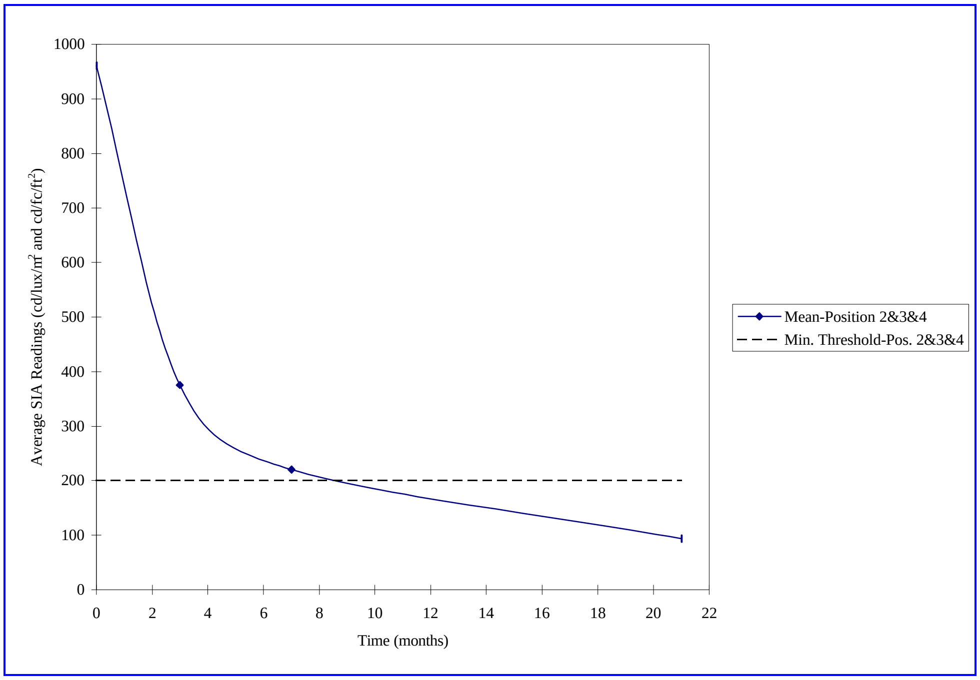


Figure 5-13. NS Hopper Cars – Mean Degradation Trend for Positions 2, 3, and 4

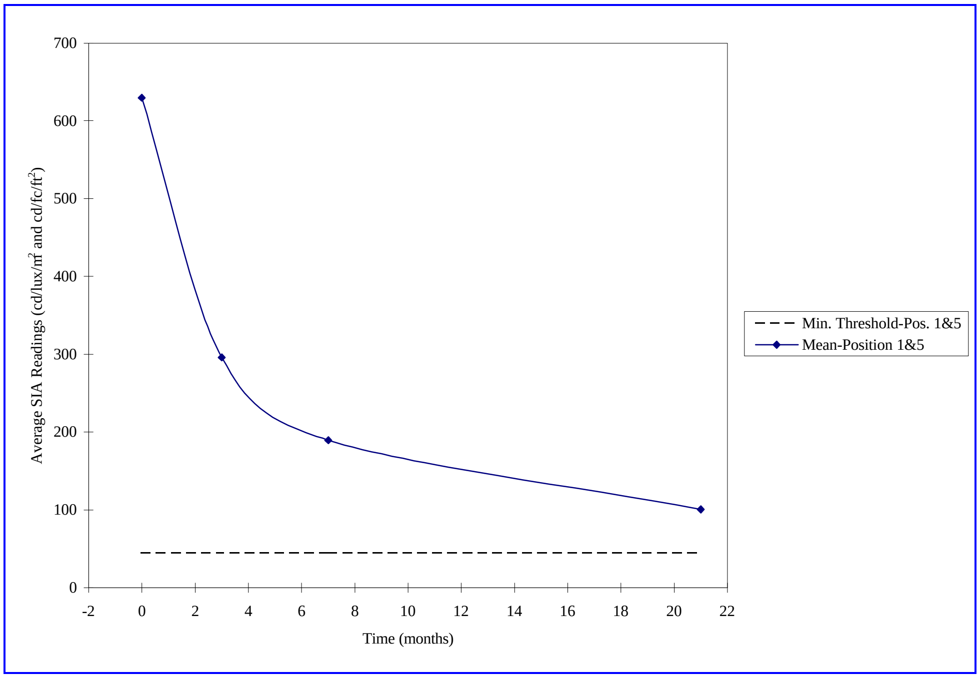


Figure 5-14. NS Hopper Cars – Mean Degradation Trend for Positions 1 and 5

Accident Reduction Potential. For the 3-year period before reflectorization of this fleet, 6 highway-railroad grade crossing accidents occurred in which the motorist hit the side of the train after the first unit had passed during hours of dawn, dusk, and darkness. During the 3-year period after these 336 open top hopper cars were reflectorized, zero accidents occurred under the same conditions. These limited results indicate reflectors can be effective in reducing accidents.

5.2.4 Box Cars

Degradation of Reflectors. This phase of the in-service test was conducted from April 1992 through June 1994. Three sets of measurements were taken over the course of the testing period. These measurements were taken at 0, 12, and 26 months. Table 5-9 illustrates the number of cars measured during each measurement cycle.

Table 5-9. Total Number of NS Box Cars Tested

Months In-Service	Box Car Count
0	74
12	9
26	3

The reflectorized box cars were placed with consists that were non-reflectorized, thereby making follow-up measurements difficult. Subsequent measurements captured a maximum of nine cars at any one time during the entire test period. The total number of measurements taken per car was 18 for the white horizontal reflectors and 16 for the red-and-white delineator strips located at the ends of each car. Due to the limited number of subsequent measurements, results and conclusions on the box car test should be considered with some caution. As can be found in Figures 5-15, 5-16, 5-17, and 5-18, the box car reflectors remained far above the threshold levels established during the course of this research effort for all positions except for Position 3. Figure 5-15, which depicts individual degradation rates based on Positions 2, 3, and 4, indicates that Position 3 has a much higher degradation rate than Positions 2 and 4. This position was located mid-car, below the sill, under the doorway of the box car. This degradation was likely caused by the proximity of this reflector to the doorway of this freight car type, which resulted in damage to the reflector during loading operations. Figure 5-16 displays individual degradation results in Positions 1 and 5 of the hopper cars. As can be seen, the delineator strip still lies above the threshold level after 25 months. Figures 5-17 and 5-18 show general degradation rates for all white horizontal markings, Positions 2, 3, and 4, and all red-and-white delineator strips, Positions 1 and 5, respectively. An analysis of various placement locations can be found in Section 5.3, Analysis of In-Service Field Test Results.

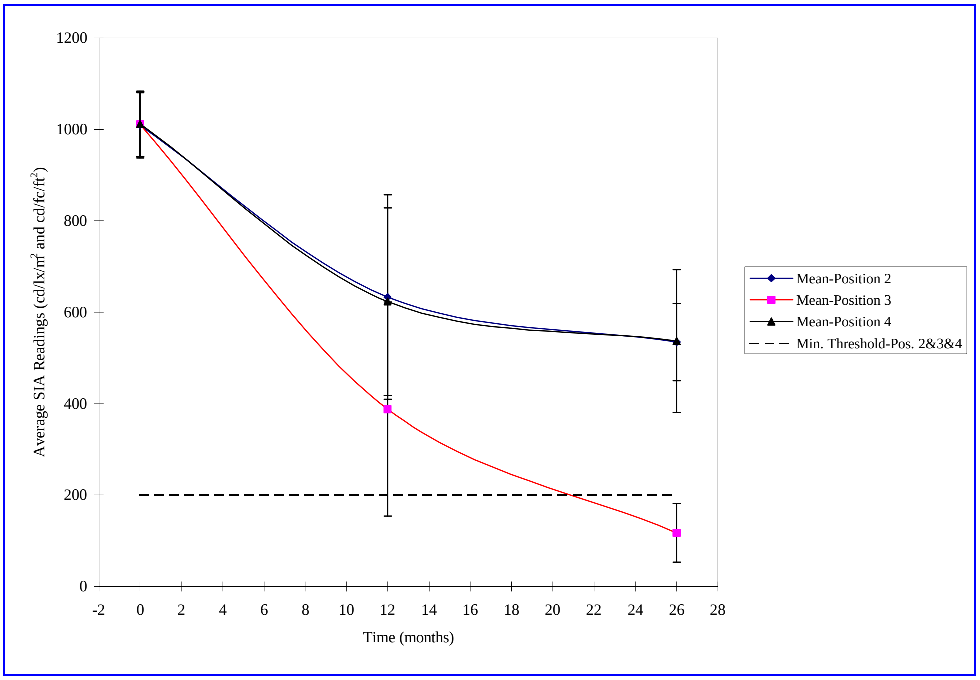


Figure 5-15. NS Box Cars – Degradation of Positions 2, 3, and 4

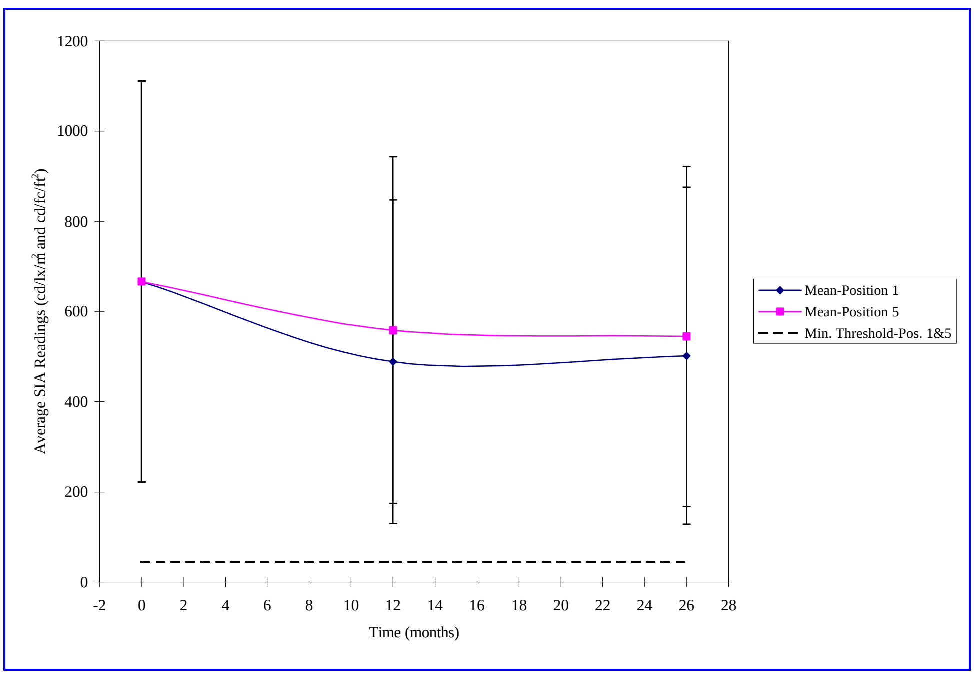


Figure 5-16. NS Box Cars – Degradation of Positions 1 and 5

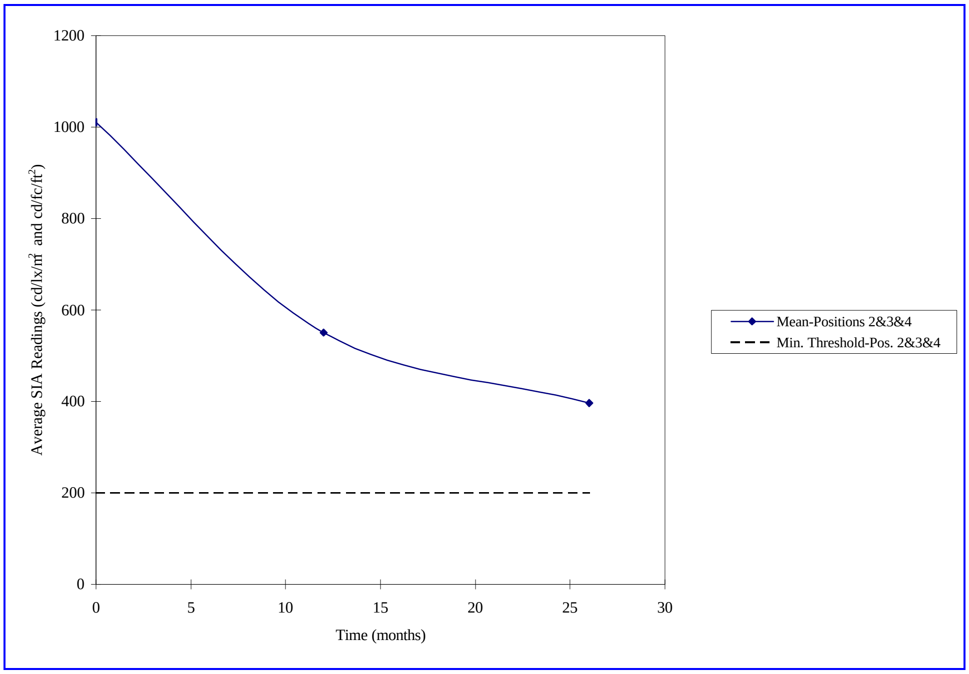


Figure 5-17. NS Box Cars – Mean Degradation Trend for Positions 2, 3, and 4

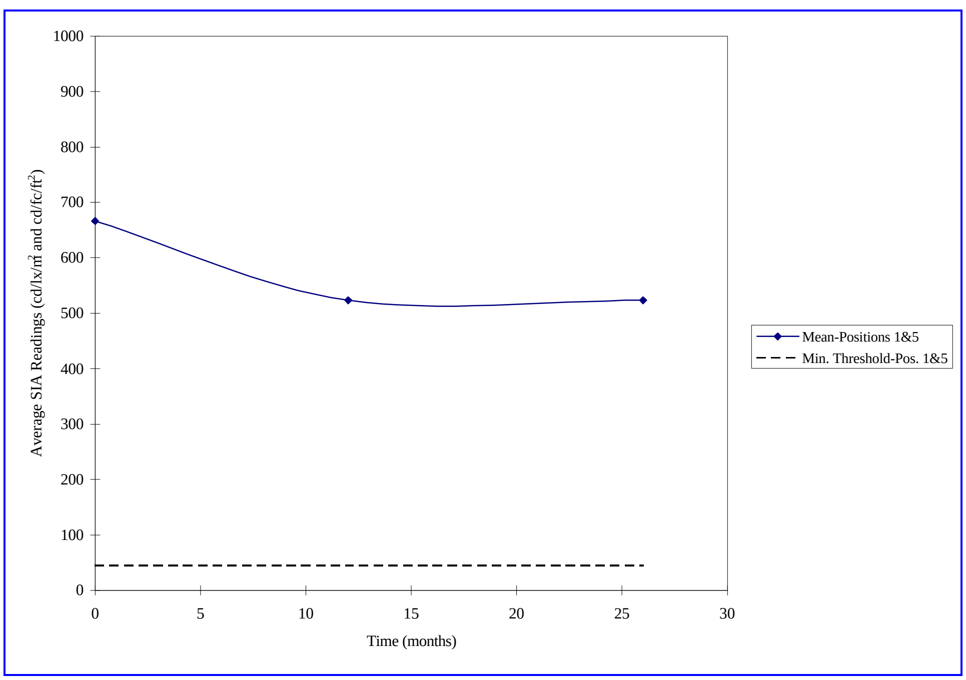


Figure 5-18. NS Box Cars – Mean Degradation Trend for Positions 1 and 5

NS Box – Natural Environmental and Operational Effects. The natural environmental conditions along the captive route within Georgia had no significant effect on the reflectors' brightness. The harsh operational environment of clay dust contributed to a severe degradation rate on Position 3 of this fleet. It is likely that forklift damage may have contributed to degradation of this reflector as well.

NS Box – Accident Reduction Potential. This fleet of captive box cars was intermingled with other non-reflectorized freight cars along this route in Georgia. Also, clay shipments were intermittent at best. Therefore, it was not possible to acquire meaningful accident data for this test condition.

5.3 ANALYSIS OF IN-SERVICE FIELD TEST RESULTS

5.3.1 Reflector Performance

A further review of the 4-inch by 36-inch delineator strip to determine any sensitivities to location above TOR is necessary. The average performance of the reflectors for each position and all car types is summarized in Figures 5-19 through 5-22. Table 5-10 shows placement locations of each white portion of the delineator strip on reflectors in Positions 1 and 5.

Table 5-10. Height Above TOR for White Portion of Delineator Strip for Three Freight Types

Freight Car Type	Upper White Portion Height Above TOR	Lower White Portion Height Above TOR
Tank Car	90 in	72 in
Double Stack Car	48 in	30 in
Hopper Car	60 in	42 in

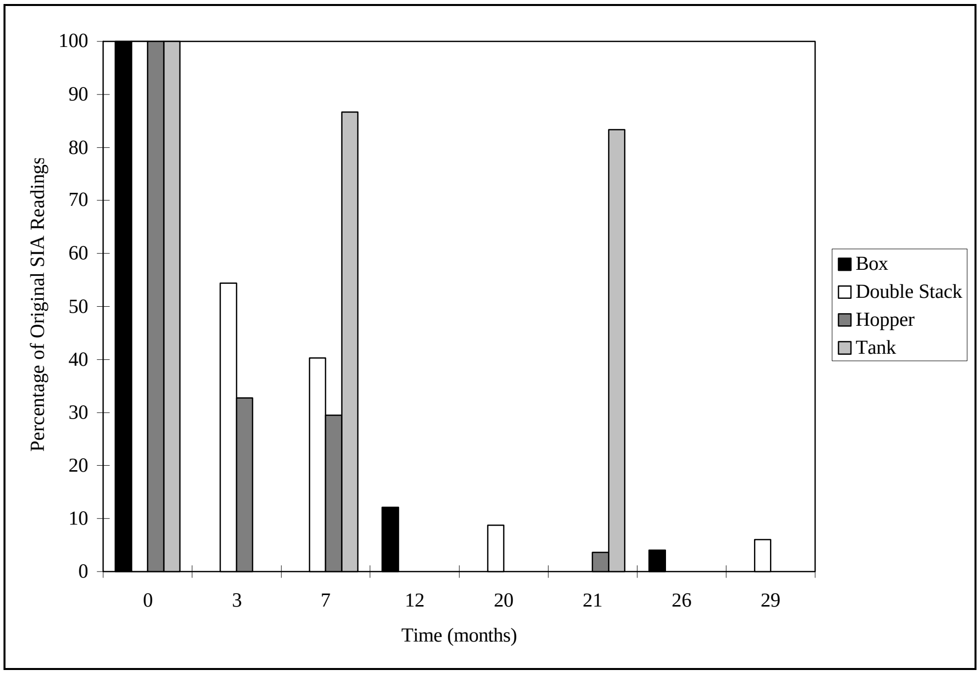


Figure 5-19. Comparative Degradation Rates for All Freight Car Types in Positions 1 and 5

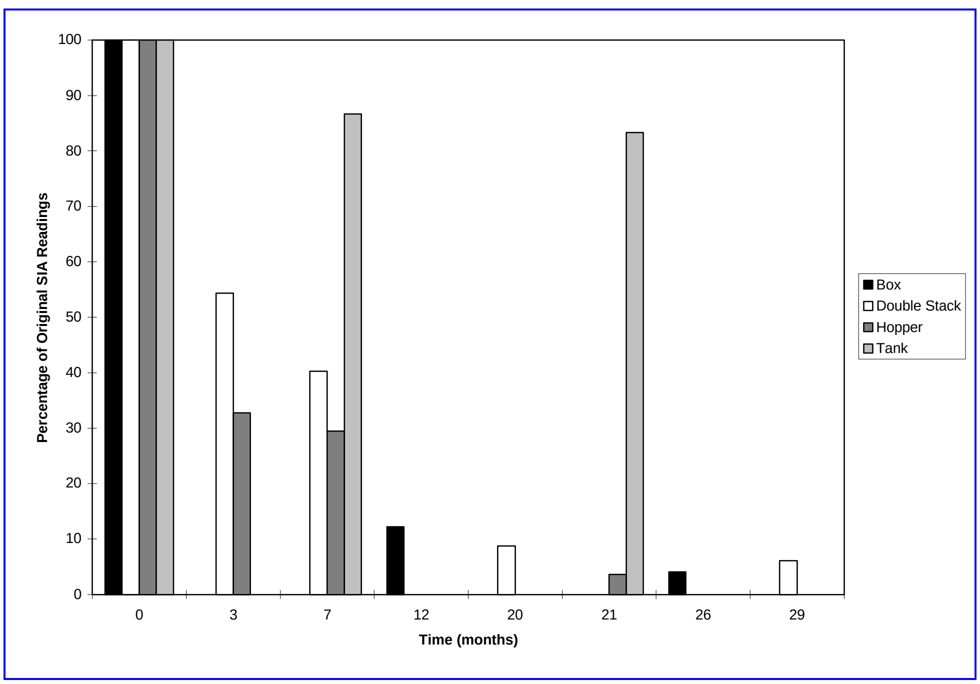


Figure 5-20. Comparative Degradation Rates for All Freight Car Types in Position 2

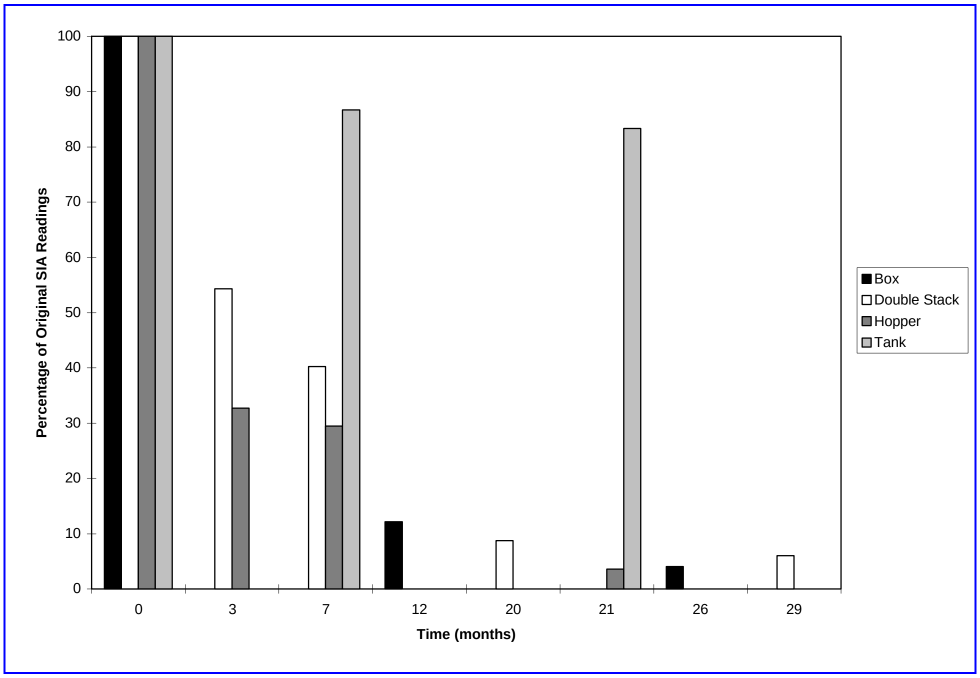


Figure 5-21. Comparative Degradation Rates for All Freight Car Types in Position 3

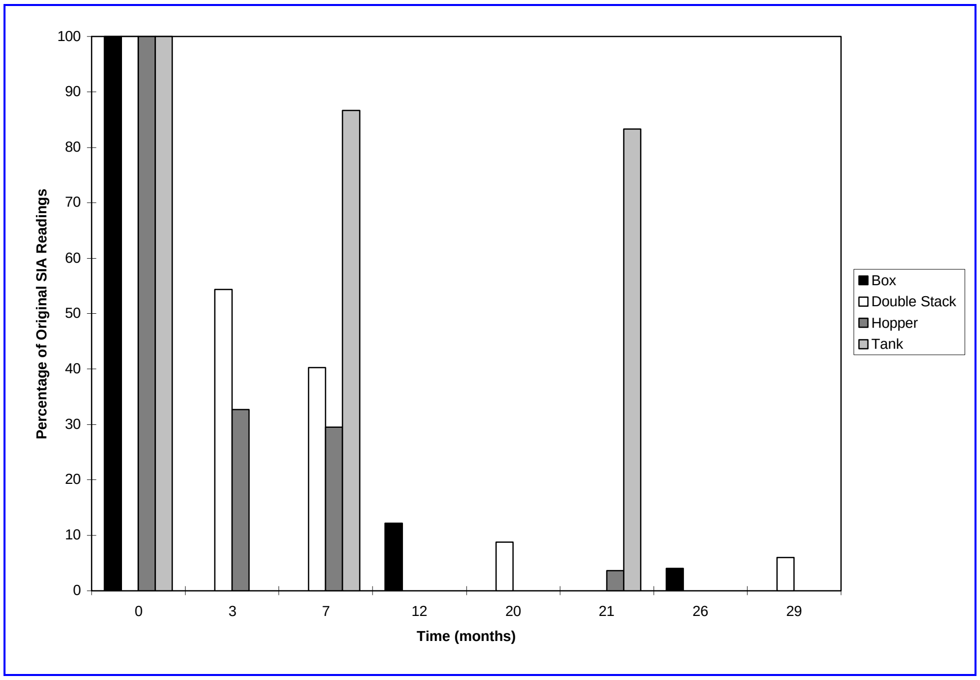


Figure 5-22. Comparative Degradation Rates for All Freight Car Types in Position 4

The results presented above indicated a general correlation of a reflector's performance to its height above TOR. The reflectors mounted highest on the tank cars performed the best, while the reflectors on the other cars, which were mounted lower, did not perform as well. This trend, however, could have been attributable to differences in the operating environment. To control for the effect of operating environment, a more detailed analysis of the reflectors located at different heights above TOR was performed within each car type. The delineator reflector strips located at Positions 1 and 5 were composed of two white (4 in by 7 in each) and two red decals (4 in by 11 in each) applied vertically, end-to-end, in an alternating pattern. Analysis of the performance of the white material will indicate if the upper patches perform better due to their higher location above TOR. Figures 5-23 through 5-26 show the degradation rates of the reflectors in Positions 1 and 5 by location of the white reflective material.

As these figures illustrate, height above TOR appears to have little general influence on reflector performance. The primary explanation for the differences in performance is, therefore, differences in the natural and operating environments. While this generally seems to be the case, the results of the hopper and box cars strongly suggest that reflectors should not be located under the sill or at loading points, since they are exposed to more extreme conditions.

5.3.2 Environmental and Other Effects on Performance of Prismatic Material

There have been no significant findings concerning natural environmental effects on the performance of these reflectors in railroad revenue service. Other effects, mainly railroad operational effects, have surfaced through the results obtained. Placement of the reflector under the sill of the freight car has been found to be detrimental to the performance of the reflector. Mid-car locations on many freight car types provide severe operational conditions; therefore, this location should not be considered in any freight car reflectorization rulemaking process. The reflectors on the petroleum tank cars seemed to benefit slightly by internal steam cleaning operations. Periodic washing of the reflectors mounted on freight cars can extend their performance to the limits of life expectancy.

