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D.R. Chatto, T.L.. Shelly

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This study was conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

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Chrome yellow has been used as the standard yellow pigment in yellow traffic paint for many years. Recently, in view of ever increasing environmental awareness and continuing investigations into the toxicity of lead and chromate compounds, a study was required to find if a suitable non lead-chromate pigment were available.

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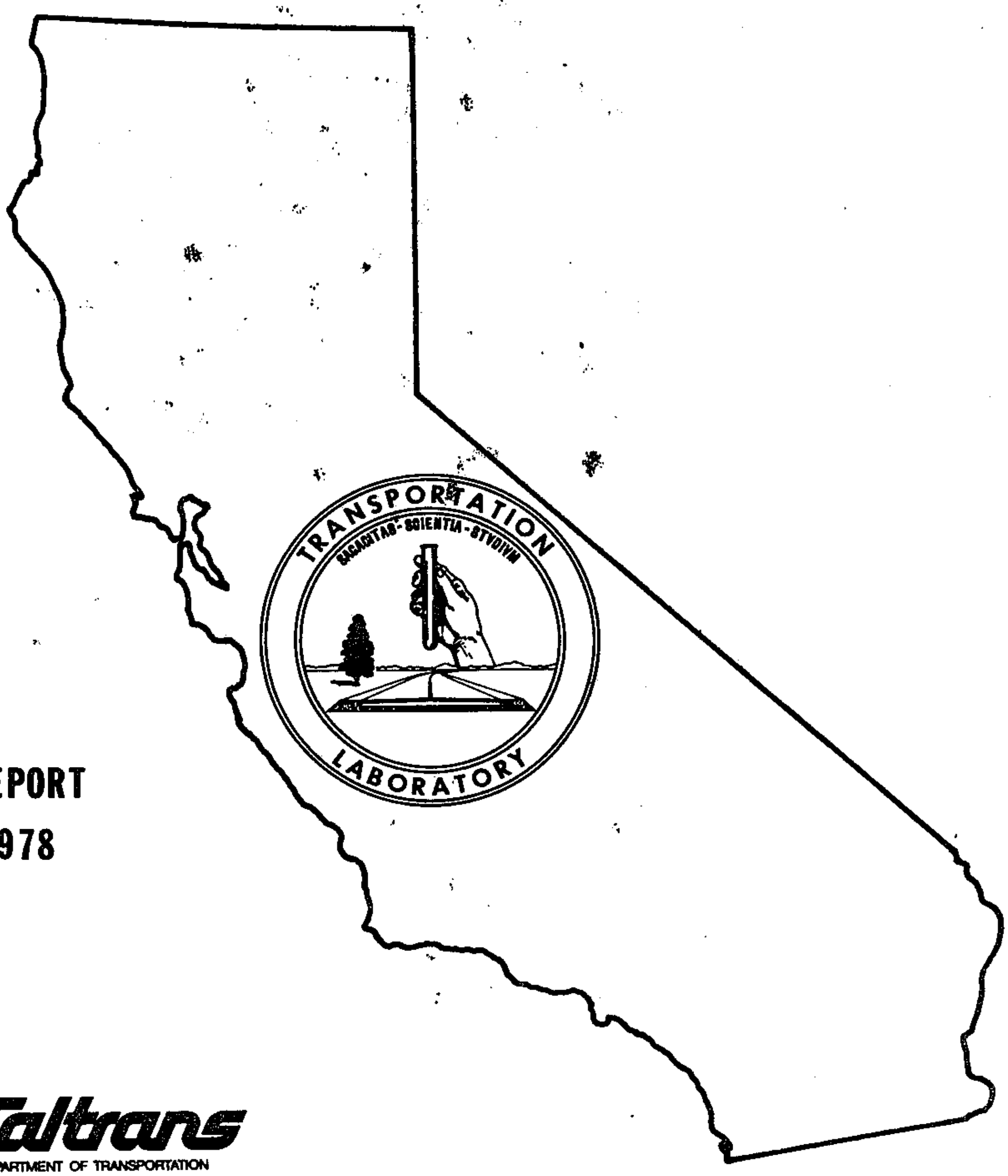
DEVELOP AND EVALUATE A SUBSTITUTE FOR CHROME YELLOW IN YELLOW TRAFFIC LINE STRIPES



FINAL REPORT
JUNE 1978

Caltrans
CALIFORNIA DEPARTMENT OF TRANSPORTATION

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TECHNICAL REPORT STANDARD TITLE PAGE

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STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF CONSTRUCTION
OFFICE OF TRANSPORTATION LABORATORY

June 1978

TL No. 657284

Mr. C. E. Forbes
Chief Engineer

Dear Sir:

I have approved and now submit for your information this final research project report titled:

DEVELOP AND EVALUATE A SUBSTITUTE FOR CHROME YELLOW IN YELLOW TRAFFIC LINE STRIPES

Study made by . . . . Enviro-Chemical Branch

Under the Supervision of . . . . E. C. Shirley

Principal Investigator . . . . T. L. Shelly

Co-Pincipal Investigator . . . . D. R. Chatto

Report Prepared by . . . . D. R. Chatto

Very truly yours,

George A. Hill

GEORGE A. HILL
Chief, Office of Transportation Laboratory

Attachment

DRC:cj

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INTRODUCTION

Chrome yellow (lead chromate) has been used as the primary yellow pigment in traffic paints for many years. The chrome yellow pigments have been widely used in paint and printing inks because of their bright clear colors, strong hiding power, ease of grinding, and reasonable cost. The color ranges from light yellow to deep orange shades, depending on method of manufacture. One drawback with chrome yellow pigments has been their tendency to darken in outdoor exposure. However, some chrome yellows have shown remarkable stability in outdoor exposure and this is reflected in the method of manufacture and a higher price.

Type III medium chrome yellow, containing 87% $PbCrO_4$, has been a standard for traffic paint in California.

There has been concern lately about the use of this pigment because it contains both lead and chromium. The use of pigments containing lead has been of concern because of ingestion by children. Regulations now limit lead content to a maximum of .06% for paint used in and around the household. There are also regulations on the permissible amount of lead and chromium per cubic meter of air. Hexavalent chromium, which occurs in lead chromate, is being studied carefully, and recently NIOSH has recommended that worker exposure to this type of chromium be very strictly controlled and that it be considered a carcinogen. As a result of these regulations and studies, automobile manufacturers are trying to eliminate lead chromate pigments from automotive finishes.

The evaluation of the hazards of such lead and chromium pigments is complicated by the fact that it is encapsulated in the paint binder. Paints used for pavement markings are eventually worn away and while some portion may become airborne, probably most is washed into the soil. Nevertheless, it is reasonable to assume that at sometime in the future there may be regulations passed which would eliminate or restrict the use of lead chromate pigments in traffic paint.

It was the intent of this investigation to determine if chrome yellow can be replaced with organic pigments comparable to chrome yellow in brightness, outdoor color stability, hiding power, ease of dispersion, and cost.

CONCLUSIONS

1) No replacement has been found for chrome yellow in yellow traffic paint that would be satisfactory for all areas and road surfaces in the State of California.

2) On portland cement concrete road surfaces, organic yellow substitutes have performed satisfactorily with respect to color stability and durability in outdoor exposures on Interstate 80 in the Sacramento area.

