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Report No. UM-HSRI-HF-74-23

STUDY OF REFLECTORIZED MATERIALS FOR LICENSE PLATES (AS PER ACT 255, PA 1972, SECT. 43)

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June 28, 1974

Contract UM-ORA-73-897-KB1
State of Michigan
Michigan Department of State
Lansing, Michigan 48900

1. Report No. UM-HSRI-HF-74-23	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Study of Reflectorized Materials for License Plates		5. Report Date June 28, 1974 6. Performing Organization Code
7. Author(s) David V. Post, William T. Pollock, Rudolf G. Mortimer		8. Performing Organization Report No. UM-HSRI-HF-74-23
9. Performing Organization Name and Address Highway Safety Research Institute The University of Michigan Ann Arbor, Michigan 48105		10. Work Unit No. 320281 11. Contract or Grant No. UM-ORA-73-897-KB1
12. Sponsoring Agency Name and Address State of Michigan Michigan Department of State Lansing, Michigan 48900		13. Type of Report and Period Covered Final Report - Feb. 1, 1973 - June 30, 1974 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract Some prior studies concerned with visibility, legibility and effects upon crashes of various types of license plates were reviewed. License plate manufacturing processes were reviewed and outlined.

A sample of license plates was constructed. License plates with painted backgrounds had legends of paint or beads, while those with a reflective sheeting background had legends of opaque or transparent paint (ink). Photometric measurements of the reflectivity of these plates and a sample of automobile reflex reflectors were made before and after exposure to the SAE J575e Corrosion Test.

Reflective sheeting used as a background of license plates provided about eleven times the reflectivity of license plates with beaded legends and about the same reflectivity as automobile reflex reflectors over entrance angles of up to 20°. At greater entrance angles, plates with reflective sheeting provided greater reflectivity than the automobile reflex reflectors. Plates with beaded legends provided up to about fourteen times the reflectivity of those using only paint.

The effects on reflectivity of the corrosion testing were generally minor, except for license plates made with the beaded legend, which also showed a moderate degree of rust in the legend. No changes in color of the legend or background were noticeable.

17. Key Words License plates, reflectivity, reflective sheeting, reflective beads, color combinations, reflex reflectors, SAE Standard J594e, Federal Specification L-S-300A.	18. Distribution Statement

19. Security Classif.(of this report)	20. Security Classif.(of this page)	21. No. of Pages	22. Price
		41+	

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ACKNOWLEDGEMENTS

This project was facilitated in various phases by Mr. Francis G. Annis, Purchasing Division, Michigan Department of Administration, and Mr. George Stevens, Administrator, Office of Driver and Vehicle Administration, Michigan Department of State.

Production of license plates was carried out at the State Prison of Southern Michigan in Jackson, Michigan. Mr. George Holmes, Director of Prison Industries, Mr. Ed Kender, Assistant Director of Prison Industries, and Mr. Frank Dean, Tag Plant Supervisor, cooperated greatly by securing manufacturing facilities for license plate production.

Mr. Orville Nordgren, Supervisor of Vehicle Registration Technical Services of Minnesota Mining and Manufacturing Company, assisted by providing reflective materials and in the production of some of the license plates.

We are grateful to Chrysler Corporation for exposing the license plates and reflex reflectors to the SAE Standard J575e Corrosion Test.

Finally, recognition is due Dr. David K. Damkot and Mr. Marshall J. Grimm, both formerly with HSRI, for their efforts in obtaining the variety of plate samples used in the project.

INTRODUCTION

Since their first use by Maine in 1949, materials available for increasing the retroreflectivity of vehicle registration plates have been used by some 42 states, with indications that the remaining jurisdictions are considering use of plate reflectorization. Enthusiasm for reflectorized plates is based on the unanimous research findings of the perceptual superiority of such plates when compared with traditional enameled plates.

The conclusion is unchalleneged that plate legend legibility under nighttime viewing conditions is greatly enhanced by the addition of any retroreflective material to plate legend or background. Daytime readability of plates is not, of course, affected by reflectivity increases. Typical of the several U.S. and European studies on the relative legibility of enameled versus reflectorized plates is that by Rumar (1). His field tests, created to resemble typical nighttime registration identification situations, showed plate reading distance increased by reflectorization as follows:

Target Car	Legibility Improvement
Rear plates, plate lights on	30%
Rear plates, plate lights off	90%
Front plates, low beams on	150%

In each instance, the observers' car had its low beam headlights on. Those general trends in legibility improvement have been confirmed by several laboratory and field tests, for example, by Stoke and Simpson (2) in 1971. Without exception, those studies show plate reflectorization associated with legibility improvements important to efficient and safe vehicle identification by law enforcement personnel.

Even greater improvements for plate visibility by reflectorization have been shown in a variety of studies. Here the concern is with increase in the nighttime distance at which plate presence, and thus vehicle presence, can be detected. Such improvements in plate detection distance have been logically assumed to have great safety benefits. The Stoke and Simpson study cited above is typical of these visibility studies in which the detection distance of reflectorized versus non-reflectorized plates has been measured. Their results show, for example, that plates with white, reflectorized sheeting background and black legend could be detected with low beam headlamps at a distance four times greater than similar enameled plates. Improvements in the visibility of license plates attributable to reflectorization have been confirmed by numerous studies, for example by Anderson (3). His visibility studies had the added feature of measuring detection distances for plates with two common reflectorization schemes--beaded legend only as currently used in Michigan, and background, or field, reflective sheeting. Anderson's data showed the beaded-legend plates were visible about three times farther than the enameled plates, and the background reflectorized plate about twice as far as the beaded legends. A much more complete study of visibility, and legibility of plates, was reported by Wortman (4). Wortman's data generally show that plates with reflective sheeting can be detected at greater distances than plates with beaded legend.

The general conclusion, then, is that reflectorization of any kind improves plate visibility. But does that necessarily mean that vehicle visibilty, and thus collision-avoidance potential, is improved? Several studies addressed that question of the relationship between reflectorized plates and nightime traffic crashes. In one of those studies (5), some 60% of the residents of Polk County, Iowa, were issued reflectorized plates in 1959 while the remainder got enameled plates. The follow-up study showed that significantly fewer of the cars with reflectorized plates were involved as struck vehicles in nighttime, rear-end collisions. The conclusions of the study have been criticized because the reflectorized plates were issued on a first-come, first-served basis. Thus, differences in accident experience could not be completely attributed to plate reflectorization differences. Those accident differences might have been due to differences in nighttime driving exposure patterns of early purchasers versus late purchasers.

While suffering similar plate assignment problems, the more recent study reported by Campbell and Rouse (6) cautiously concludes that reflectorized plates did prove cost-beneficial in reducing nightime, rear-end crashes. Those findings were based on 1967 tags in North Carolina. In contrast, Stoke (7) reports the 1971 Virginia plate experience as showing no difference between reflectorized and non-reflectorized plate-bearing cars in accident involvement. The Virginia study is considerably more compelling, mainly due to the deliberate random assignment method used in issuing the special sample of reflectorized plates, and to the precise follow-up and accident data analysis procedures used.

Resolution of the opposed findings of the North Carolina and the Virginia studies might lie in intrinsic differences in the effectiveness of vehicle retroreflectors in the vehicle populations involved in the two studies. While U.S. automobiles have been fitted with rear reflex reflectors since 1933, their performance has been improved over the years as noted by the revisions made to SAE Standard J594-Reflex Reflectors. For example, in 1967 (SAE J594d) the class B photometric performance of reflex reflectors for passenger cars was dropped and the class A standard was recommended.

Given these considerations, the Michigan Legislature in 1972 directed study of the reflective efficiency of reflective materials available for license plate use versus reflectors manufactured into vehicles. That directive, as Section 43 of Act 255 of the Public Acts of 1972, was stated as follows:

> "Sec. 43. The secretary of state shall conduct tests of paints of different manufacturers to determine reflectorability and compare such paints' reflective values against the applicable federal standards for taillight and rearend automobile standards. The tests and resulting recommendations shall not be done in such a manner as to give preference to any particular manufacturer."

The report that follows documents the study completed to implement that directive. The specific objective of the study was to develop photometric evaluations of various combinations of paint, beads, and reflective sheeting materials that are available for use in the manufacture of vehicle license plates, with particular attention to the comparison of those materials in meeting the applicable portions of Federal Motor Vehicle Safety Standard No. 108, which refers to various SAE standards for automobile rearlighting.

The following sections detail the methods and results of the study.

METHOD

SELECTION OF MATERIALS FOR EVALUATION

The testing was limited to materials suitable for multi-year use which can be manufactured in Prison Industries. This precluded flammable reflectorized paint materials.

