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USE OF HIGH INTENSITY REFLECTIVE MATERIALS IN HIGHWAY SIGNING
A LITERATURE REVIEW

by

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(A Cooperative Organization Sponsored Jointly by the Virginia
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ABSTRACT

This literature review summarizes the research findings relative to the performance of high intensity (encapsulated lens) reflective sheeting.

The study reveals that the brightness and durability of the encapsulated lens material are superior to those of the conventional enclosed lens sheeting utilized by the Highway Department. The high intensity sheeting requires less maintenance and performs well during adverse weather conditions. Minor problems are encountered in the fabrication process, however, solutions for these are expected in the near future.

Although the initial cost for encapsulated lens sheeting is higher than that of the enclosed lens material, a net savings through extended service life of signs can be anticipated through the use of the former.

It is concluded that the encapsulated lens sheeting shows sufficient promise of success to warrant greater utilization of the material, especially on construction and nighttime maintenance signs.

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INTRODUCTION

Reflectorized traffic signs have always played a significant role in the convenience and safety of drivers on the highways. Unfortunately, in the past many important factors were omitted in sign design which must be considered for current highway driving situations. Documented research reveals that the following factors support the need for sign recognition and legibility at great distances and are closely related to sign size and brightness.

1) High speeds require great recognition and legibility distances for decision making by the driver.

2) Increased traffic volumes have resulted in the common use of low beam headlights. This practice provides less illumination on the sign and results in a decreased amount of light being reflected to the driver. One study concluded that low beams were used 75% of the time when high beams were feasible. (1)

3) New safety standards require that signs be located further from the travel lanes. This placement increases the incidence angle and, in addition, contributes to less brightness due to the sign being out of the "hot spot" of the headlight beam.

4) Light transmission is reduced by tinted and angled windshields. The loss of visibility distance caused by tinted windshields amounts to between 9% and 15%. (2)

5) Heavy dirt collection on headlights and dirt accumulation on signs from the use of deicing compounds on the roadway have decreased the legibility. Dirt accumulation on signs alone can cause as much as a 50% loss of brightness.

6) Bright or large signs must compensate for the blinding effect of opposing headlights.

7) The problem of the aging driver, who requires eight times more light at age 60 than at 20, must be considered.

8) Most states are licensing drivers with a minimum visual acuity of 20/40 rather than the ideal 20/20 vision commonly used in the design of signing.

9) Improper headlamp aiming and initial headlamp brightness result in an improper headlamp beam pattern. It is estimated that one-third to one-half of all headlamps are misaimed.

10) Exposure of retroreflective signing materials to the environment results in a gradual degradation of performance characteristics, the most important of which is a loss in effective brightness.

The above factors indicate the need for improved signing which can be accomplished by the fabrication of larger signs than are now used and/or the incorporation of materials which are brighter. Since expense and appearance of larger signs along the highway discourage the first alternative, industry approached the problem by developing a brighter reflective product. The material consists of encapsulated lens sheeting and is commercially known as high intensity reflective sheeting.

The introduction of high intensity sheeting for sign facing generated much interest by traffic engineers, however, the additional initial cost and lack of factual performance data have limited the use of the product.

In this study the evaluations relative to the brightness, durability, fabrication, maintenance, safety, and cost of the high intensity reflective sheeting are reviewed. Frequently, the high intensity (encapsulated lens) sheeting is compared to the conventional sheeting (enclosed lens) presently utilized for sign facing in the state of Virginia.

BRIGHTNESS

Before evaluating the brightness of materials it is important to determine the optimum brightness requirements of traffic signs. Although additional research is needed in this area, the best available information was provided by Dr. Terrence Allen of the Virginia Council of Highway Investigation and Research in 1958. [3] Figure 1 shows the relationship between legibility of traffic signs and the brightness levels. As the brightness increases from 0.1 to 1 foot-lambert the legibility increases quite rapidly. From 1 to 10 foot-lamberts there is an additional increase but not in the same proportion. Then, between 10 and 100 foot-lamberts, the brightness does not seem to improve and, therefore, it is concluded that the optimum legibility occurs at the top of the curve at around 10 — 20 foot-lamberts.

Eighty-five percent of the maximum legibility occurs between 1.5 and 100 foot-lamberts and this range has been considered as sufficient legibility for highway signing. It has been suggested that the luminance of sign backgrounds and legends be within the sufficient and optimum legibility ranges, respectively. The reduction in legibility distance at 100 foot-lamberts has been attributed to halation or "overglow", and signs of this brightness could possibly be ineffective in rural areas. However, in another study by Allen et al. at Michigan State University, up to 100 foot-lamberts were found to be desirable in bright urban situations and where glare from oncoming traffic was a problem. [5]

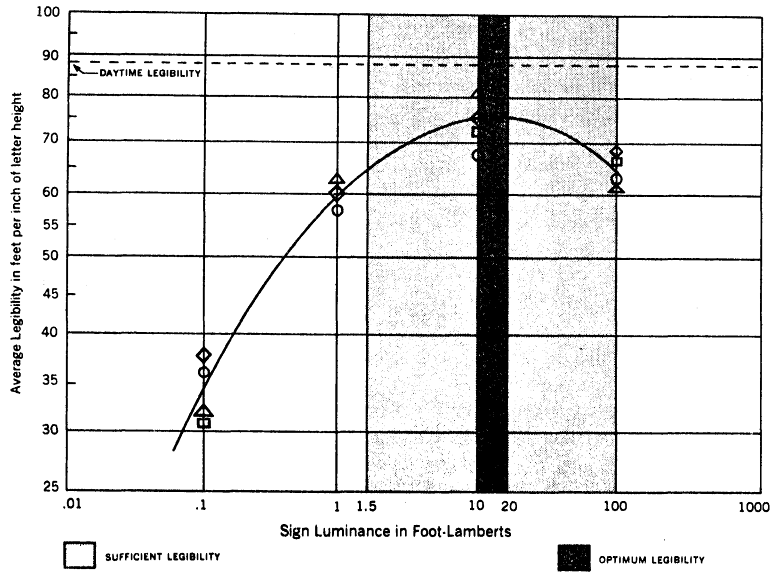

Figure 1. Optimum and satisfactory legibility distances 8 — and 18 — in. BPR Series E (Mod.) shown relative to letter luminance. (From reference 4.)

Youngblood and Woltman conducted a study in which measurements of sign brightness were recorded in five states. (6) A total of 12,552 readings were taken of 127 signs for reflected luminance in foot-lamberts for various distance, lighting, and sign configurations. The results of this evaluation are shown in Figures 2-9 and Tables 1 and 2. The data show the superiority of the encapsulated lens material. The encapsulated lens sheeting does conform to the minimum 10 foot-lamberts required for legends on signs on high beam headlights for sign distances of 300-900 feet. The enclosed lens does not meet the recommended 10 foot-lamberts for any beam or distance configuration. The encapsulated lens sign sheeting meets the recommended values for sign background (1.5 foot-lambert) on high beam for overhead signs at all distances between 350 and 1500 feet, and on shoulder mounted signs for the same distances. The enclosed lens material meets this recommendation only on shoulder mounted signs under high beams.

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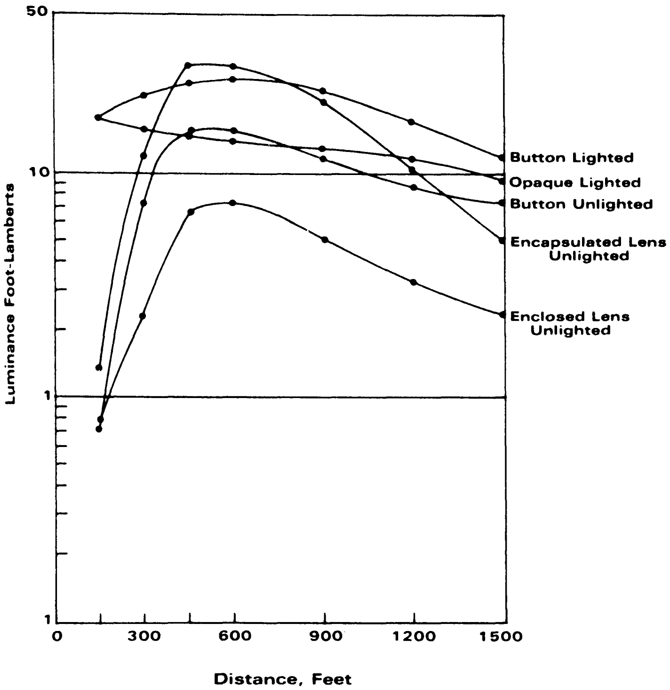

Figure 2. Nighttime luminance of sign legends versus distance for overhead signs, high beams. (From reference 6.)

