Report No. CDOH-DTD-R-90-4

PAVEMENT MARKING MATERIALS

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Final Report
July 1990

Prepared in cooperation with the
U.S. Department of Transportation
Federal Highway Administration

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Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
CDOH-DTD-R-90-4		

4. Title and Subtitle	5. Report Date
Pavement Marking Materials	July 1990
	6. Performing Organization Code: 1529A (90.11)
7. Author(s): Richard G. Griffin	8. Performing Organization Report No.: CDOH-DTD-R-90-4
9. Performing Organization Name and Address: Colorado Department of Highways, Division of Transportation Development, 4201 East Arkansas Avenue, Denver, CO 80222	10. Work Unit No. (TRAIS)
	11. Contract or Grant No.
12. Sponsoring Agency Name and Address: Colorado Department of Highways, 4201 East Arkansas Avenue, Denver, CO 80222	13. Type of Report and Period Covered: Final Report
	14. Sponsoring Agency Code

15. Supplementary Notes

Prepared in Cooperation with the U. S. Department of Transportation, Federal Highway Administration

16. Abstract

This is a final report for a study to review and evaluate the performance of pavement marking in Colorado. The report covers the performance of materials installed transverse to the road and panel review of several long-line striping projects with higher-type pavement marking. The transverse test deck included numerous brands of both permanent and removable grades of preformed plastic, extruded thermoplastic, epoxy paint, standard alkyd traffic paint, and fast dry alkyd traffic paint. These materials were applied on both asphalt and concrete.

Conclusions in this report are: 1. 100% solids epoxy paint is a durable marking material which outlasts numerous applications of standard alkyd traffic paint both on asphalt and concrete. 2. Catalyzed polyester paint seems to be unsuitable for the severe environment of Colorado Mountain interstate highways. 3. Extruded thermoplastic is a durable marking material, maintaining its retroreflectivity throughout its life when applied to asphalt. On the test deck on asphalt, the extruded thermoplastic's performance was equivalent to that of the better preformed plastics. When applied to concrete, however, extruded thermoplastic breaks up and debonds quickly.

Implementation Epoxy paint is now used statewide on rural interstate lane lines. Thermoplastic is not recommended on concrete pavement.

17. Key Words	18. Distribution Statement
Retroreflectivity, Mirolux, Alkyd Paint Epoxy Paint, Polyester Paint, Preformed Plastic, Extruded Thermoplastic	No Restrictions: This report is available to the public through the National Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	125	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

ACKNOWLEDGMENT

The author is most grateful to the following panel members for their review of the pavement markings in the field, and the review and input they had to this report.

Johan Bemelen
Staff Traffic Engineer
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I. INTRODUCTION

Pavement markings are exposed to severe punishment in many areas of Colorado. Heavy traffic, hard granite and silica based abrasives, and snow plowing down to the bare pavement place unusually high demands on pavement markings. Because of these severe conditions, even the use of the best marking materials means less than desirable delineation during some times of the year. Conversely, on some roadways in the state, the traffic volume is so low that the most basic and economical marking materials will serve adequately for several years. With the large variety of pavement marking material available today and the broad range of conditions to which they can be exposed, engineers are constantly struggling with selecting the most cost-effective material for a particular location.

The selection of the most cost-effective material is further complicated by the fact that even when traffic, environment, and winter maintenance is constant for a stretch of highway, the same pavement marking seems to perform better in some areas than in others. Almost every roadway has certain areas which receive more wear, more plowing, or more sand than the section 1/2 mile down the road. Pavement marking on high spots, in the middle of turns, and in shaded areas tends to experience more damage and wear.

Consequently, a pavement marking research program was established. The objectives of this program are:

1. To determine the most suitable, cost-effective pavement marking material for Colorado's streets and highways.

2. To establish a Colorado construction standard to provide design and maintenance personnel with a guide for selecting the pavement marking material to be used on any new construction, overlay, or restriping job.

3. To provide a continuous evaluation program that will accept new materials to be evaluated against material currently in use so that the use of improved striping material can be quickly assimilated into Colorado standards.

This report documents the installation and evaluation of a pavement marking transverse test section, established to systematically evaluate various pavement marking materials, and the pavement marking panel review of numerous long-line projects.

II. BACKGROUND

Various pavement marking systems are being evaluated in the pavement marking research program. A discussion of each type is included here as background for the reader. Further, it is also important that the reader understand the term "retroreflectivity" and the instruments used to measure it; therefore, a discussion on this subject is included. And, finally, discussion on the glass beads, which provide the retroreflectivity, is included.