With these constraints in mind the manufacturers of reflective materials listed in Appendix A were contacted. Morgan Adhesive and Primo Safety Corporation were found to lack manufacturing facilities for license plate materials. Flex-o-lite corporation was found to lack facilities for reflective sheeting manufacture; however, their beads were available from Prison Industry stock. American Decal and Manufacturing Co., Cataphote Corp. and Fasson products were developing reflective sheeting materials, but were unable to supply materials in time for our testing program. Cataphote Corp's. Alert paint and Minnesota Mining and Manufacturing's Codit paint were deemed to be too flammable for use at Prison Industries' license plate plant. Potters Bros., Inc. was only in a position to supply beads which were already available from Flex-o-lite. 3M was able to supply reflective sheeting for multi-year use in four colors. In addition transparent and opaque inks were provided by 3M for use on the reflective sheeting and upon the painted plates that 3M color matched to their reflective sheeting at our request. Prison Industries license plate plant supplied opaque paints manufactured by Flint Ink Corp. from their stock. Specific product numbers for materials provided are listed in Appendix B.

Color combinations for background and legend are practically limitless. A review of the colors available in reflectorized sheeting materials was made and color combinations which could be prepared as reflectorized sheeting, beaded reflectorization, and no reflectorization were determined. Bearing in mind that it was impractical to reflectorize large areas with beading material due to variation in paint thickness and suspension of the beads, it was evident that beading should only be used on the legend. On the other hand, it was evident that reflective sheeting should only be used on the background as individual pieces of sheeting, used as a legend, would tend to lose adherence with the background at the numerous edges. It was obvious that to obtain the most efficient reflectorization, that portion to be reflectorized should be a light color and should have a high contrast with its surround. This means, of course, that one can have light beaded legends upon a dark background or one can use light reflective sheeting for background in combination with dark lettering.

Table 1 indicates the color and reflectorization combinations which were made from the materials available and which would provide the appropriate color and reflectorization comparisons. These 47 license plate combinations were handmade at Prison Industries. The quality of hand production was good and the finished sheeting covered plates had a hardness rating of 3B. While a hardness rating of 1B would be desirable for production plates, it was concluded that it was unlikely that any problems of relevance to the objectives of this study would be encountered because of the relative softness of the license plates.

THE LEGEND USED ON TEST PLATES

All reflectorized sheeting license plates had the legend PZB-046 (1972) while those with painted backgrounds had the legend ZBP-064 (1973). These letters and numerals were chosen as being representative of an average license plate in terms of legend area and shoulder exposure. The legend comprised 26% of the total license plate area.

TABLE 1. Types of License Plates Evaluated, Listed by Rank Number.*

Background	LEGEND															
	Transparent			Opaque						Beaded					
	Red	Blue	Green	Red	Blue	Green	Black	White	Yellow	Red	Blue	Green	Black	White	Yellow
Reflectorized Sheeting	LICENSE NUMBER PZB-046 (1972)														
3M Silver	1	3	2	6	4	5	7								
3 M Yellow	8		9	15	12	10	14								
3M Light Blue							17	16							
3M Light Green							13	11							
Paint With No Reflectorization	LICENSE NUMBER ZBP-064 (1973)														
3M Silver	34	36	37	34	36	37	35			28	27	31	30		
3M Yellow				38	41	39	40			32	26	29	33		
3M Light Blue														25	
3M Light Green														20	
Dark Blue								46	47					22	18
Dark Green								43	45					23	21
Dark Red								42	44					24	19

*Rank numbers are based on the mean reflectivities obtained by measuring a pair of plates with the same reflective treatment as shown in Table 2.

MANUFACTURING PROCEDURES OF LICENSE PLATES

The general process of manufacture of the license plates is shown in Figure 1. Currently, the license plate manufacturing process involves nine steps. These steps take metal roll stock with a pre-coated background and produce a finished beaded license plate. These steps were used in the manufacture of the beaded plates with a dark blue background in Table 1.

Additional steps would have to be added for Michigan Industries to produce license plates with a reflective sheeting background. However, steps which are used only for beading could be deleted so that the process would involve 12 steps. Basically the modifications necessary to produce plates with sheeting involve installing hot water metal cleaning tanks, installing a squeeze roll sheeting applicator, rounding and polishing die edges, installing a clear coating tank, providing a drip dry area, and making adjustments to the exhaust fan and oven to assure adequate ventilation and heating. To produce the reflective sheeting plates in Table 1, 3M carried out the sheeting application at their facilities. The remaining steps were completed at Prison Industries.

Galvanized metal roll stock was used to produce the remaining painted or beaded license plates in Table 1. Additional steps were used to paint the background and produce beaded legends.

THE AUTOMOBILE RETROREFLECTORS

In addition to the 47 license plate types manufactured, a number of automobile retroreflectors were obtained. A complete listing of the automobile retroreflectors which were evaluated is presented in Appendix C. These retroreflectors are shown in Figure 2. Most of these were integral to rear lens assemblies and included construction of the interspersed, strip, and solid types. The interspersed lens type has reflective

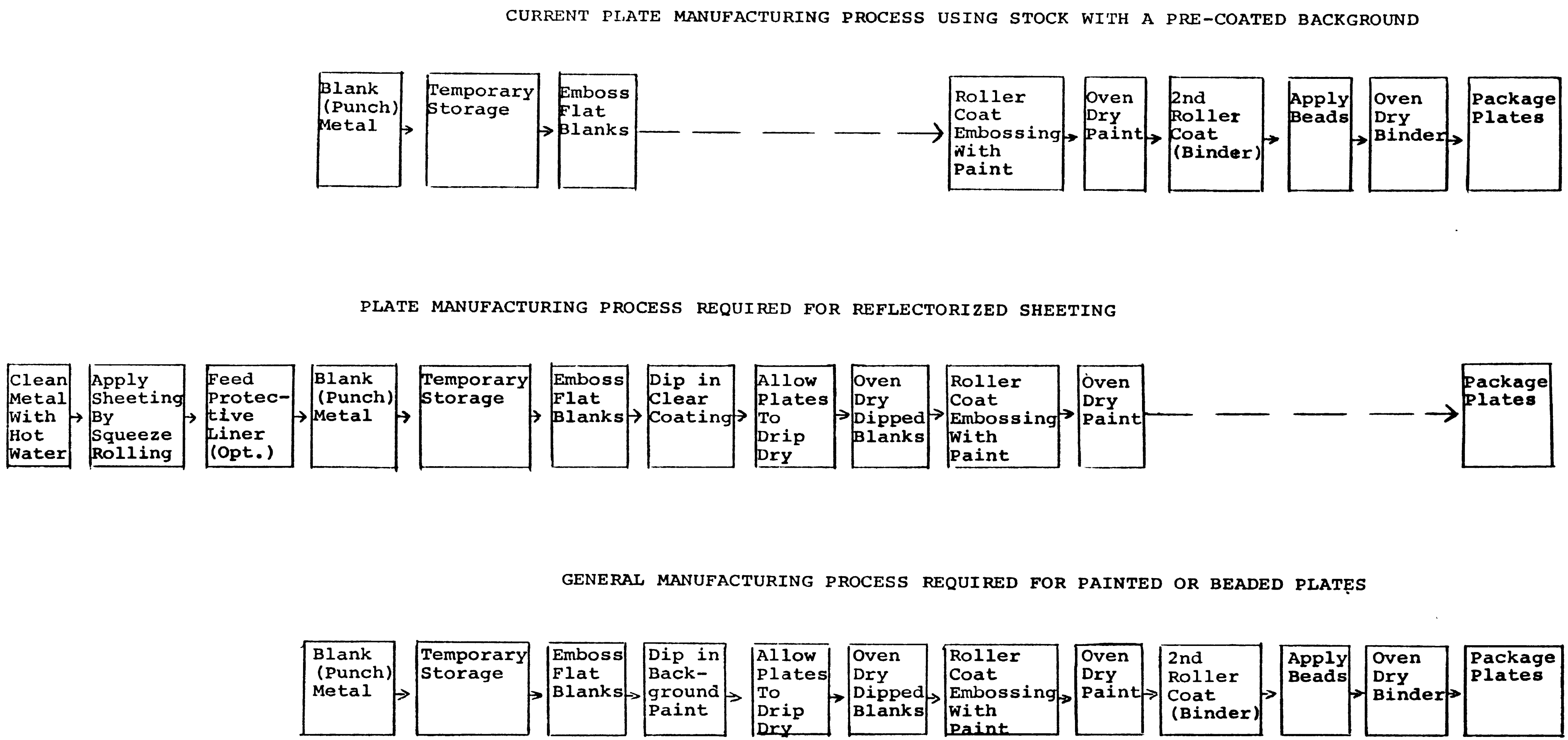

Figure 1. Typical license plate manufacturing processes.