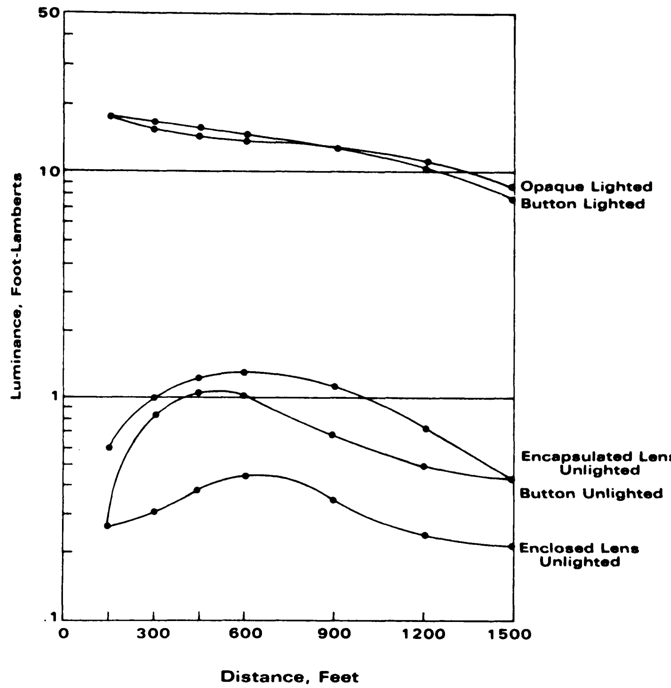

Figure 3. Nighttime luminance of sign legends versus distance for overhead signs, low beams. (From reference 6.)

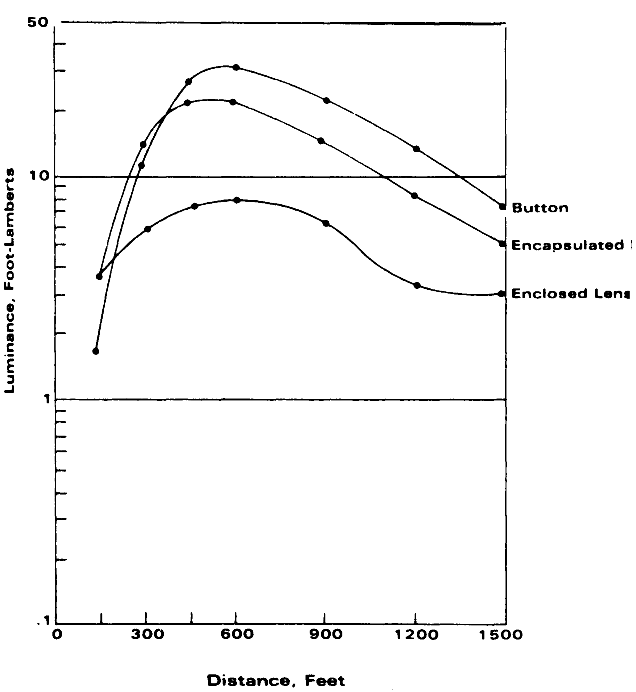

Figure 4. Nighttime luminance of sign legends versus distance for shoulder-mounted signs, high beams. (From reference 6.)

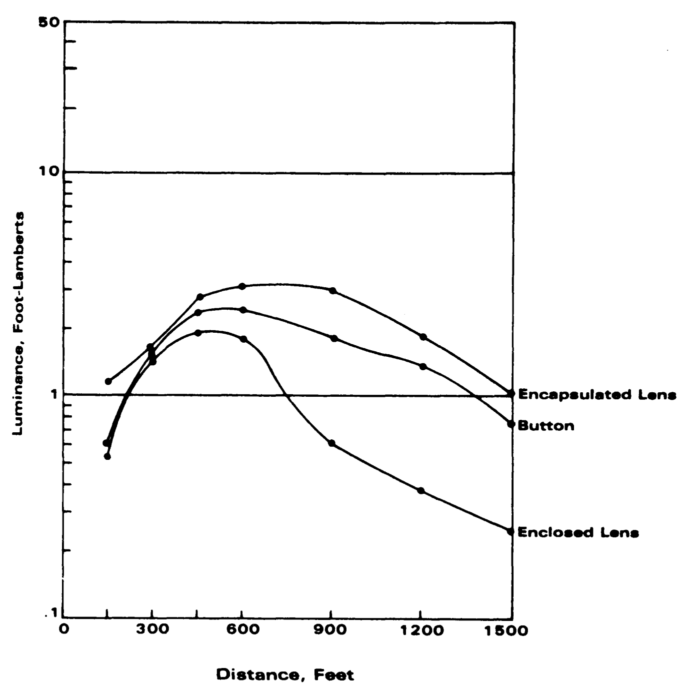

Figure 5. Nighttime luminance of sign legends versus distance for shoulder — mounted signs, low beams. (From reference 6.)

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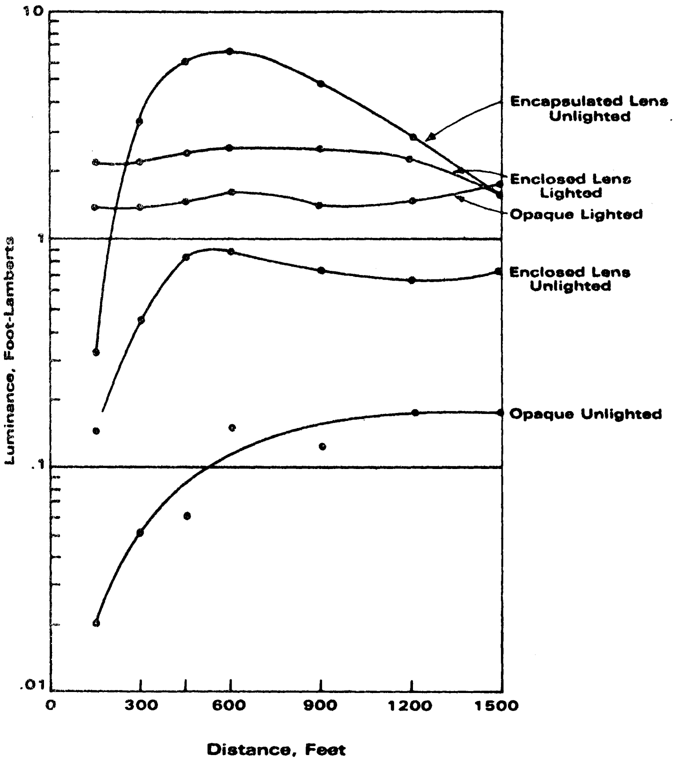

Figure 6. Nighttime luminance of sign backgrounds versus distance for overhead signs, high beams. (From reference 6.)

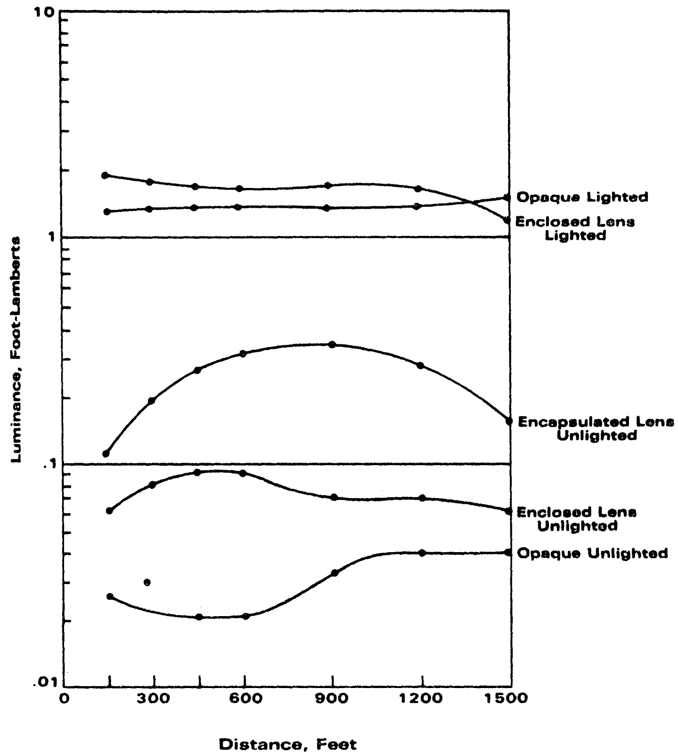

Figure 7. Nighttime luminance of sign backgrounds versus distance for overhead signs, low beams. (From reference 6.)