3) On asphaltic concrete road surfaces, organic yellow substitutes have been a complete failure with respect to color stability in outdoor exposures in the California desert, near El Centro, California on Interstate 8.

4) Organic yellow substitutes can match the medium chrome yellow in color ranges from green to red.

5) Hiding power of the organic yellow substitutes is poor but can be made to match the chrome yellows by adding titanium dioxide.

6) Organic yellow pigments, by virtue of their much higher cost, raise the raw material cost of yellow traffic paint by about $1.00 per gallon ($264 per cubic meter). This is true, even using the minimum amount of organic pigment to obtain the required color.

7) Accelerated Weatherometer testing does not always indicate the color stability of a pigment under consideration. Road testing in the environment in which the material is to be used is the only positive indication of a material's suitability.

IMPLEMENTATION

Organic yellow pigments were not found to be a suitable replacement for chrome yellow pigments in all geographical locations and road surfaces in the State of California, therefore the use of organic yellow pigments for traffic paint can not be recommended at this time.

However, in view of studies conducted by the National Bureau of Standards (FHWA Report No. RD-78-1), the use of organic yellow pigments might be suitable for other states and geographical locations. Continued research into chrome yellow replacement should be encouraged especially with types of vehicles other than alkyd-chlorinated rubber.

METHOD

A few organic yellow pigments were tested in traffic paints about 20 years ago in California. At that time they were not color stable and faded badly. Because of the increased interest in a lead and chromium free yellow pigment, it was timely to reexamine the various organic pigments again in more detail.

The major suppliers of yellow pigments were contacted and asked to submit samples of material they considered suitable for replacement of medium chrome yellow. Seven raw material suppliers each submitted several samples to bring the total number of pigments for testing to 30.

To handle this number of samples, a quick and reproducible method of making up each paint was needed. A quart size (0.95 litre) Waring blender was found to be most suitable for this purpose. One pint (0.47 litre) samples could be made easily and quickly giving suitable Hegman grinds after 8 minutes of shear.

According to the formula PT401, listed in the Appendix, about 4 gallons (0.015 cubic meters) of the vehicle were made up at one time. Then, for each paint, the appropriate amount of vehicle for 1 pint (0.47 litre) of paint was weighed and the pigment containing the different organic yellows being tested was added.

All formulas were calculated in lbs. per 100 gallons (1 lb. per 100 gal = 1.2 kilograms per cubic meter). Since the vehicle was constant, the only changes made were in the pigmentation. According to formula PT401, the pigment portion bulks 25.9 percent by volume and in all formulations 40 lbs. (48 kilograms per cubic metre) of Micro-Cel T-70 was used with varying amounts of organic pigment, usually from 15 to 30 lbs. per hundred gallons (18 to 36 kilograms per cubic metre). The remainder of the pigment system was adjusted to bulk 25.9 percent by volume, using equal portions of talc and calcium carbonate.

For example, formula PT423 was made using Hoechst 11-3012 organic yellow. For 1 pint (0.47 litre) of paint, 317.7 grams of PT401 vehicle were used.

PT423 Pigments

Pigments	lbs.*	Gals	Grams/Pint
11-3012	20	1.7	11.3
T-70 Micro-Cel	40	2.0	22.7
Talc Pfizer 38-33	254	10.9	144
Calcium Carbonate 45-3	254	11.3	144
		25.9	322

*1 lb. = 0.454 kilograms
1 gal = 3.78 litres
1 gram/pint = 2.11 grams per litre

Thus 322 grams of pigment were added to 317.7 grams of the PT401 premixed vehicle, and sheared in a Waring blender for 8 minutes. The mixture developed a temperature of about 160°F after the 8 minutes. The paint was immediately canned and let cool to 77°F before testing.

TESTING

The test conditions selected included both artificial weathering, and outdoor weathering with and without exposure to traffic. The test methods included the determination of the CIE (International Commission on Illumination) color coordinates and opacity, and the Permissible Lightness Difference (ΔL) which measures fading or darkening.

A. Weatherometer Exposure

Atlas Weatherometer - Model 600-XW-WR
Light Source - Xenon
Cycles - 102 minutes light only
18 minutes light and water spray

Samples were drawn down on clean tinplate using a Doctor blade to give a 0.015 inch wet film thickness, allowed to dry 3 days at 77°F and 50% RH, then cut to 3 inch by 9 inch (76 mm by 230 mm) coupons to fit the Weatherometer rack. Edges of coupons were bound with fiberglass tape to prevent corrosion. After 1000 hours exposure time, the samples were removed and CIE coordinates again determined and dominant wave length, purity were calculated from the x and y values and compared to the original samples before exposure.

B. Outdoor Exposure

The sample preparation was the same as for Weatherometer testing. Samples were nailed to a wooden rack facing Southeast. Usual time of exposure was 6 months. CIE Hunter readings were taken before and after exposure, The samples were gently washed with distilled water and mopped dry with a soft cloth to remove dust before taking CIE readings.

C. Road Stripes

Pavement stripes 4 inches (100 mm) wide and 12 feet (3.7 m) long were applied perpendicular to the direction of traffic flow on a high ADT freeway. The stripes were applied with a small scale airless striper at a wet film thickness of 0.015 inches (0.38 mm) on portland cement concrete road surface. In this manner, road traffic is constantly passing over the cross stripes and, by periodic observation, the degree of durability and also color stability can be noted under traffic conditions. In the desert location, the lines were placed on the shoulder only.

D. CIE Color Coordinates and Opacity

Since color determination and coverage were the most important, these tests were done on all samples. Color determinations were done by determining the CIE coordinates by a Hunter Lab Color Difference Meter, D25 D3, with an optical head of 0° luminance and 45° viewing angle, ultraviolet light included. The Hunter meter was standardized with Hunter standard SYL-11. Coverage was determined by drawdown on a Leneta opacity Chart Form 2A, using an 0.010 inch Doctor blade gap and following Federal Test Method Standard No. 141, Method 4121. The Hunter readings were also taken on the opacity chart and read over the white portion of the chart. The CIE coordinates were compared with Federal 595 No. 13538 Standard for highway yellow.

FORMULATIONS

All formulas made are listed under separate headings according to pigment manufacturers. All formulas were made according to the procedures outlined in the Methods section. Quantities listed are all in lbs per 100 gallons of finished paint.

TIO_2 used is ASTM D-476 Type II, III or IV.

Raw materials costs (RMC) shown are for the complete paint and are based on January 1976 prices. The RMC for PT401 with medium chrome yellow pigment was $2.41/Gal ($0.637 per litre) for the complete paint.

SELECTION OF FORMULAS FOR FURTHER TESTING

Each pigment submitted by the various manufacturers was made into a paint using various levels of pigment to try to establish a level that would produce a suitable dry opacity of about 0.90. Color coordinates were taken on all paints as shown in the tables and compared with Federal Standard 595 Color No. 33538, the standard for yellow traffic line paint. It became apparent that, although possessing strong tinting power, the organic pigments were very poor in coverage as indicated by low dry opacities in the range 0.60 - 0.70. It was necessary to use TiO_2 to improve the coverage in all cases. Most of the pigments also were on the green side of yellow as indicated in Figure 1, in the area around a dominant wave length of 578 namometers or less as compared with the red side of the yellow spectrum around 582 nm as shown by PT401 and the Federal Yellow Standard. The Hoechst HR70 was predominately on the red side as shown by PT482.