A. PAVEMENT MARKING MATERIAL SYSTEMS

1. Epoxy Paint

The primary change in the pavement marking program in Colorado in recent years has been the use of 100% solids epoxy paint. This material is a two-part chemistry based on two parts of epoxy resin to one part epoxy hardener. The materials are mixed in a chamber just before they are sprayed onto the pavement followed by glass beads distributed by pressurized air. The epoxy is heated to 80 - 140 degrees Fahrenheit to improve flow and mixing and to accelerate the curing rate. The material is applied at 15 mils (15/1000 inches) with beads being blown on at the rate of 25 pounds per gallon or 0.20 pounds per square foot. Dry time depends on temperature and humidity but is typically 40 minutes to complete cure. Since this material is a 100% solid formulation there is practically no VOC (volatile organic compound) emissions, and the wet thickness is equivalent to the dry thickness. See Appendix A for Colorado's latest specification.

This epoxy formulation has been used successfully in other states including: Illinois, Wisconsin, Kentucky, Ohio, Iowa, New Mexico, Arizona, and Utah. Agent and Pigman[1] (1984) found the epoxy still had good retroreflectivity after two years of service but the gray-white appearance created a daytime contrast problem on concrete. H. Gillis of the Minnesota DOT indicated that the epoxy lasted over one year on a high-traffic roadway where conventional paint would only last three months (McGrath[2]).

2. Preformed Plastic

The use of preformed plastic has also increased in Colorado for both short term and permanent pavement marking. Permanent markings have been installed on new asphalt by laying the material in place just before the final pass of the compaction roller. Material installed by this process is referred to as inlaid preformed plastic, because it ends up partially embedded in the surface of the pavement. CDOH has experienced good performance with these inlaid preformed marking materials. They remain over 90% intact and in place after several years of service on freeways with over 100,000 vehicles per day. Performance has varied, somewhat, between different brands of preformed material.

Removable grades of preformed marking materials are also being employed through construction projects where detour or short-term markings on the final roadway surface are necessary. This allows removal of these short-term markings without permanently marring the final surface.

3. Hot-Applied Thermoplastic

Hot-applied thermoplastic, originally used for special marking requirements such as crosswalks and channeling markings, is now used extensively for long lines in Colorado. The material consists of a resin binder, intermixed glass beads, coloring agents and inorganic fillers. Although thermoplastic based on hydrocarbon resins are marketed, CDOH uses only alkyd-based thermoplastics: better historical performance has been the primary reason.

Thermoplastic can be extruded or sprayed onto the surface. The extrusion technique is used for thicker application requirement (125 mils) and the spraying method is used for the thinner applications (60-90 mils). Since the material is placed above 400 degrees F., it cools quickly and requires minimal protection from traffic. Drop-on beads are usually used to provide good initial retroreflectivity.

Thermoplastic is softer than epoxy and continuously wears down. This wear continuously exposes new intermixed beads and keeps the retroreflectivity high for this material throughout its life. Because the material is applied relatively thick (90 to 125 mils) as compared to paint (15 mils), it has a long life even though it wears down.

4. Polyester Paint

Polyester paint is based on polymerization of a resin triggered by a catalyst. Immediately after the catalyst is added to the resin, it is sprayed onto the pavement; the resin rapidly polymerizes to form a strong durable polyester. Beads are either dropped-on or pressure applied to the stripe. The catalyst, methyl ethyl ketone peroxide, is highly reactive and requires special equipment, such as a teflon-coated stainless steel tank. Fortunately, only 1 to 5 percent of the polyester system is the catalyst.

B. TERMINOLOGY

1. Retroreflectivity

Retroreflectivity is the ability of a surface to return light back in the same direction that it originally came from. In other words, if light incident on a surface at 10 degrees from horizontal returns back to the source, that surface is retroreflective. Retroreflectivity is differentiated from reflectivity in that a good mirror, although highly reflective, is a poor retroreflector because it does not return light back to the source except for light striking perpendicular to the surface.

Retroreflectivity is an important property for pavement markings and traffic signs because in unlit areas, light from the vehicle headlights must be returned to the driver's eyes for information transfer.

Retroreflectivity measurements do not have a universal standard like mass or distance. Instead, retroreflectivity depends on the geometry of the instrument used to measure it. Therefore, retroreflectivity numbers are meaningless unless the instrument or the geometry used to measure it is specified. Retroreflectivity of a surface can also depend on the color composition of the light used to measure it.

2. Reflectometers

For pavement marking, two portable industrial standard instruments have evolved in recent years: the Ecolux and the Mirolux 12. These two instruments are considered "fine geometry" instruments because of the large observation angle used which closely matches the geometry of a driver viewing pavement markings illuminated by headlights. Both instruments have a light source which shines on the test point at 86.5 degrees from perpendicular. The detector for the Ecolux senses light which returns from the surface one degree above the light source (85.5 degrees from perpendicular), while the Mirolux senses light returning 1.5 degrees above the source. For a typical passenger car with the headlights at 2.25 feet high and the drivers eyes 3.5 feet high, the geometry corresponds to the observation of pavement marking about 40 feet ahead of the vehicle. The Mirolux has a digital readout which, when calibrated, has absolute units of millicandelas per lux per square metre ($mcd/m^2/lux$). That is, the luminance of a surface, in millicandelas per square metre, when illuminated at a level of 1 lux.