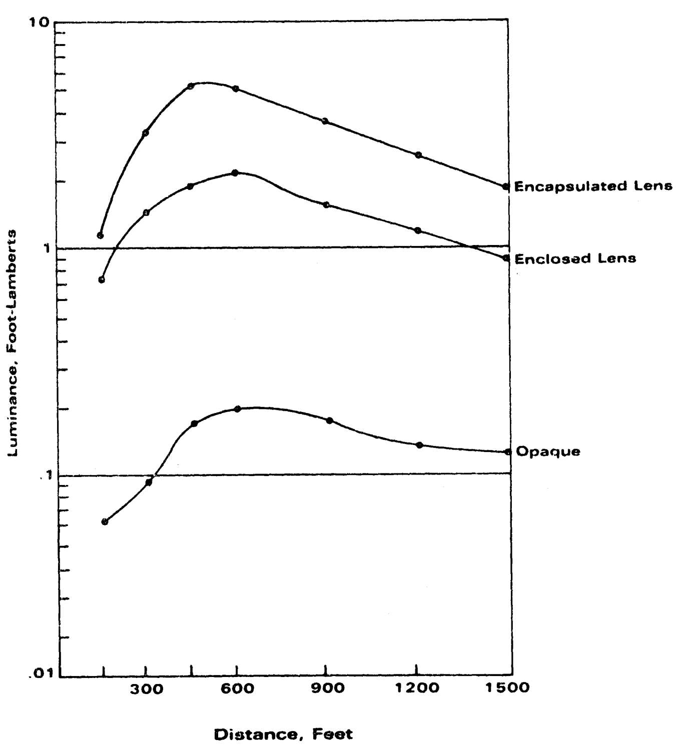

Figure 8. Nighttime luminance of sign backgrounds versus distance for shoulder — mounted signs, high beams. (From reference 6.)

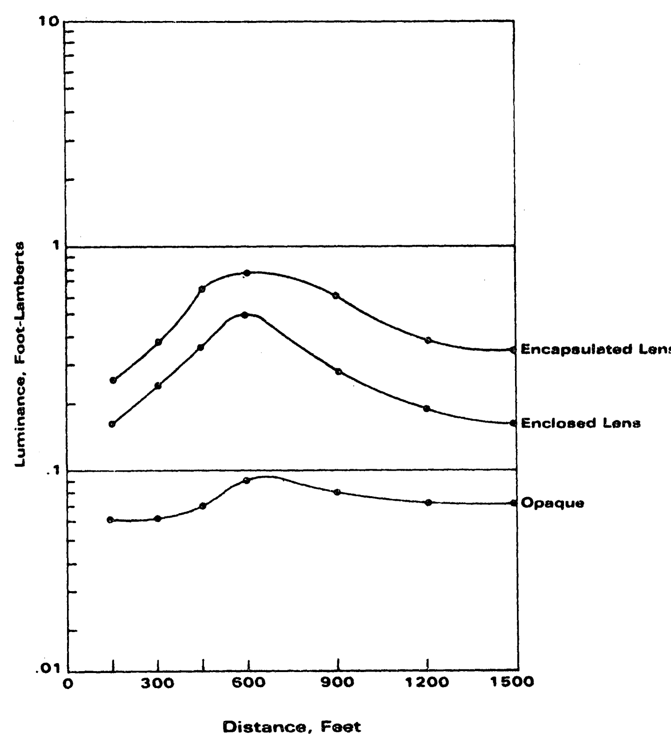

Figure 9. Nighttime luminance of sign backgrounds versus distance for shoulder — mounted signs, low beams. (From reference 6.)

TABLE 1

NIGHTTIME AVERAGE LUMINANCE IN FOOT-LAMBERTS OF SIGN LEGEND MATERIALS (From reference 6.)

Legend Materials	Distance (ft)						
	1,500	1,200	900	600	450	300	150
Shoulder-Mounted Unlighted Signs							
Encapsulated lens							
High beam	5.17	8.64	15.24	21.31	22.47	14.52	3.66
Low beam	1.07	1.88	3.05	3.02	2.85	1.65	1.16
Button							
High beam	7.55	13.30	21.61	30.42	28.37	11.52	1.66
Low beam	0.87	1.40	1.86	2.46	2.41	1.57	0.53
Enclosed lens							
High beam	3.17	3.30	6.48	8.00	7.37	5.88	3.55
Low beam	0.25	0.39	0.62	1.85	1.92	1.46	0.61
Overhead Lighted Signs							
Button							
High beam	11.49	17.56	22.68	25.11	24.98	20.63	17.20
Low beam	7.97	10.79	12.95	14.19	15.65	16.71	17.40
Opaque							
High beam	9.20	11.25	12.79	14.47	14.72	15.35	17.57
Low beam	8.97	11.17	12.60	14.37	14.62	15.29	17.57
Overhead Unlighted Signs							
Encapsulated lens							
High beam	4.28	10.02	20.86	28.70	29.16	11.82	1.30
Low beam	0.42	0.73	1.15	1.36	1.19	0.73	0.58
Button							
High beam	7.02	8.40	11.27	15.13	15.19	7.26	0.73
Low beam	0.43	0.50	0.70	1.02	1.06	0.80	0.26
Enclosed lens							
High beam	2.32	3.26	5.17	7.37	6.92	2.33	0.80
Low beam	0.22	0.24	0.35	0.44	0.38	0.30	0.27

TABLE 2

NIGHTTIME AVERAGE LUMINANCE IN FOOT-LAMBERTS OF SIGN BACKGROUNDS (From reference 6.)

Background Material	Distance (ft)						
	1,500	1,200	900	600	450	300	150
Shoulder-Mounted Unlighted Signs							
Encapsulated lens							
High beam	1.79	2.49	3.60	4.94	5.10	3.06	1.16
Low beam	0.34	0.38	0.58	0.67	0.62	0.37	0.25
Enclosed lens							
High beam	0.94	1.17	1.52	2.15	1.84	1.46	0.74
Low beam	0.16	0.19	0.27	0.33	0.32	0.26	0.18
Opaque							
High beam	0.12	0.13	0.17	0.19	0.17	0.09	0.06
Low beam	0.08	0.07	0.08	0.08	0.07	0.06	0.06
Overhead Lighted Signs							
Enclosed lens							
High beam	1.61	2.20	2.42	2.47	2.43	2.15	2.19
Low beam	1.22	1.65	1.68	1.70	1.74	1.78	1.90
Opaque							
High beam	1.73	1.47	1.40	1.60	1.43	1.38	1.38
Low beam	1.48	1.37	1.35	1.38	1.38	1.36	1.33
Overhead Unlighted Signs							
Encapsulated lens							
High beam	1.51	2.76	4.64	6.60	5.83	3.26	0.31
Low beam	0.15	0.27	0.33	0.30	0.26	0.19	0.11
Enclosed lens							
High beam	0.71	0.66	0.74	0.94	0.85	0.44	0.14
Low beam	0.06	0.07	0.07	0.09	0.09	0.08	0.06
Opaque							
High beam	0.17	0.17	0.12	0.15	0.06	0.05	0.02
Low beam	0.04	0.04	0.04	0.02	0.02	0.03	0.02

The state of Louisiana began testing high intensity sheeting in the early 60's and the material was placed under contract for routine procurement in 1968. Although the evaluations in Louisiana have not been of the magnitude of that conducted by Youngblood and Woltman, the results have been similar. [7] Figures 10 - 13 are copies of the graphs from the Youngblood and Woltman report with the mean values from the Louisiana study superimposed thereon. The values obtained in Louisiana fall within reasonable limits of the original plot, which indicates the validity of all data. It has been a policy of the Louisiana Department of Highways to use high intensity sheeting for the initial installation and maintenance of all overhead and large ground-mounted signs on both the interstate and primary highway systems.

With regard to the halation effect, the encapsulated lens sheeting does not reach the threshold of halation glow effect even when external light from traffic streams is present. The reflective readings secured in the above mentioned reports are well below the 100 foot-lambert reflective value considered the minimum point for halation.