5.3.3 Accident Analysis

Test Plans A (tank cars), B (double stack cars), and D (box cars) were operated in mixed freight consists, and typically made up a small proportion of the train consist. Because of the small proportion of reflectorized cars (often less than 5% of the total) in the train, their presence was unlikely to influence the accident rate for those trains. Also, there were many other trains operating on the same routes. The RAIRS database does not provide a means for identifying whether a train involved in an accident included reflectorized cars. Therefore, it is not possible to determine whether the operation of reflectorized cars on the route affected the frequency of grade crossing accidents. Test Plan C (hopper cars), however, had four full consists traversing a captive route, and was the only test plan within this research activity to do so. Plan C should provide the best information in terms of accident reduction potential. Therefore, in terms of accident reduction potential, this specific route should be targeted.

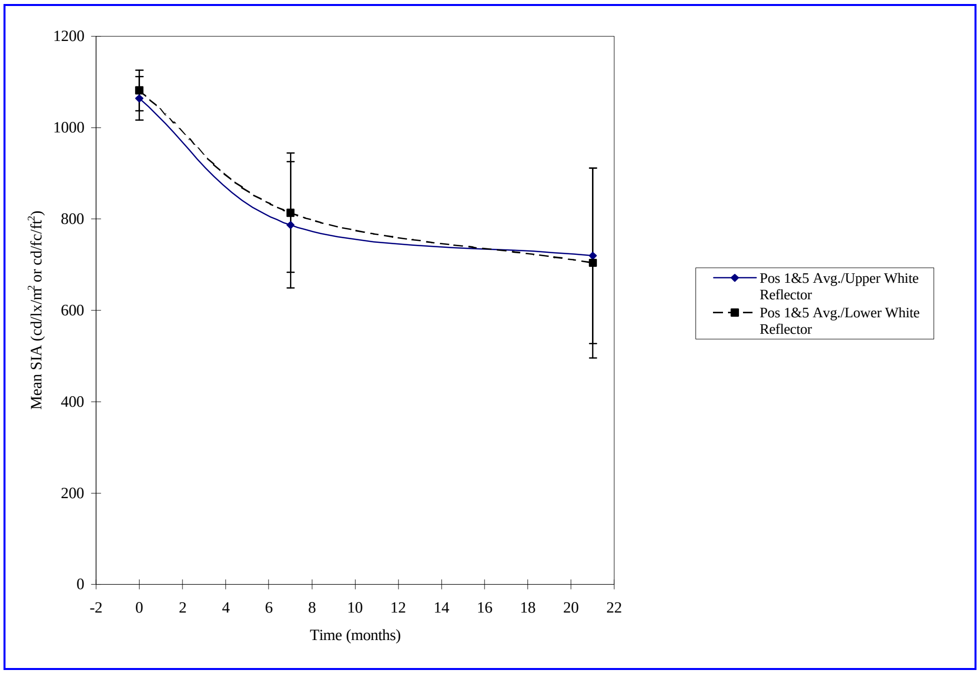


Figure 5-23. Tank Car – Upper and Lower White Reflector Degradation Rates

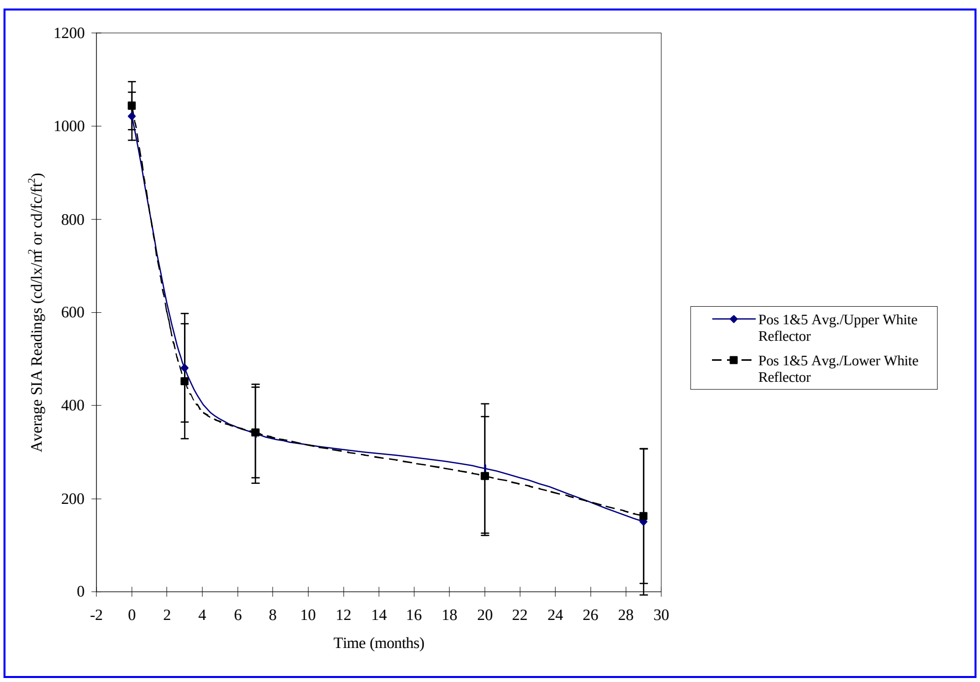


Figure 5-24. Double Stack Car – Upper and Lower White Reflector Degradation Rates

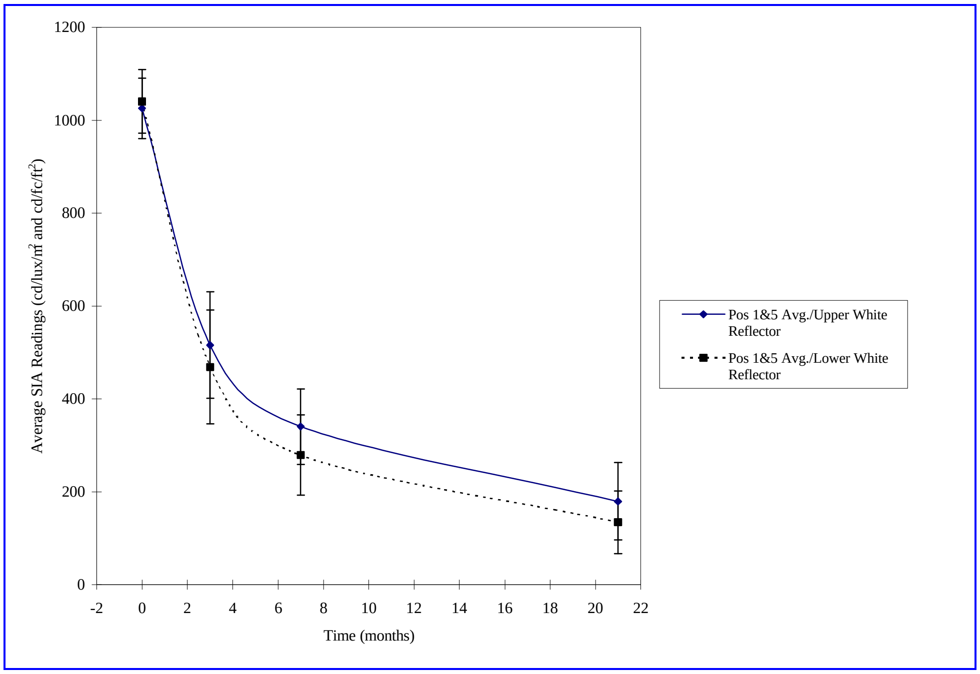


Figure 5-25. Hopper Car – Upper and Lower White Reflector Degradation Rates

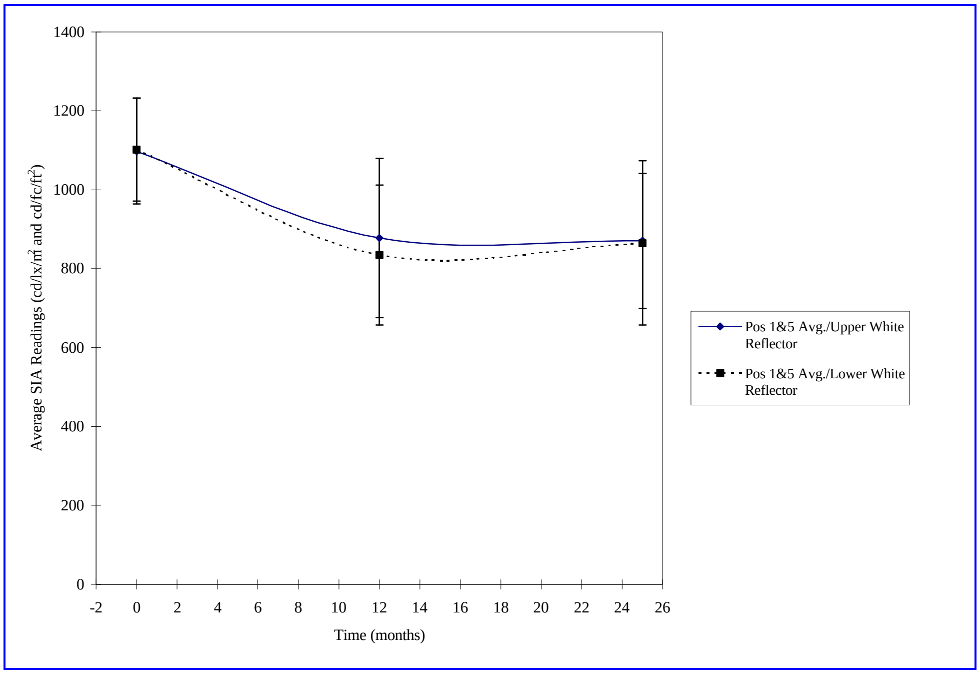


Figure 5-26. Box Car – Upper and Lower White Reflector Degradation Rates

The accident reduction potential should be concerned with only the reduction of Category 1 accidents. Therefore, Table 5-11 illustrates Category 1 accident rates for Plan C. As Table 5-11 indicates, the number of Category 1 accidents for the Plan C fleet declined from six for the period prior to reflectorization to zero for the period after reflectorization.

Table 5-11. Plan C Accident Data (Before-Test and After-Test)

	Accidents Before Test*	Accidents After Test*
Total Category 1 along captive route	6	0
Nationwide Total RIT Accidents	4213	3318
Nationwide Total Accidents	16330	13411

* The before-test period was from 5/89 to 2/92; the after-test period was from 3/92 to 12/94.

The results above indicate that freight car reflectorization has potential for reducing Category 1 accidents. This finding, while positive for reflectorization, should be viewed with caution since it is based on very limited accident experience.

5.3.4 Installation Costs and Maintenance Requirements

Material Costs. Reflectorization material and labor costs for the in-service field test:

White Material — $272 per 150-foot roll = $1.81/foot
Red/White Material — $300 150-foot roll = $2.00/foot
1990 Labor Rate[1] — $68.25 per hour

Material per Car (both sides)
White — 4 feet @ $1.81/ft = $7.24
Red/White — 12 feet @ $2.00/ft = $24.00
Total Material Cost per Car = $31.24

Labor per Car[2]
Newer Cars (minimum cleaning) – 2 people @ 15 minutes/car = $34.12
Older Cars (heavy cleaning) –2 people @ 30 minutes/car = $68.25

[1] Labor rate shown within this section is based on installation cost charged by Norfolk Southern to the Volpe Center.
[2] Labor includes surface preparation and material installation.

Total Cost per Car (Material and Labor)

Newer Cars (minimum cleaning)	=	$65.36
Older Cars (heavy cleaning)	=	$99.49

The manufacturer that provided the retroreflective material for this research was contacted recently to determine if increases in demand resulting from large tractor trailer truck reflectorization rulemaking had any affect on the cost of prismatic retroreflective material. The in-service pattern's original cost of $31.24 has now been reduced by 40% (as of December 1996) for a cost of material per car of to approximately $18.75. Using the estimates for the labor of reflectorizing an older car that may need heavy cleaning and the reduced material cost, the resultant maximum cost per car using the in-service pattern would be $87.00.

Based on the assumption that the installation of the retroreflective material would be a task of the railcar's maintenance program, the labor cost, in 1990 dollars, would have been significantly less than the amount shown above. The 1996 AAR Labor rate is approximately $20.05 per hour (Browder, 1998), which is approximately 30 percent of the labor rate of the 1990 installation. Using the estimates for the labor of reflectorizing an older car that may need heavy cleaning (using the 1996 AAR labor rate) and the reduced material cost, the resultant maximum cost per car using the in-service pattern would be approximately $38.80.

5.4 SUMMARY OF FINDINGS

5.4.1 Reflectivity and Maintenance

To allow maximum efficiency of reflector performance, a minimum height above TOR has been defined at 42 inches. A maximum placement height of 72 inches above TOR is suggested to limit the divergence angle formed between the light source and observer. There was very little change in reflector performance above this height due to dirt and grime accumulation. The average performance of all delineator strips, red and white decals measuring 4 inches by 36 inches, mounted at Positions 1 and 5 remained above the established threshold level for all freight car types for the entire testing period. The average performance of all white 4-inch by 8-inch reflectors degraded more quickly, however, especially for some car types. This finding indicates an adjustment is necessary to the reflectorization pattern to minimize their location under the sill and at loading points, and to increase their size, which will lower the acceptable threshold level.

For the average freight car involved in this study, it can be estimated that a 12- to 18-month cycle of maintenance would be sufficient to sustain the threshold levels necessary to attract the attention of a motorist. A minimum cleaning time of 15 minutes per car is considered reasonable for these reflectors with no additional cleaning solvents necessary in the process. Periodic washing of the reflectors can extend their acceptable performance to the limits of their life expectancy.

5.4.2 Natural and Operational Environmental Effects on Reflector Performance

No natural environmental factors were found to have a significant effect on reflector performance of the four freight car types studied nationwide. The severe railroad operational environment did degrade the performance of the reflectors, especially in mid-car placement locations, on two types of freight cars. Mid-car locations, specifically on tank cars and box cars, resulted in severely degraded reflector performance due to loading operations. Therefore, mid-car placement of reflectors is not recommended.

The 4-inch by 8-inch white reflectors placed under the sill level of hopper cars did not perform well due to their proximity to the effects of dirt and grime accumulation from the rail and wheel interaction. Therefore, it is recommended that a minimum height above top of rail be established at 42 in and that reflectors not be placed under the sill. This finding should be implementable for most freight car types; however, some minor exceptions to a uniform pattern will most likely have to be made to accommodate special car configurations.

5.4.3 Accident Reduction Potential

The in-service field test included one captive route, which consisted of four fully reflectorized open top hopper cars. These consists had approximately a 3-day turnaround time for a round trip. Comparing the accident rate (for the highway-railroad grade crossings involved in this study) for the 3 years before reflectorization to the accident rate for the 3 years after reflectorization revealed a significant decrease. The "before" test conditions found six Category 1 accidents occurred on this set of crossings. The "after" test conditions revealed no Category 1 accidents occurred. Although this data is very limited, it strongly supports the use of freight car reflectorization to aid in reduction of Category 1 accidents. The other three fleets investigated included reflectorized cars that were intermingled with other non-reflectorized freight cars and, therefore, could not be used as a basis for potential accident rate reductions. Two other captive fleet routes, the tank and double stack cars, had Category 1 accident rates increase after the in-service tests. These two fleets were once again intermingled with other non-reflectorized cars and should not be used to measure potential for accident reductions.

5.4.4 Material and Maintenance Costs

The demonstration test pattern's original cost of $31.24 has now been reduced by 40% (based on information stated by the manufacturer) for a cost of material per car of approximately $18.75. Additionally, the 1996 AAR labor rate is approximately $20.05 per hour. Using the estimates for reflectorizing an older car during the normal maintenance program that may need heavy cleaning (at the 1996 AAR labor rate), and reduced material costs, the resultant maximum material cost per car using the tested pattern would be approximately $38.80. Heavy cleaning of the reflectors would require 2 person for 30 minutes to complete the process approximately every 12-18 months, resulting in a cost of approximately $20.05 per event. The manufacturer specifies this prismatic material's useful life to be 10 years. Therefore, maximum projected total costs of the material and maintenance for a 10-year period would be $219.25 per car (based on lower material costs, heavy cleaning, two-person annual maintenance, at the 1996 AAR labor rate).

6. HUMAN FACTORS EVALUATION OF RETROREFLECTIVE MARKING DESIGNS

6.1 INTRODUCTION

This chapter describes the results of a study (Ford et al. 1998) to develop and evaluate several proposed designs for placing retroreflective markings on rail cars. The purpose of these retroreflective markings is to increase the conspicuity of the rail car to the approaching motorist. Conspicuity is defined as the properties of an object that result in its detection with a high probability and at a sufficient distance to allow an approaching driver to avoid a potential hazard (Olson, et al. 1992).

6.1.1 Literature Review

The typical rail car presents a poor target at night and is difficult to detect. The painted surface of the rail car is frequently painted in a dark color and is dirty. Generally, the dirt accumulation is greatest near the ground and decreases the higher the surface is above the ground. Because much of the surface of the rail car is above the mounting height of automobile headlamps, the likelihood of detection with low beam illumination is decreased. Other cars, like the flat car or double stack car, present a smaller total surface area facing the driver. Currently, there are no requirements for lighting or retroreflective markings on rail cars.

A body of research (Lauer and Suhr 1956; McGinnis 1979; Stalder and Lauer 1952; Olson 1987; Olson, et al. 1992; Ziedman, et al. 1981) suggests that retroreflective materials can increase the conspicuity of objects to which they are attached. However, previous generations of retroreflective markings reflected less light and lacked the durability to survive the harsh environment to which rail cars are regularly exposed (Poage, et al. 1983; Poage and Hopkins 1983). The prismatic (cube corner) retroreflective markings currently available overcome these problems.

There is little research that suggests how retroreflective materials should be displayed on the rail cars to maximize the conspicuity of the rail car for the approaching motorist. Studies devoted exclusively to the problem of displaying retroreflective markings on rail cars (Lauer and Suhr 1956; McGinnis 1979; and Stalder and Lauer 1952) were performed with the previous generation of retroreflective materials (enclosed lens or encapsulated lens). Lauer and Suhr (1956) tested four different configurations using the same amount of material for each pattern. They discovered that the massed applications (concentrating the material in one or two locations) were more effective than those applications that were distributed over a wider area. By contrast, studies assessing the effectiveness of retroreflective markings on trucks (Olson, et al 1992) used the prismatic materials available today. Both of these more recent studies concluded that providing a design that outlined the shape of the vehicle increases conspicuity.

While much of the research investigating the effectiveness of retroreflective markings for trucks is relevant to rail cars, there is a lack of knowledge about the optimal design of retroreflective markings for rail cars. The primary concern here is with developing a retroreflective marking design that is detectable in time for the motorist to recognize a train in the grade crossing and respond in time to avoid an accident.

The remainder of this chapter describes the methodology by which several retroreflective marking designs were developed and evaluated. The development of a set of prototype marking designs is described, followed by a subjective and objective evaluation of a subset of these designs. For readers interested in a more detailed description of this study, please refer to the full report by Ford, et al. (1998).

6.1.2 Development of Candidate Designs

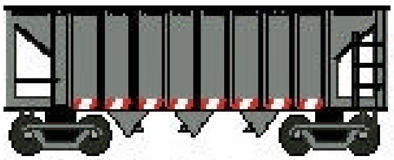
To develop a set of retroreflective marking designs for evaluation, the Nominal Group Technique (NGT) was chosen. The NGT consists of a focus group moderated by a facilitator. The group follows a systematic procedure in which the facilitator moderates the actions and interactions of the group to achieve the goals set by the moderator. The four steps in the NGT procedure are: (1) silent generation, (2) round robin discussion, (3) clarification of design alternatives, and (4) ranking of alternative designs. For this study, the group consisted of six individuals with experience in traffic engineering, railroad operations, and/or human factors.

In the silent generation step, members of the group worked alone to generate as many designs as they could. During this brainstorming period, members were given a set of materials with which to generate their designs. These materials consisted of the following:

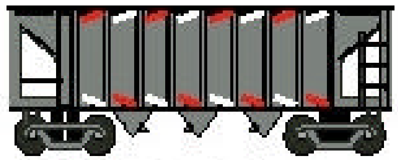
- a silhouette of an open hopper freight car;
- samples of prismatic retroreflective materials in white, red, yellow, orange, green, blue, fluorescent yellow, and fluorescent orange;
- marking pens that matched the different colored materials; and
- blank graph paper on which to sketch their designs.

The participants created 25 designs from the brainstorming process. During the round robin and clarification processes, each participant presented his or her designs to other group members. The facilitator assigned each design a number and the members discussed the ideas underlying each of the designs. Duplicate designs were discarded.

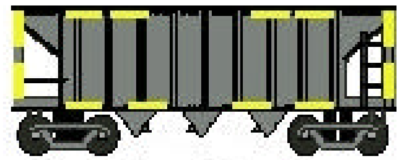
In the final step, each participant selected the 8 most “detectable” designs from the original 25 designs and ranked them from 1 to 8, with 1 being least detectable and 8 being most detectable. The individual scores for each of the designs were combined and tabulated to identify the top eight designs. The top eight designs served as the basis for further evaluation and are shown in Figure 6-1. In addition to the eight designs shown in Figure 6-1, three additional designs were added for evaluation. These markings include: a design being evaluated as part of the in-service test to evaluate the durability of the current generation of microprismatic materials; the design required by federal regulations for enhancing truck conspicuity; and an unreflectorized car to serve as a baseline condition against which the other designs are compared. These designs are also shown in Figure 6-1.



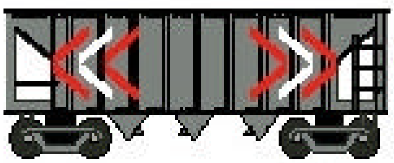
Red and White Crossing Gate. Alternating red-white-red diagonal strips applied to the full length of the car just above the side sill.



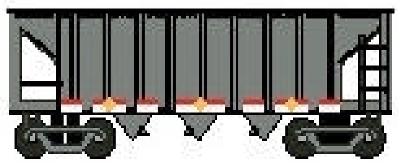
Red-White Sawtooth. Alternating red and white strips applied in a 30° counterclockwise sawtooth pattern just below the top cord and a mirror image white and red 30° clockwise sawtooth pattern just above the side sill.



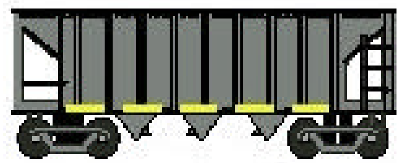
Yellow Outline. Outline of the car body with fluorescent yellow strips.



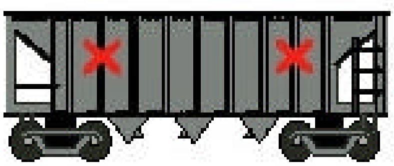
Red-White Chevron. A red-white-red chevron applied to the left and right side of the car body.



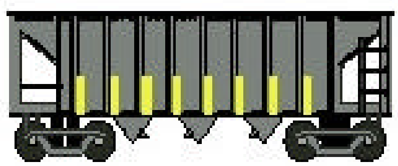
Orange Diamonds in Bars. A Red over white stripe just above the side sill with fluorescent orange diamonds superimposed on the red and white stripe.



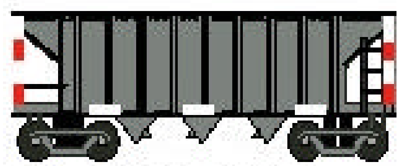
Yellow Dash. Horizontal fluorescent yellow strips, spaced symmetrically about the horizontal centerline of the car body just above the side sill.



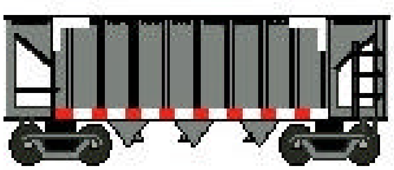
Red Crossbucks. A red crossbuck applied to the left and right ends of the car.



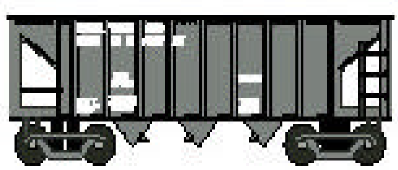
Yellow Fence. Vertical fluorescent strips, spaced symmetrically about the horizontal centerline of the car body just above the side sill.



Red and White Partial Outline. Vertical red and white strips, placed on the corners of the car body and three short horizontal white dashes placed symmetrically about the vertical centerline just above the side sill.



Red and White Highway Truck. A red and white stripe just above the side sill with white corner markings applied just below the top cord.



Unreflectorized Car. A black car with nonreflective white markings showing reporting marks, logo, and car data.

Figure 6-1. Illustration of Marking Designs Generated from Brainstorming Session

The designs selected for further study can be characterized by their color and pattern. All of the designs used the following colors: fluorescent yellow, fluorescent orange, red, or some combination of red and white. The red-and-white combination and yellow alone were the most frequently selected colors. For pattern, the eight designs consisted of rectangular strips of material. Their arrangement can be differentiated on the basis of the categories shown in Table 6-1. Table 6-1 also summarizes how the eight designs fit into the three classes of patterns.

6.2 SUBJECTIVE EVALUATION OF CANDIDATE DESIGNS

6.2.1 Method

A subjective evaluation was conducted to measure the preferences of transportation experts and potential drivers for the eleven candidate marking systems described earlier. The primary concern was with the detectability of the proposed marking systems. The expert group represented those people who might install, maintain, and monitor the safety of the proposed marking designs. The expert group was composed of people with job experience in grade crossing safety, human factors, and traffic engineering. Completed surveys were received from 44 of the 150 people invited to participate in this group. The driver group represented those people who would use and depend upon the marking systems to avoid collisions at highway-rail grade crossings. The driver group was drawn from licensed drivers with at least 2 years of experience, living near the University of Tennessee. Serving as participants in this group were 51 drivers living in or near Knoxville, Tennessee.

Table 6-1. Pattern by Class

Class	Definition	Pattern
I	A fixed amount of material concentrated in a relatively small area.	Red-White Chevron Red Crossbucks
II	A fixed amount of material outlining the shape of the rail car.	Yellow Outline
III	A fixed amount of material spaced uniformly over a relatively large area.	Red and White Crossing Gate Red-White Sawtooth Orange Diamonds in Bars Yellow Dash Yellow Fence

Three scaling methods were implemented to measure the preferences of the two groups: (1) paired comparisons, (2) ranking, and (3) semantic differential ratings of selected markings' attributes. In making paired comparisons, participants viewed the pairs of markings and decided which design better enhanced the visibility of the rail car. The participants viewed all possible combinations of the marking pairs. In the simple ranking procedure, participants ranked the 11 marking designs from 1 to 11, on the basis of how well they enhanced the visibility of the rail car (1 being least effective and 11 being most effective). For the semantic differential method, participants rated each of the 11 markings on several attributes. These attributes or dimensions included: (1) detectability, (2) recognition, (3) understanding, (4) confusability, (5) conspicuity, (6) uniqueness, (7) contrast, (8) placement, (9) color, and (10) pattern. For each attribute, the participant selected an adjective (ranging from extremely good or extremely easy to extremely poor or extremely bad) that best described how they felt about the marking design in question.

Each of the 11 marking systems was fabricated from diamond grade (microprismatic) retroreflective materials. The markings were attached to both sides of a 1:23.5 scale model of an open hopper car. Each marking design used 1.4 square inches of retroreflective material. This amount of retroreflective material was scaled to match the quantity of material, 382 square inches, used in the in-service field test.

Presentation of the marking patterns differed in the two groups. For each of the methods, the driver group viewed the actual scale models in a dark room illuminated by simulated headlights. The transportation experts viewed color photographs of the scale models. The color photographs of the individual model cars were set against a plain dark background. The method by which the transportation experts evaluated the marking designs consisted of a survey administered by mail. This method was necessary due to the wide geographical dispersion of the group.