At least one paint with pigment or mixtures of pigments from each manufacturer was selected for initial testing in the Weatherometer and in outdoor exposure. These results are shown in Figure 1. All samples before and after 1000 hours Weatherometer exposure were plotted on CIE coordinate paper. Any paints showing significant loss of Purity or shift in dominant wave length were considered unsuitable. This was taken into consideration by visual examination also.

Using duplicate samples, the same paints were tested on outdoor exposure on the roof of the Laboratory for a 6 month period. Hunter coordinates were taken before and after exposure and are shown in Figure 1.

Composite photographs of the exposed and unexposed samples of both Weatherometer and outdoor tests are shown in Pictures 1 and 2.

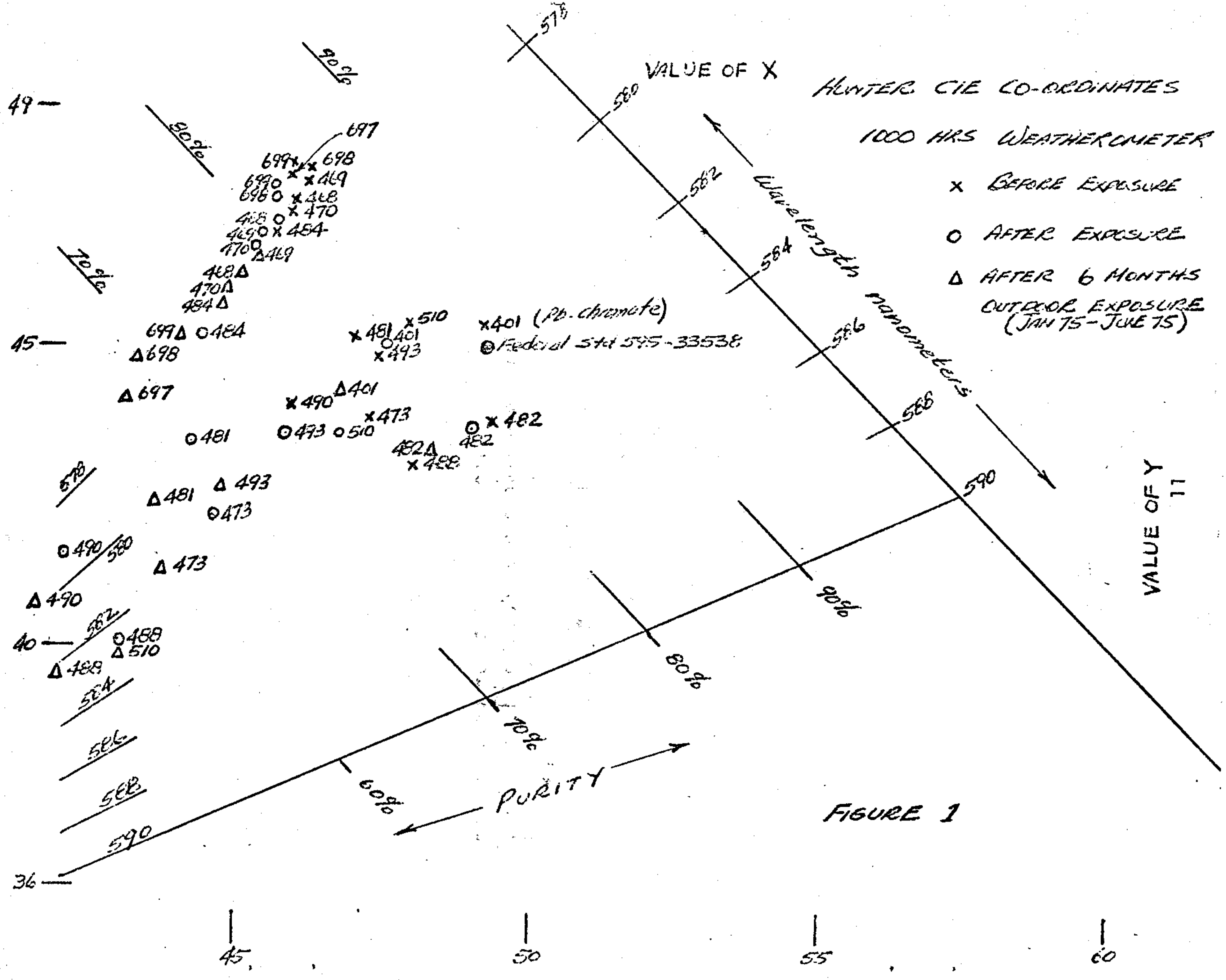

HUNTER CIE CO-ORDINATES
1000 HRS WEATHEROMETER
x BEFORE EXPOSURE
o AFTER EXPOSURE
Δ AFTER 6 MONTHS OUTDOOR EXPOSURE (JAN 75 - JUNE 75)
VALUE OF X
VALUE OF Y
Wavelength nanometers
PURITY
60%
70%
80%
90%
578
580
582
584
586
588
590
49
45
40
36
45
50
55
60
x401 (Pb. chromate)
⊙ Federal Std 595-33538

FIGURE 1

RESULTS OF INITIAL TESTING

The following formulations were considered satisfactory:

PT	Pigment	Manufac-turer	Color Index	Type	Comments
482	HR70(11-1418)	Hoechst	83	DISAZO	Best
468	YT8371	Chemtron	-	AZO	Satisfactory
469	X-3410	Hercules	74	AZO	Satisfactory
470	YT717D	Du Pont	74	AZO	Satisfactory

Examination of Figure 1 and Pictures 1 and 2 shows the general tendency to fade in most of the formulations and also the substantial loss in purity. The 6 months outdoor exposure appears to be more severe than the Weatherometer data and is certainly more realistic.

Since PT468 - 469 - 470 are all on the green side of yellow and PT482 is redder than the Federal Standard, another paint was formulated with a color between the red and green shades of yellow by using a blend of HR70 and one of the green shades. Hercules X3410 was chosen arbitrarily. For further testing, formulas PT482, PT470 and the blend PT496 were used. The complete formulas for these paints are as follows:

	lbs/100 Gallons*		
	PT482	PT496	PT740
Alkyd Resin	120	120	120
Chlorowax 40	40	40	40
Alloprene 20	80	80	80
Methyl Ethyl Ketone	150	150	150
Chevron 225 Thinner	150	150	150
Propylene Oxide	2	2	2
Exkin	1	1	1
6% Co Napthenate	0.5	0.5	0.5
24% Pb Napthenate	1.5	1.5	1.5
Soya Lecithin	4	4	4
Bentone 38	8	8	8
95% Methanol	3	3	3
11-1418 (HR70)	20	5	-
X-3410	-	15	-
YT7170	-	-	20
TiO_2	20	20	10
Pfizer Talc 38-33	245	245	250
Pfizer $CaCO_3$ 45-3	245	245	250
Micro Cel T-70	40	40	40
Non Volatile, %	68.5	68.5	68.5
Pigment, %	51.2	51.2	51.2
Dry Opacity	0.93	0.94	0.92
Viscosity, KU	77	79	78
ASTM Dry (D-711)	2 Minutes	2 Minutes	2 Minutes

*1 lb./100 gallons = 1.20 kilograms per cubic meter

The paints listed were made on a ceramic pebble mill and ground for 20 hours. The CIE coordinates of the PT496 blend were as follows:

Y = 61.26
x = .4810
y = .4573

Dominant wave length, nm = 580.2
% Purity = 84.0

FINAL TESTING

A. Transverse Road Stripes

On Interstate 80, eastbound near P.M. 4.50 on 3-10-77, transverse paint stripes were applied to the portland cement concrete road at right angles to the traffic flow. Stripes were 4 inches (100 mm) wide and 12 feet (3.7 m) long. The 3 organic yellow formulas PT470, PT482 and PT496 were applied with an airless paint system. Several chrome yellow formulas were also applied for comparison. All lines were 0.005 inches (0.13 mm) thick when dry and contained approximately 6 lbs beads per gallon (720 grams/litre) wet paint.