The above tests were conducted on signs in the field that actually were in service to the motoring public. In addition, the sign material industry has conducted many laboratory experiments and at least one manufacturer states that the encapsulated lens sheeting is three times as bright as the enclosed lens. New silver-white encapsulated lens sheeting has a brightness value of 250 average candlepower per foot candle per square foot as compared to 70 candlepower for the enclosed lens. Equally impressive are the guarantees for the products. Encapsulated lens sheeting is guaranteed to have 200 candlepower (a loss of 20% in brightness) after ten years of normal exposure. Enclosed lens sheeting has a guaranteed 35 candlepower, a decrease of 50%, after seven years of service.

DURABILITY

As previously stated, the manufacturer guarantees the encapsulated and enclosed lens sheeting to have a useful life of 10 and 7 years, respectively. However, the field experience in Louisiana indicates that the green encapsulated lens sheeting has an expected life of 12 years and can be expected to last approximately twice as long as enclosed lens sheeting.

The results of accelerated weathering tests conducted by the Kentucky Department of Highways are shown in Figure 14, and they substantiate the Louisiana experience. [8] The green enclosed lens sheeting was considered to have failed at an average of approximately 2,100 hours in the weatherometer. Using one hour in the weatherometer as being equivalent to 18 hours of normal weathering, a life of 4.3 years for the enclosed lens sheeting would result. The encapsulated lens sheeting failed after approximately 7,000 hours in the weatherometer, or an equivalent of 14 years. The material, of course, may be considered as performing satisfactorily beyond the cited weatherometer hours as the graph shows that the specific reflectivity of the encapsulated lens sheeting at the designated time of failure was greater than that of the new enclosed lens sheeting.

Figure 15 shows the results of accelerated weathering of the silver-white sheeting and as can be seen the durability was similar to that of the previously mentioned green sheeting.

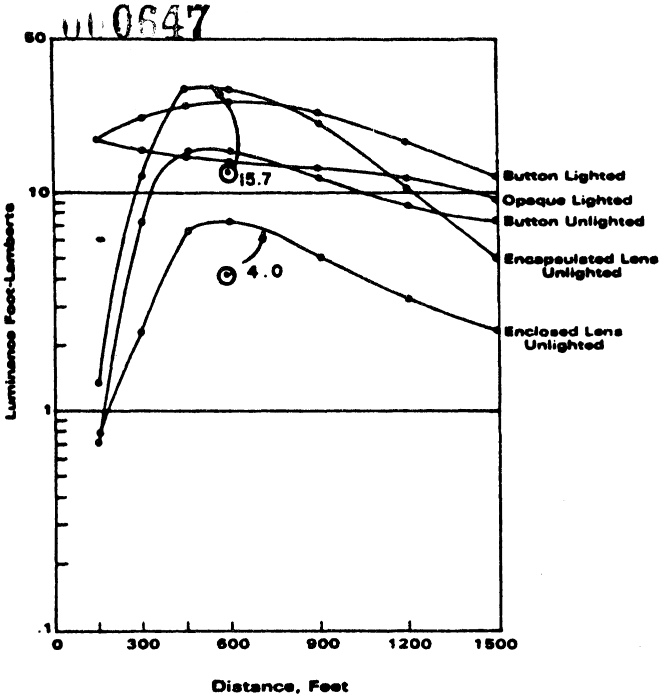

Figure 10. Nighttime luminance of sign legends versus distance, overhead signs — high beams. ⊙ = mean reflective values. (From reference 7.)

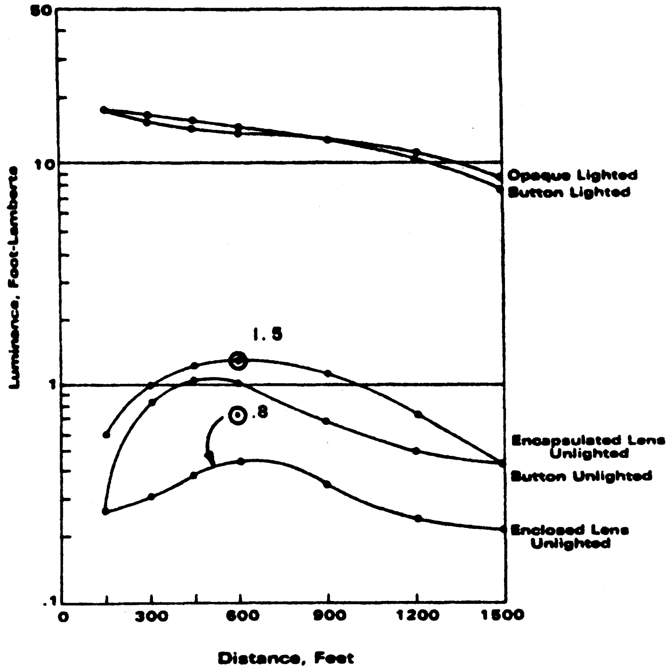

Figure 11. Nighttime luminance of sign legends versus distance, overhead signs — low beams. ⊙ = mean reflective values. (From reference 7.)

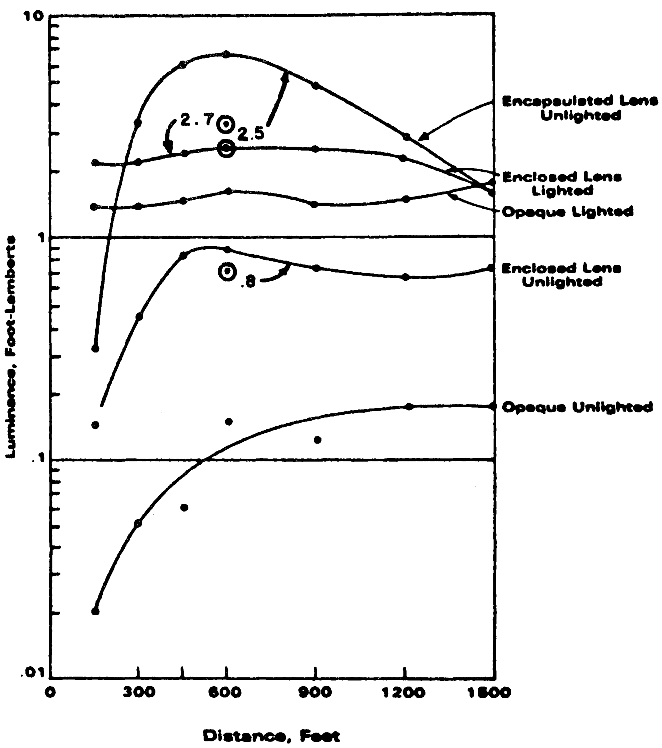

Figure 12. Nighttime luminance of sign backgrounds versus distance, overhead signs — high beams. ⊙ = mean reflective values. (From reference 7.)

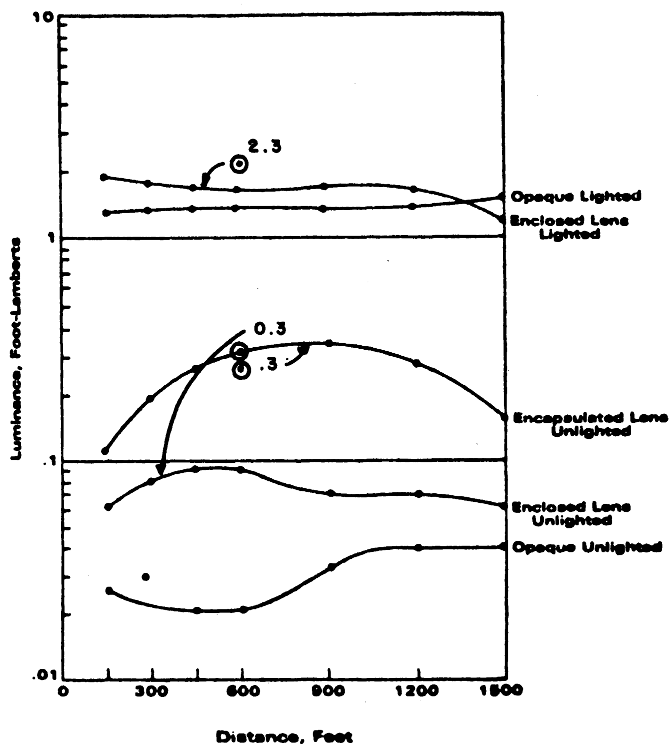

Figure 13. Nighttime luminance of sign backgrounds versus distance, overhead signs — low beams. ⊙ = mean reflective values. (From reference 7.)