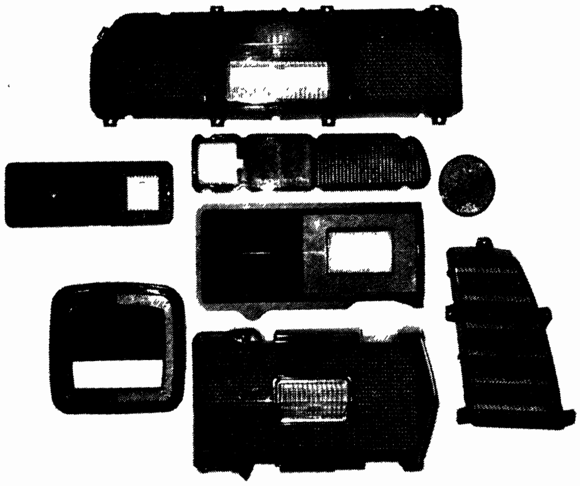

Figure 2. The vehicle retroreflectors used in the study.

cubes alternating in all directions with transparent lens material (e.g., 1974 Ford Mustang II). The strip type has rows of retroreflector alternating with rows of transparent lens material (e.g., 1974 Chevrolet Monte Carlo). The solid type is composed of adjacent retroreflective cubes (e.g., 1974 American Motors Gremlin).

DERIVATION OF THE PHOTOMETRIC TEST POINTS

In order to evaluate the reflective properties of the various materials, SAE Standards J575e and J594e were reveiwed along with Federal Specification L-S-300A. SAE Standard J594e for vehicle reflex reflectors was deemed to be too limited in scope to be the sole criterion for the measurement technique for license plates. The 20 degree left and right entrance angles are somewhat limited, as SAE J774c specified 30 deg left and right for Type 1 emergency warning devices.

Federal Specification L-S-300A, which is used by the U.S. government and many states for specifying retroreflective sheeting for signs and license plates, measures entrance angles up to 50 deg. Thus, both the SAE entrance angles (0°, 10° up, 10° down, 20° left, and right) and the Federal specification entrance angles (-4°, +30°, +50°) were used. As Figure 3 shows, the physical setup used is identical to the SAE J594e procedure. Deviation from the SAE procedure was adoption of the Federal specification measurement technique which photometers the whole sample to determine the total light reflected. The SAE technique would have photometered only part of the area of each license plate. This procedure was unacceptable for this study because the legend was ordered in two different ways on the plate, although the same leters and numerals were used on all of them; and the criticality of aim the procedure would require. Also, only the 0.2° observation angle was used, as it was common

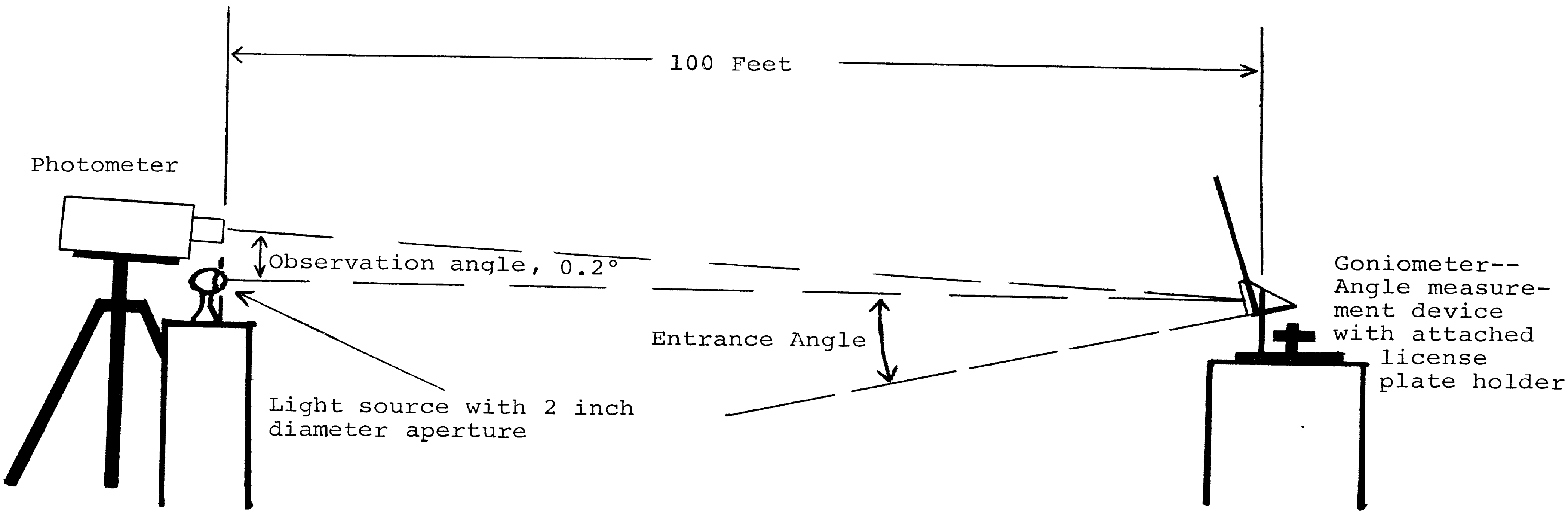

Figure 3. Set-up for photometry of license plates and reflex reflectors.

to both the SAE and Federal specification procedures and is the only angle required by the Federal specification procedures for the accelerated weathering and rainfall tests. In addition, the 0.2° observation angle and an entrance angle of 0° are requirements of the State of Michigan, Department of administration, Purchasing Division Specifications for Glass Beads for License Plate Legends, Mich. 5305-S1, Aug. 11, 1971. The L-S-300A angles were measured in a horizontal plane as the rear of a vehicle generally varies more in its horizontal than vertical attitude. Measurements were also taken at 10 degrees left and right. Thus, measurements taken at 10° up, 10° down, 0°, 4°, 10°, 20°, 30°, and 50° entrance angles, both left and right, would cover all necessary angles for both SAE and Federal specifications. As the SAE horizontal measurements are done with both a left and right orientation, the vehicle reflex reflectors were done in this manner. A pilot study involving one license plate of each background and legend combination revealed that the left/right and up/down variation in light reflected was minimal (well below 5%). Therefore, the license plates were only measured in the up and right directions. This enabled HSRI to photometer two license plates of each color combination.

This was done after the three license plates of each color and material combination with the fewest irregularities and best color match were selected from those that were manufactured. The two most similar plates were used for photometry while the third was retained as a color standard.

THE CORROSION TEST

After photometry of the license plates and retroreflectors was completed they were sent to Chrysler Corporation for corrosion testing as per SAE J575e. All materials were subjected to the salt spray (fog) test in accordance with the latest ASTM B117, Method of Salt Spray (Fog) Testing, for a period of 50 hours, consisting of two periods of 24 hour exposure and one hour of drying time each. These materials were then returned to HSRI, rinsed thoroughly, and blotted dry. Post-corrosion photometry was then undertaken to determine whether the standard corrosion test had affected the reflectivity of any of the materials. In addition, a description of visible corrosion was prepared.

VISUAL COMPARISON OF THE COLOR OF TEST MATERIALS AFTER CORROSION TEST

Subsequently, three drivers viewed the two license plates which had undergone corrosion testing and the third plate which was retained as a color standard. For the three plates of each combination, they decided whether there was a discernable color difference in legend and background. Where color differences existed a description of the difference was produced.

APPARATUS

A Spectra Pritchard Photometer, Model 1970-PR, which is shown in Figure 4, and a Regulated Brightness Source, Code BSR-100, were used to obtain photometric measurements. These instruments were calibrated May 20, 1973.