6.2.2 Results and Discussion

Expert Group. Figure 6-2 shows the expert group preferences for the different marking designs, using the paired comparisons and the ranking method. Color appears to be the primary attribute affecting the preferences of this group. The experts preferred designs with fluorescent yellow followed by the red-and-white combinations and red-only for both the paired comparisons and ranking method. The results of the semantic differential scaling also support these preferences. As expected, the rail car without any retroreflective material was ranked worst. Within color, there was no clear preference for pattern. However, because there were unequal numbers of each pattern distribution by type of class within colors, it is difficult to draw meaningful conclusions regarding pattern preferences.

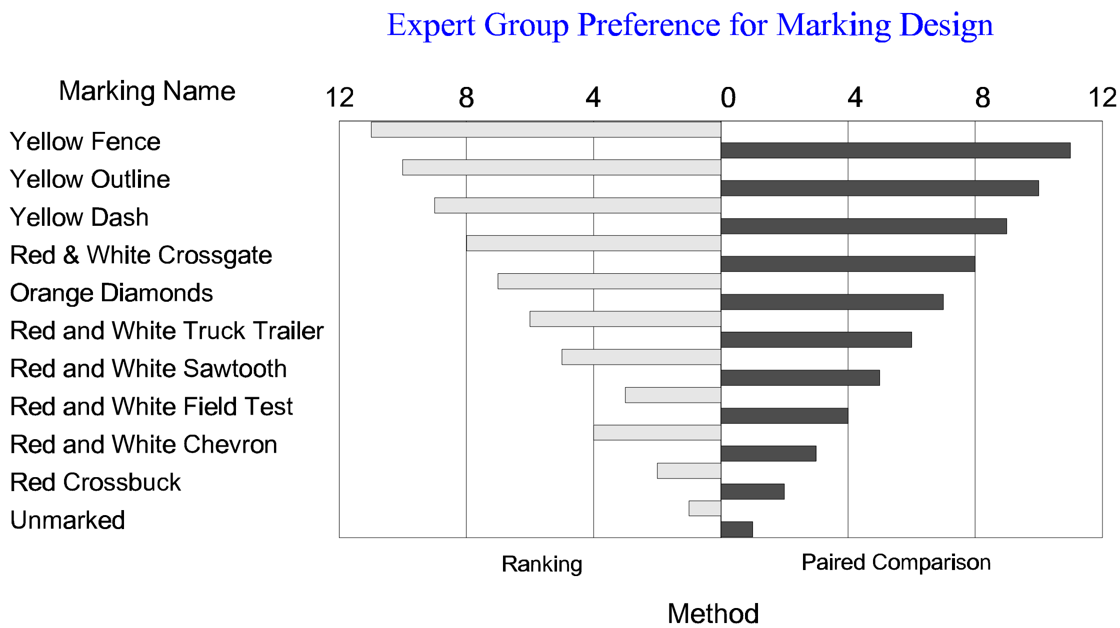


Figure 6-2. Expert Preferences for Individual Marking Designs by Type of Method: Simple Ranking and Paired Comparison

Driver Group. Figure 6-3 shows the driver group preferences for the different marking designs, using the paired comparison and the ranking methods. The data from semantic differential scale were consistent with the results of the paired comparison and the ranking methods. The driver group showed no clear preference for a marking design by color or pattern. As expected, the rail car without any retroreflective material was ranked worst. Two of the yellow marking designs that were ranked high by the experts were also ranked high by the driver group, while one yellow design (the yellow dash) was ranked considerably lower. For pattern, the Class 1 patterns that massed a fixed amount of material within a small area tended to be in the middle range of driver preferences, while the Class 3 pattern was ranked highly. The Class 2 designs were both the most preferred and among the least preferred. For example the yellow dash and orange diamonds in bars pattern were among the least preferred, while the red and white sawtooth and yellow fence patterns were among the most preferred. This data suggests that the driver group was responding to some combination of color and pattern or some other aspect of the design that is not readily apparent. Unlike the expert group, the driver group did not appear to focus on either color or pattern alone. The driver group also showed greater variability in its preferences by method used than the experts. The preferences of several marking designs changed somewhat between methods. However, this change was not dramatic. A marking design that was ranked best with one method, e.g., the yellow fence, tended to do well in another method. On a scale from 1 to 11, marking designs may have varied 1 to 3 units between methods.

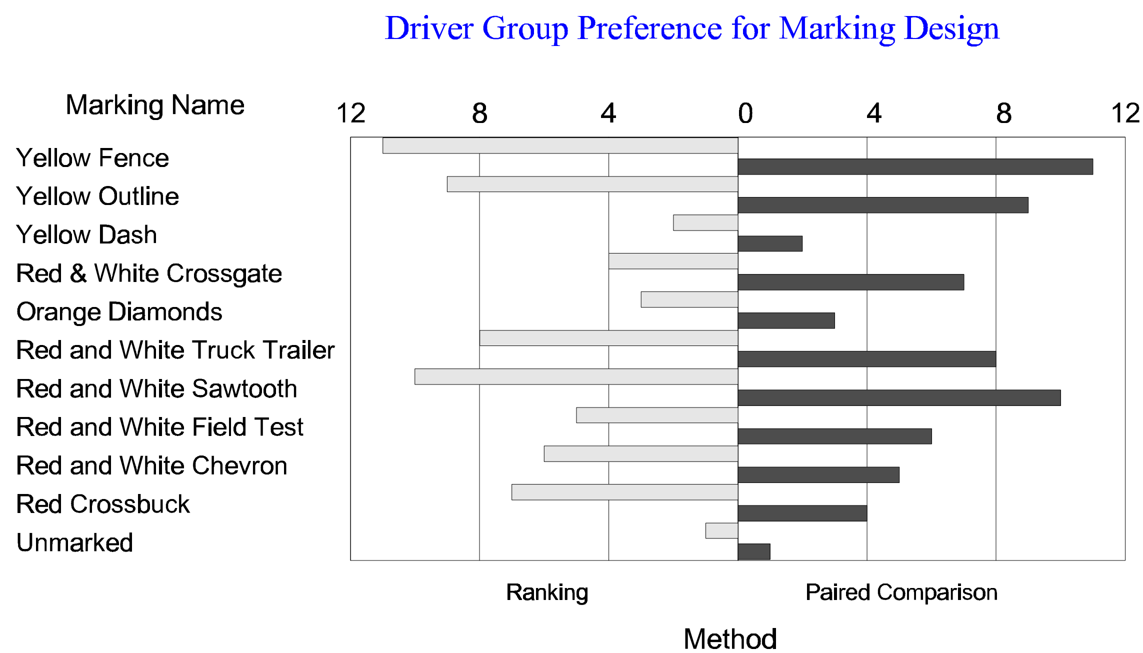


Figure 6-3. Driver Preferences for Individual Marking Designs by Type of Method: Simple Ranking and Paired Comparison

Comparison between Groups. In comparing the preferences of the two groups, it is clear that they responded differently to the marking systems. A number of factors may explain the observed differences. The greater variability between different methods for drivers compared to the experts may be due to differences in the homogeneity of the two groups. The experts may be a more homogenous group than the driver group, given their interest in the transportation field and knowledge of transportation operations. The experts, for example, may have responded primarily to color because they were aware of the relationship between color and the amount of light returned by the material. In these designs, fluorescent yellow returns the most light, followed by red and white combined and red alone.

Another factor that may have influenced the outcome of the subjective evaluations was the means by which the participants viewed the retroreflective markings. The experts responded to a mail survey and viewed color photographs of the retroreflective markings. The photographs displayed how the retroreflective markings might appear on a rail car in daylight. The different lighting condition displayed in the photographs may have contributed to the experts perceiving color as a more salient or attention-getting cue than pattern alone or the combination of color and pattern. The driver group saw scale models of the retroreflective markings in a dark room illuminated by a set of headlights. This view corresponds more closely with the conditions under which drivers may view retroreflective markings at night. Thus, each group viewed the retroreflective markings under different viewing conditions. To the extent that the nighttime conditions are more representative of conditions likely to be found in an actual driving environment, the results of the driver group may be more representative of how detectable a given design may be.

The results of the driver group suggest that it may be the combination of color and pattern that significantly influences preference, rather than either factor alone. For example, the driver group exhibited a similar preference to the expert group for two of the yellow patterns, the fence and the outline. However, the third yellow dash design scored much lower. The low score received by the yellow dash suggests that something about the pattern makes it less detectable.

The process by which the retroreflective marking designs were generated for evaluation resulted in a set of designs that differed in one or more attributes (color or pattern). Since not all combinations of color and pattern were evaluated, it is not possible to draw definitive conclusions regarding driver preference for one design over another. Additionally, preference for one design over another may not be indicative of objective performance. An objective test is necessary to establish the detectability of potential marking designs by drivers. This objective test is the subject of the next section.

Nevertheless, both groups' preferences for fluorescent yellow designs over the red-and-white combination and red-only designs are supported by previous research. Olson, et al. (1992), and Ziedman, et al. (1981), documented the relationship between detectability and Specific Intensity of Area (SIA), showing that the higher the SIA, the greater distance at which a retroreflective marking could be detected. Fluorescent yellow has a higher SIA than red-and-white together or red alone.

With regard to pattern, the greater preference of both groups for the outline pattern is consistent with Olson, et al.'s (1992) evaluation of retroreflective markings for trucks, which demonstrated that patterns that outline the shape of the vehicle improve recognition performance. However, the poor preference for patterns that concentrated material in a relatively small area (crossbuck and chevron) was surprising in light of the Lauer and Suhr (1956) research suggesting that concentrating retroreflective material improves detection performance compared to spreading it out over a larger area. This change may be attributable to the greater retroreflective properties of the current generation of retroreflective materials, as well as to differences in the designs between the two studies.

6.3 OBJECTIVE EVALUATION OF CANDIDATE DESIGNS

To avoid a collision with a train in the grade crossing, a driver must detect its presence in time to stop. The design preferences described in the previous section suggest which potential marking designs drivers would like. However, these preferences are not necessarily indicative of the best performance. The features that may influence preference are not necessarily the same ones that result in effective performance (Andre and Wickens 1995). The purpose of the following experiment was to determine how color and pattern affect detection performance for potential drivers.

6.3.1 Method

Overview. An absolute detection task was used to determine the distance at which subjects would detect nine retroreflective markings and an unreflectorized rail car. For each trial, subjects viewed a series of color slides showing a single retroreflective marking design mounted on an open hopper car under nighttime conditions. The projected image of the rail car increased in size to simulate the movement of a motor vehicle toward the grade crossing. The subject responded by indicating when he or she detected the rail car and indicating which of the marking designs or the unreflectorized car was displayed.

Experimental Design. Color and pattern were the two independent variables used. From the previous evaluation of driver preferences, three patterns (the fence, the partial outline [Volpe field test], and the dash) were selected for evaluation. In the evaluation of the driver group, these three patterns scored in the top, middle, and bottom ranking of preferences, respectively. The dash was selected because it was ranked last except for the unmarked car. The partial outline pattern (also referred to as the Red and White Field Test) which was among the moderately preferred patterns was selected because it was evaluated in the field for durability. Among the most preferred designs, the fence was selected because its vertical spatial orientation varied from the horizontally oriented dash pattern. These three patterns were selected to determine whether the differences in user preferences were reflected in detection performance. Each of the three patterns was evaluated using three color sets (fluorescent yellow, red and white adjacent to each other, and red alone), generating a total of nine retroreflective marking designs. In addition, an unreflectorized car was added as a baseline condition against which to compare the other nine designs.

The two independent variables, color and pattern, were combined in a repeated measures design in which all subjects received all treatment combinations. There were four observations by each subject for each of the 10 marking designs. Thus, each subject received 40 trials. To minimize learning effects, the presentation order of each marking design was randomized.

The dependent variables were detection distance, detection time, recognition distance, recognition time, and recognition errors. Detection time represents the time at which the subject first detects the unreflectorized hopper car or marking design. Directly related to detection time is the detection distance measure. Detection distance is the distance from the hopper car at which the hopper car or marking design was first detected. Recognition time represents the time at which the subject identified the hopper car or marking design. Directly related to recognition time is the recognition distance measure. Recognition distance is the distance from the hopper car at which the unreflectorized hopper car or marking design was identified.

Apparatus. The experiment was conducted in a windowless room, where the ambient light level could be controlled. The presentation of the slides and the recording of the subject's responses was accomplished using an IBM Personal System/2, Model 50 microcomputer coupled to a Kodak model 4600 autofocus slide projector with an f/3.5 102 to 152 mm zoom lens. A special backlighted 12-key control panel was used to input the subjects' responses, and a standard keyboard was used by the laboratory assistant to control the experiment. A diagram of the system setup is shown in Figure 6-4, and the special keyboard is shown in Figure 6-5.

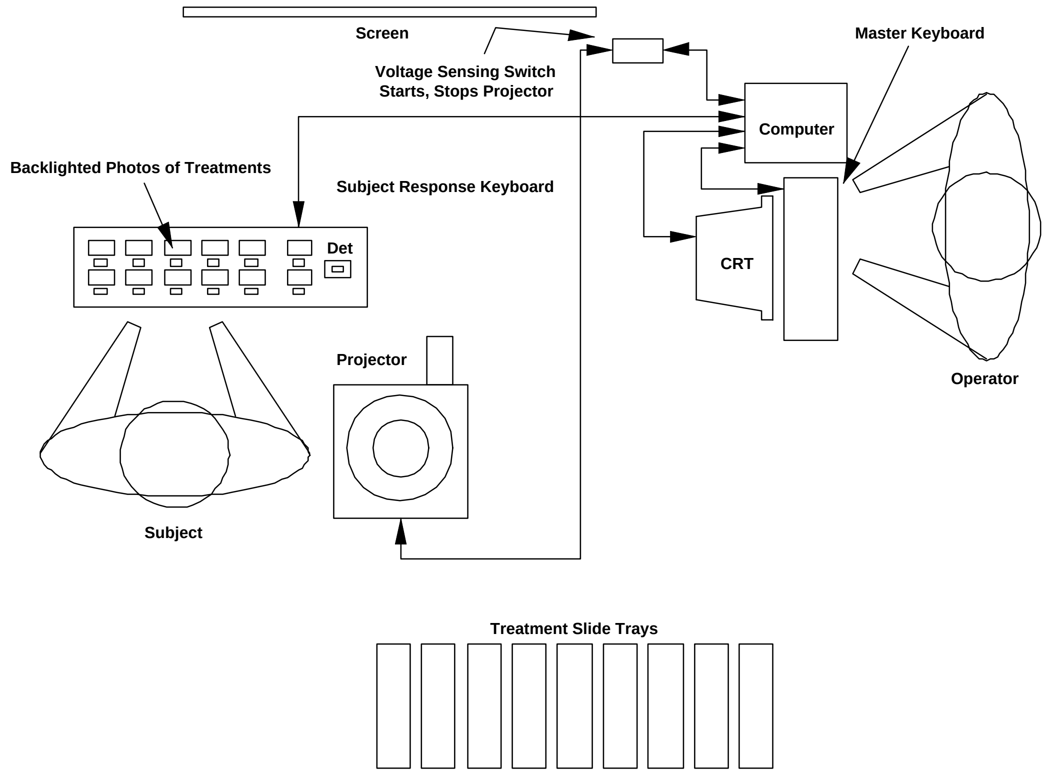


Figure 6-4. Layout of Experiment

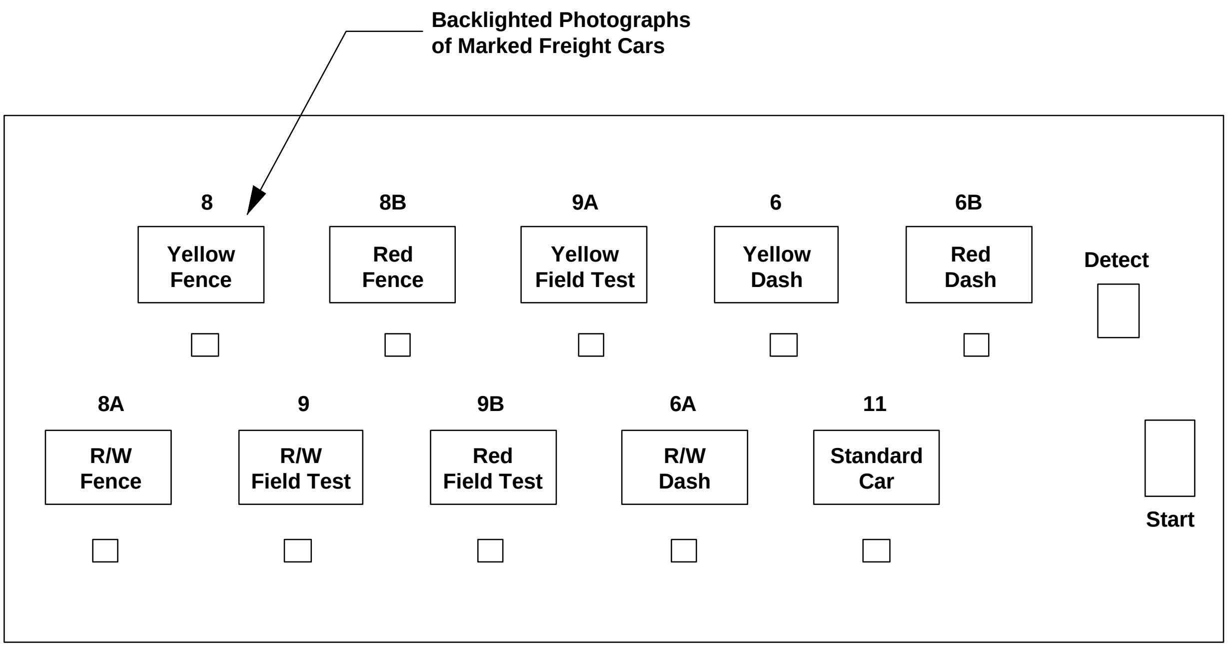


Figure 6-5. Keyboard Arrangement

Construction of Retroreflective Markings. To construct the marking designs for this experiment, 10 scale model rail cars were used. Prismatic retroreflective material was attached to each of nine open hopper cars. The same amount of material, 1.4 square inches, was attached to each car using the 9 designs previously described. A 10th open hopper car contained no retroreflective markings, and displayed only the standard AAR markings for an open hopper rail car. Figure 6-6 shows the 10 retroreflective marking designs.

For each retroreflective marking design 20 slides were created that varied the distance of the camera to the scale model. Starting at a scale equivalent of 2,500 feet from the open hopper car, each successive slide was photographed in 100-foot increments closer to the open hopper car. The last slide was photographed at the scale equivalent of 100 feet from the hopper car. The slides were photographed in a windowless room and illuminated only by two 4.5-watt halogen headlamps. The headlamps were mounted on the tripod just below the camera lens. For each marking design, 25 slides were created — a total of 250 slides for the 10 designs.

Within a single retroreflective marking design, the order in which the slides were created was preserved during presentation to the subjects. However, the presentation order of the different retroreflective marking designs was randomized.

Subjects. Participating in the experiment were 36 licensed drivers from the surrounding Knoxville, Tennessee, area; 22 participants were male and 14 were female. They ranged in age from 20 to 40. Each participant had a visual acuity of 20/40 or better. Participants who normally wore corrective lenses while they drove were asked to wear them during the experiment. None of the participants reported any color vision deficits.

Procedures. When the subject reported to the testing room, the experimenter had the subject complete a biographical data form and explained the purpose of the experiment, namely, to learn the distance at which the subject could detect and recognize several retroreflective marking designs. The main room lights were turned off and the subject was shown a set of 10 slides that displayed each of the 10 marking systems. The subject viewed the slides until he or she could recognize and name each system.

The experimenter instructed the subject to view a series of slides of hopper cars with the various marking systems attached. Each set of slides depicted one marking system, and each subsequent slide in the set showed the hopper car and attached markings at a closer distance. The experimenter indicated that the hopper car image would be located near the center of the screen and that there would be a rail car in all slides shown. The experimenter instructed the subject in the use of the 12-key control panel shown in Figure 6-5 and gave several practice trials. The experimenter coached the subject until he or she could perform satisfactorily and clearly understood the task.

A trial began when the subject struck the key with a green backlight. Each slide was displayed for 5 seconds. When the subject detected one of the marking systems, he or she responded by pressing the yellow backlighted key. The subject continued watching the progression of slides until he or she could identify which of the 10 marking systems was displayed. When the subject recognized the marking system, the subject pressed the backlighted key that corresponded to that particular marking system. Pressing this key ended the trial. The slide tray was replaced and another trial was initiated by instructing the subject to strike the green key again.

Figure 6-6. Nine Experimental Marking Designs

6.3.2 Results and Discussion

Data from two subjects was dropped due to errors or missing data in files containing their data. This action reduced the number of subjects' data from 36 to 34.

Detection of Retroreflective Marking Designs. Detectability will be discussed in terms of detection distance rather than detection time. The results are the same for both detection distance and detection time. However, detection distance from the rail car or grade crossing is a more meaningful concept since it relates the distance of a potential driver to the grade crossing.

A one-way Analysis of Variance (ANOVA) was performed to compare each of the nine marking designs to the unreflectorized hopper car. Table 6-2 shows the mean detection distance for each of the marking designs. There was a significant effect for retroreflective marking ($F(9,297) = 2921.76$, $p < 0.0001$)[1]. All of the retroreflective markings were more detectable than the unreflectorized car. Clearly, the use of all of the proposed marking designs improved the detectability of the rail car compared to an unreflectorized rail car. The differences between any of the marking designs and the unreflectorized car were much greater than the differences between the individual marking designs by several orders of magnitude. Nevertheless, there were statistically significant and meaningful differences among the individual marking designs as well.

A two-way ANOVA was performed to evaluate the differences between the individual marking designs. This analysis showed significant effects for color and pattern, and a significant interaction between color and pattern as shown in Table 6-3. Of the variance accounted for by the independent variables, color accounted for 5%, pattern accounted for 23%, and the interaction between color and pattern accounted for 51%. Each of these effects will be discussed in turn.

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[1] F stands for the F ratio. This value, like other test statistics such as the T-statistic and the post-hoc comparison tests (i.e., Tukey test), represents the ratio of systematic errors plus unsystematic errors to unsystematic errors. The numerator includes the effects of the experimental treatment (e.g., alerting lights) plus the individual differences and measurement errors. The denominator includes everything found in the numerator except the effects of the experimental treatment. More specifically, the F ratio equals the mean square between subjects divided by the mean square within subjects. The more the F ratio rises above 1, the greater likelihood the observed results were due to the result of the experimental effects being evaluated.

P stands for probability. The accompanying number represents the probability that the F ratio is due to chance. For example, $p = 0.01$ means that there is one chance in one hundred that the observed result was due to chance. CR_T stands for the Tukey Studentized Range statistic. The critical range (CR) represents the difference that two means must exceed to be considered statistically significant. t stands for the t-ratio. Like the F ratio, the t-ratio represents a ratio of systematic errors to unsystematic errors. It measures the difference between two sample means divided by the standard deviation for the sample.

Table 6-2. Effect of Retroreflective Marking on Detection Distance

Marking	Detection Distance (feet)	Significant Differences ($p < 0.05$)*
Yellow Partial Outline	2049	A
Red and White Fence	1854	B
Red Partial Outline	1595	C
Red Fence	1585	C
Yellow Fence	1496	D
Red Dash	1440	E
Yellow Dash	1401	E
Red and White Dash	1337	F
Red and White Partial Outline	1245	F
Unreflectorized Hopper Car	160	G

* Statistical evaluations were made between all possible pairs of markings. Differences between markings with the same letter are not statistically significant. For example, the red partial outline and the red fence do not differ from each other, statistically. However, these two patterns differ statistically from all the other patterns.

Table 6-3. Significant Effects for Detection Distance

	Degrees of Freedom	F value	P value
Color	2, 66	217.11	$p < 0.0001$
Pattern	2, 66	912.69	$p < 0.0001$
Color × Pattern	4, 132	1034.90	$p < 0.0001$

Table 6-4 shows the relationship between detection distance and color. The fluorescent yellow designs were detected farthest away, followed by the red, and the combined red-and-white designs, respectively. The difference between each of the colors is statistically significant using Tukey's studentized range test (CR_t (3, 66) = 16.61, $p < 0.05$). Previous research reported by Olson, et al. (1992), and Ziedman, et al. (1981), indicate that detection distance is directly related to SIA; the greater the SIA, the farther away an observer may detect the material. Of the color combinations used in this study, fluorescent yellow has the highest SIA followed by red-and-white, and red alone, respectively, as shown in Table 6-4.

While performance with the yellow markings was consistent with this relationship, the poorer performance of the combined red-and-white compared to the red-only markings was a surprise. Based upon the SIA, observers would be expected to detect the combined red-and-white designs sooner than the red-only designs. The opposite results, however, occurred. One possible explanation for this outcome is described in the section discussing the interaction between color and pattern.

Table 6-4. Effect of Color on Detection Distance

Color	Detection Distance (feet)	SIA (candela/fc/ft^2)
Yellow	1648	900
Red	1540	170
Red-and-White	1512	535

Table 6-5 shows the relationship between detection distance and pattern. The mean detection distance was greatest for the fence, followed by the partial outline and the dash. The differences between all three patterns were statistically significant using Tukey's studentized range test (CR_t (3,66) = 16.95, $p < 0.05$). However, the differences between the fence and the partial outline were much smaller than those between the fence and dash, as well as between the partial outline and the dash. That is, the fence and partial outline were detected at much greater distances than the dash.

Table 6-5. Effect of Pattern on Detection Distance

Pattern	Detection Distance (feet)
Fence	1663
Partial Outline	1644
Dash	1393

The poorer performance of subjects when viewing the dash was surprising given that it maximizes the amount of material in the area where headlamp illumination is greatest under actual driving conditions. As height above the sill level where the retroreflective material is placed increases, the light falling on the retroreflective material should decrease, resulting in less light reflected back toward the driver. It is possible that when the slides were photographed, the light source was positioned so that the material in the dash design was not in the optimal position. Conversely, the fence and partial outline share one attribute that may have contributed to their better detectability. Both designs have some of their material oriented in the vertical axis. The rectangular strips were placed so that the longer dimension was in the vertical plane. This orientation may have increased the likelihood that some portion of the retroreflective material received the maximum headlamp illumination and thus returned the brightest possible signal to the subject.