The following lists the yellow pigment content of the test lines:

Road No.	Paint No.	Yellow Pigment	Lbs. Yellow Pigment/Gal*
24	PT470	YT717D	0.2
25	PT482	HR70	0.2
26	PT496	HR70 X3410	0.05 0.15
27	PT498	ONCOR Y47A (Pb Chromate)	1.0
28	PT505	ONCOR Y47A (Pb Chromate)	1.0
29	PT508	ONCOR Y47AG (Pb Chromate)	1.0
30	PT401	Reichhold 1290 (Pb Chromate)	1.0

Picture No. 3 shows the original colors on the day of application. Picture No. 4 shows the lines after 1 year of road exposure. The organic yellows (24-25-26) although faded, were considered satisfactory after 1 year of road service, both in color and wearability. No. 29, the ONCOR Y47A G is a green shade of lead chromate and faded badly.

B. Light Fastness Test per ASTM D211

The 168 hour carbon arc exposure is part of the ASTM specification for chrome yellow pigments and is a measure of the light fastness. The maximum allowable difference in reflectance after exposure (ΔL) is 6.0 for this specification. The ΔL was calculated according to the formula:

$$\Delta L = K\,(Y_2^{1/2} - Y_1^{1/2})$$

where

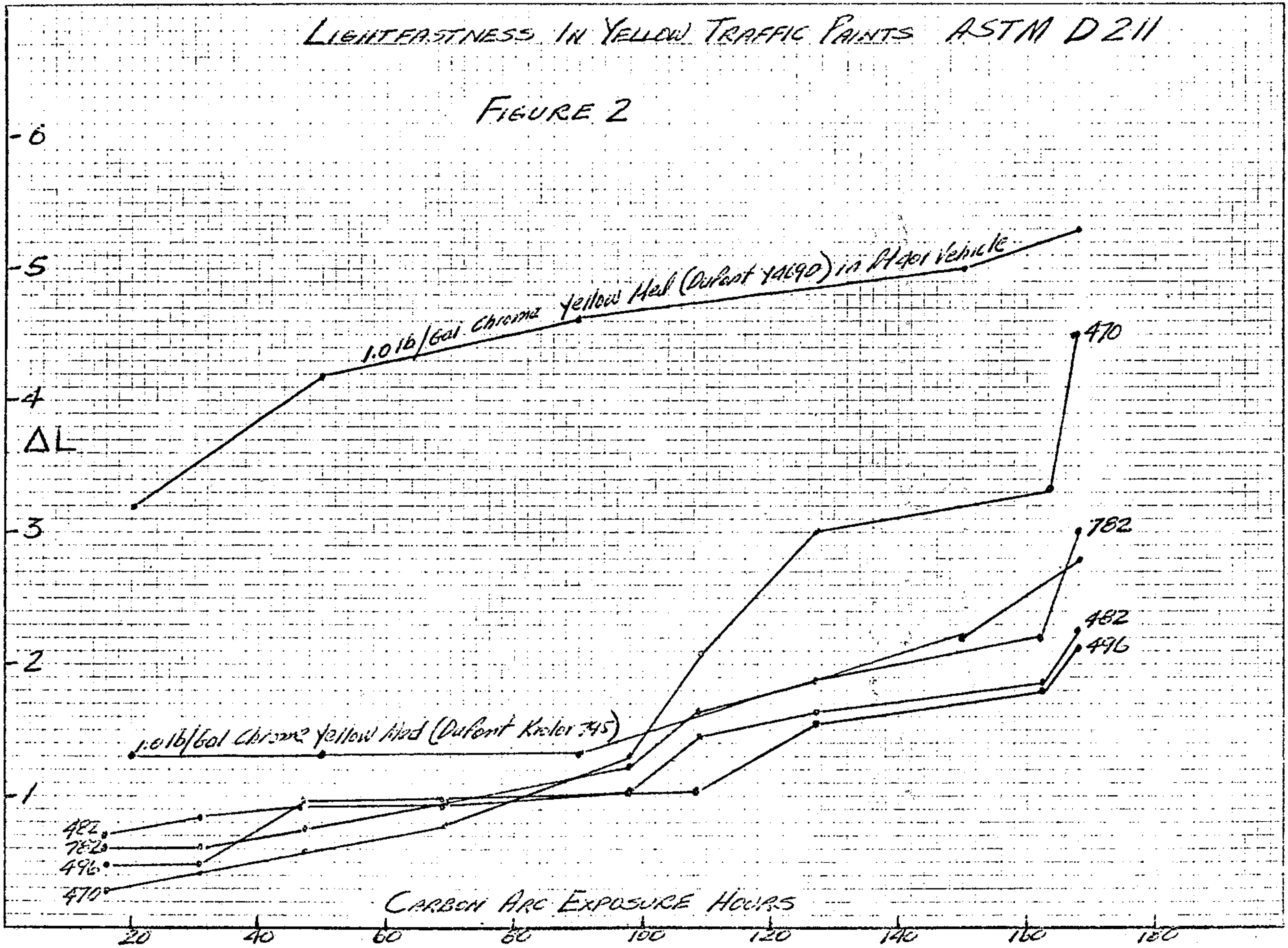
$K = 10$

Y_2 = Reflectance after exposure

Y_1 = Reflectance before exposure

A Photovolt meter, model 670 with a green filter was used. For comparison, 2 chrome yellow pigments were used, Du Pont Y469D and Du Pont Krolor 795 which is probably one of the most stable chrome yellows available. PT782 containing Hercules X3513 was also tested.

Examination of Figure 2 would indicate the organic yellows to be more light-fast than the chrome yellows but unfortunately this type of test does not always predict the performance in outdoor road exposure.


LIGHTFASTNESS IN YELLOW TRAFFIC PAINTS ASTM D211
FIGURE 2
1.0 lb/Gal Chrome Yellow Med (DuPont Y4690) in D401 Vehicle
1.0 lb/Gal Chrome Yellow Med (DuPont Krolor 795)
470
782
482
496
ΔL
6
5
4
3
2
1
CARBON ARC EXPOSURE HOURS
20
40
60
80
100
120
140
160
180

C. Road Stripes California Desert

In order to be suitable for statewide use in California, a yellow pigment must be able to withstand the hot summer condition encountered in the California desert on asphaltic pavement.