The photometer had a 1° aperture which measured a 21.0 inch diameter circle at 100 ft. The license plate was centered and completely enclosed within this area. A photograph of a reflectorized license plate taken under laboratory conditions is shown in Figure 5. Figure 6 shows the goniometer, which enabled up/down measurements of 0-15° and left/right measurements of 0-90°. The goniometer was used to pivot a black license plate holder which is shown in Figure 7 on a black cloth background. The surrounding area behind the goniometer was painted black. An optical system consisting of a headlamp spot aimer and a mirror was used to set particular

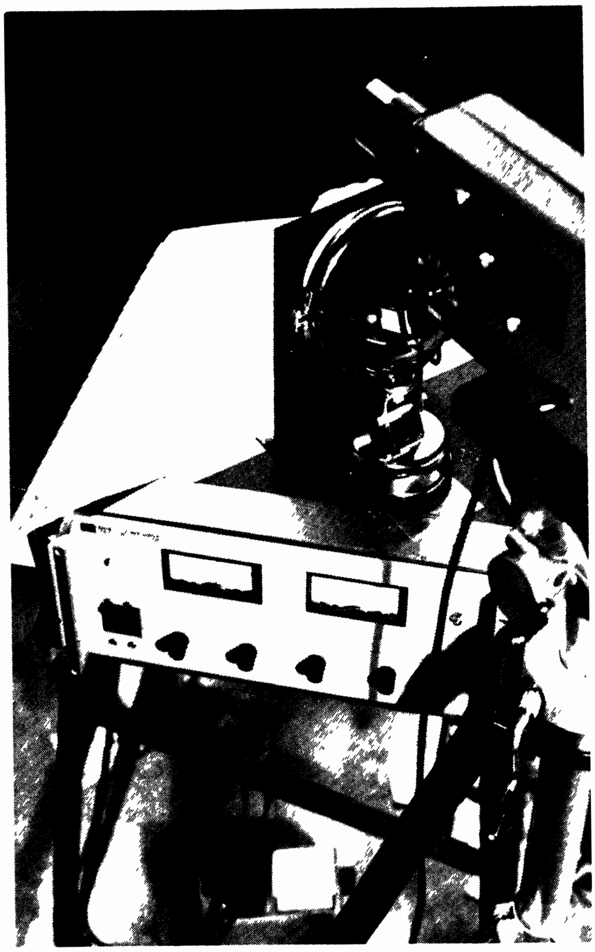

Figure 4. The photometer, lamp providing source of illumination with baffle plate having 2" dia. opening, and regulated power supply.

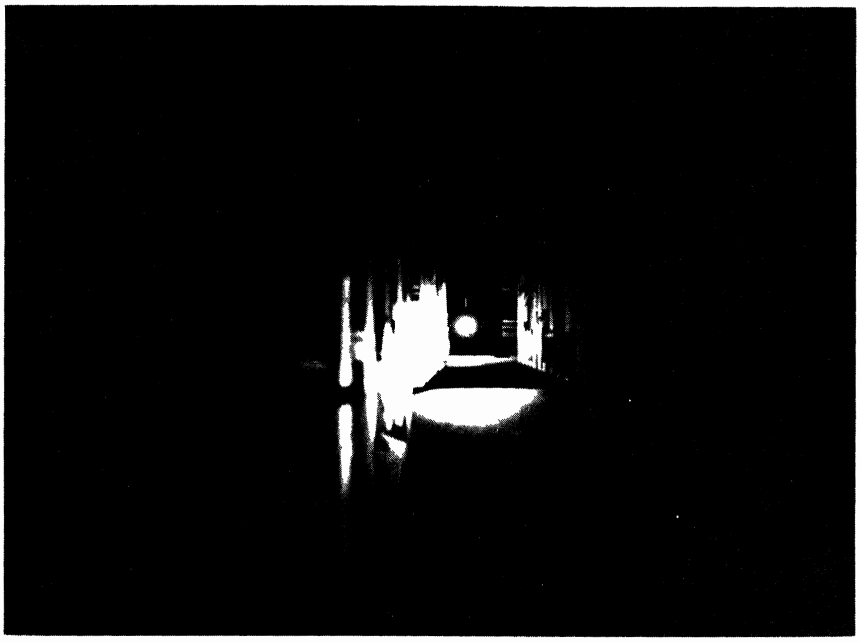

Figure 5. View of reflectorized license plate at 100 feet from source, showing light baffles used to reduce stray light.

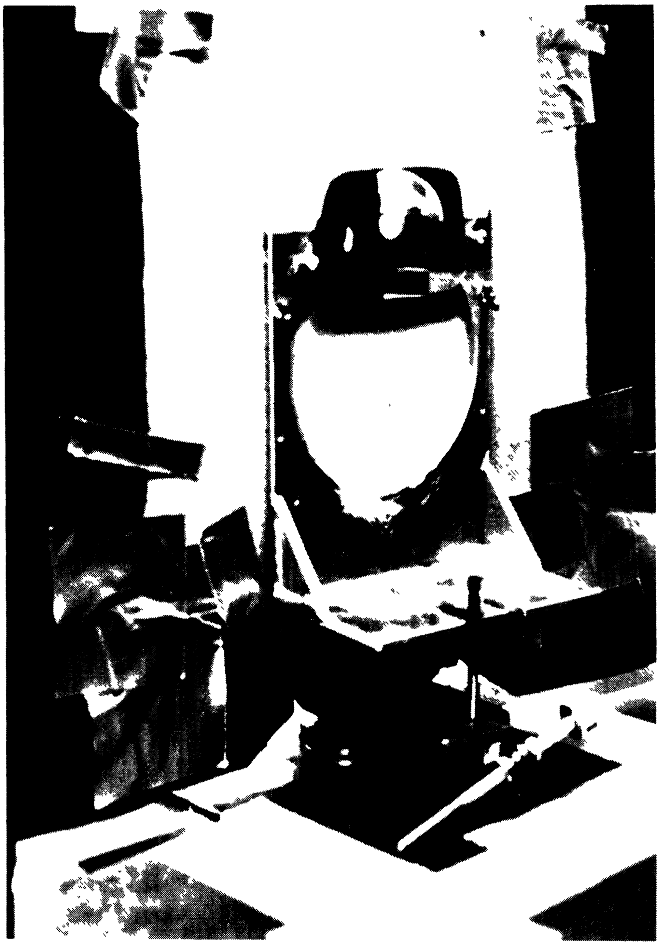

Figure 6. The goniometer used for setting the entrance angles and supporting the license plates and retroreflectors.

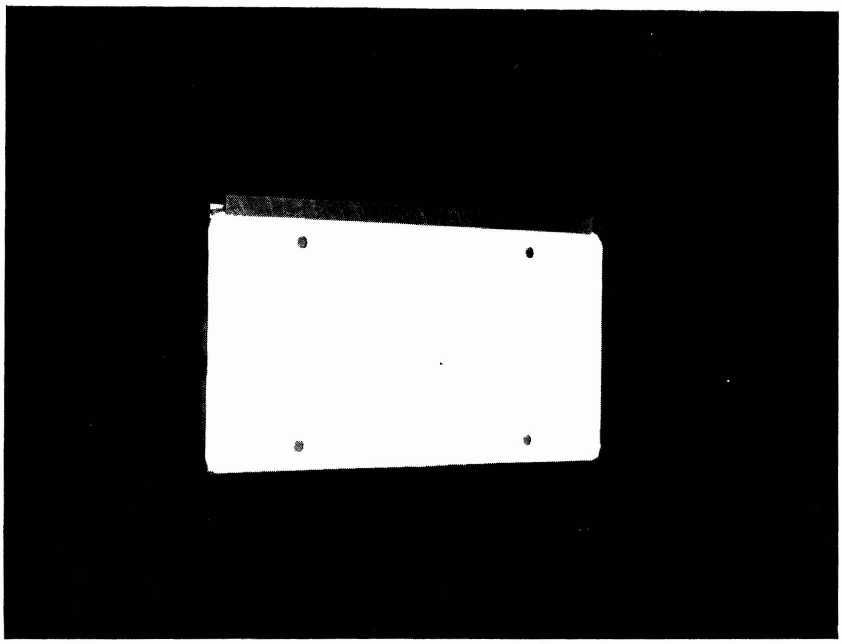

Figure 7. A license plate in the supporting holder.

angles after the optical system was calibrated to the goniometer turret.

A GE 4435 spotlamp with a nominal voltage of 12.8 volts was used as a light source after its color temperature was calibrated with the Spectra Pritchard Photometer. The spotlamp was controlled by a regulated power supply which was monitored by a digital voltmeter. This light source was found to radiate at 2860°K at its nominal voltage.

PROCEDURE

INITIAL PHOTOMETRY. The goniometer optical alignment system was checked daily via a vertical level and the calibrated goniometer turret. The photometer and light source were warmed up for at least 18 minutes before the brightness calibration was made. The brightness calibration of the photometer was made by setting the sensitivity to produce a meter reading equivalent to the calibrated output of the regulated brightness source. The sensitivity was recorded and the photometer was refocused while the aim was also checked. A measurement was then taken at 0° vertical and 0° horizontal of a white card-board test plate which closely approximated the area of a license plate. A desired level of illumination was obtained by calibrating the light source to 2860°K and adjusting the lamp aim to achieve maximum illumination. To maintain a constant illumination, minor adjustments were made from the nominal 12.8 volts until the desired illumination was obtained. The white test plate was then used as the first sample of the day by recording the light reflected at entrance angles of right 50°, right 30°, right 20°, right 10°, right 4°, 0° and 10° up. The entrance angle is the angle made at the reflector by a line from the reflector to the source of illumination and a line normal to the reflector (Figure 3). The entrance angle was designated left, right, up, and down in accordance with the position of the source of illumination with respect to the axis of the reflex reflector as viewed from behind the reflector. These definitions are in accordance with SAE standard - SAE J594e. When these measurements had been taken, the photometer zero and sensitivity were checked while the next license plate was installed. This procedure was repeated until all license plates had been measured, with all same-color pairs measured successively. Various colors of a particular type of background and legend combination were photometered before the next background and legend combination was photometered. For the vehicle reflex reflectors the corresponding left and down entrance angles were measured instead of a duplicate reflector. At the end of each day the reflectance of the white test plate was again measured as a check on the consistency of the procedure.