Figure 6-7 shows the interaction between color and pattern for detection distance. A statistically significant interaction was found between color and pattern, as shown in Table 6-3. It is evident in this case that the subjects exhibit the poorest detection performance across the three colors for the dash pattern, supporting the pattern effect described above. For both fluorescent yellow and red, the dash shows the lowest detectability. The differences between the dash and the other two patterns for both yellow and red were statistically significant. For the combined red-and-white

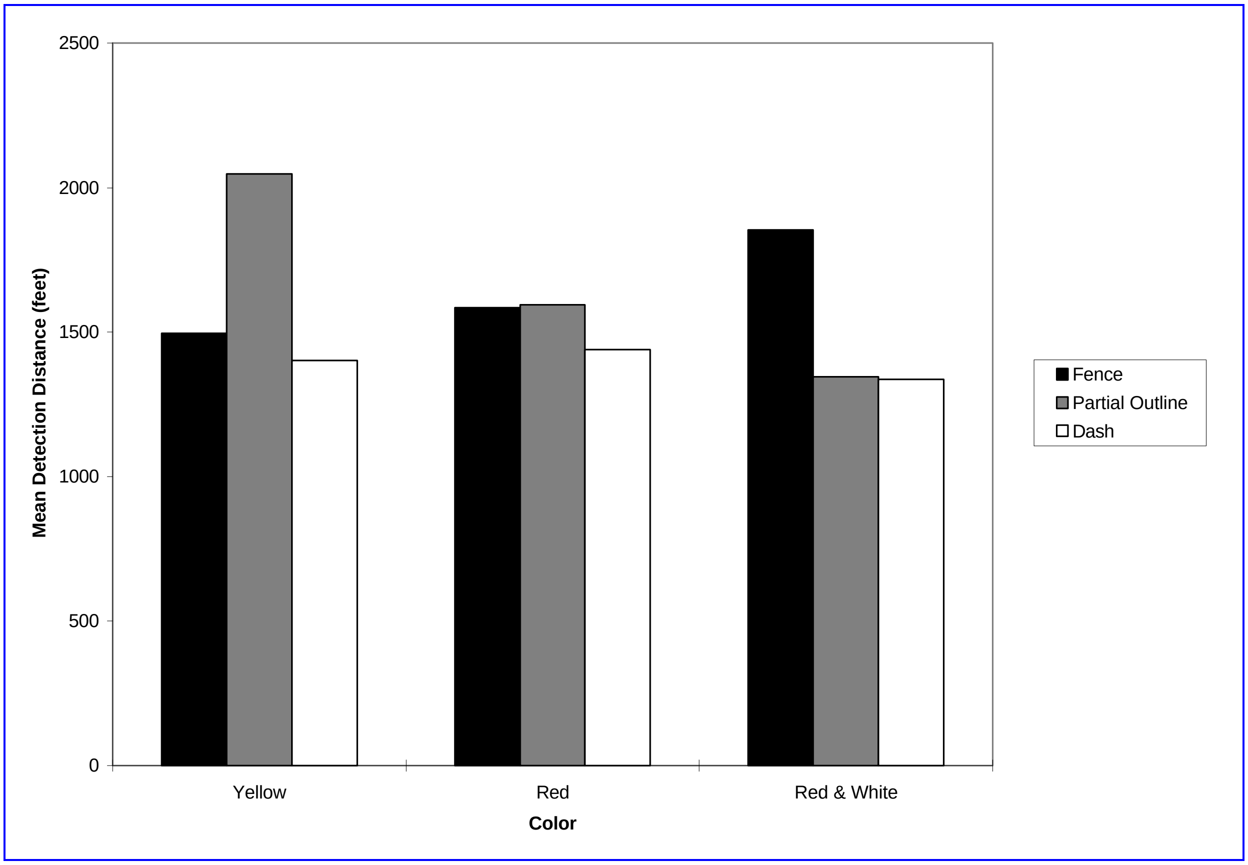


Figure 6-7. Effect of Color and Pattern on Detection Distance

condition, the dash is less detectable than the fence. The difference between the dash and the partial outline was not statistically significant in the combined red-and-white condition.

The detection performance for the fence and partial outline varies with the color of the marking design. The fence scores best when it is red-and-white and worst when it is yellow. These differences are statistically significant (CR_t (9, 297) = 41.69, $p < 0.05$). Given the higher SIA associated with fluorescent yellow, this was unexpected. The partial outline shows the opposite trend. Subjects detected the partial outline farthest away when it was yellow and closest when it was red-and-white. These differences were also statistically significant. Performance with the fence and partial outline is comparable when red-only is used. For the fence and partial outline, subjects detected the red-only design at greater distances than the combined red-and-white designs. Again, this was surprising since the SIA for the combined red-and-white design should be higher than the red-only designs. In the context of this experiment, it appears that SIA serves as only a rough guide to determining the detectability of different markings.

<u>Recognition of Retroreflective Marking Designs</u>. As their final task, subjects identified which individual marking design they saw on the projection screen. Overall, subjects excelled at this task. Subjects correctly identified the individual marking designs between 94.8% and 99.6% of the time. Subjects identified the unreflectorized car 100% of the time. However, a confusion matrix displayed in Table 6-6, illustrating which marking designs were confused with each other, shows that recognition errors were unevenly distributed. This distribution is statistically significant using a chi square test of independence (χ^2 (9) = 64.9, $p < 0.05$). The uneven distribution of recognition errors by pattern and color is captured more clearly in Tables 6-7 and 6-8. Table 6-7 summarizes the recognition errors by pattern and Table 6-8 summarizes the recognition errors by color.

Table 6-6. Confusion Matrix Showing Recognition Errors by Marking System

	Response									
Stimulus	Yellow Fence	R/W Fence	Red Fence	Yellow Outline	R/W Outline	Red Outline	Yellow Dash	R/W Dash	Red Dash	**Row Total**
Yellow Fence		8	3				1	6		18
R/W Fence	18		3				1	8	1	31
Red Fence									6	6
Yellow Outline*	1				3			1		5
R/W Outline				2		14				16
Red Outline			1		7					8
Yellow Dash		3				1		3		7
R/W Dash		3					12		2	17
Red Dash			4					2		6
Column Total	19	14	11	2	10	15	14	20	9	114

* Outline refers to partial outline markings

Within a pattern, subjects tended to confuse marking designs that varied by color. This is illustrated by the gray shaded cells in Table 6-7. Table 6-6 shows which colors are most likely to be confused within a pattern. For example, a red-and-white fence design might be confused with a yellow fence or a red fence. This type of error occurred across all three patterns as shown in Table 6-8. Looking more closely at the recognition errors by color, the majority of the errors (88%) involved the combined red-and-white designs. These cells are shaded in Table 6-8. The red-and-white designs were confused with both yellow and red designs. The subjects also tended to confuse the yellow designs with the red-and-white designs. That the red-and-white designs might be confused is consistent with a review of the literature by Aurelius and Korobow (1971), showing that identifying color hue becomes more difficult as the visual angle subtending an object decreases. At sufficiently long distances, contrasting colors tend to blend together. The farther away an object of contrasting color is detected, the larger it must be to be recognized unambiguously.

The recognition errors observed in this experiment resulted from misidentification of similar multiple-marking designs for rail cars. However, the misidentification of one rail car design for another may not represent a safety hazard for the driver, since the driver would still receive the message that a train was in the grade crossing. The situation in which the driver confuses a retroreflective marking that represents a rail car with one that does not, is more likely to present a safety hazard. However, this situation was not evaluated in the current experiment. Development of a standard marking that becomes associated with a rail car and that is difficult to confuse with other objects, such as pedestrians, motor vehicles, and traffic signs, will minimize this type of error. A future study could examine the likelihood that a given retroreflective marking design will be confused with other objects found in the driving environment.

Table 6-7. Confusion Matrix of Recognition Errors by Pattern

	Response		
Stimulus	Fence	Partial Outline	Dash
Fence	32	0	23
Partial Outline	2	26	1
Dash	10	1	19

Table 6-8. Confusion Matrix of Recognition Errors by Color

	Response		
Stimulus	Yellow	Red	R/W
Yellow	2	4	24
Red	0	11	9
R/W	33	20	11

6.4 CONCLUSIONS

All of the retroreflective marking designs evaluated in this experiment were more effective than an unreflectorized car. All of the retroreflective marking designs were detected considerably farther from the train than the unreflectorized car.

The relationship between color and detection distance was an unexpected finding, given the previous research finding a linear relationship between the amount of light returned to the observer (SIA) and detection distance. While subjects were expected to detect fluorescent yellow at the greatest detection distances, it was surprising to observe better performance with red-only than the red-and-white design. In addition, no interaction was expected between color and pattern, yet performance, particularly for the fence and the partial outline, changed as a function of color. While the spatial arrangement of these colors may have contributed partly to these results, some artifact resulting from how the marking designs were presented may also have contributed to this outcome.

Although the current study focused on detection performance, the fact that even the poorest design was several orders of magnitude better than an unreflectorized car, suggests that detection of a prismatic retroreflective material has improved considerably the distance at which a rail car could be detected. While field testing will be necessary to establish the actual distances at which a retroreflective marking is likely to be detected, the current generation of retroreflective materials appears to improve the detectability of materials to which they are attached, to the point where detectability is no longer a major concern.

A more important concern becomes associating the marking design with a train (recognition). Olson, et al. (1992), indicated that a driver can observe a truck with marker lights at 1,000 feet or more under good lighting conditions. They indicate that 740 feet is the minimum acceptable detection distance to stop in time. Mace and Gabel (1993) suggest that 900 feet is a reasonable value for detection distance. However, these isolated point sources were not always associated with a truck trailer. Hence, there is a need for an additional visual aid to help the driver recognize the object as a truck. The problem of recognition becomes more difficult in complex visual environments. To facilitate recognition of rail cars, a standard marking design that could fit on all types of rail cars from flat cars to tank cars should be developed that is unlikely to be confused with other roadway hazards.

In this regard, the work performed by Olson, et al. (1992), in developing a standard retroreflective marking for trucks bears consideration. Olson and his colleagues found that a design that outlines the vehicle improves the driver's recognition of the object. In this study, both the partial outline and the fence designs fit this criterion. The regulations covering the use of retroreflective markings for trucks stated in the Code of Federal Regulations 49 CFR 571.108, (1994) incorporate the use of an outline on the rear of the truck trailer.

Olson also recommended the use of an alternating pattern of red-and-white as the design colors. Excluding the fluorescent pigments, which are not as durable, white returns the greatest amount of light to the driver. Red is recommended because of its long association with danger and warnings. The combination of red and white is frequently used in the driving environment (e.g., stop signs, gates at highway-rail grade crossings) and is now part of the regulations for truck retroreflective markings. The use of two contrasting colors, like red and white, also contributes to better conspicuity during the daytime. The logic behind the use of red-and-white retroreflective markings for trucks applies equally well to the development of a retroreflective marking for rail cars. However, if some combination of red and white is selected, the pattern should be sufficiently different from the pattern selected for trucks so that the two patterns are not confused with one another. Avoiding this potential confusion is particularly important, as truck trailers are transported on rail cars and thus the opportunity for confusion is quite real.

In this regard, a vertically oriented pattern similar to the fence would contrast with the horizontally oriented pattern of the retroreflective pattern required for trucks. A vertically oriented pattern on rail cars would have one advantage over a horizontally oriented pattern. Not all approaches to the grade crossing are level. To the extent that the motor vehicle's headlights are aimed away from the retroreflective material, less light will reach the retroreflective material. As a result, less light is returned to the driver and the detection task becomes more difficult. Detection difficulty due to variation in the grade of the roadway is compounded by the fact that headlights have a narrower beam width in the vertical axis. Orienting the retroreflective material in the vertical axis increases the likelihood that the maximum available light from the headlight will enter the retroreflective material and be returned to the motorist when the road grade is not level.

Another concern that will need to be addressed is the driver's ability to estimate the motor vehicle's closing rate to the train. Drivers have difficulty estimating their closing rate at night as they approach the train, or estimating how far they are from the train. Estimating closing rate or distance to the rail car would enable the driver to determine when and at what rate braking must take place. Accurately estimating the rate of approach and distance to the train would help avoid rear-end accidents resulting from braking too quickly, as well as avoiding a collision with the train.

6.5 SUMMARY OF FINDINGS

Considering the review of the literature and the results of the University of Tennessee's effort, the following findings are offered for the design of retroreflective markings for rail cars.

- A reflectorized freight car is significantly more detectable than an unreflectorized freight car.
- A standardized pattern should be used for all types of rail cars to facilitate recognition.
- A pattern of red-and-white will facilitate recognition of the train and convey a sense of warning.
- The design should be sufficiently distinctive so that it is not confused with the retroreflective markings used on trucks and warnings for other roadway hazards.
- The spatial configuration should give some indication of the shape of the rail car to facilitate recognition. This might include some type of outline or modified outline or spatial arrangement in which the material is evenly distributed across the rail car.

7. FINDINGS AND CONCLUSIONS

Accidents at the approximately 168,000 highway-railroad grade crossings in the United States have been documented as a significant safety problem. One factor that contributes to these figures is the difficulty motorists have in seeing a train consist at a crossing, particularly during dawn, dusk, and darkness (i.e., nighttime conditions), thereby causing an accident in which the motorist's vehicle runs into the train (or RIT accident). Of the 4,257 accidents in 1996, 967 (22.72% of the total accidents) were RIT accidents; 473 of these 967 (or 11.11% of the total accidents) occurred in nighttime conditions. The Federal Railroad Administration (FRA) is therefore investigating measures to enhance the visibility of trains in order to reduce the number of accidents/incidents at highway-railroad grade crossings where train visibility is a contributing factor. One such countermeasure involves the use of retroreflectors on freight cars. The Volpe Center conducted research into the use of reflectorization as a conspicuity device, in support of the FRA's program to improve highway-railroad grade crossing safety. The findings and conclusions of this research effort are summarized below, according to its four phases.

7.1 FINDINGS

7.1.1 Review of Reflectorization Experiences in Transportation

Specific findings include:

- Reflective materials can enhance motorists' ability to detect the presence of a train in a highway-railroad grade crossing.
- A material with the maximum intensity available should be used (prismatic) to provide the highest level of illuminance to the observer and to reduce maintenance requirements.
- A uniform pattern will enhance the motorist's recognition of a train in time to avoid a collision.
- A favorable placement location for reflectors is 42 inches above top of rail.
- Using visibility assumptions established by previous reflectorization studies, a reflector measuring 4 inches by 8 inches would require a minimum specific intensity per unit area (SIA) of 200 cd/fc/ft^2 to attract a motorist's attention. A reflector measuring 4 inches by 36 inches and using the same conditions would require a minimum threshold of 45 cd/fc/ft^2.
- Several railroads have voluntarily reflectorized their rolling stock.
- The use of reflectors has been successful in other modes of transportation as a means to enhance conspicuity.

7.1.2 Demonstration Test

The demonstration test resulted in the following findings:

- The preferred configuration consisted of three white 4 in by 8 in horizontal reflectors spaced 9 ft apart at a height of 42 in from the top of rail (TOR). Additionally, 2 alternating red-and-white reflectors measuring 4 in by 36 in were placed vertically at the ends of the car for delineation, such that a typical freight car would resemble the following:

The installation and material costs for this phase totaled $31.24 per car.

- This configuration would be the "typical" pattern used for the next phase of testing.

7.1.3 In-Service Test

The in-service test resulted in the following findings:

- Reflectors in Positions 1 and 5 performed, on average, above the minimum threshold levels for the entire test period, but the reflectors in Positions 2, 3, and 4 varied from 7 months to the entire testing period.
- The performance of the reflectors was not observed to be significantly affected by natural environmental factors. Mechanical washing of the reflectors resulted in their performance rebounding significantly to levels near original SIA values. Periodic washing of the reflectors mounted on freight cars can extend their performance to the limits of life expectancy.
- Railroad operations had a severe effect on the performance of the reflectors; especially the reflectors that were located where loading and unloading of commodities took place. Placement of the reflector under the sill of the freight car has been found to be detrimental to the performance of the reflector. Mid-car locations on many freight car types provide severe operational conditions; therefore, this location should not be considered in any freight car reflectorization rulemaking process.
- For the average freight car involved in this study, it can be estimated that a 12- to 18-month cycle of maintenance would be sufficient to sustain the threshold levels necessary to attract the attention of a motorist. A minimum cleaning time of 15 minutes per car is considered reasonable for these reflectors with no additional cleaning solvents necessary in the process. Periodic washing of the reflectors can extend their acceptable performance to the limits of their life expectancy.

- The hopper car consists, the only fully reflectorized fleet of the in-service test, recorded a reduction of Category 1 RIT accidents along its dedicated route from 6 (occurring in a 33-month period prior to the reflector's installation), to 0 (occurring in a 33-month period after the reflector's installation). This accident reduction potential may reflect the reduction of this type of RIT accident, which occurs when the vehicle strikes the train after the lead unit. This finding, while positive for reflectorization, should be viewed with caution since it is based on very limited accident experience.
- The demonstration test pattern's original cost of $31.24 has now been reduced by 40% (based on information stated by the manufacturer) for a cost of material per car of approximately $18.75. Additionally, the 1996 AAR labor rate is approximately $20.05 per hour. Using the estimates for reflectorizing an older car during the normal maintenance program that may need heavy cleaning (at the 1996 AAR labor rate), and reduced material costs, the resultant maximum material cost per car using the tested pattern would be approximately $38.80. Heavy cleaning of the reflectors would require 2 persons for 30 minutes to complete the process approximately every 12-18 months, resulting in a cost of approximately $20.05 per event. The manufacturer specifies this prismatic material's useful life to be 10 years. Therefore, maximum projected total costs of the material and maintenance for a 10-year period would be $219.25 per car (based on lower material costs, heavy cleaning, two-person annual maintenance, at the 1996 AAR labor rate).

7.1.4 Human Factor Test

The fourth phase of testing and literature review obtained the following findings:

- A reflectorized freight car is significantly more detectable than an unreflectorized freight car.
- A standardized pattern should be used for all types of rail cars to facilitate recognition.
- A pattern of red-and-white will facilitate recognition of the train and convey a sense of warning.
- The design should be sufficiently distinctive so that it is not confused with the retroreflective markings used on trucks and warnings for other roadway hazards.
- The spatial configuration should give some indication of the shape of the rail car to facilitate recognition. This might include some type of outline or modified outline or spatial arrangement in which the material is evenly distributed across the rail car.

7.2 CONCLUSIONS

The significant conclusions resulting from this freight car reflectorization research program are summarized as follows:

1. A uniform recognizable pattern of reflective markings can be applied to most freight car types, with a few exceptions.

2. Based on human factors studies, a reflectorized freight car is significantly more detectable than a non-reflectorized freight car.

3. Also, based on the human factors studies, a uniform pattern of reflectorized material can facilitate recognition of the hazard as a freight car. The pattern should indicate the shape of the car, should employ the colors red and white, and be sufficiently distinctive so as not to be confused with large truck markings.

4. A minimum favorable placement location of reflectors is 42 inches above TOR.

5. The large reflectors, measuring 4 inches by 36 inches, maintained, on average, acceptable reflective performance over the entire testing period (2 years) on all freight car types. Placement of the reflector under the sill of the freight car has been found to be detrimental to the performance of the reflector. Due to their smaller size, position below sill level, and location near loading points, the smaller white reflectors did not perform as well under the harsh railroad operating conditions. Mid-car locations on many freight car types provide severe operational conditions; therefore, this location should not be considered in any freight car reflectorization rulemaking process.

6. The performance of the reflectors was not observed to be significantly affected by natural environmental factors. Mechanical washing of the reflectors resulted in their performance rebounding significantly to levels near original SIA values. Periodic washing of the reflectors mounted on freight cars can extend their performance to the limits of life expectancy. Recently developed prismatic materials' durability and adhesiveness possess the likelihood to perform above threshold levels for up to 10 years with routine maintenance.

7. Based on very limited accident experience, freight car reflectorization was observed to be potentially effective in reducing accidents.

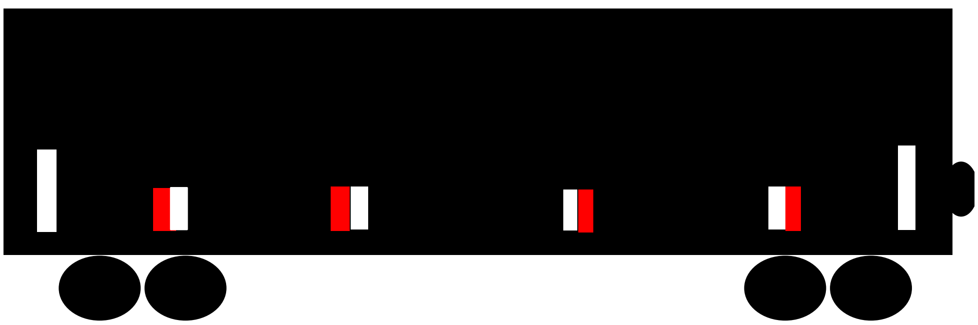
8. The demonstration test pattern's original cost of $31.24 has now been reduced by 40% (based on information stated by the manufacturer) for a cost of material per car of approximately $18.75. Additionally, the 1996 AAR labor rate is approximately $20.05 per hour. Using the estimates for reflectorizing an older car during the normal maintenance program that may need heavy cleaning (at the 1996 AAR labor rate), and reduced material costs, the resultant maximum material cost per car using the tested pattern would be approximately $38.80. Heavy cleaning of the reflectors would require 2 persons for 30 minutes to complete the process approximately every 12-18 months, resulting in a cost of approximately $20.05 per event. The manufacturer specifies this prismatic material's useful life to be 10 years. Therefore, maximum projected total costs of the material and maintenance for a 10-year period would be $219.25 per car

(based on lower material costs, heavy cleaning, two-person annual maintenance, at the 1996 AAR labor rate).

9. Based on the results of the in-service and human factors tests, improvements to the second phase pattern are suggested. Two *suggested* reflector designs are shown in Figure 7-1.

   Both designs use red and white reflectors in combination, as suggested by the human factors recommendations, and are mounted vertically to permit an increase in their size. Figure 7-1(a) depicts a more conservative design than Figure 7-1(b) in terms of the amount of material required. Based on the suggested configuration, the cost of material and maintenance will not be significantly increased.

(a)



(b)

Figure 7-1. Suggested Improved Reflector Patterns on a Typical Freight Car

Although these findings are representative of all reflectors tested within this current research study, other operational findings lend themselves to suggest an alternative pattern from the original Volpe Center configuration (used in the in-service test). The human factors studies provide guidance as to the color and pattern necessary to most effectively use freight car reflectorization.

APPENDIX A

CANADIAN REQUIREMENTS

THE BOARD OF TRANSPORT COMMISSIONERS FOR CANADA
(Reprint)

ORDER NO. 123336

THURSDAY, THE 26TH DAY OF JANUARY, A.D. 1967.

H. H. GRIFFIN,
Assistant Chief Commissioner.
A. S. KIRK,
Commissioner..

IN THE MATTER OF the placing of reflective markings on the sides of railway cars; and the apportionment of the cost thereof:

File No. 45463

WHEREAS by Order 114295 the Board prescribed that each railway company subject to the jurisdiction of the Board shall cause reflective markings to be placed on the sides of each of its new box cars delivered during the calendar years 1964, 1965 and 1966;

AND WHEREAS it is required that the program of placing reflective markings be carried on for a further period of time

IT IS HEREBY ORDERED AS FOLLOWS:

1. The Canadian National Railways and the Canadian Pacific Railway Company shall each place reflective markings on each side of at least four thousand of its railway cars in the year 1967, and each year thereafter pending further direction from the Board; and all other railway companies subject to the jurisdiction of the Board shall, effective with the year 1967, each inaugurate an annual programme which will be designed to place reflective markings on each side of their Canadian built freight cars within a period of four year. Exemption may be granted to this requirement with respect to equipment of unusual design or equipment specifically assigned to a service which makes it impractical to maintain reflective markings on such cars.

2. The said reflective markings shall be placed and spaced along the sides of the cars and be of such shape, size and material as may be approved by the Board. Each railway company shall file with the Board fill particulars of the reflective markings which will be used, if not already approved, together with an estimate of the cost of placing them on the cars. Excepting cars on which reflective markings have been applied in accordance with previous Board Orders prior to the date of this Order, four reflective markings, complying with the requirements of this section shall be applied to each side of cars having a length of fifty feet or less and six such markings shall be applied to each side or cars of greater length than fifty feet.

3. Eighty per cent of the cost of placing the said reflective markings shall be paid out of Railway Grade Crossing Fund, which contribution shall not exceed $8.00 per car, and the remainder of such cost shall be borne by the Applicant Company.

4. Each such company shall, at the end of June, and at the end of calendar year, make a return to the Board showing the number of its cars marked as prescribed in this Order.

Assistant Chief Commissioner,
The Board of Transport Commissioners for Canada.

APPENDIX B

REFLECTOR INSTRUMENTATION AND MEASUREMENT PROCEDURE

APPENDIX B

REFLECTOR INSTRUMENTATION AND MEASUREMENT PROCEDURE

B-1 Reflector Instrumentation

Measurement of retroreflector efficiency entails a precise measurement of the light reflected from the surface as a function of the illumination reaching it. For this demonstration test a Advanced Retro Technology Model 920 Field Retroreflectometer was used to measure the Coefficient of Retroreflection. The Coefficient of Retroreflection or SIA (specific intensity per unit area) is measured in metric units of candelas per lux per square meter ($cd/lux/m^2$) as defined in ASTM E-809 and CIE publication 54.

The measurement of the reflective intensity is highly dependent on the angle the light source strikes the surface (Entrance Angle) and the angle at which it observed (Observation Angle). For this demonstration test the industry standard entrance angle of -4 degrees and the observation angle 0.2 degrees was used. The Model 920 consists of the following components:

1. Optical head with an optical system, detector, and light source.
2. Control unit with digital readout display and operating controls.
3. Rechargeable battery pack with power supply.
4. Calibration reference standards.

Before measuring the instument is calibrated against a secondary standard. The Model 920 is operated by pressing the optical head against the surface to be measured which activates the device's light source. The design permits measurements to be made during either day or night.

The equipment was maintained through the following procedure:

1. Calibrated the reflectometer for each type of retroreflective material and also after every 15 minutes of measurement time.
2. Checked the battery level every two hours of real time.
3. Recharged the battery every night.

B-2 Measurement Procedeure

The following data was collected from each car examined:

- Car number
- Car owner
- Type of car and, if special service car, specific commodities usually carried (e.g., coal-carrying hopper car)
- Date car built or rebuilt
- Measurement of distance between bottom of reflective decal and top of rail (TOR)
- Photographic record showing the entire side of each car measured
- Date of measurement
- Yard location where measurements were taken
- Retroreflective measurements before and after washing
- Status of reflective decals, e.g., identification of missing or damaged decals
- Three measurements of the coefficient of retroreflection on each decal.

The form for recording the data is shown in Appendix B-5. The SIA measurements are given in Appendix B-6 through B-15 for the TTC test..

REFLECTIVITY MEASUREMENTS FORM
Using a Advanced Retro Technology, Inc. Retroreflectometer

Model 920, Serial # RT1213

Car No.: __________ Date of Measurement: __________
Owner: ___________ Yard where measured: __________
Date car Build/Rebuilt: ______ Distance from bottom of decal to TRO: ______
Type of Car: __________
Is this a measurement after washing decals: __________
Months in service at time of measurements: __________

Reflectivity Measurement Data

Right side of car (side on right when standing at brake end looking toward A end). Group 2 nearest A end.

	Group 1		Group 2		Group 3		Group 4		Group 5
Red		1st		1st		1st		Red	
Wht		2nd		2nd		2nd		Wht	
Red		3rd		3rd		3rd		Red	
Wht		Avg		Avg		Avg		Wht	
Avg								Avg	

Left side of car (side on left when standing at brake end looking toward A end). Group 1 nearest A end.

	Group 1		Group 2		Group 3		Group 4		Group 5
Red		1st		1st		1st		Red	
Wht		2nd		2nd		2nd		Wht	
Red		3rd		3rd		3rd		Red	
Wht		Avg		Avg		Avg		Wht	
Avg								Avg	

Note: Write M if decal is missing, Write D if decal is defective and explain nature of damage.