On 5-25-77, the following paints were applied in the asphalt median on Interstate 8 at P.M. R16.00, eastbound. This location is in Imperial County, California near El Centro where summertime temperatures frequently exceed 100°F with the asphalt pavement surface temperature as high as 160°F.

Line No.	Formula No.	Yellow Pigment
1	PT470	Du Pont YT717D
2	PT482	Hoechst HR70
3	PT496	Hercules X3410 & HR70
4	PT704	Y47A chrome yellow 1.0 lb/gal*
5	PT707	Y469D chrome yellow 1.0 lb/gal
6	PT776	Krolor 795 chrome yellow 1.0 lb/gal

*1 lb./gal. = 120 grams per litre

All lines were 4 inches (100 mm) wide and 4 feet (1.2 m) long and applied with a separate brush for each paint to prevent contamination. Paint thickness was approximately 0.015 inches (0.38 mm) wet thickness.

On 11-15-77 the lines were inspected and photographed. Pictures No. 5 and 6 show the appearance of the lines at that time (7 months exposure). Samples of the original paint on tin plates are shown for comparison of the original color with the test lines.

As shown in the photographs, the paint lines containing the organic pigments were completely faded and bore no resemblance to the original yellow color. The Oncor Y47A lead chromate also was a complete failure. The other medium chrome yellow controls, the Du Pont Y469D and Krolor 795 were in excellent condition showing almost no color change. The yellow median line shown in photographs was a routine stripe applied about 2 months before the test lines and was the State Specification yellow paint containing 1.0 lbs/gal (120 grams per litre) of medium chrome yellow.

APPENDIX

SPECIFIC PROVISIONS

Yellow Rapid Dry Traffic Paint

Formula PT 401

Composition	Specifications	Theoretical Lbs per 100 Gals*
Alkyd Resin, 60% Solids[1]		120.0
Chlorinated Paraffin[2]		40.0
Chlorinated Rubber, 20 Cps[3]		80.0
Methyl Ethyl Ketone	TT-M-00261	150.0
Aliphatic Thinner[4]		150.0
6% Cobalt Napthenate	TT-D-643	0.5
24% Lead Napthenate	TT-D-643	1.5
*Epichlorohydrim		2.0
Anti-skinning Agent		1.0
*Anti-settling Agent[5]		8.0
*95% Methanol		3.0
*Soya Lecithin		4.0
Medium Chrome Yellow	TT-P-346, Type III	100.0
Magnesium Silicate[6]		247.0
Synthetic Hydrated Calcium Silicate[7]		40.0
Calcium Carbonate[8]		247.0

*See Manufacturing note

Characteristics of the Finished Paint

Viscosity, K.U., at 77°F	76 - 85
Weight per Gallon, Lbs at 77°F**	11.7 - 12.0
Nonvolatile, Percent by Weight	68.0 - 71.0
Pigment, Percent by Weight	52 - 55
Fineness of Grind, Hegman	2.5 Minimum
Dry Time, ASTM D-711, without Beads, Minutes	1.0 - 3.0
Chlorine, Percent in Nonvolatile Vehicle	33 - 39
Color, Approximate	Federal Standard 595, No. 33538
45° Directional Reflectance, 0.010-in. Doctor Blade Gap, Green Filter	61.0 Minimum

X-ray diffraction analysis of the pigment, infrared absorption curve of the vacuum dried vehicle solids, and the gas chromatograph analysis of the solvent system each shall be in agreement as to positions of peaks and relative intensities when compared to the respective curves made from a Caltrans Laboratory prepared sample of the paint.

*1 lb./100 gals = 1.20 kilograms per cubic meter
**1 lb./gal = 120 grams per litre

RAW MATERIALS SPECIFICATION

Pt 400 and Pt 401

[1]The alkyd resin solution shall be a medium length, pure drying alkyd prepared from soya oil and shall contain no rosin or phenolic resin modifiers.

The composition of the solid resin shall be as follows:

Iodine Number of Fatty Acids	115 Minimum
Refractive Index of Fatty Acids	1.4660 Minimum

	Percent by Weight
Phthalic Anhydride	33 - 37
Oil Acids	48 - 55
Acid Number	8 Maximum
Ash Residue	0.05 Maximum
Unsaponifiable	1.0 Maximum

The alkyd resin solution shall be processed in such a manner as to yield the following characteristics at 59 - 61% solids by weight at 77°F:

Viscosity, Gardner-Holdt	Z 1 - 3
Acid Number	2 - 6
Pounds Per Gallon*	7.69 - 7.77
Color, Gardner 1933	5 - 7

The volatiles shall be VM&P Naptha, TT-N-95, meeting all air pollution control rules in the State of California.

[2]Chlorine, Percent by Weight	40 - 43
Color, Gardner	12 Maximum
Viscosity at 25°C, Poise	20 - 30
Specific Gravity at 25/25°C	1.150 - 1.170
Stability Maximum Percent of HCl Liberated in 4 Hours at 175°C	0.80

*1 pound per gallon = 120 grams per litre

Raw Materials Specification (Continued)

[3]Chlorine, Percent by Weight	65 - 68
Viscosity, 20% in Toluene, Centipoise at 25°C, Bingham-Murray Plastometer	17 - 25
Specific Gravity	1.555 - 1.565
Index of Refraction	1.550 - 1.560

[4]Color, Saybolt	+30
Gravity, API, at 60°F	58.2 to 58.4
Gravity, Specific, at 60°F	0.744 - 0.746
Pounds per Gallon at 60°F*	6.19 - 6.21
Flash Point, TCC, °F	23 - 25
Aniline Point, °F	115 - 120
Kauri Butanol Value	41 - 43
Toluene and Ethylbenzene, Percent by Volume, Maximum	7.0
Initial Boiling Point, °F	198 - 204
50% Recovered, °F	204 - 209
Dry Point, °F	215 - 219

[5]Organic derivative of a special magnesium montmorillonite clay:

Color	Cream white
Form	Finely divided powder
Specific Gravity	1.70 - 1.80
Fineness	Less than 5% retained on U.S. Standards Sieve No. 200

[6]Specific Gravity		2.810 - 2.910
Oil Absorption, ASTM D-281		20 - 35
pH		8.9 - 9.5
Hegman Rating		3 - 4
Maximum Particle Size		70 Microns
Shape		Acicular, Platey
Reflectance:	Amber	93 - 95
	Blue	92 - 94
	Green	92.5 - 94.5

[7]Oil Absorption, Lbs/100 lbs, Gardner-Coleman Method	210 - 230
Water Absorption, Percent	240 - 270
pH	9.2 - 9.6
Bulking Value, Gals/Lb	0.0498 (0.416 litres/kg
Color	White
Refractive Index	1.50 - 1.60
Moisture, Percent	5 - 7
Average, 325 Mesh Residue, Percent	1.0

*1 lb./gal = 120 grams per litre

Raw Materials Specification (Continued)