PHOTOMETRY AFTER CORROSION TEST. The photometry process was repeated after the 47 pairs of license plates and 9 retroreflectors were returned from corrosion testing at Chrysler Corporation.

VISUAL APPRAISAL OF PLATES AFTER CORROSION TEST. After undergoing the standard corrosion test, the condition of the license plates and retroreflectors was visually evaluated and a description produced. In addition, three drivers were presented with the two corroded license plates and non-corroded color standard plate. Their task involved the following instructions: "If you can detect an appreciable color difference for a triad of similar license plates, record the code number and describe the differences. If you feel that there is no appreciable color difference, circle the code number of those license plates."

RESULTS AND DISCUSSION

INITIAL PHOTOMETRY OF LICENSE PLATES AND REFLEX REFLECTORS

The results of the initial photometry of the license plates before they were exposed to the corrosion test, are presented in Table 2. Each reflectivity value is a mean (average) measure of the ability of a pair of similar plates to efficiently reflect light. These data are ordered by decreasing reflective efficiency measured at 4° right. These values should be considered reasonable maximum values[1] while the values at 0° should be considered absolute maximum values[2]. This is because at 0° reflective glare can occur from any smooth flat surface. This glare is primarily a function of the smoothness of the surface and not a measure of reflective efficiency. For this reason the 0° value should be considered an absolute maximum. This special case can occur only when the observer happens to be located nearly perfectly perpendicular to the surface of the license plate.

As can be seen in Table 2 the range of maximum reflectivities is extremely large. The most reflective license plate (No. 1) returns 250 times as much light (at 4° right) as the least reflective (No. 47). Plate number 22 represents the plate used in Michigan in 1974, consisting of white beads on a dark blue background. While it returns 21 times as much light (at 4° right) as the opaque yellow legend on dark blue plate (No. 47),

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[1] Hereafter referred to as "maximum" reflectivity values.

[2] Hereafter referred to as "absolute maximum" reflectivity values.

TABLE 2. Mean* Reflectivity (Candelas/Foot-Candle) of License Plates at Various Entrance Angles, Before Salt Spray (Cont.)

Plate Rank Number**	Group***	Entrance Angle 0°	4°R	10°R	20°R	30°R	50°R	10°UP
1	1	10.8	10.4	9.87	8.27	6.41	2.71	9.99
2	1	10.8	10.3	9.87	8.39	6.66	2.88	9.99
3	1	10.8	10.3	9.80	8.14	6.28	2.59	9.93
4	2	10.1	9.67	9.29	8.01	6.47	2.78	9.35
5	2	9.93	9.55	9.03	7.88	6.34	2.76	9.35
6	2	9.61	9.23	8.71	7.50	6.02	2.68	8.84
7	2	9.74	9.10	8.78	7.75	6.32	2.95	8.90
8	3	7.62	7.11	6.86	6.03	4.76	2.08	6.92
9	3	7.24	6.86	6.60	5.91	4.69	2.06	6.66
10	4A	6.79	6.54	6.33	5.55	4.45	1.97	6.40
11	4A	7.11	6.54	6.33	5.52	4.41	2.30	6.47
12	4A	6.86	6.54	6.32	5.55	4.46	1.97	6.37
13	4A	6.86	6.40	6.17	5.78	4.56	1.95	6.64
14	4A	6.79	6.34	6.14	5.69	4.31	1.94	6.20
15	4A	6.66	6.32	6.11	5.38	4.32	1.92	6.16
16	4B	5.17	4.65	4.52	4.21	3.53	1.83	4.59
17	4B	4.63	4.20	4.08	3.75	3.22	1.74	4.11
18	5	1.58	1.05	1.02	.942	.820	.511	1.03
19	5	1.24	1.05	1.01	.942	.820	.508	1.01
20	5	1.35	1.03	.981	.891	.756	.456	.987
21	5	1.24	.987	.948	.859	.756	.474	.955
22	5	1.67	.865	.820	.711	.579	.302	.846
23	5	1.09	.807	.743	.622	.500	.254	.756
24	5	.974	.807	.743	.641	.484	.190	.782
25	5	1.12	.743	.686	.598	.478	.246	.698

TABLE 2. Mean* Reflectivity (Candlas/Foot-Candle) of License Plates at Various Entrance Angles, Before Salt Spray (Concl.).

Plate Rank Number**	Group ***	Entrance Angle 0°	4°R	10°R	20°R	30°R	50°R	10°UP
26	6	.891	.486	.458	.417	.354	.234	.465
27	6	.794	.480	.450	.411	.351	.238	.457
28	6	1.26	.480	.456	.411	.366	.212	.457
29	6	.737	.450	.424	.393	.338	.219	.429
30	6	1.33	.440	.490	.399	.345	.214	.429
31	6	.769	.424	.398	.362	.308	.194	.404
32	6	.955	.418	.397	.362	.308	.185	.401
33	6	.987	.405	.388	.363	.317	.219	.393
34	7	.762	.096	.074	.068	.063	.033	.076
35	7	1.40	.090	.072	.066	.067	.033	.075
36	7	1.26	.090	.070	.065	.063	.030	.073
37	7	.833	.090	.070	.065	.056	.043	.074
38	7	.743	.088	.070	.066	.059	.032	.074
39	7	.533	.088	.067	.061	.049	.032	.069
40	7	.705	.086	.066	.060	.056	.031	.068
41	7	.660	.082	.065	.060	.056	.030	.067
42	8	.366	.076	.049	.044	.040	.023	.053
43	8	.503	.073	.052	.048	.044	.037	.056
44	8	.317	.067	.037	.031	.030	.017	.038
45	8	.543	.060	.038	.035	.030	.018	.041
46	8	.974	.055	.045	.044	.041	.022	.049
47	8	.743	.041	.028	.027	.024	.013	.033

*The Mean of a pair of identical license plates was calculated.

**Rank numbers were based on the ranks of the mean luminances at the 4° right entrance angle to assure that the effect of glare was negligible. Where tie rankings existed the plate type with the higher mean luminance at 0° was ranked highest.

***Groups were formed of all license plates having similar mean reflectivity at 4° right (entrance angle).

it only returns one twelfth (1/12) as much light as the red transparent legend on silver sheeting plate (No. 1). To make comparisons easier the broad range of reflectivites were split into groups based upon general clustering of reflectivites at 4° right. Table 3 presents these groups and the license plate types and maximum reflectivity values included within each group.

TABLE 3. Group Numbers Associated With License Plate Types and Maximum Reflectivity Values.

Group Number	License Plate Type	Maximum Reflectivity (4° right) (Candelas/Foot-Candle)
1	1-3	10.3 - 10.4
2	4-7	9.10 - 9.67
3	8-9	6.86 - 7.11
4A	10-15	6.32 - 6.54
4B	16-17	4.20 - 4.65
5	18-25	.743 - 1.05
6	26-33	.405 - .486
7	34-41	.082 - .096
8	42-47	.041 - .076

By reference to Table 1 it can be seen that this grouping of the data categorizes together plates of the same legend and background construction, regardless of color.

It is reasonable to group the plates by their general type of construction because the inter-group differences are much greater than the within-group differences. This means that within group 2, for example, whether the legend is opaque red, blue, green, or black is of little consequence as all of these legends on a 3M silver sheeting background have nearly identical reflectivity. Even more dramatic is the fact that among group 4A whether the legend is opaque red, blue, green, black or white is of little importance. In these cases one is dealing with a highly reflective background and therefore the much less reflective legend is of little importance. This effect may appear reversed in cases where one is dealing with a highly reflective legend; in this case the much less reflective background will be of little importance. For example in group 5 whether the background is a light green or a very dark green (blue or red) is of little consequence due to the more highly reflective white beaded legend.

Table 4 (page 26) shows the mean (average) reflectivity values, at each entrance angle, for the license plates in each group. To compare the maximum reflectivity of each group, the mean reflectivity of each group at an entrance angle of 4° right was calculated. From these mean reflectivity values, Table 5 was derived by assigning the mean reflectivity of group 8 at 4° right a value of one and computing how many times more reflective each group mean was compared to the mean reflectivity of group 8 at 4° right.