REFLECTIVITY MEASUREMENTS FORM
Using a Advanced Retro Technology, Inc. Retroreflectometer

Model 920, Serial # RT1213

Car No.: UP 31936
Date of Measurement: 3/19/91
Owner: UNION PACIFIC
Yard where measured: TTC
Date car Build/Rebuilt: 4/69
Distance from bottom of decal to TRO: 4' 4"
Type of Car: HOPPER
Is this a measurement after washing decals: NO
Months in service at time of measurements: UNWASHED REFERENCE CAR INITIAL MEASUREMENTS

Reflectivity Measurement Data

Right side of car (side on right when standing at brake end looking toward A end). Group 2 nearest A end.

	Group 1			Group 2			Group 3			Group 4		
	3M-O	3M-N	ATM	3M-O	3M-N	ATM	3M-O	3M-N	ATM	3M-O	3M-N	ATM
1st	80.1	1098	1.4	81.9	1185	1.5	80.7	1106	1.4	83.6	1113	1.6
2nd	80.9	1015	1.4	80.4	1175	1.4	87.2	1117	1.4	83.7	1176	1.6
3rd	80.3	1046	1.4	81.0	1193	1.5	83.8	1144	1.4	85.9	1171	1.6
Avg	80.4	1053	1.4	81.1	1184	1.47	83.9	1122	1.4	84.4	1153	1.6

Left side of car (side on left when standing at brake end looking toward A end). Group 1 nearest A end.

	Group 1			Group 2			Group 3			Group 4		
	3M-O	3M-N	ATM	3M-O	3M-N	ATM	3M-O	3M-N	ATM	3M-O	3M-N	ATM
1st	80.3	1175	2.0	77.8	1243	2.1	75	1164	1.8	74.9	1198	1.7
2nd	80.4	1189	1.9	77	1188	2.1	74	1155	1.8	76	1210	1.3
3rd	80.5	1190	1.8	79	1169	2.1	75	1205	1.8	75	1202	1.7
Avg	80.4	1185	1.9	77.9	1200	2.1	74.7	1175	1.8	75.3	1203	1.57

Note: Write M if decal is missing, Write D if decal is defective and explain nature of damage.

REFLECTIVITY MEASUREMENTS FORM
Using a Advanced Retro Technology, Inc. Retroreflectometer

Model 920, Serial # RT1213

Car No.: UP 32039
Date of Measurement: 3/19/91
Owner: UNION PACIFIC
Yard where measured: TTC
Date car Build/Rebuilt: 12/70
Distance from bottom of decal to TRO: 4' 4"
Type of Car: HOPPER
Is this a measurement after washing decals: NO
Months in service at time of measurements: WASHED REFERENCE CAR INITIAL MEASUREMENTS

Reflectivity Measurement Data

Right side of car (side on right when standing at brake end looking toward A end). Group 2 nearest A end.

	Group 1			Group 2			Group 3			Group 4		
	3M-O	3M-N	ATM	3M-O	3M-N	ATM	3M-O	3M-N	ATM	3M-O	3M-N	ATM
1st	79.5	1136	1.4	70.4	1093	1.2	81.2	1198	1.4	80.6	1076	1.4
2nd	81.4	1149	1.4	63.2	1094	1.4	81.4	1182	2.0	78.5	1072	1.4
3rd	78.3	1158	1.4	57.5	1080	1.6	83.9	1190	1.5	77.8	1087	1.5
Avg	79.7	1148	1.4	63.7	1089	1.4	82.2	1190	1.63	79	1078	1.43

Left side of car (side on left when standing at brake end looking toward A end). Group 1 nearest A end.

	Group 1			Group 2			Group 3			Group 4		
	3M-O	3M-N	ATM	3M-O	3M-N	ATM	3M-O	3M-N	ATM	3M-O	3M-N	ATM
1st	76	1132	0.6	79	1250	1.6	70	1160	1.4	76	1150	1.6
2nd	76	1105	0.6	78	1232	1.6	77	1186	1.6	78	1170	1.7
3rd	80	1186	0.4	81	1203	1.4	76	1175	1.5	75	1158	1.4
Avg	77.3	1141	0.53	79.3	1228	1.53	74.3	1174	1.5	76.3	1159	1.57

Note: Write M if decal is missing, Write D if decal is defective and explain nature of damage.

REFLECTIVITY MEASUREMENTS FORM
Using a Advanced Retro Technology, Inc. Retroreflectometer

Model 920, Serial # RT1213

Car No.: UP 32014 — Date of Measurement: 3/19/91

Owner: UNION PACIFIC — Yard where measured: TTC

Date car Build/Rebuilt: 12/70 — Distance from bottom of decal to TRO: 3' 6"

Type of Car: HOPPER

Is this a measurement after washing decals: NO

Months in service at time of measurements: OLD MATERIAL VS NEW INITIAL MEASUREMENTS

Reflectivity Measurement Data

Right side of car (side on right when standing at brake end looking toward A end). Group 2 nearest A end.

	Group 1		Group 2		Group 3		Group 4	
	3M-O	3M-N	3M-O	3M-N	3M-O	3M-N	3M-O	3M-N
1st	74.5	1188	79.7	1236	75	1164	76.8	1207
2nd	74.5	1139	79.6	1185	76	1156	75.6	1088
3rd	76.5	1150	80.5	1236	73	1176	78.4	1117
Avg	75.2	1159	79.9	1219	74.7	1165.3	76.9	1137.3

Left side of car (side on left when standing at brake end looking toward A end). Group 1 nearest A end.

	Group 1		Group 2		Group 3		Group 4	
	3M-O	3M-N	3M-O	3M-N	3M-O	3M-N	3M-O	3M-N
1st	76	1200	78	1110	76	1125	81	1136
2nd	78	1180	78	1122	79	1125	79	1113
3rd	74	1222	77	1107	78	1081	80	1120
Avg	76	1200.7	77.7	1113	77.7	1110.3	80	1123

Note: Write M if decal is missing, Write D if decal is defective and explain nature of damage.

REFLECTIVITY MEASUREMENTS FORM
Using a Advanced Retro Technology, Inc. Retroreflectometer

Model 920, Serial # RT1213

Car No.: UP 32087/td> Date of Measurement: 3/19/91

Owner: UNION PACIFIC Yard where measured: TTC

Date car Build/Rebuilt: 12/70 Distance from bottom of decal to TRO: 3' 6" -- 140$quot;

Type of Car: HOPPER

Is this a measurement after washing decals: NO

Months in service at time of measurements: SIDE BRACE

Reflectivity Measurement Data

Right side of car (side on right when standing at brake end looking toward A end). Group 2 nearest A end.

Left side of car (side on left when standing at brake end looking toward A end). Group 1 nearest A end.

	Right side		Left side
	Top		Top
White	908	White	225
Red	208	Red	1029
White	865	White	227
Red	198	Red	985
White	920	White	230
Avg.	619.8	Avg.	539.2
	Bottom		Bottom

Note: Write M if decal is missing, Write D if decal is defective and explain nature of damage.

REFLECTIVITY MEASUREMENTS FORM
Using a Advanced Retro Technology, Inc. Retroreflectometer

Model 920, Serial # RT1213

Car No.: UP 32001

Owner: UNION PACIFIC

Date car Build/Rebuilt: 2/70

Type of Car: HOPPER

Is this a measurement after washing decals: NO

Comments on car or decals: SOLID RED SQUARE INITIAL MEASUREMENTS

Date of Measurement: 3/19/91

Yard where measured: TTC

Distance from bottom of decal to TRO: 3' 6"

Solid Red

#1
#2
#3

Reflectivity Measurement Data

Right side of car (side on right when standing at brake end looking toward A end). Group 2 nearest A end.

	Group 1	Group 2	Group 3	Group 4
1st	217	198	225	202
2nd	226	210	216	213
3rd	226	213	220	201
Avg	223	207	220.3	205.3

Left side of car (side on left when standing at brake end looking toward A end). Group 1 nearest A end.

	Group 1	Group 2	Group 3	Group 4
1st	220	198	220	198
2nd	211	196	217	196
3rd	207	202	214	205
Avg	212.7	198.7	217	199.7

Note: Write M if decal is missing, Write D if decal is defective and explain nature of damage.

REFLECTIVITY MEASUREMENTS FORM
Using a Advanced Retro Technology, Inc. Retroreflectometer

Model 920, Serial # RT1213

Car No.: UP 31990

Date of Measurement: 3/19/91

Owner: UNION PACIFIC

Yard where measured: TTC

Date car Build/Rebuilt: 4/69

Distance from bottom of decal to TRO: 3' 6"

Type of Car: HOPPER

Is this a measurement after washing decals: NO

Comments on car or decals: PATTERN HALF WHITE HALF RED

Solid Red

#1	#1
#2	#2

INITIAL MEASUREMENTS

Reflectivity Measurement Data

Right side of car (side on right when standing at brake end looking toward A end). Group 2 nearest A end.

	Group 1 White	Group 1 Red	Group 2 White	Group 2 Red	Group 3 White	Group 3 Red	Group 4 White	Group 4 Red
1st	975	224	935	222	960	227	1006	204
2nd	1000	225	940	209	985	224	956	212
Avg.	606		573.8		599		594.5	

Left side of car (side on left when standing at brake end looking toward A end). Group 1 nearest A end.

	Group 1 White	Group 1 Red	Group 2 White	Group 2 Red	Group 3 White	Group 3 Red	Group 4 White	Group 4 Red
1st	958	228	955	204	980	226	975	208
2nd	976	227	924	205	975	224	947	209
Avg.	597.3		572		601.3		584.8	

Note: Write M if decal is missing, Write D if decal is defective and explain nature of damage.

REFLECTIVITY MEASUREMENTS FORM
Using a Advanced Retro Technology, Inc. Retroreflectometer

Model 920, Serial # RT1213

Car No.: UP 32080

Date of Measurement: 3/19/91

Owner: UNION PACIFIC

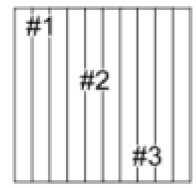
Yard where measured: TTC

Date car Build/Rebuilt: 1/71

Distance from bottom of decal to TRO: 3' 6"

Type of Car: HOPPER

White @ Red Stripes



Is this a measurement after washing decals: NO

Comments on car or decals: PATTERN RED @ WHITE STRIPES

INITIAL MEASUREMENTS

Reflectivity Measurement Data

Right side of car (side on right when standing at brake end looking toward A end). Group 2 nearest A end.

Measurement Taken 1/2 on Red 1/2 on White

	Group 1	Group 2	Group 3	Group 4
1st	580	508	470	637
2nd	659	540	480	573
3rd	640	536	540	720
Avg	626.3	528	496.7	643.3

Left side of car (side on left when standing at brake end looking toward A end). Group 1 nearest A end.

Measurement Taken 1/2 on Red 1/2 on White

	Group 1	Group 2	Group 3	Group 4
1st	468	650	547	526
2nd	505	579	558	515
3rd	598	610	492	523
Avg	523.7	613	532.3	521.3

Note: Write M if decal is missing, Write D if decal is defective and explain nature of damage.

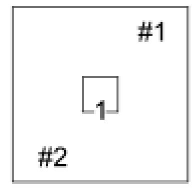
REFLECTIVITY MEASUREMENTS FORM
Using a Advanced Retro Technology, Inc. Retroreflectometer

Model 920, Serial # RT1213

Car No.: UP 32070
Owner: UNION PACIFIC
Date car Build/Rebuilt: 1/71
Type of Car: HOPPER
Is this a measurement after washing decals: NO
Comments on car or decals: PATTERN RED ON WHITE SQUARE

Date of Measurement: 3/19/91
Yard where measured: TTC
Distance from bottom of decal to TRO: 3' 6"

Red on White



INITIAL MEASUREMENTS

Reflectivity Measurement Data

Right side of car (side on right when standing at brake end looking toward A end). Group 2 nearest A end.

	Group 1		Group 2		Group 3		Group 4	
	White	Red	White	Red	White	Red	White	Red
1st	1125	206	1067	207	1140	208	1120	206
2nd	1036		1065		1095		1110	
Avg.	789		779.7		814.3		812	

Left side of car (side on left when standing at brake end looking toward A end). Group 1 nearest A end.

	Group 1		Group 2		Group 3		Group 4	
	White	Red	White	Red	White	Red	White	Red
1st	1072	205	1028	206	1070	202	1057	208
2nd	995		1105		1115		1118	
Avg.	757.3		779.7		795.7		794.3	

Note: Write M if decal is missing, Write D if decal is defective and explain nature of damage.

REFLECTIVITY MEASUREMENTS FORM
Using a Advanced Retro Technology, Inc. Retroreflectometer

Model 920, Serial # RT1213

Car No.: UP 32005

Owner: UNION PACIFIC

Date car Build/Rebuilt: 12/70

Type of Car: HOPPER

Is this a measurement after washing decals: NO

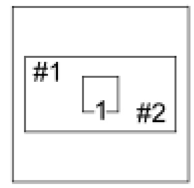
Comments on car or decals: PATTERN WHITE ON RED SQUARE

Date of Measurement: 3/19/91

Yard where measured: TTC

Distance from bottom of decal to TRO: 3' 6"

White on Red



INITIAL MEASUREMENTS

Reflectivity Measurement Data

Right side of car (side on right when standing at brake end looking toward A end). Group 2 nearest A end.

	Group 1		Group 2		Group 3		Group 4	
	Red	White	Red	White	Red	White	Red	White
1st	290	723	346	778	238	719	204	795
2nd	220		216		240		235	
Avg.	411		446.7		399		411.3	

Left side of car (side on left when standing at brake end looking toward A end). Group 1 nearest A end.

	Group 1		Group 2		Group 3		Group 4	
	Red	White	Red	White	Red	White	Red	White
1st	245	771	309	696	260	690	220	726
2nd	290		298		288		208	
Avg.	435.3		434.3		412.7		384.7	

Note: Write M if decal is missing, Write D if decal is defective and explain nature of damage.

REFLECTIVITY MEASUREMENTS FORM
Using a Advanced Retro Technology, Inc. Retroreflectometer

Model 920, Serial # RT1213

Car No.: UP 31902
Date of Measurement: 4/19/91
Owner: UNION PACIFIC
Yard where measured: TTC
Date car Build/Rebuilt: 4/69
Wheel measurement 120 Deg.
Type of Car: HOPPER
Is this a measurement after washing decals: NO
Comments on car or decals: 120 DEGREE ALL WHITE
1 MONTH MEASUREMENTS

Reflectivity Measurement Data

Right side of car (side on right when standing at brake end looking toward A end). Group 2 nearest A end.

AVERAGE NEW WHITE = 1205

PERCENTAGE OF ORIGINAL COEFFICIENT OF RETROREFLECTION = 41%

	Wheel 1	Wheel 2	Wheel 3	Wheel 4
1st			463	
2nd			513	
3rd			503	
Avg			494.7	

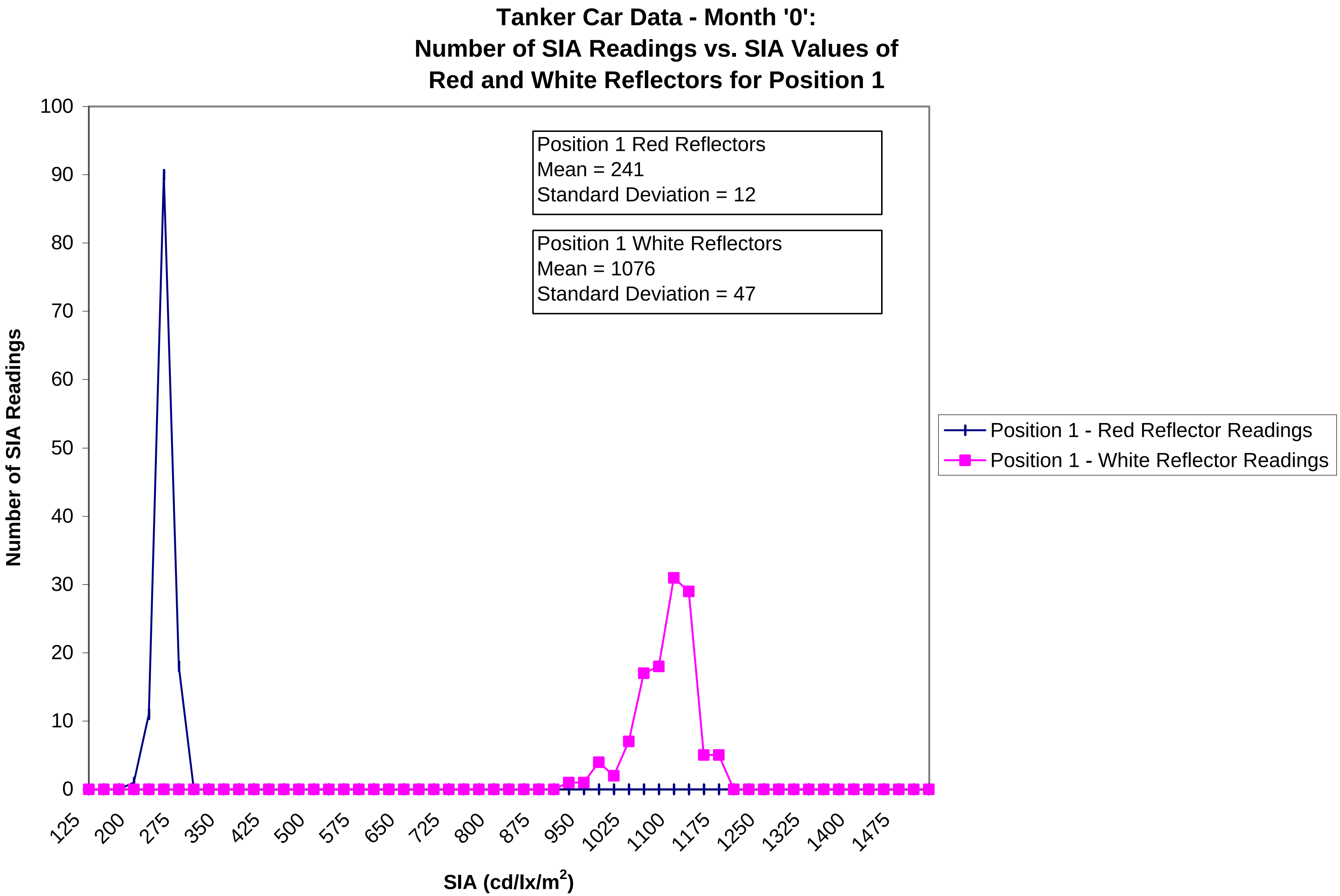
Left side of car (side on left when standing at brake end looking toward A end). Group 1 nearest A end.

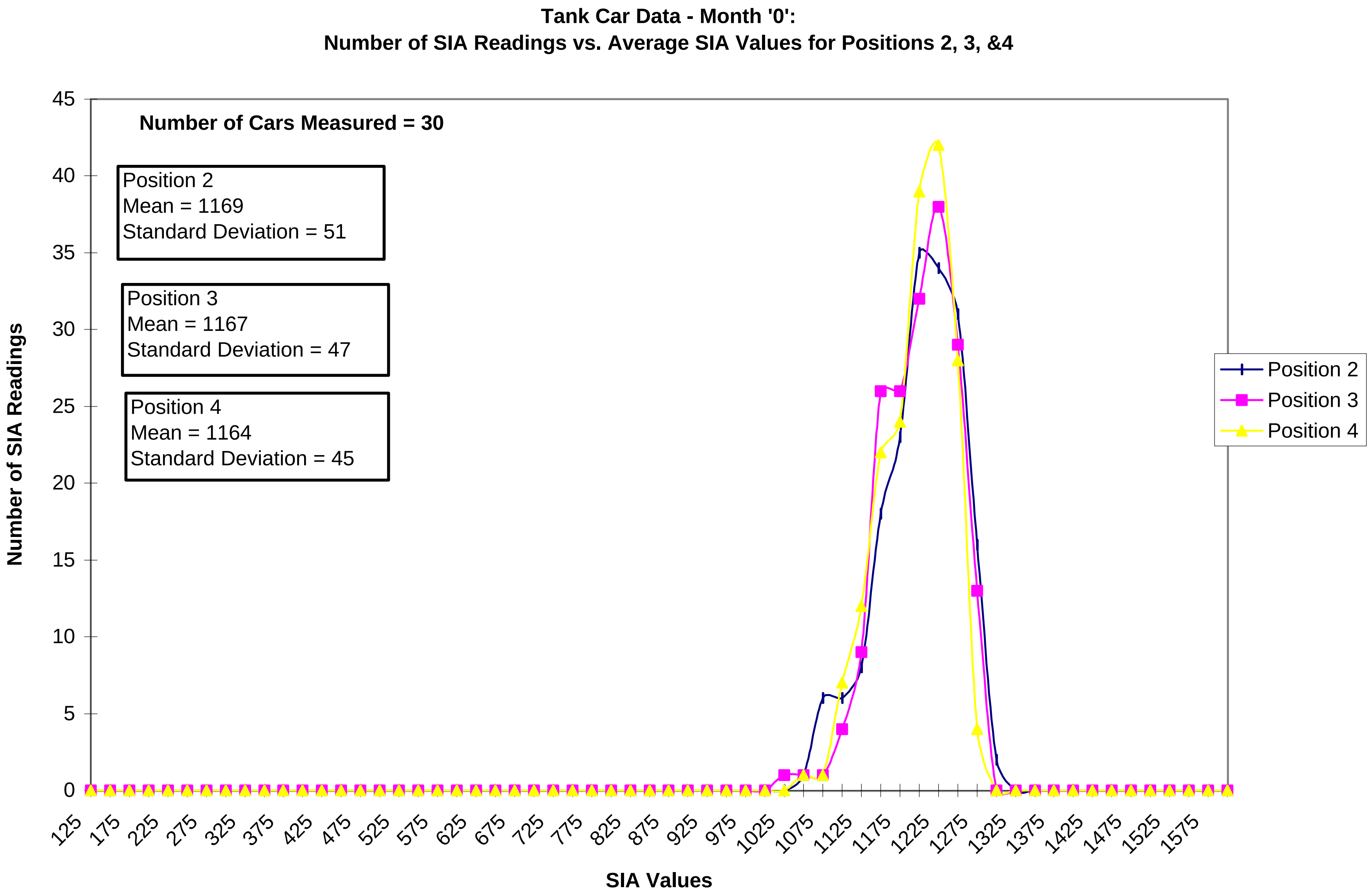
	Wheel 1	Wheel 2	Wheel 3	Wheel 4
1st				
2nd				
3rd				
Avg				

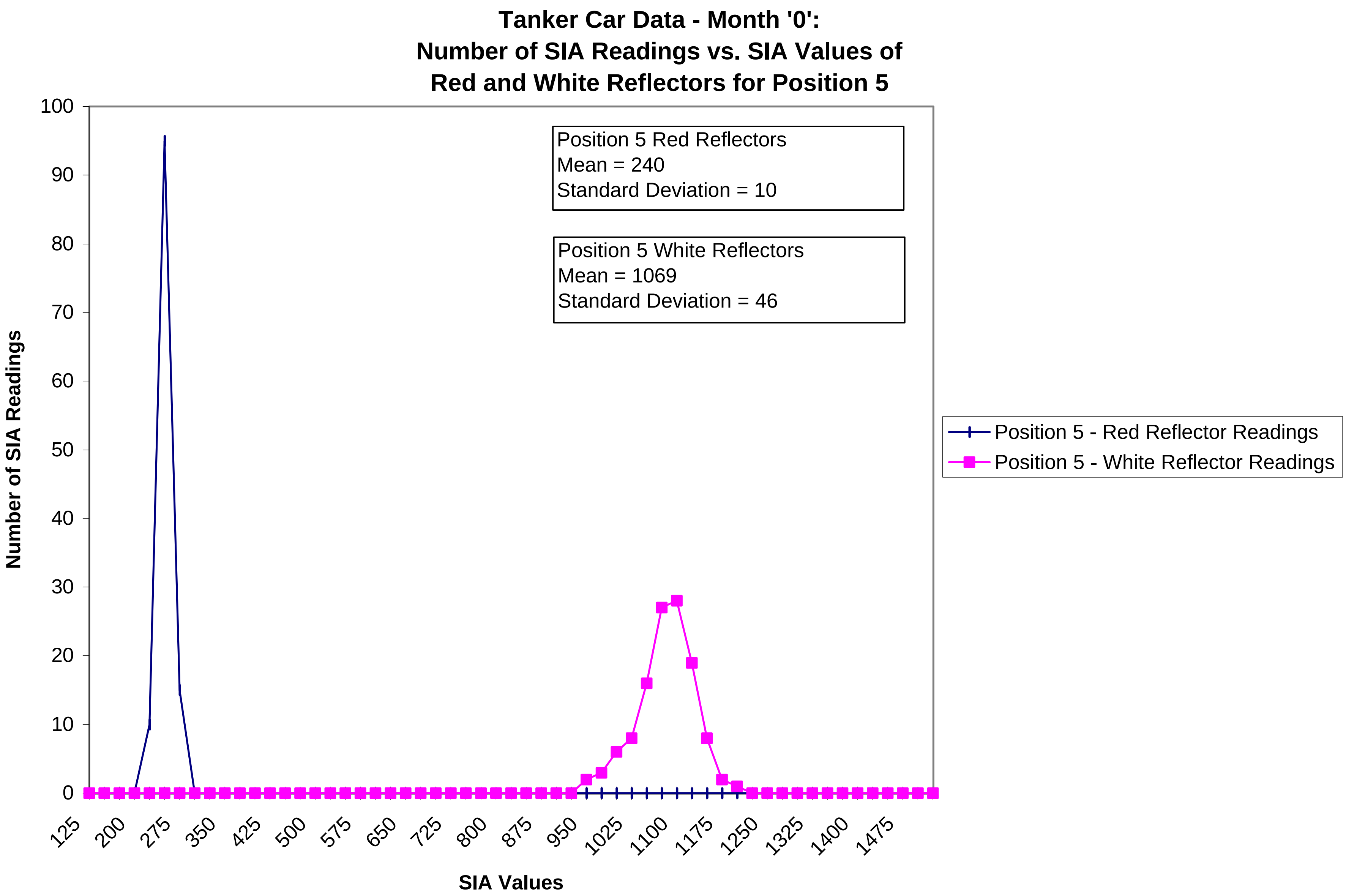
Note: Write M if decal is missing, Write D if decal is defective and explain nature of damage.