[8]Oil Absorption (Spatula)	14
Surface Area, Square Centimeters/Gram	2500

Particle Size Distribution		Percent by Weight Below Indicated Size
Micron Diameter:	44 (325 Mesh)	100.0
	40	94.0
	30 (450 Mesh)	84.0
	20 (625 Mesh)	66.0
	15	54.0
	10 (1250 Mesh)	38.0
	7.5	28.0
	5	18.0
	1	4.0

Dry Brightness, Percent	97.0
Specific Gravity	2.71
Hardness, Mohs Scale	3.0
Particle Shape	Rhombohedron

A. Hoechst Pigments

*Iron Oxide

Pt	FGL 11-3012	*MAPICO 2100	11-1418 HR 70	HR 11-1400	YR 11-3200	NCG70 11-3004	YLO* 2288	VIS KU	ASTM Dry (Min)	TiO_2	Dry Opacity	Y	x	y	% Purity	λ nm	RMC $/Gal
423	20							81	3		0.77	65.41	.4639	.4817	86.0	576.5	3.08
424	15							81			0.68	67.41	.4601	.4838	85.0	576.0	2.73
425	30							82			0.78	64.52	.4674	.4786	86.0	577.2	3.76
426	15	3.5						79			0.67	55.81	.4727	.4646	83.8	578.8	2.75
427	15	5						79	2	2	0.73	53.42	.4717	.4594	82.0	579.2	2.76
428	15	10								10	0.92	48.67	.4648	.4480	77.0	579.8	2.81
429	30	5								5	0.88	54.06	.4719	.4611	83.0	579.5	3.80
430	15		15							5	0.85	53.98	.5036	.4435	86.0	583.4	4.10
431	20		10							5	0.86	54.96	.4992	.4468	86.0	582.7	3.99
432	20		5							5	0.76	57.46	.4920	.4533	85.5	581.5	3.55
436			20							5	0.76	54.67	.5058	.4441	87.0	583.5	3.52
465	20									10	0.85	68.06	.4609	.4819	85.0	576.3	3.12
466	20									15	0.86	67.40	.4584	.4779	83.0	576.3	3.14
475				20				80		10	0.78	51.40	.5075	.4395	86.3	584.2	3.24
476					20					10	0.94	49.19	.5121	.4260	83.8	586.2	2.75
477						20				10	0.83	68.36	.4565	.4820	84.0	575.8	2.72
478					10	10				10	0.87	51.98	.5055	.4349	84.3	584.6	2.74
479						20				20	0.86	69.54	.4508	.4792	82.0	575.5	2.76
481					2	20				25	0.91	61.14	.4759	.4564	82.0	580.0	2.88
482			20							20	0.88	55.38	.4977	.4417	84.0	583.2	3.57
491	[illegible]						10			10	0.93	49.93	.4710	.4505	79.8	580.0	2.81
492	[illegible]						5			10	0.83	53.37	.4664	.4543	79.0	579.3	2.79

A. **Hoechst Pigments** (Cont'd.)

PT	NCG70 11-3004	HR70 11-1418	5GX 11-2503	RA 11-3100	TiO_2	Dry Opacity	Y	x	y	% Purity	λ nm	RMC $/Gal
509	10	10			20	0.90	56.78	.4880	.4456	82.3	582.0	3.17
510	15	5			20	0.89	59.76	.4796	.4523	82.0	580.9	2.97
698			20		10	0.88	66.16	.4621	.4760	84.0	576.8	2.97
699				20	10	0.82	63.40	.4630	.4837	86.0	576.3	2.73

B. Ciba-Geigy and Chemtron Pigments

*Iron Oxide

	Ciba-Geigy				Chemtron												
PT	IRGAZIN 2GLT	*MAPICO 2100	GR Toner	3G Toner	RYT 8358	YL 3861	YT 8371	TiO_2	VIS KU	ASTM Dry (Min)	Dry Opacity	Y	x	y	% Purity	λ nm	RM($/Ga
433	20								76	3	0.74	70.10	.4528	.4886	85.0	475.0	4.(
434	15	10						5			0.91	48.20	.4695	.4494	79.0	580.2	3.9
435	20	5						5			0.81	54.46	.4673	.4586	80.2	579.0	4.6
437			20					5	85		0.64	59.05	.4897	.4632	88.0	580.3	4.9
438				20				5			0.81	65.42	.4648	.4812	86.0	576.7	5.3
439					20				75		0.77	62.11	.4776	.4673	86.0	579.0	2.4
440						20					0.59	69.99	.4356	.4641	73.0	575.3	1.8
441							20				0.83	66.04	.4675	.4760	85.0	577.5	2.7
493		5	10					10			0.89	53.71	.4785	.4533	82.0	580.5	3.3
468							20	10			0.90	67.96	.4633	.4766	84.2	576.9	2.7
467					20			10			0.87	64.21	.4661	.4626	81.5	578.3	2.4

C. Hercules Pigments

*Ni-Titanate

PT	X-2846	X-3410	X-3473	X-3513	*10345	TiO_2	Dry Opacity	Y	x	y	% Purity	λ nm	RMC $/Gal
442	20						0.66	64.96	.4708	.4790	87.0	577.2	2.53
443		20					0.86	64.81	.4690	.4752	85.0	577.6	2.70
444			20				0.75	67.06	.4702	.4814	87.0	577.2	2.70
445				20			0.67	56.89	.4978	.4470	86.0	582.7	2.74
469		20				10	0.90	65.11	.4672	.4775	86.5	577.1	2.74
782				20		20	0.90	56.21	.4820	.4383	79.0	582.4	2.80
450					20		0.65	74.48	.3839	.4174			2.01
451					100		0.90	74.36	.4042	.4454			3.74

D. Du Pont Pigments

PT	YT808	YT820	YT717	YT858	YT888	YT868	TiO_2	Dry Opacity	Y	x	y	% Purity	λ nm	RMC $/Gal
447	20							0.70	66.52	.4692	.4771	86.0	577.5	2.70
448		20						0.75	53.15	.5030	.4318	83.0	584.8	2.70
449			20					0.84	65.86	.4686	.4791	88.0	577.4	2.70
462				20				0.86	66.20	.4701	.4823	87.0	577.0	2.90
463					20			0.83	65.70	.4711	.4799	87.0	577.4	2.90
697						20	10	0.88	63.86	.4606	.4775	84.0	576.5	3.14
474				20			10	0.89	66.37	.4642	.4761	84.1	577.0	2.94
470			20				10	0.91	66.38	.4628	.4740	83.5	577.1	2.74