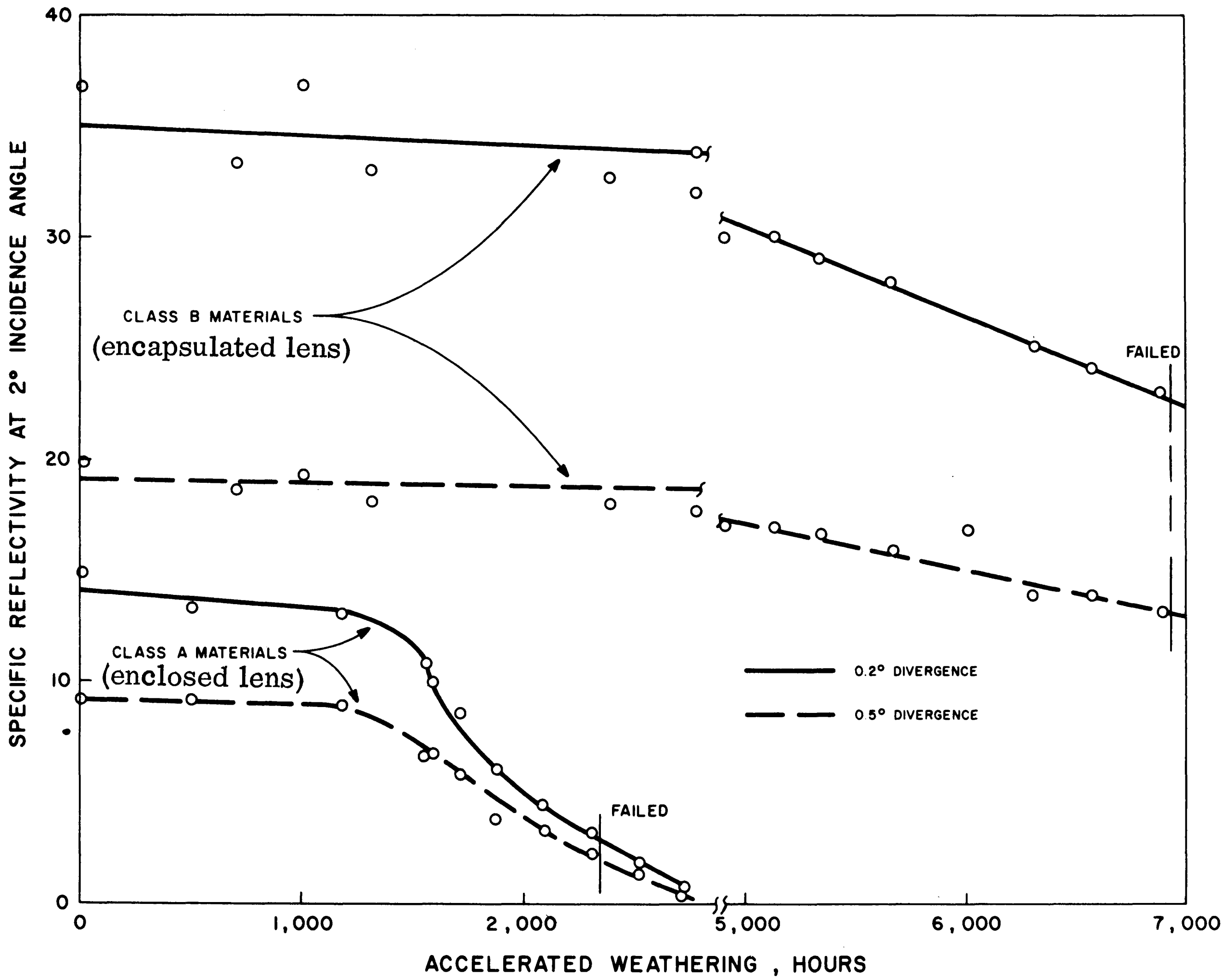

Figure 14. Accelerated weathering of green Scotchlite sheeting — classes A and B. (From reference 8.)

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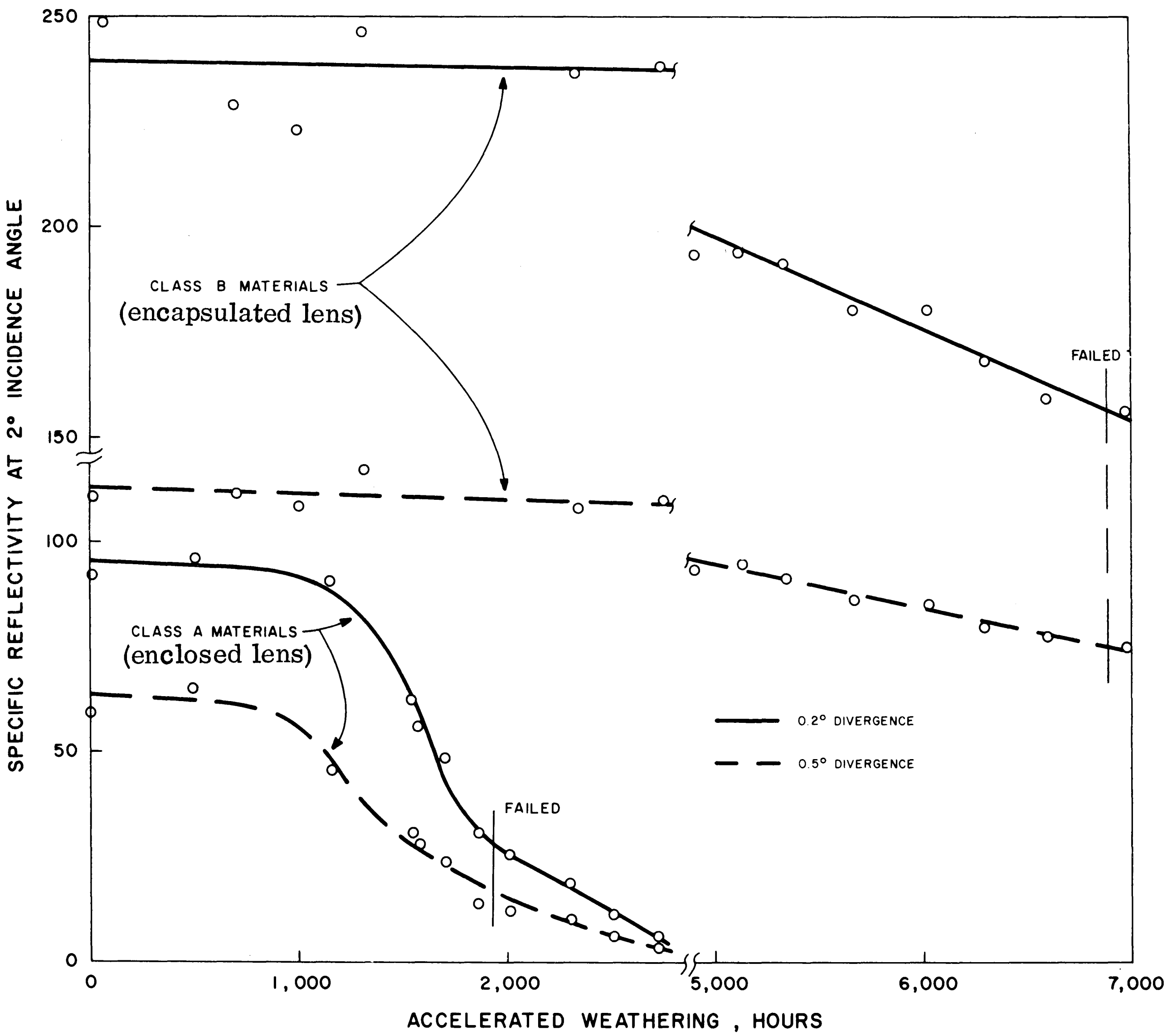

Figure 15. Accelerated weathering of silver — white Scotchlite sheeting — classes A and B. (From reference 8.)

Kentucky has also completed a comparative test of yellow sheeting (Figure 16), in which the encapsulated lens sheeting was superior, as its weatherometer life was approximately $2\frac{1}{2}$ times that of the enclosed lens sheeting.

Figures 17 and 18 show the results of current testing of the red and orange sheeting, respectively. The red enclosed lens sheeting failed after 1,200 hours of accelerated weathering; the encapsulated lens sheeting was still in good condition after 2,500 hours.