APPENDIX C

TANK CAR REFLECTOR INITIAL MEASUREMENTS

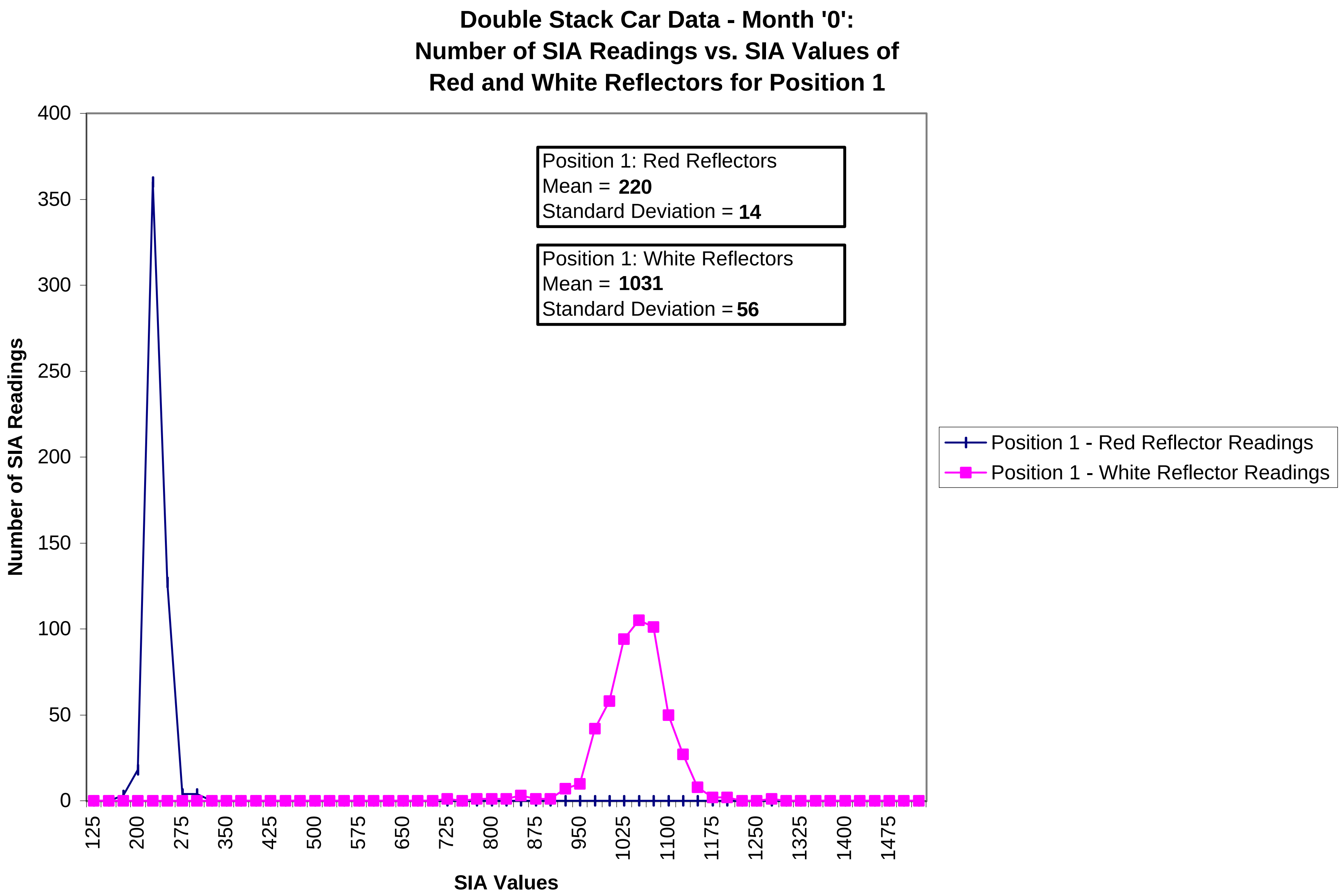

Tanker Car Data - Month '0':
Number of SIA Readings vs. SIA Values of
Red and White Reflectors for Position 1
Position 1 Red Reflectors
Mean = 241
Standard Deviation = 12
Position 1 White Reflectors
Mean = 1076
Standard Deviation = 47
Number of SIA Readings
SIA (cd/lx/m2)
Position 1 - Red Reflector Readings
Position 1 - White Reflector Readings
0
10
20
30
40
50
60
70
80
90
100
125
200
275
350
425
500
575
650
725
800
875
950
1025
1100
1175
1250
1325
1400
1475

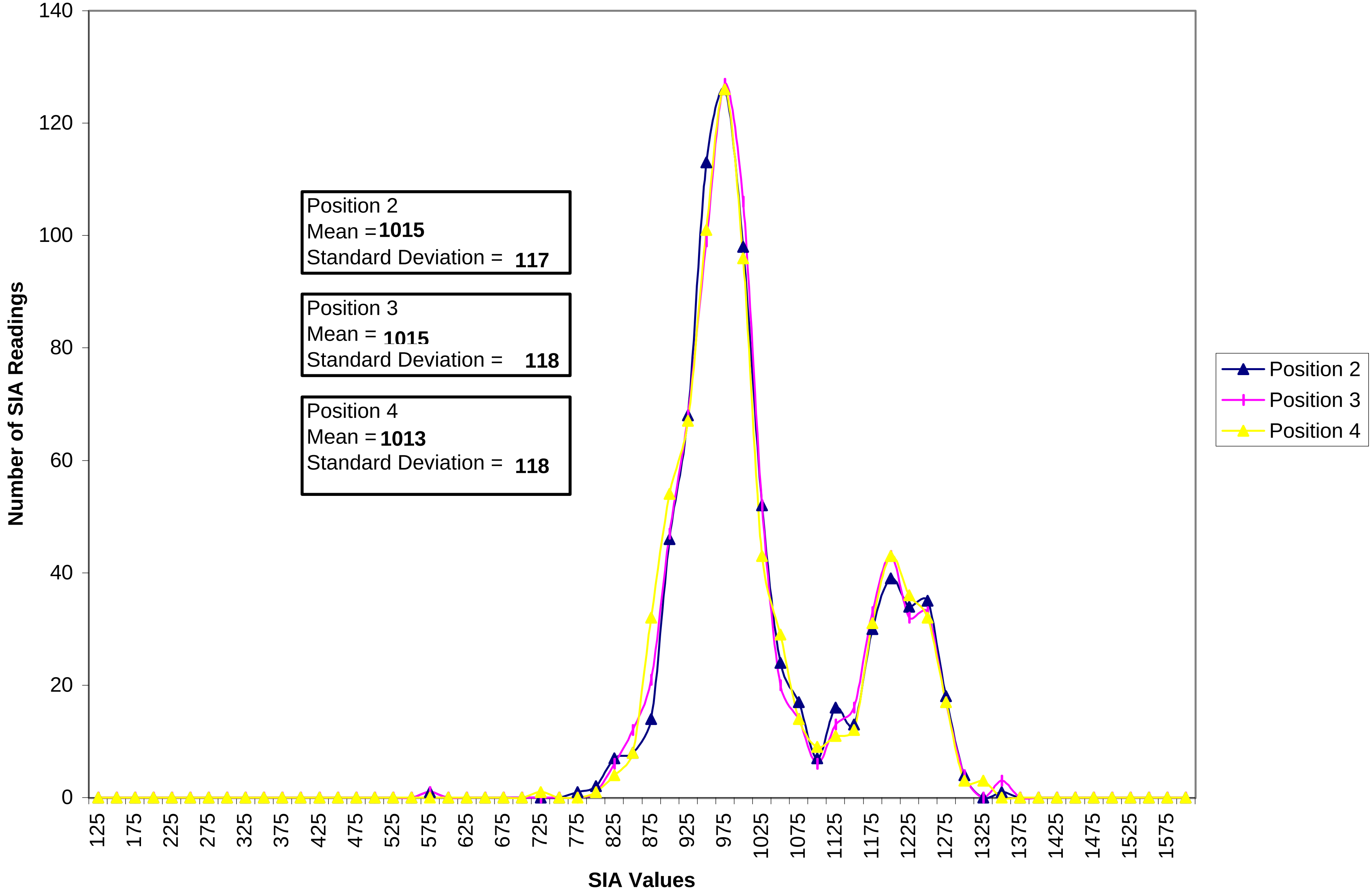

Tank Car Data - Month '0':
Number of SIA Readings vs. Average SIA Values for Positions 2, 3, &4
Number of Cars Measured = 30
Position 2
Mean = 1169
Standard Deviation = 51
Position 3
Mean = 1167
Standard Deviation = 47
Position 4
Mean = 1164
Standard Deviation = 45
Number of SIA Readings
SIA Values
Position 2
Position 3
Position 4
0
5
10
15
20
25
30
35
40
45
125
175
225
275
325
375
425
475
525
575
625
675
725
775
825
875
925
975
1025
1075
1125
1175
1225
1275
1325
1375
1425
1475
1525
1575

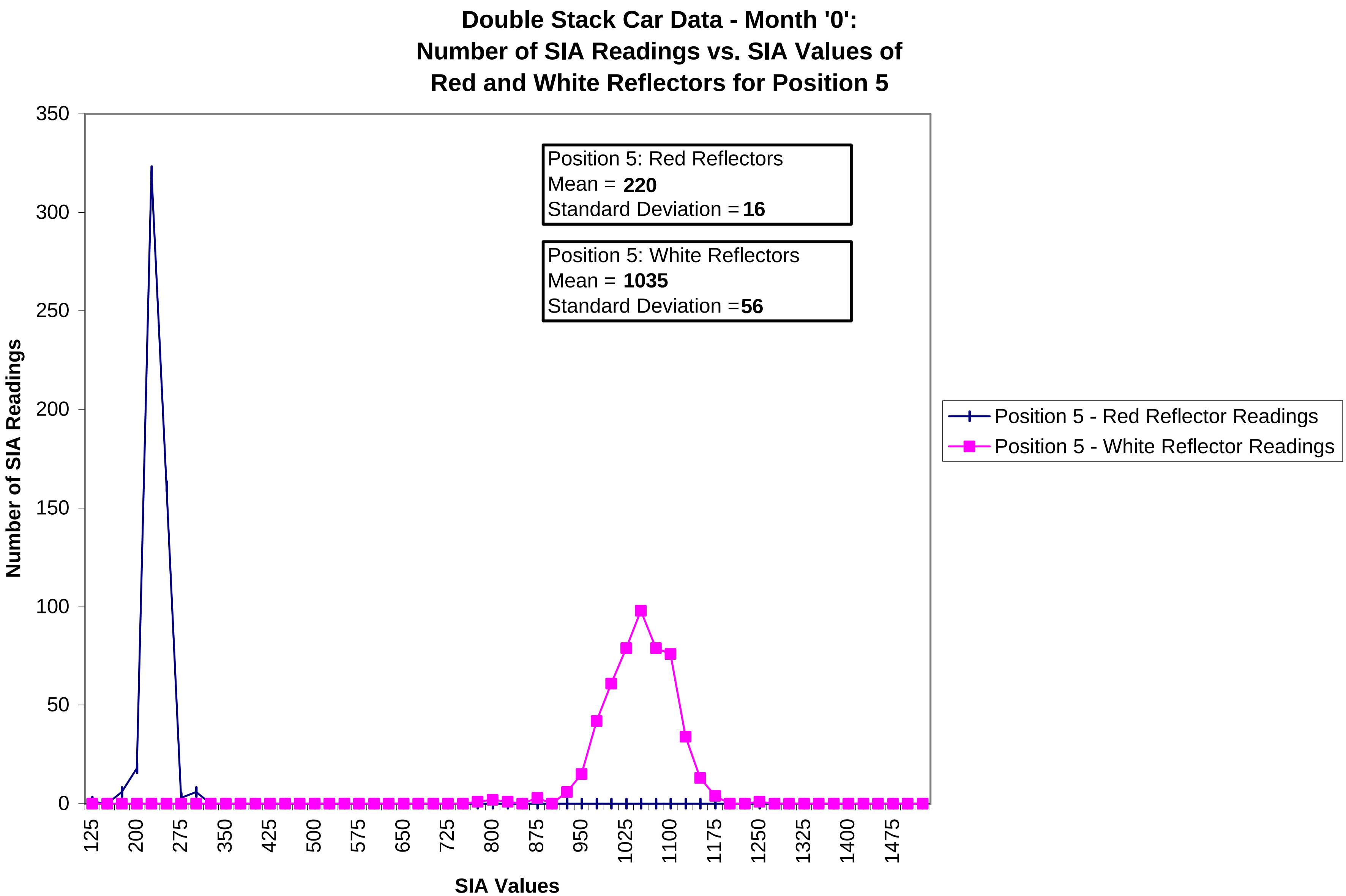

Tanker Car Data - Month '0':
Number of SIA Readings vs. SIA Values of
Red and White Reflectors for Position 5
Position 5 Red Reflectors
Mean = 240
Standard Deviation = 10
Position 5 White Reflectors
Mean = 1069
Standard Deviation = 46
Position 5 - Red Reflector Readings
Position 5 - White Reflector Readings
Number of SIA Readings
SIA Values
100
90
80
70
60
50
40
30
20
10
0
125
200
275
350
425
500
575
650
725
800
875
950
1025
1100
1175
1250
1325
1400
1475

APPENDIX D

DOUBLE STACK CAR REFLECTOR INITIAL MEASUREMENTS

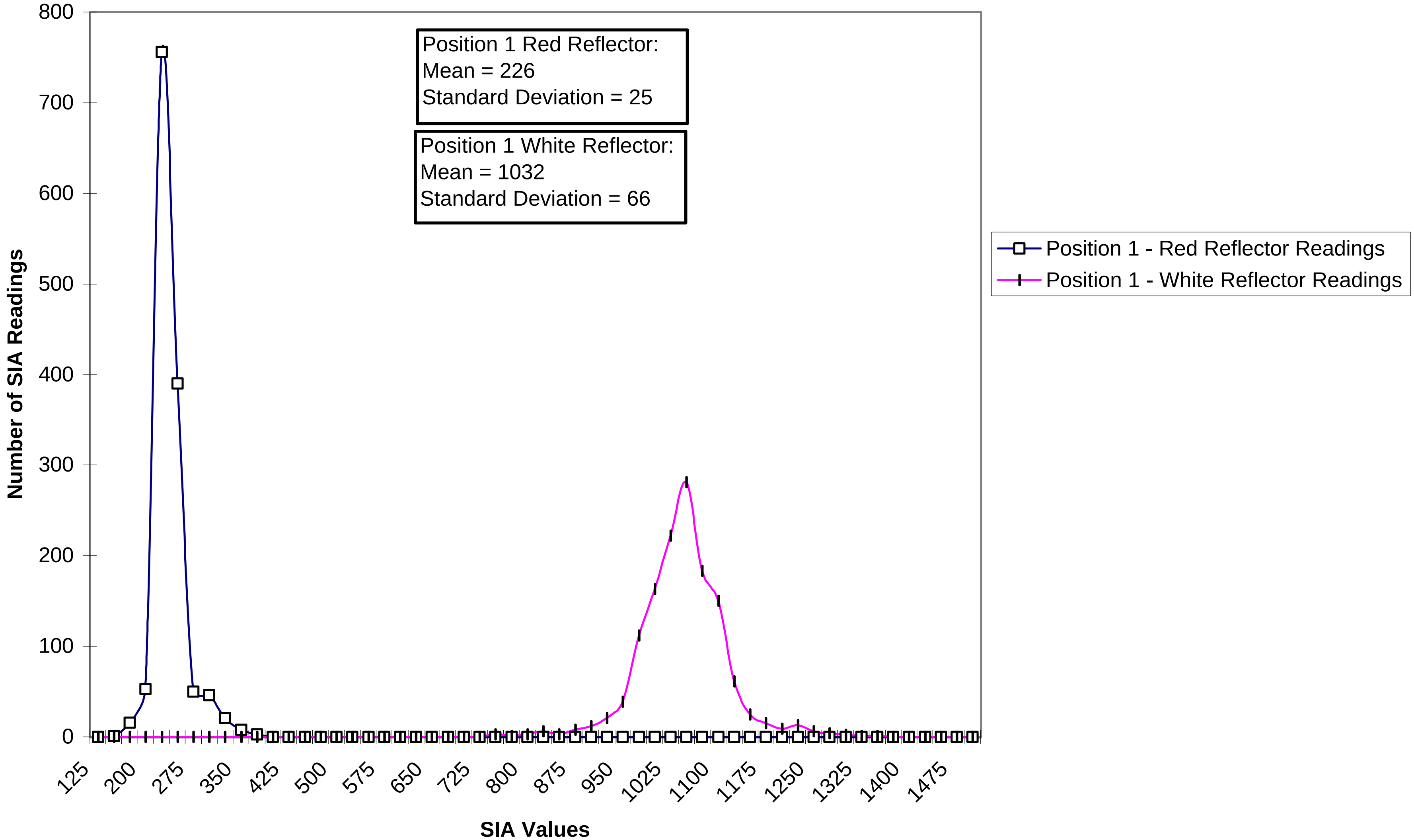

Double Stack Car Data - Month '0':
Number of SIA Readings vs. SIA Values of
Red and White Reflectors for Position 1
Position 1: Red Reflectors
Mean = 220
Standard Deviation = 14
Position 1: White Reflectors
Mean = 1031
Standard Deviation = 56
Number of SIA Readings
400
350
300
250
200
150
100
50
0
125
200
275
350
425
500
575
650
725
800
875
950
1025
1100
1175
1250
1325
1400
1475
SIA Values
Position 1 - Red Reflector Readings
Position 1 - White Reflector Readings

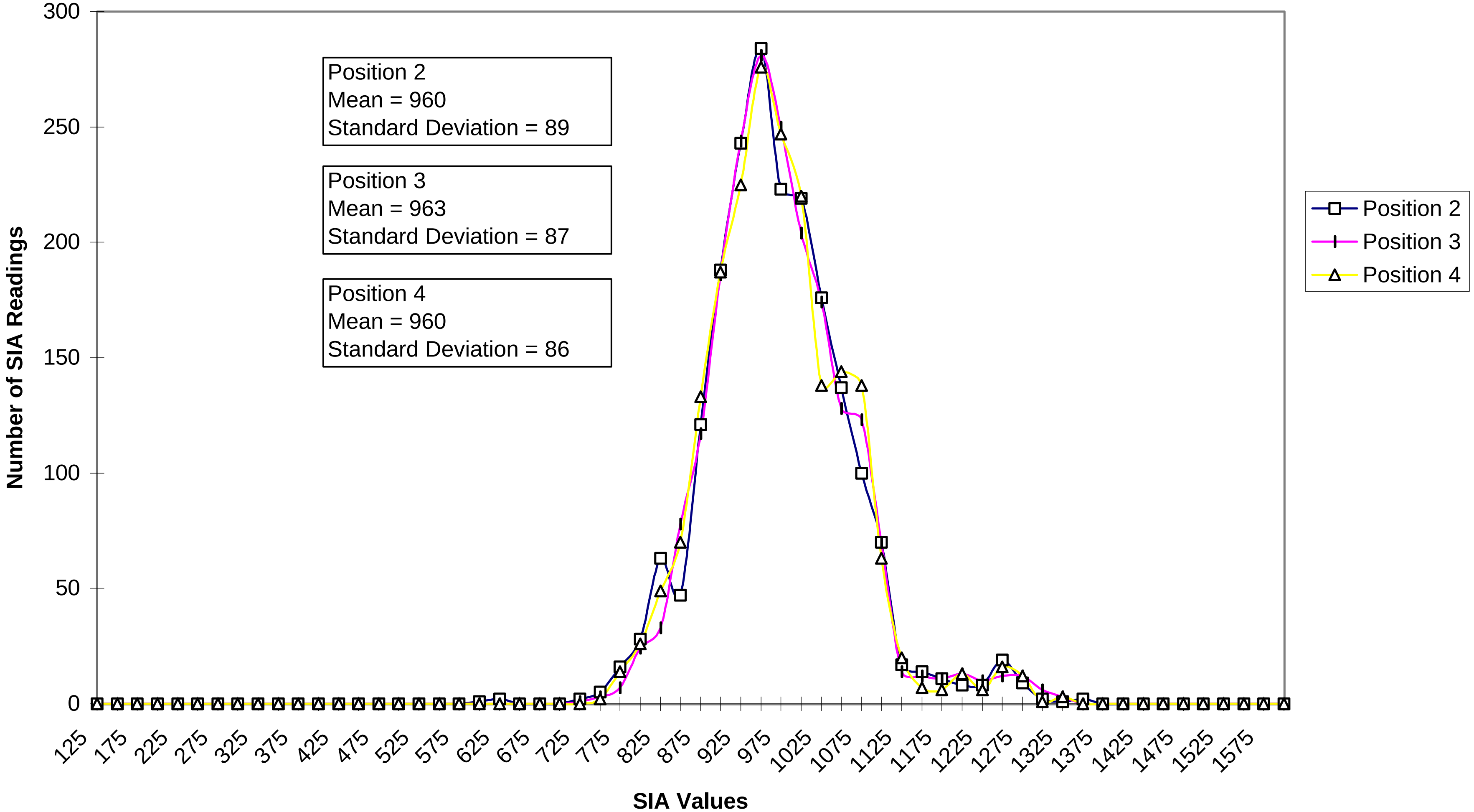

Number of SIA Readings
140
120
100
80
60
40
20
0
Position 2
Mean = 1015
Standard Deviation = 117
Position 3
Mean = 1015
Standard Deviation = 118
Position 4
Mean = 1013
Standard Deviation = 118
125 175 225 275 325 375 425 475 525 575 625 675 725 775 825 875 925 975 1025 1075 1125 1175 1225 1275 1325 1375 1425 1475 1525 1575
SIA Values
Position 2
Position 3
Position 4


Double Stack Car Data - Month '0':
Number of SIA Readings vs. SIA Values of
Red and White Reflectors for Position 5
Position 5: Red Reflectors
Mean = 220
Standard Deviation = 16
Position 5: White Reflectors
Mean = 1035
Standard Deviation = 56
Number of SIA Readings
SIA Values
0
50
100
150
200
250
300
350
125
200
275
350
425
500
575
650
725
800
875
950
1025
1100
1175
1250
1325
1400
1475
Position 5 - Red Reflector Readings
Position 5 - White Reflector Readings

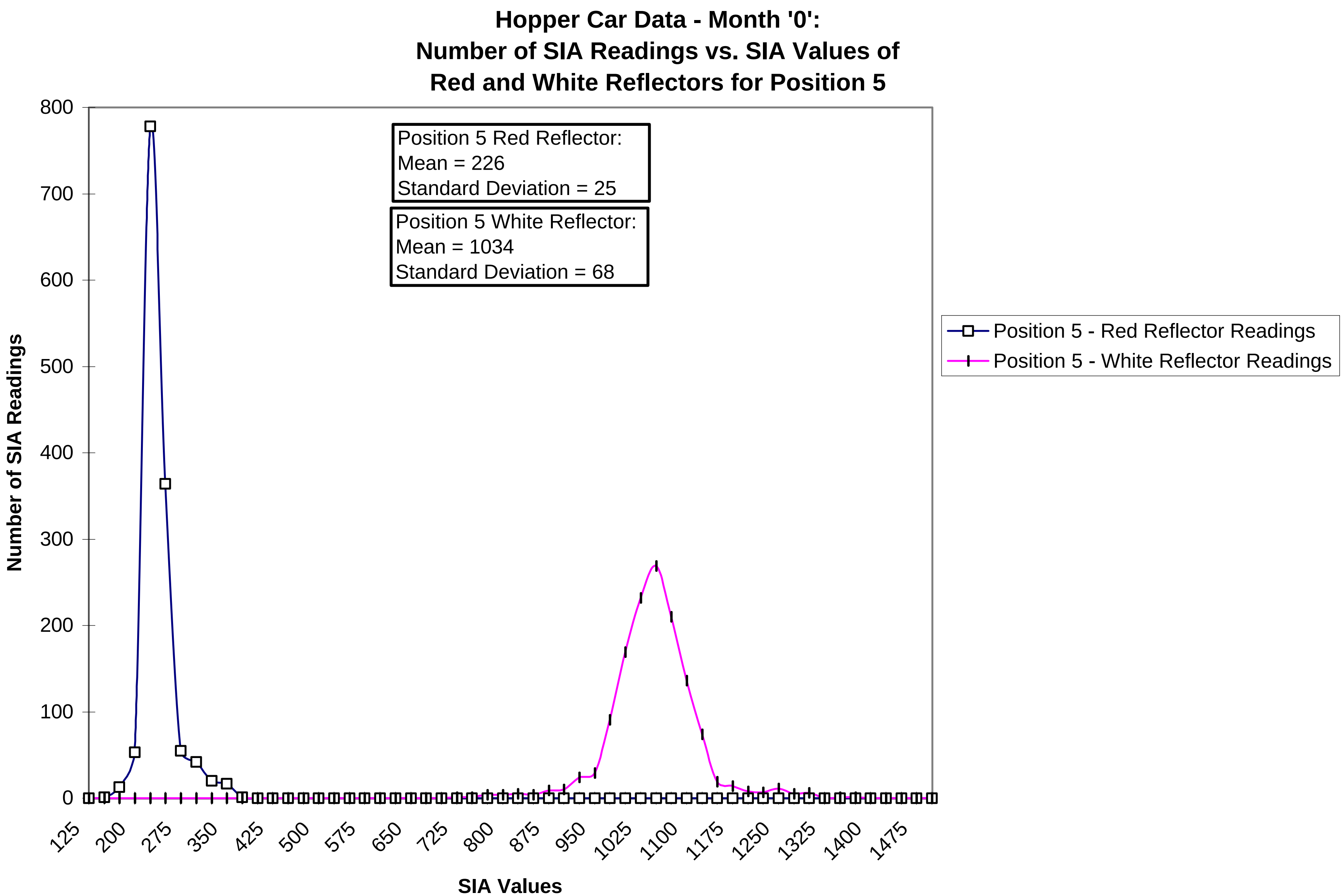
APPENDIX E

HOPPER CAR REFLECTOR INITIAL MEASUREMENTS


Position 1 Red Reflector:
Mean = 226
Standard Deviation = 25
Position 1 White Reflector:
Mean = 1032
Standard Deviation = 66
Position 1 - Red Reflector Readings
Position 1 - White Reflector Readings
Number of SIA Readings
SIA Values
0
100
200
300
400
500
600
700
800
125
200
275
350
425
500
575
650
725
800
875
950
1025
1100
1175
1250
1325
1400
1475