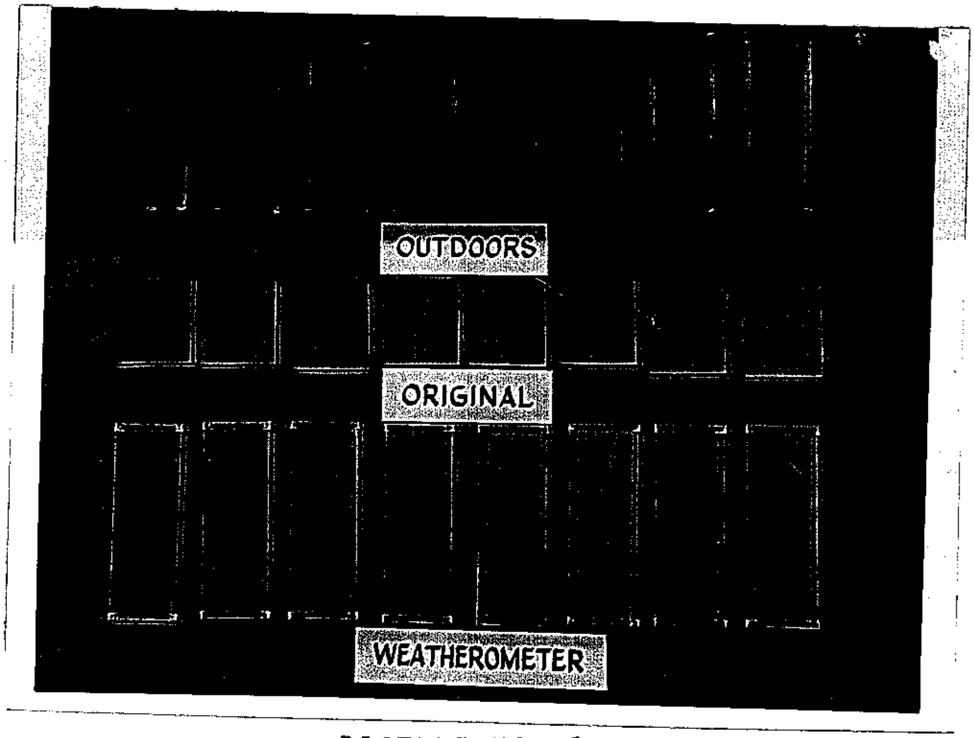
E. Harshaw and Sumitomo Pigments

*Ni-Titanate

		Harshaw					Sumitomo									
PT	*Sun C	1239	1240	5R 1240	1235	1236	0418y	0418R	TiO_2	Dry Opacity	Y	x	y	% Purity	λ nm	RMC $/Gal
452	100									0.88	73.68	.4060	.4478	67.0	575.8	3.21
453		20								0.65	49.41	.4972	.4271	80.0	584.8	2.50
454			20							0.69	55.07	.5046	.4448	87.0	583.3	2.48
455				20						0.65	54.30	.5055	.4429	87.0	583.6	2.48
456					20					0.73	67.72	.4708	.4868	89.0	576.7	2.53
457						20				0.82	67.13	.4694	4797	86.0	577.5	2.70
399							20			0.77	60.09	.4750	.4501	81.5	581.0	2.32
404								20		0.73	60.84	.4790	.4531	82.2	581.0	2.43
471								20	10	0.86	61.76	.4698	.4469	78.0	580.3	2.48
472								40	10	0.91	58.65	.4808	.4452	81.5	581.5	2.93
473							40		10	0.93	58.33	.4780	.4437	80.0	581.2	2.93
485							30		20	0.89	61.06	.4678	.4447	77.0	580.3	2.88
484						20			20	0.91	68.13	.4613	.4733	83.0	577.0	2.78

F. Pigment Mixtures

PT	10345	YT8371	YT858	11-3200	11-3004	11-1418	X-3410	YT717	TiO_2	Dry Opacity	Y	x	y	% Purity	λ nm	RMC $/Gal
458	100	5								0.91	70.88	.4335	.4666	76.0	575.2	3.49
459	25	5								0.81	68.88	.4510	.4755	80.2	575.9	2.34
460	20	5								0.74	68.79	.4512	.4759	80.2	575.9	2.26
464	20		5							0.82	68.26	.4546	.4790	82.5	576.0	2.31
480	50	5								0.83	69.38	.4461	.4727	78.3	575.6	2.72
486	25	10							10	0.87	69.47	.4521	.4737	80.0	476.0	2.63
487	25			10					10	0.91	52.84	.5011	.4327	83.0	584.4	2.63
488	30			5					10	0.91	55.90	.4869	.4350	79.6	583.2	2.46
489	30			5	2				10	0.90	55.29	.4900	.4373	81.0	583.2	2.55
490	30			2	5				20	0.92	62.04	.4643	.4445	76.0	580.0	2.59
494		10				10			20	0.91	56.65	.4885	.4455	83.0	582.0	3.18
495		15				5			20	0.92	59.93	.4789	.4527	82.0	580.5	2.98
496						5	15		20	0.90	59.16	.4800	.4544	83.0	580.5	2.98
497						5		15	20	0.91	59.33	.4782	.4511	81.0	580.5	2.98



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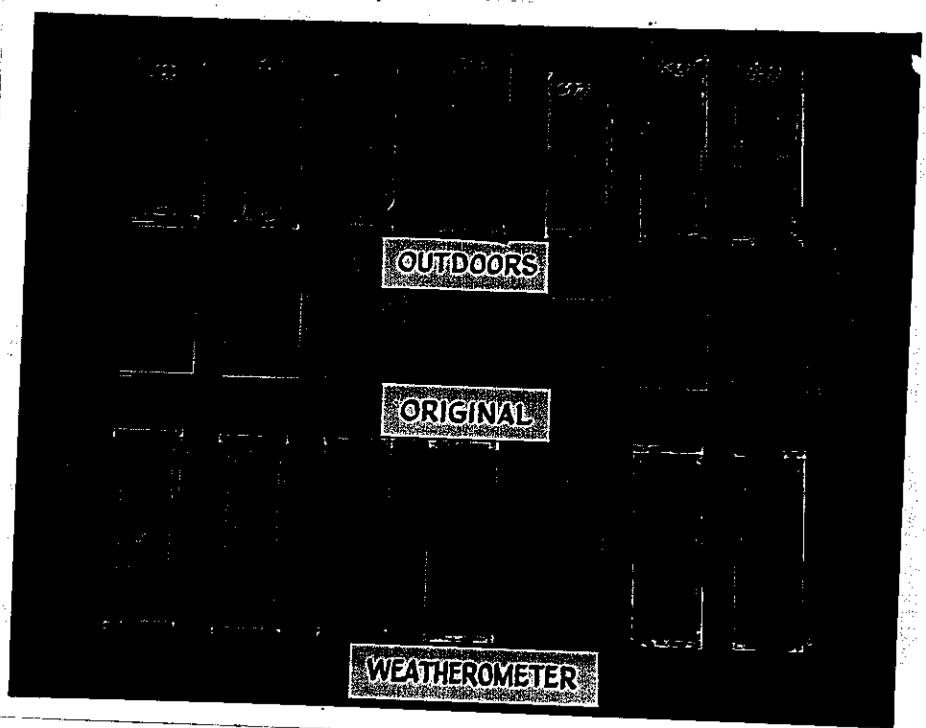