The Manual on Uniform Traffic Control Devices requires the use of orange reflective signs only on construction and maintenance projects; consequently, the durability of the sheeting is a secondary consideration inasmuch as the signs are expected to survive only for a limited time. [9] Figure 18 shows that the durability of both the enclosed and encapsulated lens sheeting exceeded 2,000 weatherometer hours, an equilivalent of 4 years, which is more than sufficient for the average construction and maintenance project. The major consideration for this type signing is the attention-demanding qualities, which will be covered in another section of this report. Under no circumstances should durability be the primary basis for a decision to utilize either sheeting on construction and maintenance signing.

FABRICATION

Reflective sheetings can be applied to sign blanks through either a heat-activated or a pressure process. Except for the consolidated shop in Petersburg, the Department's sign fabrication process is geared toward the use of heat-activated enclosed lens sheeting. This fact presents a problem in the application of the encapsulated lens sheeting, which cannot withstand the intense heat needed to apply the enclosed lens sheeting. Consequently, the existing equipment must be modified. Several Districts have already modified the equipment and the change appears to be inexpensive and requires only a minimum of equipment downtime. Of course, the modern equipment installed in the consolidated shop can apply the pressure-sensitive sheeting and no difficulties have been encountered.

At the present time, the major disruption in the fabrication process is the fact that the encapsulated lens sheeting is available in only 24- and 36-inch widths, depending upon the color. For large signs, splicing of the sheeting is required, which necessitates additional passes through the rollers. The manufacturer has indicated that the wider material will be available in the near future.

Engineers responsible for the fabrication of signs estimate that the application of the encapsulated lens sheeting onto sign blanks costs approximately 10 cents per square foot more than the enclosed lens sheeting.

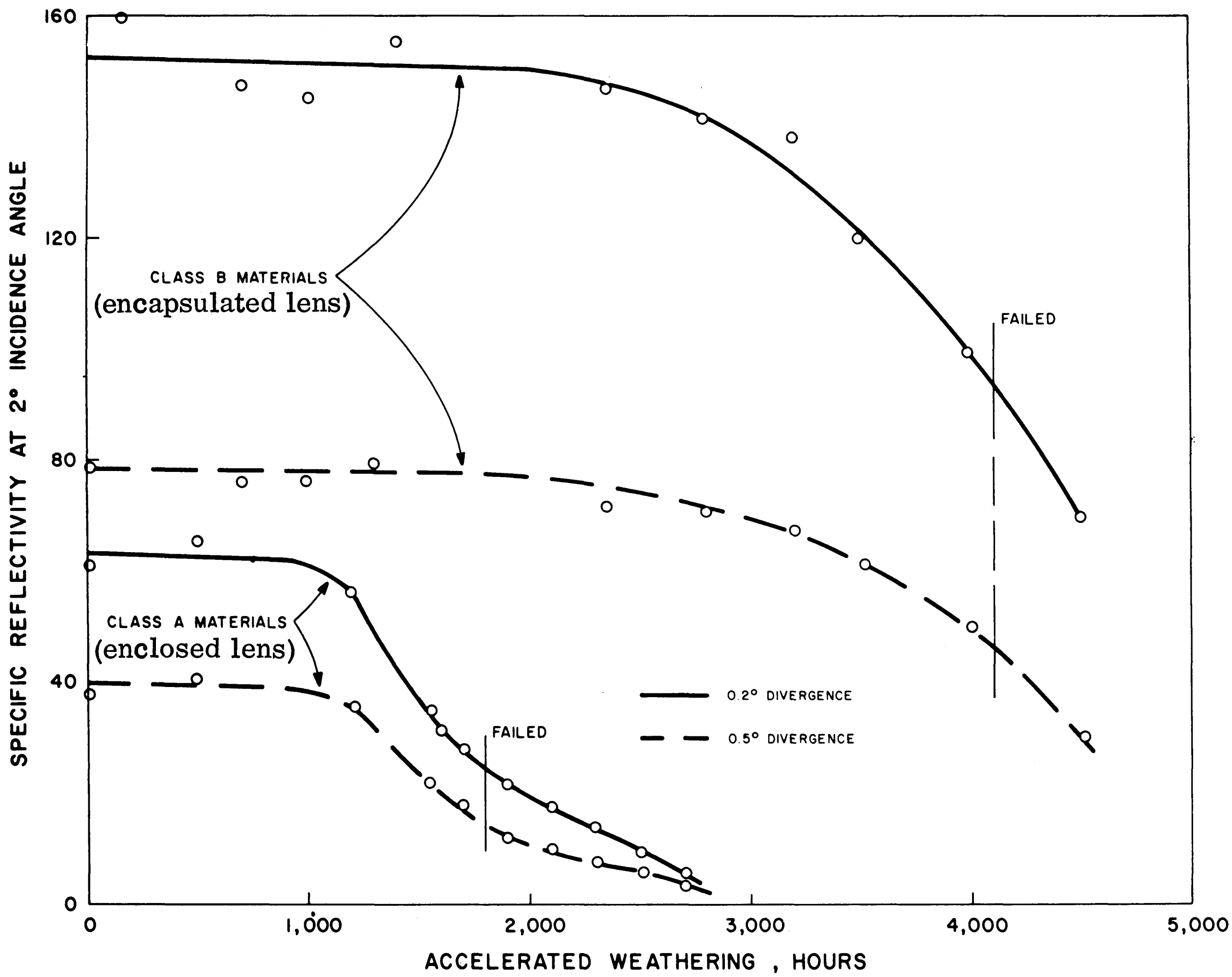

Figure 16. Accelerated weathering of yellow Scotchlite sheeting — classes A and B. (From reference 8.)

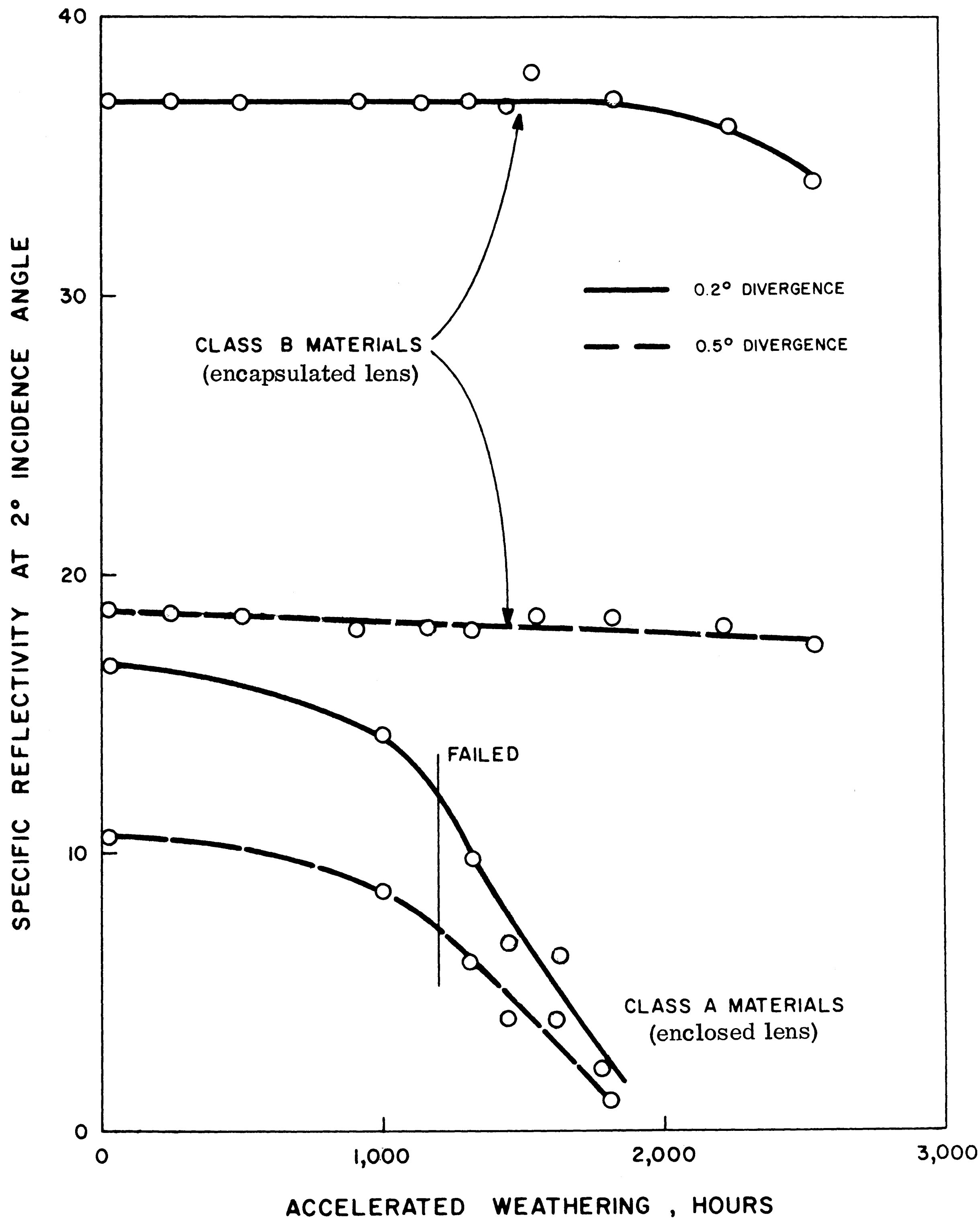

Figure 17. Accelerated weathering of red Scotchlite sheeting — classes A and B. (From reference 8.)