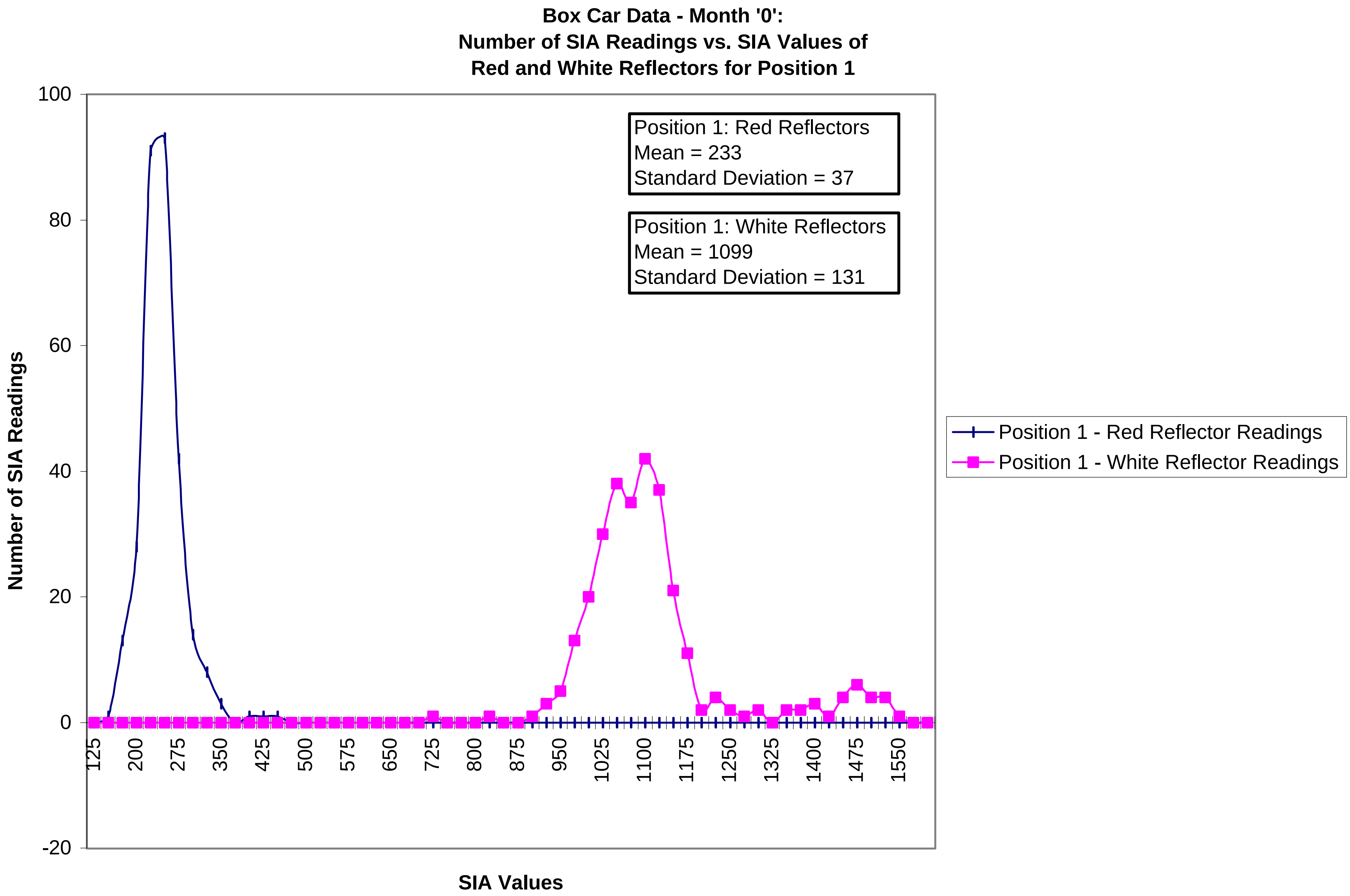
Position 2
Mean = 960
Standard Deviation = 89
Position 3
Mean = 963
Standard Deviation = 87
Position 4
Mean = 960
Standard Deviation = 86
Number of SIA Readings
SIA Values
Position 2
Position 3
Position 4
0
50
100
150
200
250
300
125
175
225
275
325
375
425
475
525
575
625
675
725
775
825
875
925
975
1025
1075
1125
1175
1225
1275
1325
1375
1425
1475
1525
1575

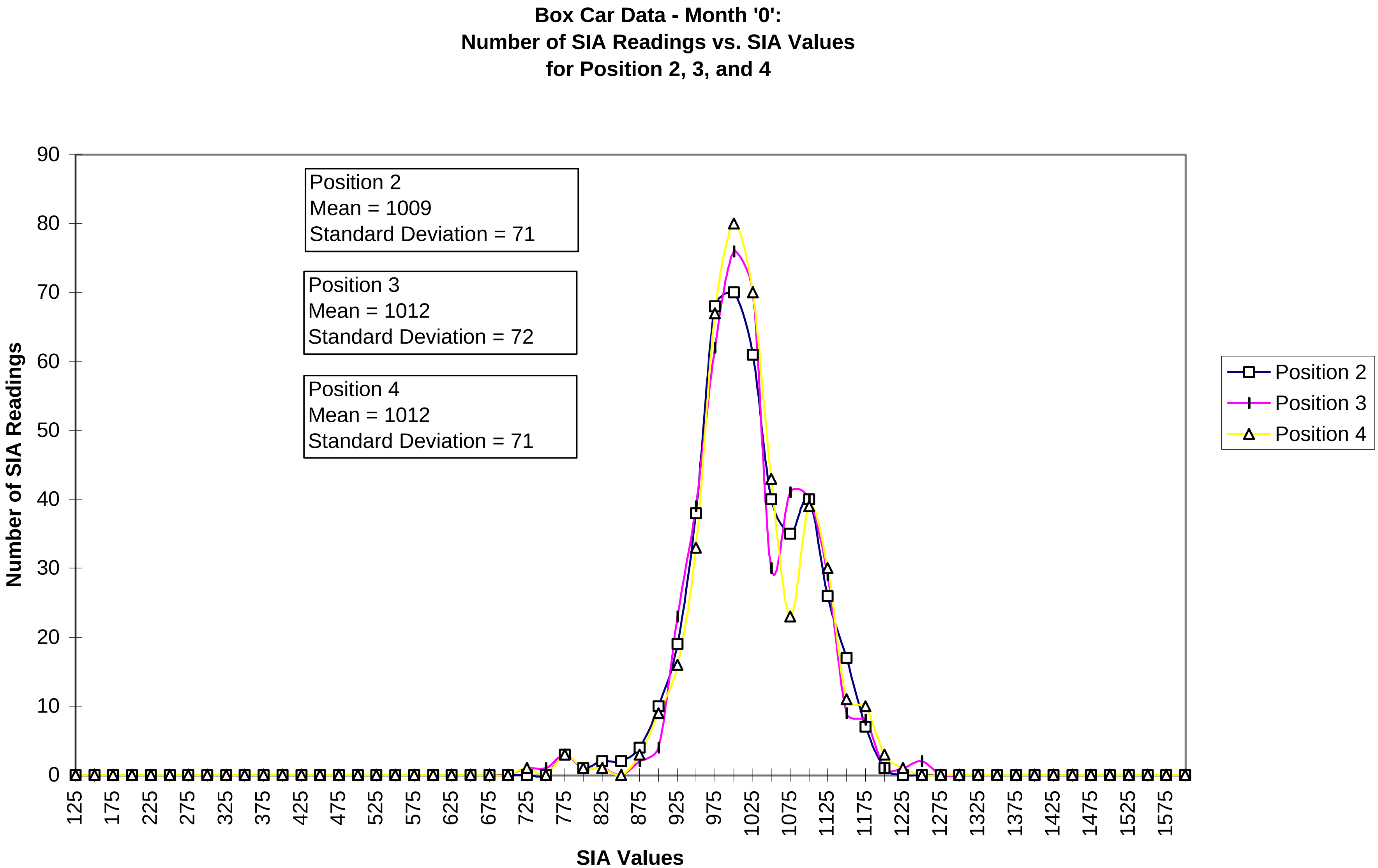


Hopper Car Data - Month '0':
Number of SIA Readings vs. SIA Values of
Red and White Reflectors for Position 5
Position 5 Red Reflector:
Mean = 226
Standard Deviation = 25
Position 5 White Reflector:
Mean = 1034
Standard Deviation = 68
Position 5 - Red Reflector Readings
Position 5 - White Reflector Readings
Number of SIA Readings
0
100
200
300
400
500
600
700
800
SIA Values
125
200
275
350
425
500
575
650
725
800
875
950
1025
1100
1175
1250
1325
1400
1475

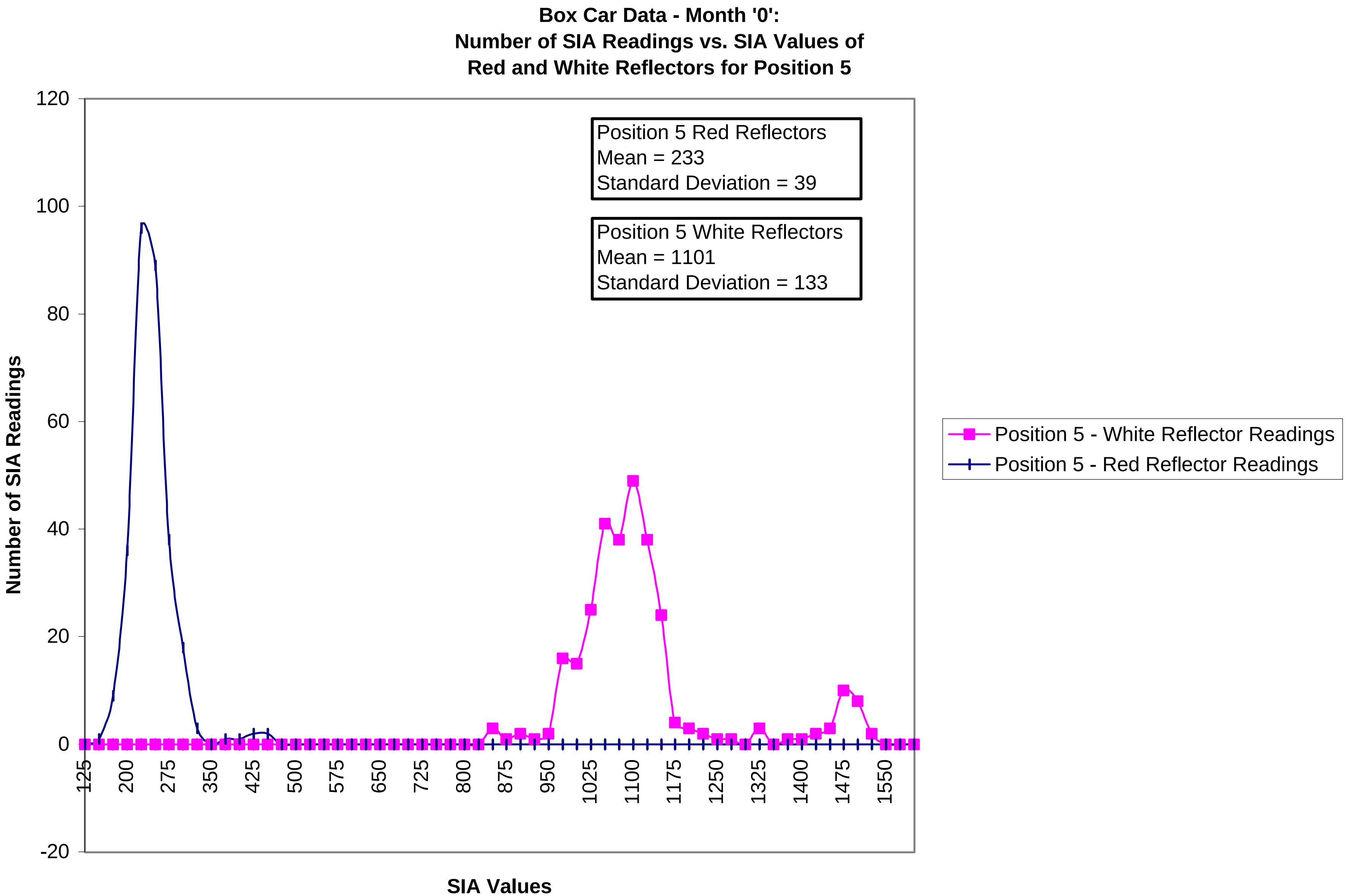
APPENDIX F

BOX CAR REFLECTOR INITIAL MEASUREMENTS


Box Car Data - Month '0':
Number of SIA Readings vs. SIA Values of
Red and White Reflectors for Position 1
Position 1: Red Reflectors
Mean = 233
Standard Deviation = 37
Position 1: White Reflectors
Mean = 1099
Standard Deviation = 131
Position 1 - Red Reflector Readings
Position 1 - White Reflector Readings
Number of SIA Readings
SIA Values
100
80
60
40
20
0
-20
125
200
275
350
425
500
575
650
725
800
875
950
1025
1100
1175
1250
1325
1400
1475
1550



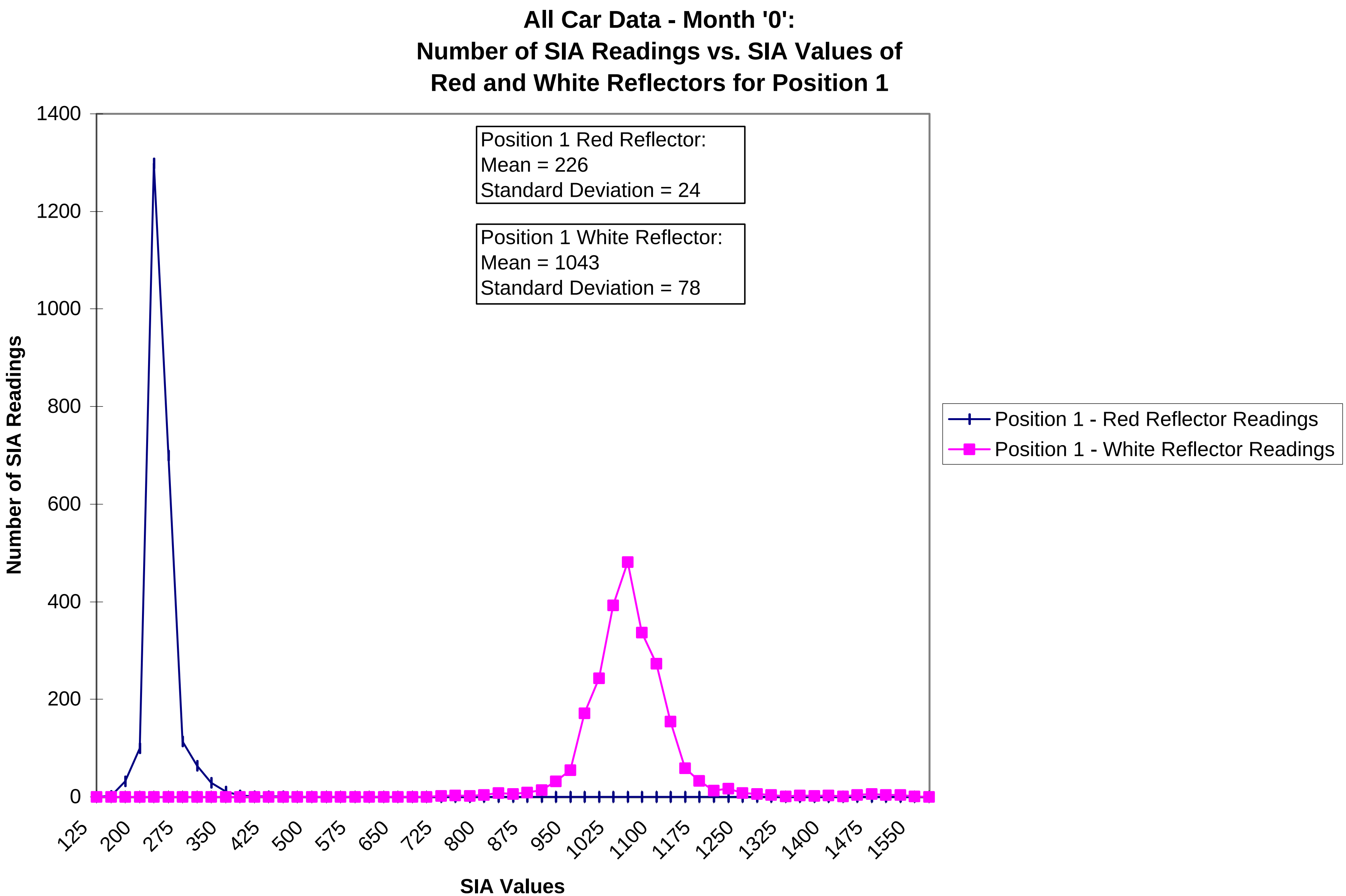
Box Car Data - Month '0':
Number of SIA Readings vs. SIA Values
for Position 2, 3, and 4
Position 2
Mean = 1009
Standard Deviation = 71
Position 3
Mean = 1012
Standard Deviation = 72
Position 4
Mean = 1012
Standard Deviation = 71
Number of SIA Readings
0
10
20
30
40
50
60
70
80
90
SIA Values
125
175
225
275
325
375
425
475
525
575
625
675
725
775
825
875
925
975
1025
1075
1125
1175
1225
1275
1325
1375
1425
1475
1525
1575
Position 2
Position 3
Position 4

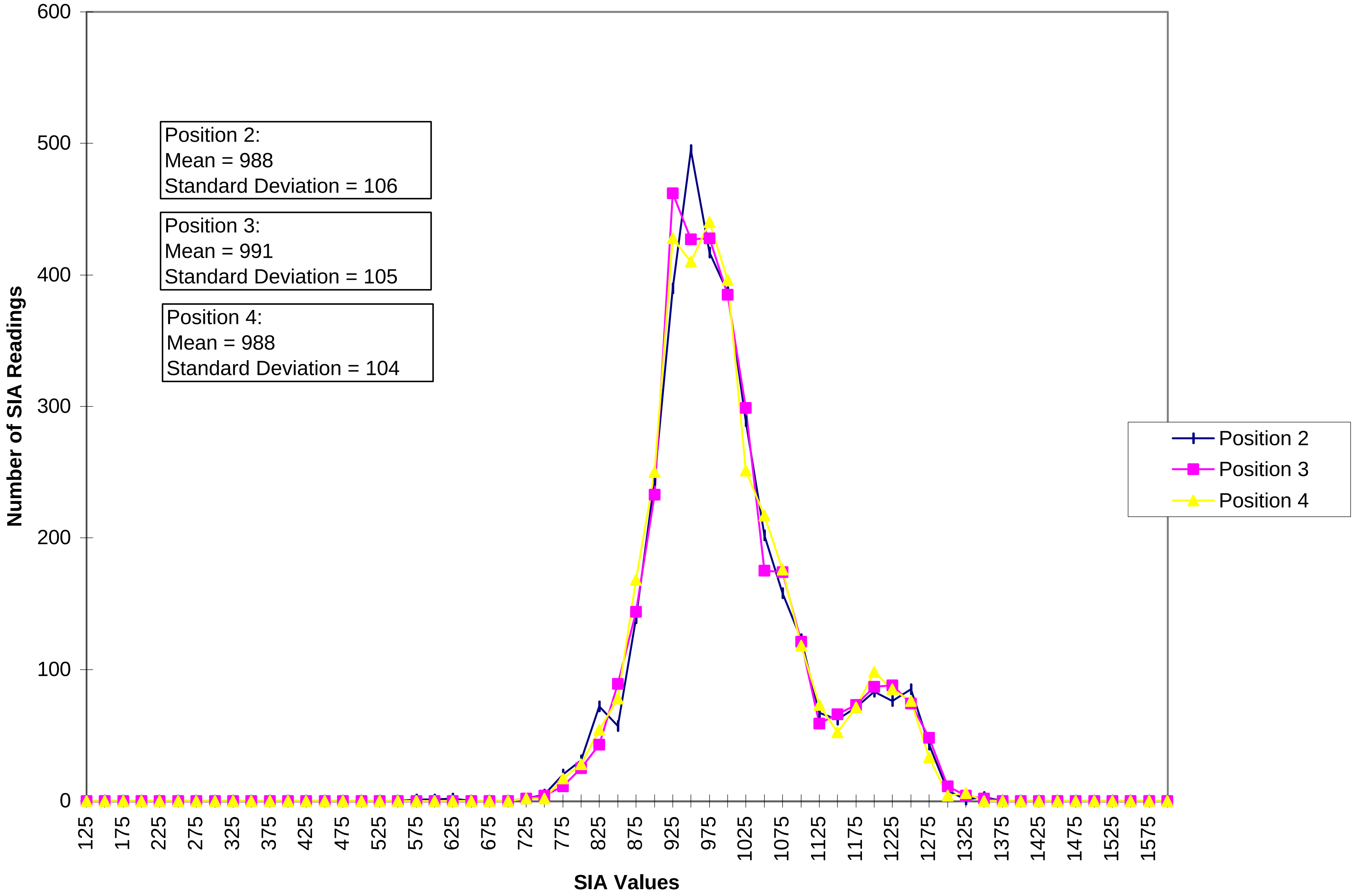


Box Car Data - Month '0':
Number of SIA Readings vs. SIA Values of
Red and White Reflectors for Position 5
Position 5 Red Reflectors
Mean = 233
Standard Deviation = 39
Position 5 White Reflectors
Mean = 1101
Standard Deviation = 133
Position 5 - White Reflector Readings
Position 5 - Red Reflector Readings
Number of SIA Readings
SIA Values
120
100
80
60
40
20
0
-20
125
200
275
350
425
500
575
650
725
800
875
950
1025
1100
1175
1250
1325
1400
1475
1550

APPENDIX G

ALL CAR TYPE REFLECTOR AGGREGATE INITIAL MEASUREMENTS


All Car Data - Month '0':
Number of SIA Readings vs. SIA Values of
Red and White Reflectors for Position 1
Position 1 Red Reflector:
Mean = 226
Standard Deviation = 24
Position 1 White Reflector:
Mean = 1043
Standard Deviation = 78
Number of SIA Readings
0
200
400
600
800
1000
1200
1400
125
200
275
350
425
500
575
650
725
800
875
950
1025
1100
1175
1250
1325
1400
1475
1550
SIA Values
Position 1 - Red Reflector Readings
Position 1 - White Reflector Readings


Position 2:
Mean = 988
Standard Deviation = 106
Position 3:
Mean = 991
Standard Deviation = 105
Position 4:
Mean = 988
Standard Deviation = 104
Position 2
Position 3
Position 4
Number of SIA Readings
SIA Values
0
100
200
300
400
500
600
125
175
225
275
325
375
425
475
525
575
625
675
725
775
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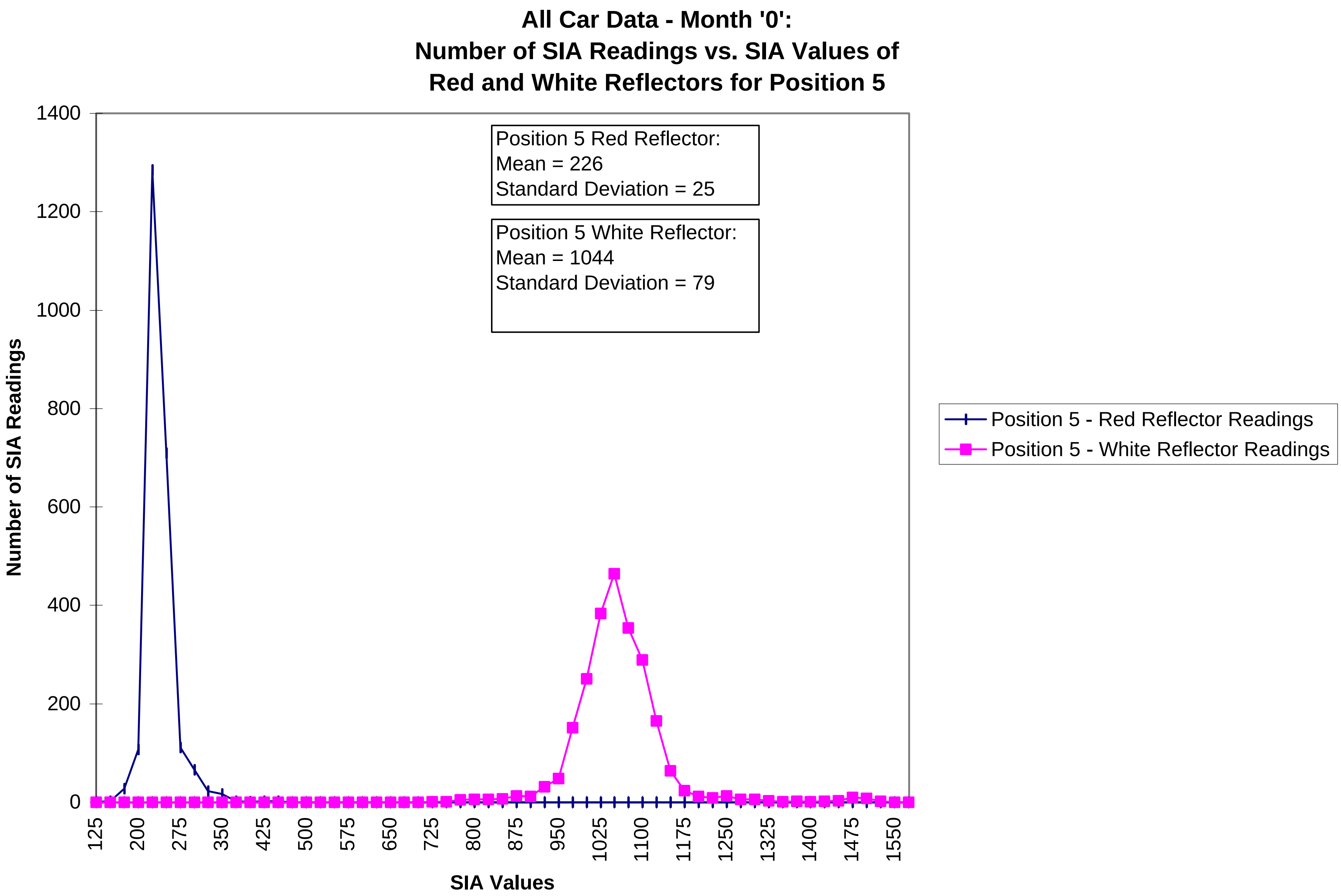
1425
1475
1525
1575


All Car Data - Month '0':
Number of SIA Readings vs. SIA Values of
Red and White Reflectors for Position 5
Position 5 Red Reflector:
Mean = 226
Standard Deviation = 25
Position 5 White Reflector:
Mean = 1044
Standard Deviation = 79
Number of SIA Readings
0
200
400
600
800
1000
1200
1400
SIA Values
125
200
275
350
425
500
575
650
725
800
875
950
1025
1100
1175
1250
1325
1400
1475
1550
Position 5 - Red Reflector Readings
Position 5 - White Reflector Readings

APPENDIX H

FREIGHT CAR REFLECTORIZATION MEMORANDUM

U.S. Department
of Transportation

Research and Special Programs Administration

Memorandum

John A. Volpe
National Transportation Systems Center

Subject: Freight Car Reflectorization

Date: November 2, 1998

From: Erica Rhude

Reply to Attn of: Anya A. Carroll, DTS-73

To: Claire Orth

Thru: John Hitz, Anya Carroll, Jordan Multer and Debra Williams

Background

The Volpe Center previously completed two studies evaluating the reflectorization of freight cars as a means of improving the safety of highway-railroad grade crossings. The first study involved field operational tests, which included a demonstration test at the Transportation Technology Center in Pueblo, Colorado and in-service testing on Alaska Railroad and Norfolk Southern Corporation freight trains. From this testing it was concluded that a vertical pattern of red and white microprismatic retroreflectors meet visibility requirements for detection of freight cars at night. It was also found that under the harsh operating conditions of the railroad, larger (4" x 36") vertically oriented reflectors maintained acceptable visual performance longer than smaller (4" x 8") horizontally oriented reflectors. With routine maintenance, this newly developed prismatic material is likely to perform above the visual threshold for up to 10 years.

The second study involved the human behavior testing. At the University of Tennessee, human factors testing was conducted to determine the detection characteristics of the new reflective material in various colors and mounting configurations. Further testing was done with Massachusetts Institute of Technology (MIT) to determine how well people recognize various reflector patterns on the sides of trains. From these human factors studies, a reflectorized freight car was found to be significantly more detectable than a non-reflectorized freight car. Further consensus was that a uniform vertical reflector pattern yields the highest level of detection and recognition.

Grady Cothen, FRA, Office of Safety, Deputy Associate Administrator for Safety Standards & Programs, requested that the following analysis be provided. The analysis documented in this memorandum serves as a supplement to the freight car reflectorization studies discussed above. It will be used, by the FRA, in determining the effectiveness of this technology for a cost-benefit study. This memorandum specifically addresses the effects of automotive headlights, weather conditions and highway-rail crossing geometry on the effectiveness of freight car reflectorization.

Headlight Effects

There are two main factors that affect the relationship between automotive headlight intensities and their role in the effectiveness of reflectorization of railroad freight cars: manufacturing variation and headlamp misalignment. While light-output regulations dictate luminance ranges at selected points, the headlamp beam pattern is a non-uniform feature dependent on the individual manufacturer.