TABLE 5. Ratios of Maximum Reflectivities (Candelas/Foot-Candle) of License Plate Groups Relative to Group 8.

	Group Number								
	1	2	3	4A	4B	5	6	7	8
Maximum Reflectivity (at 4° right) Relative to Group 8	224	205	152	141	96	20	10	1.4	1

TABLE 4. Mean Reflectivity (Candelas/Foot-Candle) of License Plate Groups at Various Entrance Angles, Before Salt Spray.

Group Description	Entrance Angle 0°	4°R	10°R	20°R	30°R	50°R	10°UP
1. Silver sheeting, dark transparent legend	10.8	10.3	9.86	8.26	6.47	2.73	9.99
2. Silver sheeting, dark opaque legend	9.86	9.41	8.47	7.81	6.29	2.79	9.09
3. Yellow sheeting, dark transparent legend	7.43	6.98	6.72	5.97	4.73	2.08	6.79
4. Light colored* sheeting, dark or white opaque legend	6.35	5.94	5.74	5.17	4.16	1.95	5.82
4A. Yellow or light green sheeting, dark or white opaque legend	6.85	6.47	6.23	5.58	4.42	2.01	6.31
4B. Light blue sheeting, black or white opaque legend	4.90	4.42	4.30	3.95	3.38	1.79	4.35
5. White or yellow beaded legend, light or dark painted back-ground	1.28	.916	.871	.775	.647	.367	.884
6. Dark beaded legend, silver or yellow painted background	.967	.447	.433	.390	.335	.215	.429
7. Dark paint legend, silver or yellow painted back-ground	.637	.066	.051	.048	.043	.025	.054
8. White or yellow painted legend, dark painted background	.426	.046	.031	.028	.026	.016	.033

*Yellow, light green, and light blue

Thus, as the present license plate construction scheme (plate 22) falls within group 5, it is evident that it is about 20 times as reflective as a non-beaded version of the same color scheme (plate 46) which falls within group 8. Similarly, making the background a reflectorized light blue with white opaque legend (like license plate no. 17, group 4B) would produce about a 5-fold increase in reflectivity compared to a white beaded legend on dark blue background.

The reflectivity values of groups of license plates shown in Table 4 are also shown in Figure 8, so that the differences between the groups and the effects of entrance angles can be seen more clearly. The most striking effect is the 5- to 11-fold increase in reflectivity available by use of any combination within the reflectorized sheeting groups (groups 1-4B) when compared to group 5, which includes the present (1973-1974) white beads on dark blue background. Secondly, the groups of plates all show a similar reduction in reflectivity with increasing entrance angle. They retain a substantial proportion of their maximum reflectivity at 20°R (61-89%) and at 30°R (57-75%). The rate of decline in reflectivity increases only slightly as the entrance angle is increased up to 50°R.

Figure 9 shows the analogous data for the automobile reflex reflectors. It is evident that the fall-off in reflectivity with increasing entrance angle, particularly beyond the upper SAE limit of 20°, is greater for the reflex reflectors than for the license plates. Table 6 shows that the sample of reflex reflectors retain 43-54% of their maximum reflectivity at 20°H and only 4-17% at 30°H.

A reflector must also possess sufficient maximum reflectivity to produce adequate visibility. Using the SAE Standard J594e

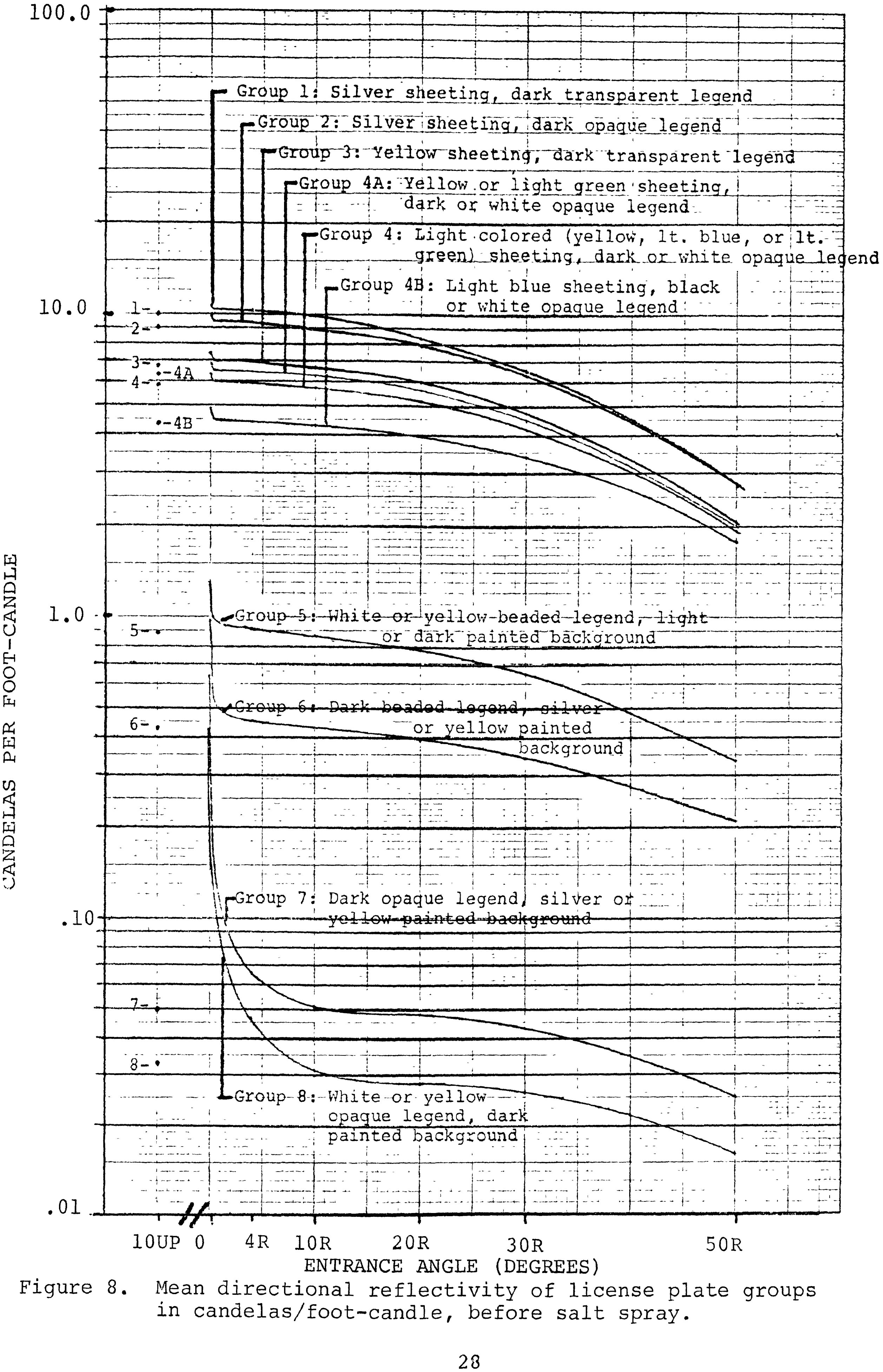

Figure 8. Mean directional reflectivity of license plate groups in candelas/foot-candle, before salt spray.