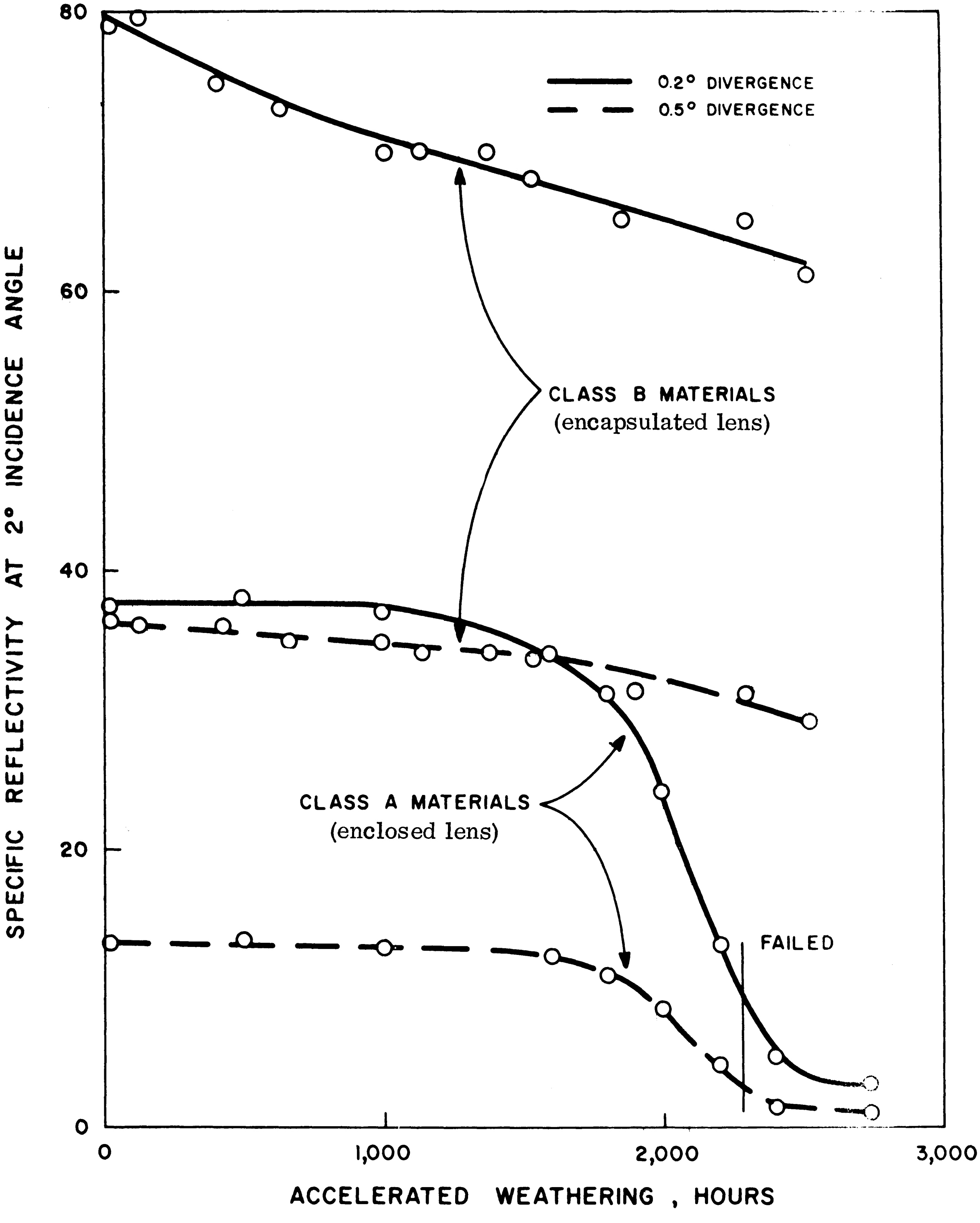

Figure 18. Accelerated weathering of orange Scotchlite sheeting — classes A and B. (From reference 8.)

MAINTENANCE

Reflective sheeting tends to become dull and to abrade, as do most coatings, when subjected to normal outdoor exposure. The Department's maintenance policy requires that all signs fabricated with enclosed lens sheeting be washed and cleaned annually and clear-coated once every 4 years in accordance with the manufacturer's recommendations. The cleaning will usually restore the sheeting to normal color and reflectivity; however, after prolonged weathering an application of "clear" is required to increase durability and restore reflection.

The clear coating is applied to signs in the field by spraying or hand rolling. Occasionally a brush is required to properly apply the clear coating around raised messages and borders. An incorrect application of "clear" can permanently damage a sign; therefore, even an experienced workman must exercise extreme caution in ideal weather to ensure that a uniform coat of "clear" is applied. During the life of the enclosed lens sheeting all signs should be cleared at least once and many will require two or more applications, depending upon the sign's position in relation to the sun. It is estimated that each coat of "clear" costs 8 cents per square foot of sign.

The encapsulated lens sheeting requires washing and cleaning as described above, but at the present time it is not felt that the field clear coating will enhance or extend the performance life. Consequently, the manufacturer does not recommend clear coating of encapsulated lens sheeting.

SAFETY

The Virginia Department of Highways has a strong feeling of responsibility to provide for the safe, rapid, comfortable, convenient, and economic movement of people and goods on the highway system. Signing is an important element as it relates regulation, warning, guidance, and directional information to the motoring public. It is imperative that sign materials be used which will provide the best performance in all conditions.

Due to the geographic and weather conditions of the Commonwealth, a sign material that does not lose nighttime reflectivity due to dew, frost, rain, and fog is a prime consideration. The Louisiana highway officials have observed that the performance of the encapsulated lens sheeting is not as adversely affected by dew, rain, or fog as compared to the enclosed lens sheeting. A moisture sheen on the enclosed lens material drastically reduces its reflectivity. R. L. Rizenbergs, research engineer chief of the Kentucky Department of Highways, concluded that "the reflectivity of this material (encapsulated lens) is relatively unaffected by dew, fog and rain. Only impacted snow and sleet cause blackout."

Another study concluded that the dew-affected reflectivity time is approximately 65% less for the encapsulated lens sheeting than for other sign materials.[10]

A secondary safety factor which should be considered is electrical malfunctions that result in the loss of the external illumination on overhead signs fabricated with enclosed lens sheeting.

Figures 2 and 3 reveal that the loss of illumination on overhead signs would be critical and an enclosed lens sheeting would not perform satisfactorily under either high or low beam headlignts.

Construction and maintenance work sites are always given special considerations because of the safety hazards involved in requiring tne motorists to make unusual maneuvers around the work zone and the exposure of workmen to traffic. Unfortunately, the problem is compounded due to several factors that commonly are present on construction projects. These factors which adversely affect the brightness and effectiveness of signs are:

1. Significant increase in dirt accumulation on signs and markings.

2. Possible random positioning of signs by untrained personnel.

3. Misalignment of signs and barricades by high winds, construction equipment, and passing traffic.

4. Abrupt changes in normal road patterns.

5. Unexpected and distracting hazards.

With the issuance of the revised Manual on Uniform Traffic Control Devices in 1971, construction and maintenance warning signs were changed from yellow to orange. The intent was to differentiate between these signs and other warning signs and, tnerefore, to improve the attention values of the signs used in construction and maintenance areas. Research during daytime has revealed that the orange signs produce a slight improvement over the yellow signs in reducing traffic conflicts and merges near the barricades. Although no formal studies have been conducted on the effectiveness of orange signs at night, inspections under headlight illumination have shown reduced attention values of orange signs in contrast to yellow signs.