From a 1997 study done by the University of Michigan Transportation Research Institute, “A Market-Weighted Description of Low-Beam Headlighting Patterns in the U.S.”, a typical light output pattern was established for headlights currently used in the US. While the median headlamp exhibits luminous intensities consistent with estimates used in our previous study, the 25th percentile headlamp is roughly one third of this intensity (see Figure 1). Such low intensity headlights still maintain acceptable threshold SIA (*specific intensity per unit area*) values for all large reflectors tested in the in-service testing. In the case of the smaller reflectors, where degradation levels on some freight car reflectors were found to fall below the current threshold in the testing cycle, half the acceptable life cycle would result from the 25th percentile headlight intensity.

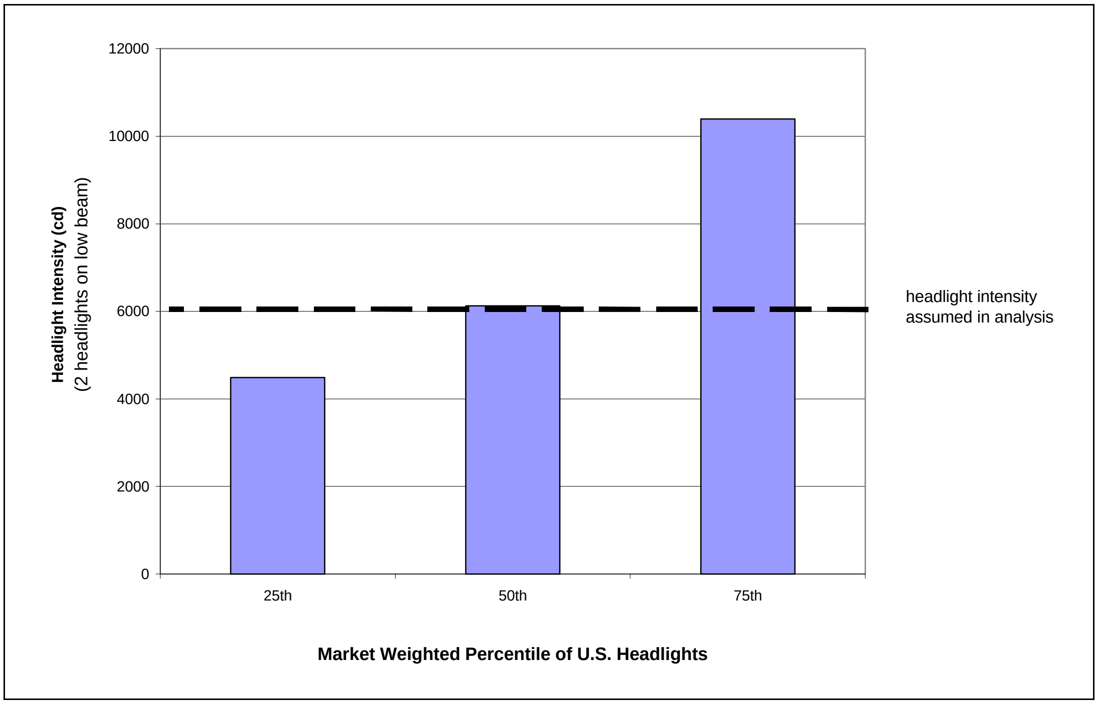


Figure 1. Light intensities from pairs of low beam headlights at freight car reflector location, from a market-weighted database of U.S. headlights (Savik, 1997)

All analyses in Volpe studies were done assuming the use of two headlights at low beam settings. In the case of high beam headlights, the reflectivity would only be enhanced and detectable at a further distance from the crossing. A study conducted by the Southwest Research Institute found that only 25% of motorists, in the vehicles studied, used high beams in an environment when a they would be unable to see a train in a crossing and it was appropriate to do so (McGinnis, 1979). An additional condition arises for vehicles with only one working headlight. The resulting illuminance is roughly half that produced by two headlights, but depends further on which side of the vehicle it is on. U.S. headlights are aimed down and to the right for driving on the right side of the road. If the passenger's side headlight is the functioning headlight, less light is directed in the driver's line of sight at the level of the reflectors, than the from the driver's side headlight.

Misaimed headlights pose further discrepancy in the luminance projected upon the reflectors. Vertically misaimed headlights have a greater effect on the detection distance of the retroreflectors than misaim in the horizontal direction. Although vertically and horizontally misaimed headlights can affect the detection distance of reflectors, the microprismatic retroreflectors recommended, virtually eliminate this effect, compared with enclosed or embedded reflective sheeting (Zwahlen, 1989).

Recent changes and advancements in headlight technology may potentially affect the performance of proposed freight car reflectorization. One consideration, by the NHTSA, is to conform US headlamp profiles with European Standards, which have a sharp beam cutoff for minimum glare to opposing traffic. While such a profile also improves visual headlight alignment and reduces misaiming problems, it drastically reduces the illumination of reflective signs and warnings in the driver's line of sight, as less light is aimed above the horizontal axis of the headlight. Consequently, new headlight regulations may reduce the effectiveness of proposed freight car reflectorization. NHTSA has recently begun investigation into such changes in order to reduce glare to oncoming traffic.

Weather Condition Effects

Changes in weather conditions alter the atmospheric transmissivity through which light must travel to reach the reflectors and return back to the eyes of the driver. Threshold SIA values, for tested reflectors in our previous study, were determined using an atmospheric transmissivity corresponding to conditions of light haze. Both the small and large reflectors recommended in that report, exhibit safe SIA values under conditions of clear skies, haze and thin fog. The large reflectors tested in the in-service test, performed with a safety margin that would allow adequate reflection, at the required detection distance, up to the condition of moderate fog. In thick fog, the visual threshold, recommended by the FAA and the IES Lighting Handbook, would occur at approximately 100-ft short of the 500-ft detection distance required for safe stopping from a vehicle speed of 50 mph. Through most conditions of reduced visibility, detection of larger reflectors may occur as much as fifty feet before that of the smaller reflector. Figure 2 shows how changes in atmospheric conditions affect the minimum SIA for both reflector sizes. The atmospheric transmissivity characteristic of each weather condition, as defined by the IES Lighting Handbook, can be found in the Appendix.

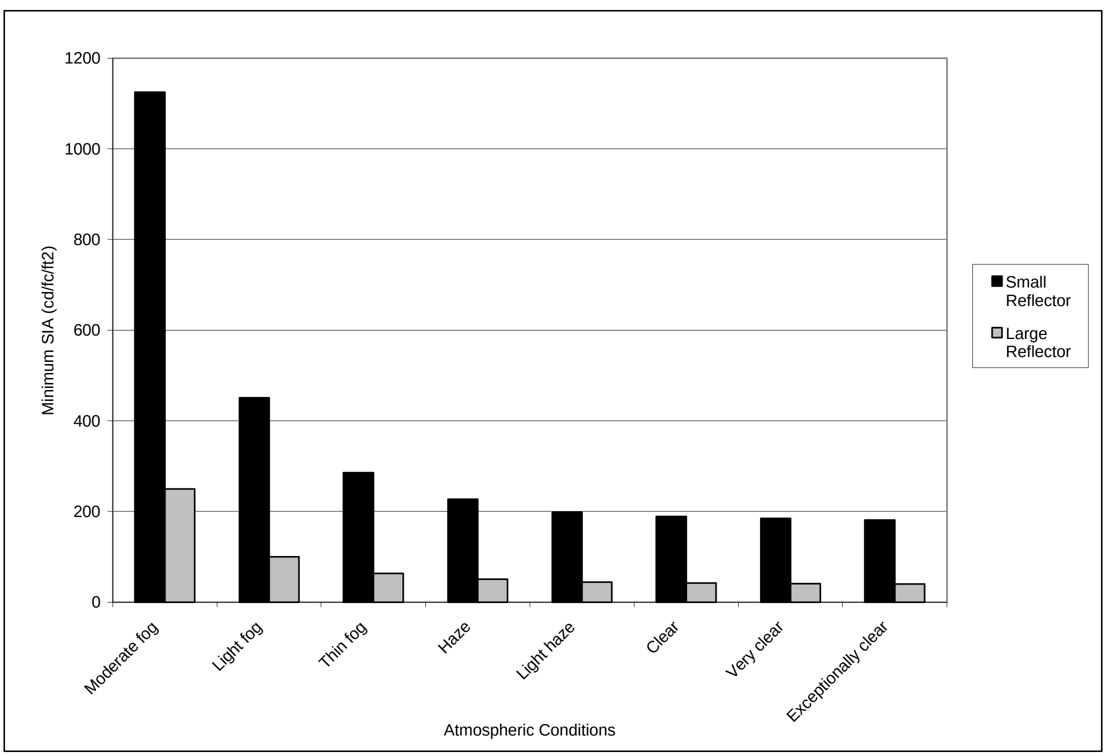


Figure 2. Effects of atmospheric conditions on minimum detection levels for both the small (4" x 8") and the large (4"x 36") reflectors.

Roadway Geometry Effects

The crossing geometry used in our previous study, to establish reflector requirements, assumes that the road is level with the tracks and that the vehicle approaches perpendicular to the direction of the train (90^{o} intersection). This situation obviously does not account for the common humped crossings or angled and curved approaches encountered in many highway-rail crossings. Reflector effectiveness is maximized as both the observation and entrance angles (as seen in Figure 3) approach zero. The closer the vehicle is to the crossing, the larger both of these angles become. The observation angle however has a greater effect on the reflectivity than does the entrance angle.

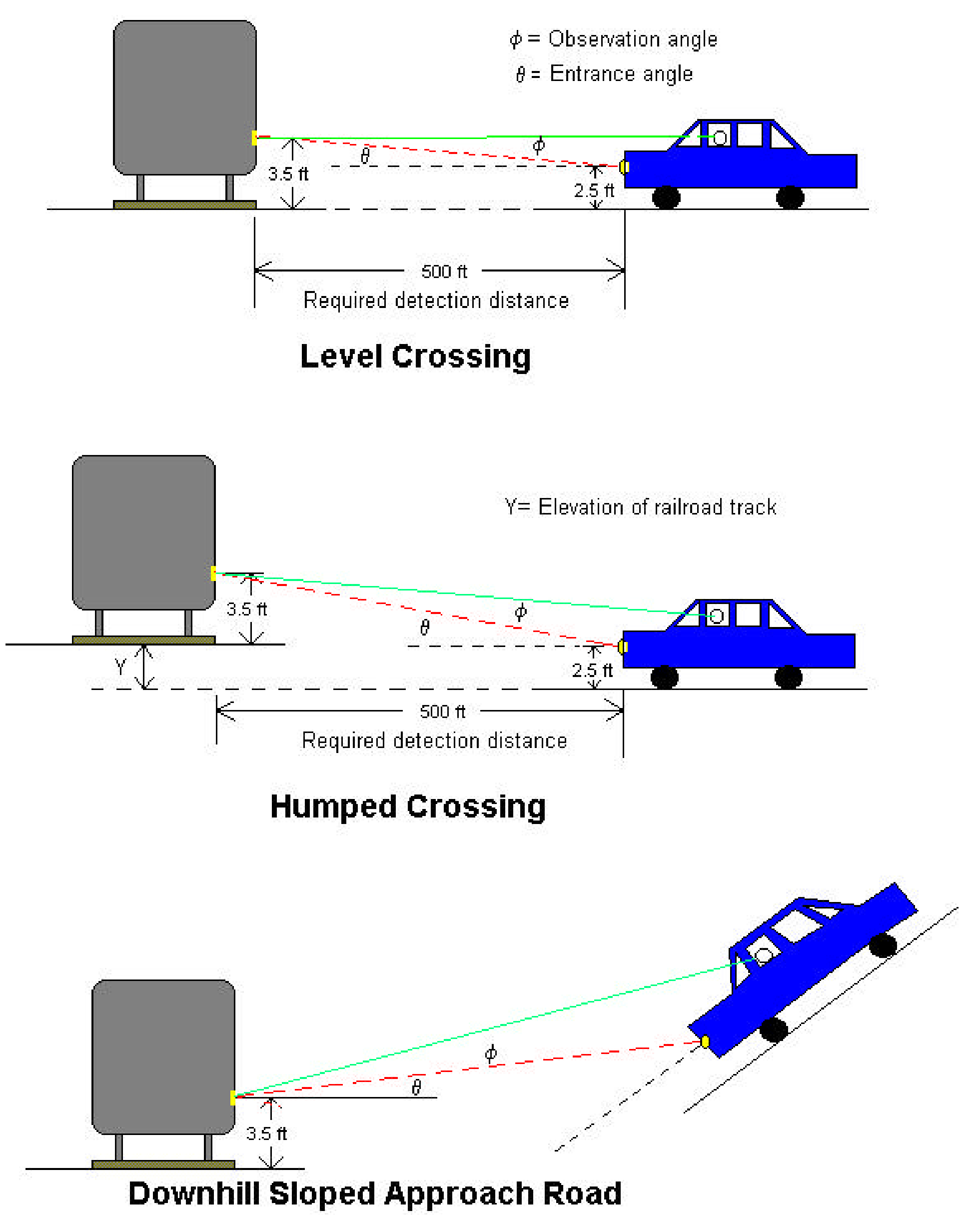


Figure 3. Side view of various highway-rail crossing geometry

In the case of humped crossings, where the track is at a higher elevation than the road, the luminous intensity estimated to reach the reflectors, in the calculations of minimum reflectance, are higher than the actual intensities at this geometry. Standard US headlights are aimed 2^o below the horizontal axis of the vehicle so that above the horizontal axis the luminous intensity drops off sharply to light the roadway while reducing glare to oncoming vehicles. However, at the optimal detection distance of 500-ft, a track raised to the elevation of 4 ft above road level, would result in a 0.5^o offset from the current angle. At this angle, light intensities are roughly half of the values assumed in our previous study (Savik, 1997). This would result in a doubling of the threshold SIA levels of the requirements of both reflector sizes. As with the case of atmospheric deviations, the margin between the actual and threshold SIA levels of the larger reflector allows this variation of intensity within acceptable levels. Additionally, the 36" height of the large reflector allows for greater variability of light intensity resulting from the larger range in angle. In the situation where the highway is elevated above the level of the grade crossing, headlight aim would result in increased luminance intensities and better reflector performance. When this approaching road has a downward slope, as seen in Figure 3, the luminous intensities are again decreased as they are emitted from above the horizontal beam. The exact effects are dependent on specific road geometry that varies by crossing.

The Federal Railroad Administration's Grade Crossing Inventory identifies crossings into three categories of crossing angles: 60-90^o, 30-59^o, and 0-29^o. Approximately 80% of all crossing have crossing angles between 60-90^o, 16% are 30-59^o, and only 4% are 0-29^o (*The Highway-Rail Crossing Accident/Incident and Inventory Bulletin*, *1996*). Many roads do not approach the intersection in a straight path but rather with some independent curvature as seen in Figure 4. There is also the possibility of obstructions such as trees or buildings, which may restrict the path of the headlight illumination as well as the driver's site triangle. Although it is impossible to account for all such variations, if it is assumed that the vehicle does approach the intersection in a straight path, as seen in Figure 5, an effective degree of crossing angles can be established.

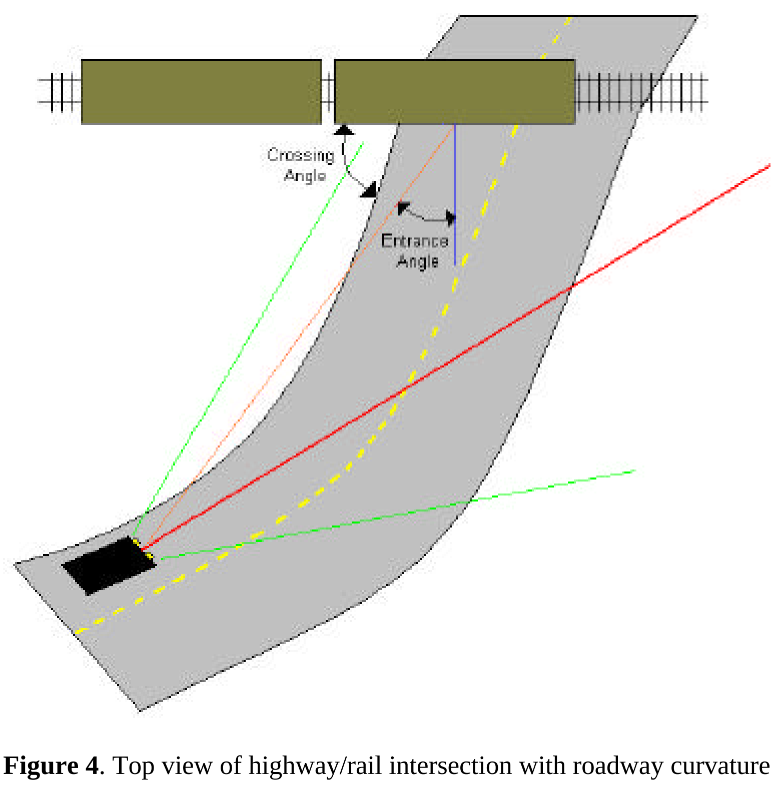


Figure 4. Top view of highway/rail intersection with roadway curvature

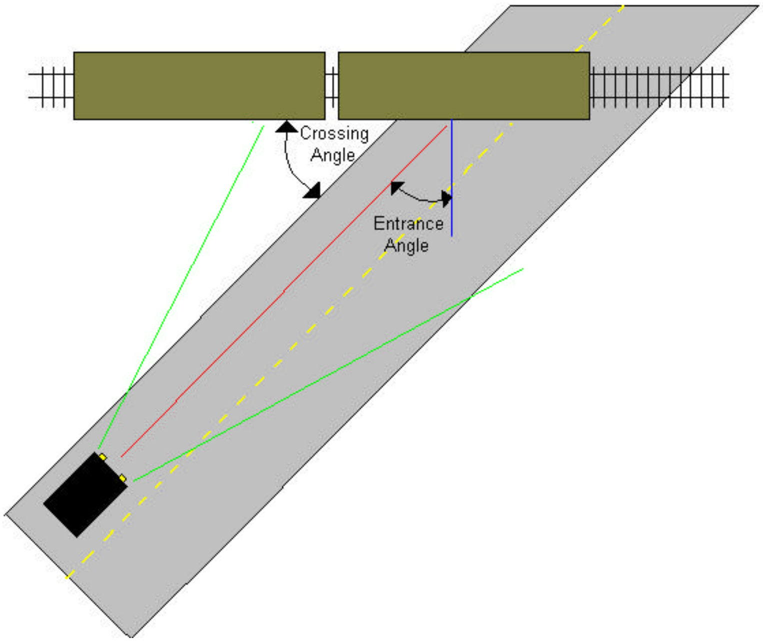


Figure 5. Top view of highway/rail intersection without roadway curvature (tangent).

From specifications provided by one retroreflective material manufacturer, the average reflector performance as a function of crossing angle can be seen in Figures 6 and 7. Figure 6 shows the typical values for the coefficient of reflectivity for 3M's series 981 sheeting for the small 4" x 8" white retroreflectors. Figure 7 is averaged values for the red & white 4" x 36" sheeting. Both plots show values at observation angles of 0.2^o and 0.5^o. At the detection distance of 500 ft, the observation angle on a level road ranges from 0.15^o for small passenger cars to 0.55^o for cab-over-engine trucks, as the elevation from the driver to the headlight increases. (McGinnis, 1979)

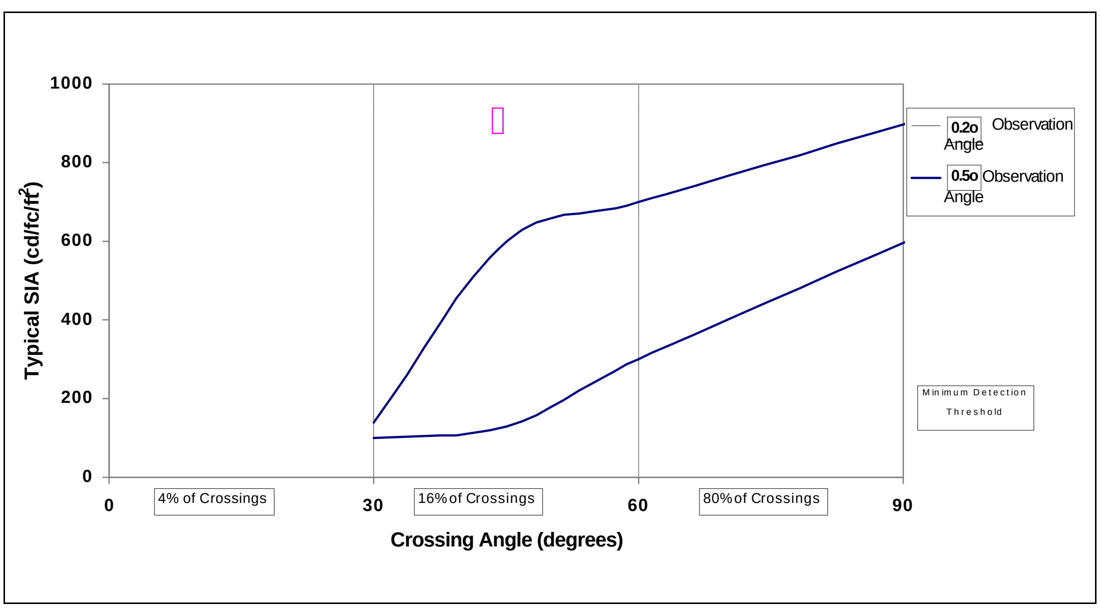


Figure 6. Typical Coefficients of Retroreflection for 3M's 981 sheeting series as a function of grade crossing angle (white 4" x 8")

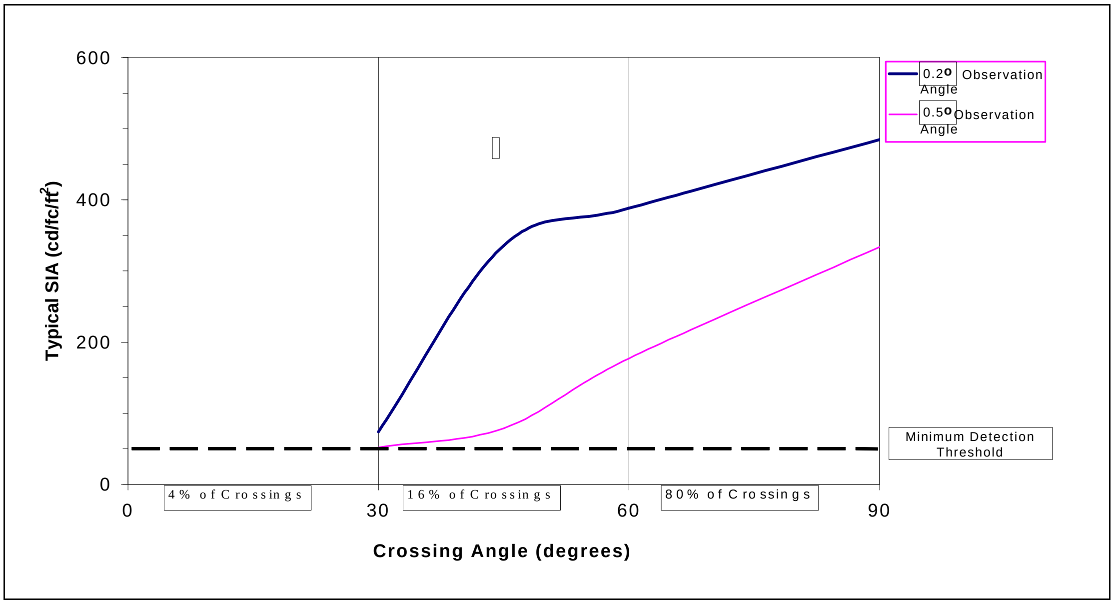


Figure 7. Typical Coefficients of Retroreflection for 3M's 981 sheeting series as a function of grade crossing angle (red & white 4" x 36")

Both reflectors are found to perform above the detection threshold for crossing angles from 30^{o} to 90^{o}, for the average vehicle. This accounts for 96% of the crossings for cars and small trucks. The larger red & white reflectors perform at or above the threshold level for all vehicles from 30^{o} to 90^{o} crossing angles. Values beyond 30^{o} were not available at this time and would require further investigation. These values represent measurements made by the manufacturer prior to service use and dirt accumulation.

Summary

From the previous Volpe studies performed on the use of reflective material on the sides of railroad freight cars, it was concluded that reflectorized freight cars are more detectable than non-reflectorized freight cars. Both human factors testing and field operational testing also concluded that vertically oriented reflectors enhance freight car visibility to the motorist. Larger (4" x 36") vertically oriented reflectors were found to be both more detectable and withstand the harsh railroad environment better than smaller (4" x 8") reflectors. The analysis presented here further substantiates the use of larger vertically oriented reflectors for use on freight cars, despite variability in headlamps and crossing geometry. Together these studies conclude that a uniform pattern of vertically oriented retroreflectors, significantly enhances the conspicuity of railroad freight cars.

Appendix

Transmissivities for various weather conditions according to IES Lighting Handbook:

Weather	Maximum Transmissivity (per statute mile)
Exceptionally clear	0.91+
Very clear	0.91
Clear	0.79
Light Haze	0.62
Haze	0.30
Thin fog	0.090
Light fog	0.0081
Moderate fog	0.000065
Thick fog	3.4×10^{-11}
Dense fog	1.3×10^{-42}
Very dense fog	1.6×10^{-70}
Exceptionally dense fog	2.6×10^{-140}

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GLOSSARY

Candela (cd): The base unit of luminous intensity. One candela is equal to 1 lumen per unit solid angle.

Category 1 Accident: A term used to describe a collision at a highway-rail intersection where a motor vehicle strikes a train at a point on the train which indicates the driver could have stopped safely if the train's presence was detected the moment it entered the crossing.

Coefficient of Retroreflection (also known as Specific Intensity per Unit Area [SIA])**:** The ratio of the luminous intensity of the surface to the normal illuminance and to the area of the retroreflective surface. This is expressed in units of candela per lux per square meter (candela per footcandle per square foot), and the SI and English units are numerically equal (ASTM, 1981).

Footcandle (fc): Unit of luminance equal to one lumen per square foot. One footcandle equals 10.764 lux.

Illuminance: The ratio of the optical power of incident light by the area of a surface exposed.

Intensity (formally known as Luminous Intensity)**:** The ratio of optical power of incident light per unit solid angle in the direction in question.

Lumen: Unit of optical power equal to 0.00146 watts.

Luminance: The luminous intensity per unit area of a given surface.

Lux: Unit of illuminance equal to 1 lumen per square meter. One lux equals 0.093 footcandle.

Microprismatic Corner Cube Material (also referred to as prismatic, retroreflective, and/or corner cube material)**:** Thin plastic-like material containing microprisms used to channel incident light to and near the source of the incident light.

Minimum Threshold: The lowest luminance value that allows a motorist to detect the presence of a retroreflector, (hence, a freight car) in a crossing.

Natural Environmental Effects: Changes in a retroreflector's intensity due to meteorological/ atmospheric events (e.g., rain, strong sun rays, snow, etc.).

Operational Effects: Changes in a retroreflector's intensity due to the operation of the freight car (e.g., dust, grease, loading damage, etc.).

Specific Intensity per Unit Area (SIA): See "Coefficient of Retroflectorization" above.

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