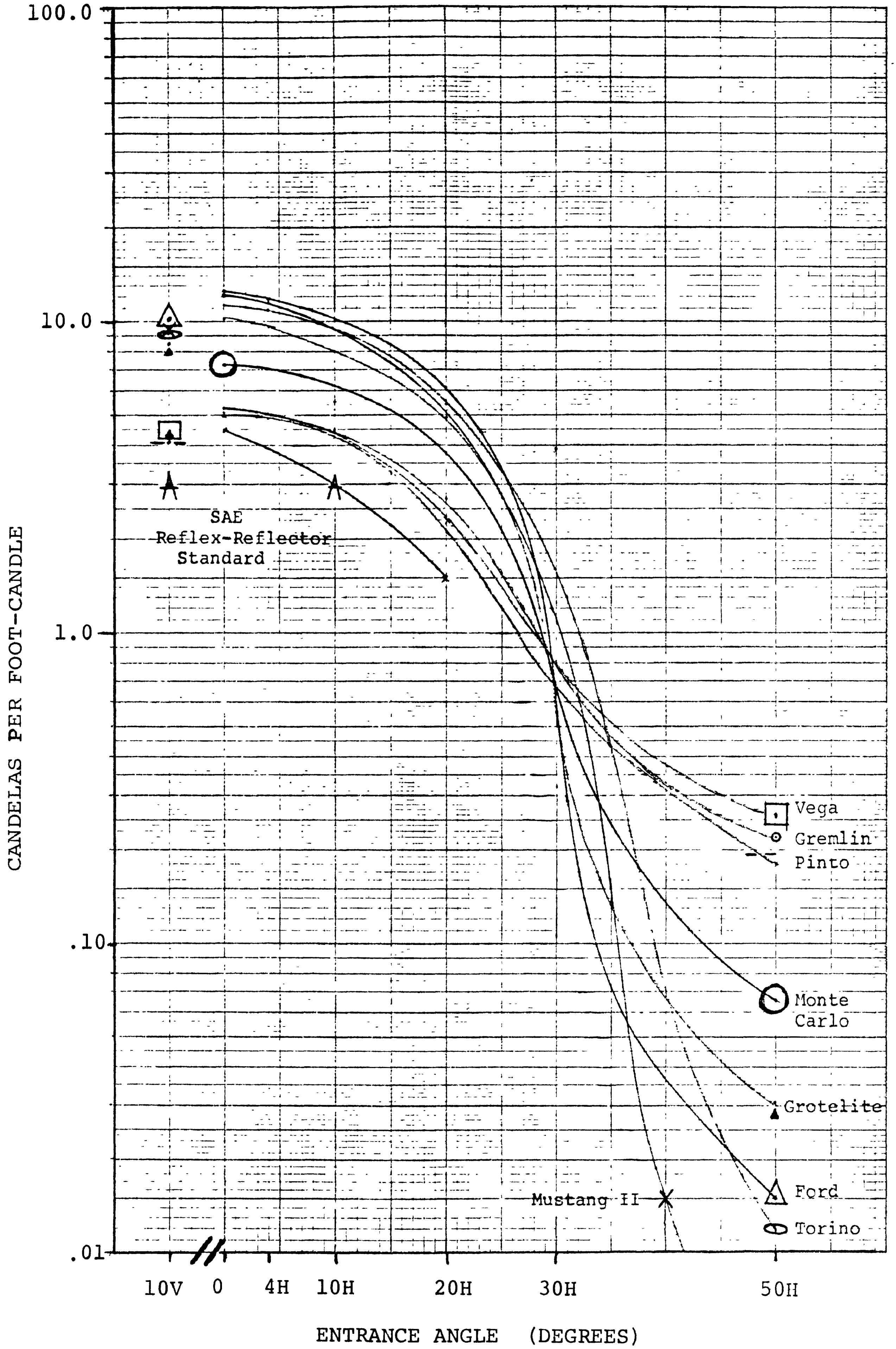

Figure 9. Directional reflectivity of reflex reflectors in candelas/ foot-candle, before salt spray.

TABLE 6. Mean* Reflectivity (Candelas/Foot-Candle) of Vehicle Retroreflectors at Various Entrance Angles, Before Salt Spray.

	Entrance Angle						
Year & Model	0°	4°H	10°H	20°H	30°H	50°H	10°V
1974 Maverick/ Pinto	4.99	4.90	4.38	2.12	.820	.018	4.09
1974 Gremlin	5.23	5.04	4.49	2.70	.810	.022	4.32
1974 Vega	5.24	5.11	4.44	2.38	.814	.026	4.40
1974 Monte Carlo**	7.24	7.08	5.55	3.78	.658	.066	-
SAE-A Grotelite	10.3	9.61	8.14	4.88	.554	.031	8.52
1974 Torino	11.3	10.8	9.55	5.46	.392	.012	9.16
1974 Mustang II	12.0	11.3	9.55	5.11	.390	.003	9.42
1974 Ford**	12.7	11.8	10.0	6.16	.557	.013	10.1

*Values are based on the mean of values obtained at horizontal angles left and right and vertical angles up and down.

**Measured only after weathering; thus these values should probably be somewhat higher, because the effect of weathering is generally a small decrement in reflectivity.

for reflex reflectors as a guide, it is found that automotive reflex reflectors should be visible at night from all distances between 100 and 600 feet when illuminated by the lower beam, and they should meet the .2° entrance angle photometric requirements, as shown in Table 7.

TABLE 7. Minimum Candlepower per Incident Foot-Candle For A Class"A" Red Reflex Reflector at 0.2 Degrees Entrance Angle (SAE J594e).

	Entrance Angles, deg				
	0	10 Up	10 Down	20 Left	20 Right
Minimum Candlepower per Incident Foot-Candle	4.5	3.0	3.0	1.5	1.5

Using these values the minimum SAE standard reflex reflector was plotted on Figure 9 using the 10° Up and Down values to establish to 10° vertical and 10° horizontal values (Note - this assumption of directional equality between 10° vertical and 10° horizontal is supported by the close similarity of all the automobile reflex reflectors tested at these positions as shown in Table 6). From Figure 9 it can be seen that all the automobile reflex reflectors tested meet the SAE standard, and Table 6 shows that some provide more than double the SAE minimum values; however, our technique measures the total area while the SAE technique restricts the area.

Assuming that one would want to have a vehicle reflector at least meet SAE minimum values for such devices, would lead one to conclude that a license plate, to be used as a vehicle reflector, should at least meet SAE minimum photometric specifications. Comparing the SAE Reflex Reflector Standard curve (Figure 9) with the license plate curves in Figure 8 leads one to conclude that only the reflectorized sheeting groups (1-4B) meet the SAE minimum specifications. The reflectorized sheeting groups compare quite favorably in maximum reflectivity with the actual vehicle reflex reflectors in Figure 9. In addition, the reflectorized sheeting groups 1-3 can exceed a reflectivity of 4.5 cd/fc at 30° whereas the best automobile reflector tested could only produce 18% of that value at that angle.

PHOTOMETRY AFTER CORROSION TEST

Tables 8 and 9 exhibit the post-corrosion photometric results for license plates and reflex reflectors, respectively, in terms of percentage change in mean reflectivity from the pre-corrosion values. The Table 8 data show that corrosion effects on reflective sheeting (groups 1-4B) were less than a 3% loss of reflectivity. The substantial loss of reflectivity of groups 5-8 at 0° appears to be the result of reflective glare. Therefore, ignoring the 0° value in order to assess the loss of reflective efficiency, one finds that groups 7 and 8 generally suffer little loss in reflectivity (the small positive values may be considered measurement errors due to the low absolute level of reflectivity, although they may be actual increases caused by an increase in diffuse reflectivity due to surface roughness). As group 7 shows as little effect of corrosion as group 8 (i.e., minimal change in reflectivity), the fact that group 7 contains license plates made of paints formulated only for color matching does not seem to have occasioned excessive loss of reflectivity. Therefore, the rather large decrements in reflectivity among groups 5 and 6 must be due to the fact that these groups were composed of beaded plates.

Table 9 exhibits the data for automobile reflex reflectors in a format similar to that for license plates in Table 8. The caution applied to the 0° data for license plates in Table 8 is not necessary for the automobile reflex reflectors. Table 6

TABLE 8. Percent Change in Mean Reflectivity of License Plate Groups at Various Entrance Angles, After Salt Spray.

Group Description	Entrance Angle 0°	4°R	10°R	20°R	30°R	50°R	10°UP
1. Silver sheeting, dark transparent legend	+.6	0	0	+.8	0	+2.8	0
2. Silver sheeting, dark opaque legend	-1.3	-1.4	-.7	-1.6	-2.0	+1.4	-.7
3. Yellow sheeting, dark transparent legend	-1.7	-1.8	0	-1.2	-.3	+.3	-.9
4. Light colored* sheeting, dark or white opaque legend	-2.0	-1.5	-1.8	-1.4	-.5	-2.3	-1.4
4A. Yellow or light green sheeting, dark or white opaque legend	-1.9	-2.0	-2.1	-1.6	-.4	-2.9	-1.8
4B. Light blue sheeting, black or white opaque legend	-2.0	-.7	-.7	-.8	-2.9	+.7	-.1
5. White or yellow beaded legend, light or dark painted background	-11.5	-13.3	-14.0	-13.2	-12.7	-9.9	-14.5
6. Dark beaded legend, silver or yellow painted background	-23.7	-12.2	-19.1	-11.0	-1.0	-17.5	-13.0
7. Dark paint legend, silver or yellow painted background	-11.9	+2.2	+1.9	+1.0	+4.4	0	0
8. White or yellow paint legend, dark painted background	-5.0	+3.1	0	0	+1.8	-8.8	-1.4

*Yellow, light green, and light blue.

TABLE 9. Percent Change in Mean* Reflectivity of Vehicle Retroreflectors at Various Entrance Angles, After Salt Spray.