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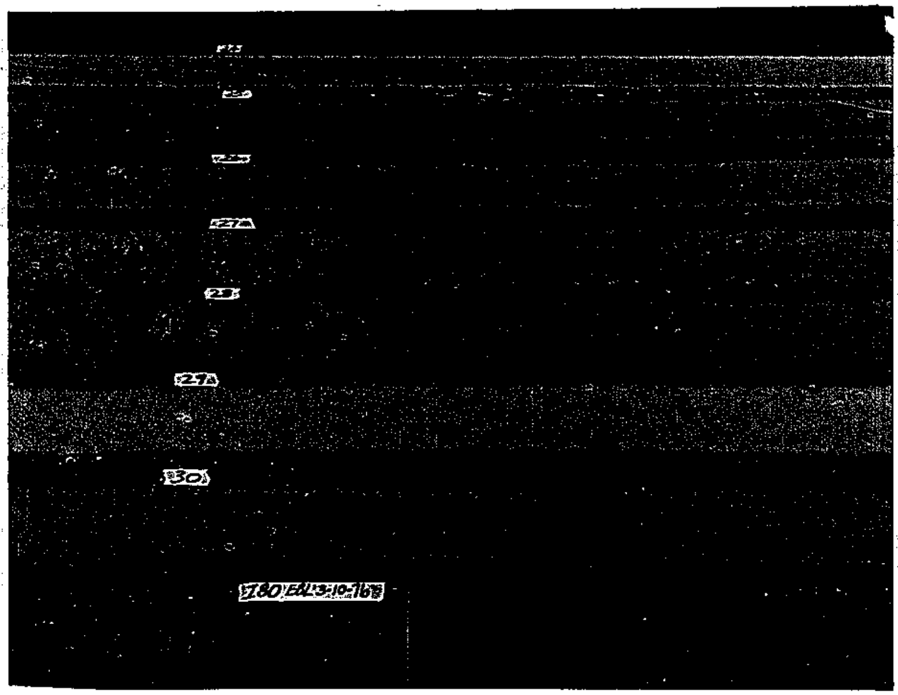

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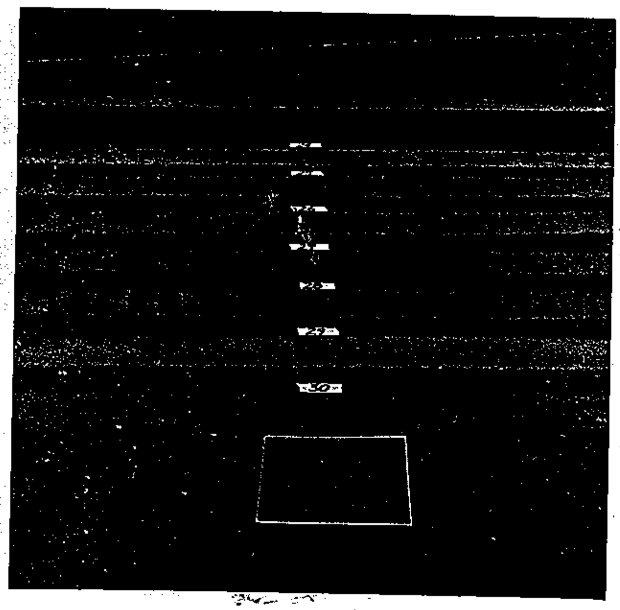

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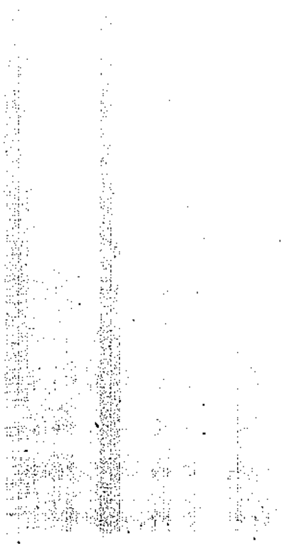

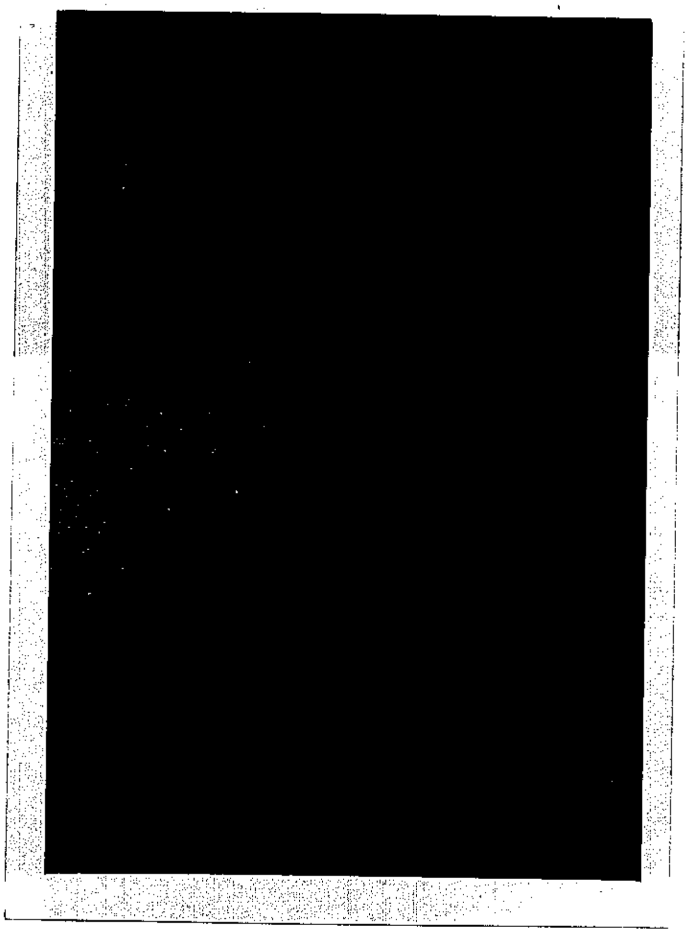

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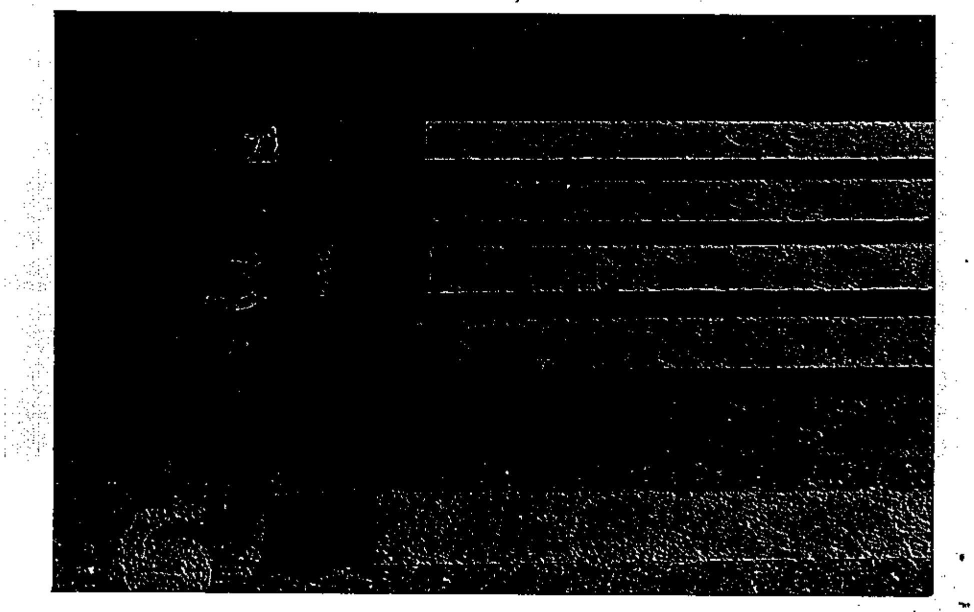

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