In the proposed draft of the Virginia 1974 Road and Bridge Specifications, the yellow and orange enclosed lens sheetings must meet the specific reflective requirements given in Table 3.

TABLE 3

MINIMUM BRIGHTNESS VALUES FOR ENCLOSED LENS SHEETING
(AVERAGE CANDLEPOWER PER FOOTCANDLE PER SQUARE FOOT)

COLOR / Incidence Angle	0.2° Divergence		0.5° Divergence	
	-4°	40°	-4°	40°
Yellow	50.0°	11.5°	25.0°	7.0°
Orange	25.0	1.0	13.5	0.8

As is shown in the table, the change from yellow to orange has resulted in reduced brightness of maintenance and construction signs and adversely affected the advantages gained in the change of color. The reduction in brightness is substantiated by the results in Kentucky's accelerated testing, which indicate that the yellow enclosed lens sheeting was brighter than the orange enclosed lens sheeting. (Figures 16 and 18.)

Orange encapsulated lens sheeting is available and the proposed <u>1974 Road and Bridge Specifications</u> require the specific reflective values given in Table 4.

TABLE 4

MINIMUM BRIGHTNESS VALUES FOR ORANGE ENCAPSULATED LENS (AVERAGE CANDLEPOWER PER FOOTCANDLE PER SQUARE FOOT)

Incedence Angle	0.2° Divergence		0.5° Divergence	
	$-4.^{\circ}$	40°	-4°	40°
	60.0°	25.0°	20.0°	13.0°

The reflectivity of this material can be considered comparable to the reflectivity of the yellow signs used previously and would, therefore, greatly enhance the effectiveness of orange signs on construction and maintenance projects.

As previously noted, many signs and barricades are improperly placed on construction projects, therefore, the angularity of traffic signs is of vital concern to every traffic official. The proposed specifications have adequately covered this matter. The orange encapsulated lens sheeting at a 40° incidence angle is up to 25 times brighter than the enclosed lens at the same angle.

COST

Intuitively, one of the major disadvantages of the encapsulated lens sheeting is the higher initial cost ($0.90 per square foot for enclosed lens compared to $1.65 for the encapsulated lens sheeting). However, the real cost of the signs depends upon the price of the materials, expected service life, and maintenance and replacement costs. Therefore, the cost per unit service life is the proper index in comparing materials. Kentucky and Louisiana report that in total return for the life of a sign the use of the enclosed lens sheeting costs approximately $0.75 per square foot more than the encapsulated lens material.

An analysis using the cost figures of typical ground-mounted signs (wood posts) from five highway districts in Virginia reveals that the annual cost of a sign fabricated with encapsulated lens sheeting is less than that of an enclosed lens sign. The data in Appendix A show that an annual savings of $0.15 per square foot of sign ($0.94 for a 30 — inch STOP sign) could be anticipated through the use of the encapsulated lens sheeting.

Additionally, significant savings in labor, maintenance, and equipment costs would be realized from less frequent replacement of sign faces. Vandalism or damage from accidents, of course, would diminish the cited savings.

It has been determined that the encapsulated lens sheeting is much brighter and this factor should not be overlooked in the economic consideration. Appendix B contains a comparison of the cost per footcandle per year based upon the Department's cost estimates. When considering the brightness of the materials the Department could anticipate a 70% less cost per footcandle per year through the use of encapsulated lens sheeting.

CONCLUSIONS

Current driving conditions demand that the recognition and legibility of signs be improved. The results of this study indicate that increased brightness is an alternative to enhance the effectiveness of highway signing. Furthermore, it appears that the use of encapsulated lens sheeting is a feasible approach in obtaining brighter signs. It is concluded that the high intensity sheeting shows sufficient promise of success to warrant greater utilization on highway signs, especially those used on construction and nighttime maintenance projects.

The following conclusions are based on the findings from this review.

1. The encapsulated lens reflective sheeting has better reflection characteristics than the enclosed lens material for all sign and headlight configurations.

2. The brightness retention of the encapsulated lens sheeting is superior to that of the enclosed lens. After seven years, enclosed lens sheeting generally provides a minimum of 35 candlepower (50% of the initial brightness) while encapsulated lens sheeting has over 200 candlepower, only a 20% reduction in the brightness of the new material.

3. Field and accelerated weathering tests conclude that the durability of encapsulated lens sheeting is approximately twice that of the enclosed lens sheeting.

4. In the fabrication process, minor problems exist with the encapsulated lens; however, solutions will be realized in the near future. The heat-activated applicators are easily and inexpensively modified and soon the encapsulated lens material will be available in wider widths than can now be obtained.

5. Encapsulated lens sheeting does not require field clear coating of installed signs in order to achieve maximum sign life, which reduces maintenance costs.

6. The performance of encapsulated lens sheeting is affected less by adverse weather conditions than is that of enclosed lens sheeting.

7. Changing the color of construction and maintenance signs from yellow to orange has resulted in a loss of sign brightness and legibility when enclosed lens sheeting is utilized. The orange encapsulated lens sheeting has better reflective characteristics than the previously used yellow enclosed lens sheeting and is capable of compensating for the loss in brightness created by the color change.

8. Although the initial material cost for encapsulated lens sheeting is higher than that of the enclosed lens sheeting, a projected annual savings of $0.15 per square foot is anticipated through the use of encapsulated lens sheeting. Additional savings in labor, maintenance, and equipment costs would be realized from less frequent replacement of sign faces.

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L. C. Taylor II	Salem District
J. L. Thomas	Staunton District

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APPENDIX A

Typical In-Place Cost of Ground-Mounted Signs on Wood Posts

Prices include enclosed lens sheeting, backing, fabrication, posts, mounting hardware, field labor, and equipment.

Culpeper District	$5.00/sq. ft.
Salem District	5.60/sq. ft.
Lynchburg District	5.80/sq. ft.
Suffolk District	6.00/sq. ft.
Staunton District	5.17/sq. ft.
Average	$5.51/sq. ft.

Cost Per Year of Useful Life

Enclosed Lens Sheeting

$$C = \frac{IC}{PF}$$

$$C = \frac{\$5.51}{7} = \$0.79 \text{ per sq. ft. per year of useful life}$$

where C = Cost per sq. ft. per year of useful life
IC = Installed cost per sq. ft.
PF = Performance years (manufacturer's guarantee)

Encapsulated Lens Sheeting

$$C_{HI} = \frac{IC + AMC + AFC}{PF}$$

$$C_{HI} = \frac{\$5.51 + \$0.75 + \$0.10}{10} = \$0.64 \text{ per sq. ft. per year of useful life}$$

where C_{HI} = Cost per sq. ft. per year of useful life
IC = Installed cost per sq. ft. (enclosed lens)
AMC = Additional cost of encapsulated lens sheeting per sq. ft.
AFC = Additional fabrication cost for encapsulated lens sheeting per sq. ft.

APPENDIX B

Cost Per Footcandle Per Year of Useful Life

Enclosed Lens

$$C = \frac{PC}{\frac{B_n + B_o}{2} \times PF}$$

$$C = \frac{\$0.90}{\frac{70 + 35}{2} \times 7} = \$0.002449 \text{ per footcandle per year}$$

where
C = Cost per footcandle per year of enclosed lens sheeting
PC = Purchase cost of sheeting
B_n = Average minimum candlepower of new material
B_o = Average minimum candlepower of worn material at end of useful life

Encapsulated Lens

$$C_{HI} = \frac{PC}{\frac{B_n + B_o}{2} \times PF}$$

$$C_{HI} = \frac{\$1.65}{\frac{250 + 200}{2} \times 10} = \$0.000733$$

where C_{HI} = Cost per footcandle per year of encapsulated lens sheeting

Savings — Encapsulated Lens Sheeting

$$S = \frac{C - C_{HI}}{C} \times 100\%$$

$$S = \frac{\$0.002449 - 0.000733}{0.002449} \times 100 = 70\% \text{ less cost per footcandle per year}$$

where S = Cost savings per footcandle per year of useful life.