Year & Model	Entrance Angle 0	4°H	10°H	20°H	30°H	50°H	10°V
1974 Maverick/ Pinto	-3.47	-6.14	-5.26	-9.31	-6.58	-14.5	-6.59
1974 Gremlin	-7.32	-6.92	-6.76	-14.39	-6.78	-8.51	-8.36
1974 Vega	-7.21	-7.61	-7.15	-4.74	+20.13	.215	-4.41
SAE-A Grotelite	-1.88	-.67	-.79	+5.12	+12.5	+16.3	-3.76
1974 Torino	-2.26	-3.27	-3.02	+2.24	+13.03	-12.77	-7.96
1974 Mustang II	-4.25	-3.13	-2.36	+.83	+2.82	-17.15	-1.73

*Values are based on the mean of values obtained at horizontal angles left and right and vertical angles up and down.

and Figure 9 do not exhibit disproportionate increases in reflectivity between 4°H and 0° as was the case for the license plates (especially groups 5-8 as shown in Table 4 and Figure 8). However, caution must be applied to the 30°H and 50°H reflex reflector data points in Table 9, as the measured reflectivities had such low absolute values that small measurement errors could produce seemingly large changes in reflectivity, especially since individual reflectors rather than groups are being measured. It can be concluded that there appears to be a small loss of reflectivity of about 10% or less in the sample of automobile reflex reflectors after corrosion testing.

ANALYSIS OF MATERIALS AFTER CORROSION TEST

The only imperfections detectable among the 17 license plates constructed of reflective sheeting were 4 cases of minor legend change.

Among 6 license plate types painted with prison stock paint (nos. 42-47), there were no signs of corrosion. However, among the beaded versions of these combinations (nos. 18-19, 21-24), all 6 license plate types exhibited rust on the legend, generally of a moderate nature.

The remaining 18 license plate types (nos. 20 and 25-41) were constructed with 3M paint formulated for color matching which was not compounded for production (i.e., to withstand salt spray and other materials tests). Most of these plates exhibited a moderate loss of paint and/or minor rust spots. The 3M yellow color match paint appeared to be of high quality. Only 2 license plate types with 3M yellow background were affected by corrosion and these exhibited only a slight wearing of the opaque legend.

VISUAL APPRAISAL OF CHANGES IN COLOR DUE TO CORROSION TEST

Only six color differences were considered appreciable by the three judges. Each had reviewed three license plates of each type; two had been exposed to a salt spray test meeting SAE standard J575e. None of the color differences were between pre-corrosion and post-corrosion samples. This indicates that any color changes due to corrosion testing were not considered appreciable, and were less noticeable than original production variations.

Six beaded combinations were not evaluated as it had been necessary to use all three license plates of each combination in the photometry and corrosion tests because of large variations in reflectivity.

SUMMARY

The literature is inconclusive as to whether or not highly reflective license plates result in fewer nighttime rear-end collisions; however, the recent controlled study in Virginia concluded that they do not.

When reflectorized material (e.g., reflectorized sheeting or beads) is used as either the background or legend of a license plate, that material is the main determinant of the reflectivity of the plate. In such a case, the color of the non-reflectorized portion of the plate has little effect on the overall reflectivity.

A background of reflectorized sheeting can provide about an 11-fold increase in reflectivity when compared with light beaded legends on a dark background.

Plates witn light beaded legends and dark paint backgrounds provided about a 14-fold increase in reflectivity compared to plates using dark painted legends and light backgrounds.

Reflectorized license plates retain much of their reflectivity at light entrance angles of up to 50 degrees. On the other hand, automotive vehicle reflex reflectors retain much of their reflectivity at light entrance angles of only up to 20 degrees.

A license plate of reflectorized sheeting is of about the same reflectivity as an automobile reflex reflector at entrance angles up 10-15 degrees. Thus, all things being equal, a reflectorized license plate would return the same amount of light as a vehicle reflex reflector, if the incident light was within 10-15 degrees from their axes. Beyond entrance angles of 20 degrees license plates of reflectorized sheeting will generally return more light than a vehicle reflex reflector.

Among the license plates tested, only the license plates with reflective sheeting backgrounds conformed to the SAE standard for vehicle reflex reflectors.

Among the materials tested, only the beaded license plates had substantial losses of reflectivity following a salt spray test conforming to SAE standards.

Among production materials only the beaded plates had visually detectable defects of at least a moderate nature. All of the beaded legends on production quality paint exhibited moderate legend rust after the salt spray.

No license plates were found to exhibit legend or background color changes following the salt spray.

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2. Stoke, C. B., and Simpson, C. H., Jr. A comparison of the legibility and visibility of enamel and reflectorized 1971 Virginia license plates. Rept. No. VHRC 71-R15, Virginia Highway Research Council, December 1971.

3. Anderson, A. Evaluation of weathering and safety properties of license plates. Industrial and Engineering Services Division, Research Council of Alberta (Canada), 1971.

4. Wortman, R. H. An evaluation of reflectorized annual license plate materials. Research Rept. No. 2, Highway Traffic Safety Center, University of Illinois, May 1968.

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6. Campbell, B. J., and Rouse, W.S. Reflectorized license plates and rear-end collision at night. Highway Safety Research Center, Univesrity of North Carolina, January 1968.

7. Stoke, C.B. Reflectorized License plates: Do they reduce nighttime rear-end collisions? Rept. No. VHRC 73-RP2, Virginia Highway Research Council, December 1973.

8. 3M Company, License Plate Production Manual. St. Paul, Minnesota, undated.

APPENDIX A

MANUFACTURERS OF REFLECTIVE MATERIALS WHO WERE CONTACTED IN THIS STUDY

3M Company
Traffic Control Products Division
3M Center
St. Paul, Minnesota
(612) 733-1110

Felx-O-Lite Mfg. Corp.
Technical Service
Box 4366
St. Louis, Missouri 63123
(314) 351-4450

Fasson Products
Government Sales Dept.
250 Chester Street
Painesville, Ohio 44077
(216) 352-4444

Cataphote Corporation
Box 2369
Jackson, Miss. 39205
(601) 939-4693

Potters Industries, Inc.
600 Industrial Road
Carlstadt, New Jersey 07072
(201) 933-3355

American Decal and Mfg. Co.
4402 West Fullerton
Chicago, Ill. 60639
(312) 489-4700

Morgan Adhesive Co.
Film and Decorative Division
4560 Darrow Rd.
Stowe, Ohio 44224
(216) 668-6062

Prismo Safety Corporation
Maryland
(301) 948-5800

APPENDIX B
LICENSE PLATE MATERIALS USED IN THIS STUDY

<u>3M</u>

<u>Multi-Year Reflective Sheeting</u>

Silver	3770
Lemon Yellow	3781
Light Blue	3776
Light Green	3777
Clear Coat	743
Thinner	746

<u>Roller Coating Colors</u>

Transparent Red	P-84L
Transparent Blue	P-86L
Transparent Green	P-85L
Opaque Black	P-88L
Opaque White	Fe-71L
Opaque Red	Fe-72K
Opaque Blue	Fe-74K
Opaque Green	Fe-73K
Thinner	P-87L

<u>Flint Ink Corporation</u>

<u>Opaque Paints</u>

Dark Red (Maroon)
Dark Blue
Dark Green
Yellow
White

<u>Flex-O-Lite</u>

Lead free high index of refraction sign beads No. 831.

APPENDIX C

THE AUTOMOBILE REFLEX REFLECTORS USED IN THIS STUDY

1. 1974 Chevrolet Monte Carlo rear lens having approval marking "SAE (11A(2)I(2)S(2)T 74 Guide 1A1" uses "strip" type reflex reflector.

2. 1974 Chevrolet Vega rear lens having approval marking "SAE AIRST 74 Guide 1A" uses "solid ring" type reflex reflector.

3. 1974 Ford Mustang II rear lens having approval marking "SAE-A-IR (2)S(@)T 74 MG," uses interspersed type reflex reflector.

4. 1974 Ford Torino rear lens having approval marking "SAE AIRST 74 CR," uses interspersed type reflex reflector.

5. 1974 Ford Maverick/Pinto rear lens having approval marking "SAE TSIAR 70 FN," uses solid patch type reflex reflector.

6. 1974 American Motors Gremlin rear lens having approval marking "SAE IASTR 70 AE," uses solid ring type reflex reflector.

7. 1974 Ford rear lens having approval working "SAE-(2) A (2) IPsR (2) S (2)T - 74 FE," uses interspersed type reflex reflector.

8. A round Grote Manufacutring Co. retro-reflector having approval marking "SAE-A," uses solid patch type reflex reflector.

Except for the retroreflector No. 8, each was integral with the lens of the rear lamp. All were red in color.