Although no standards have been established for minimum retroreflectivity, Attaway[3] has determined, based on limited study in this area, that 100 $mcd/m^2/lux$ as measured by the Ecolux or 130 $mcd/m^2/lux$ as measured by the Mirolux 12 may be considered as a rough guide for a desirable level of retroreflectivity. This level is in the range used in European countries and corresponds to the findings of our evaluation panel.

The CDOH Beadreader was developed by the department in the late sixties and has been used over the years until commercially available machines were developed and acquired. It would be classified as a course-geometry instrument because it uses a small incident angle (77 degrees from normal). The Beadreader uses an arbitrary scale based on a standard beaded stripe on a board being equal to 250. Correlation studies between the beadreader and the Mirolux 12 resulted in Figure 1. Based on this correlation, a desirable value of 130 $mcd/m^2/lux$ as measured by the Mirolux 12, is equivalent to a value of 100 as measured by the CDOH

Beadreader. This is also consistent with departmental experience, that a reading of 100 with the Beadreader is a desirable minimum retroreflectivity.

Hoffman has found that the fine geometry instruments, such as the Ecolux and Mirolux, are important in determining embedment of the glass beads on new pavement marking. However, the coarse geometry instruments such as the Beadreader are effective in measuring the retroreflectivity loss over time as beads are displaced. One advantage of the Beadreader is that its thick soft gasket is much more effective at sealing out ambient light. Fine geometry instruments cannot use such a gasket because variations in the incident angle upon set down is much more critical. This soft gasket was a very definite advantage when measuring the retroreflectivity on our transverse marking materials on the rutted asphalt pavement. Therefore, even though the fine geometry instruments more closely approximate the driver/headlight configuration, the coarse geometry instruments still have an important part in pavement marking evaluation.

A correlation between different Mirolux 12 machines was also performed. Mirolux 12s borrowed from Inline Traffic Markings and FHWA were compared to the CDOH's Mirolux 12. The retroreflectivity data analysis, shown in Appendix B, shows good correlation between the FHWA and Inline Miroluxes. Correlation with CDOH's Mirolux is not so good with the CDOH Mirolux generally reading higher than the other two. These results led to the use of two Miroluxes late in the study.

C. GLASS BEADS

Until 1988, CDOH used AASHTO Type 2 glass beads on its epoxy paint. The Type 2 specification relates to certain requirements for refractive index, roundness, and range of sizes. See Appendix A for the AASHTO Type 2 specification. General practice for 20 years, has been to apply Type 2 beads at 6 pounds per gallon of paint applied at 15 mils wet. Before then, AASHTO Type 1 beads were more common. CDOH research[4] has found that the uniform and smaller gradation of the Type 2 flotation grade beads created a brighter stripe even at an application rate of only 4 pounds per gallon.

In 1988, several contracts were let based on a larger-bead specification. This specification was patterned after a specification written by the Utah DOT. Glass beads meeting this specification are available from many suppliers, for example, the Potters Industries PE-115 beads meet this specification. The larger beads were designed to provide the proper embedment* when used with epoxy with a 15-mil dry film thickness. The larger beads have the potential of protruding higher above the paint surface and may improve the retroreflectivity on wet pavements. Because they were particularly designed for epoxy paint, this gradation of glass beads will be referred to as <u>epoxy beads</u>.

Three specifications for bead sizes are as follows:

ASTM E-11 sieve #	size (mm)	size (mils)	AASHTO Type 1 % passing	AASHTO Type 2 % passing	epoxy beads (CDOH 1988) % passing
14	1.400	55.1			100
16	1.180	46.5			95-100
20	.850	33.5	100		10-50
30	.600	23.6	75-95	100	
40	.425	16.7		90-100	0-5
50	.300	11.8	15-35	50-75	
80	.180	7.1		0-5	
100	.150	5.9	0-5		

* Hoffman[5] demonstrated for a fine incident angle (85 to 90 degrees) the embedment is critical for good retroreflectivity. For embedment less than 50%, the contribution of retroreflectivity from the beads is nil. For embedment greater than 50%, retroreflectivity rises rapidly to a peak at 60% embedment and remains high until about 70% embedment.

III. PANEL REVIEW

A pavement marking review team was established for this research study to review and evaluate the in-service performance of new pavement marking materials. The primary direction of the team, up to this point, was to review the performance of 100%-solids epoxy and polyester paint. Some review of hot-applied thermoplastic, standard traffic paint, and preformed materials was included, although, for a standard reference.

The panel members were originally:

The Staff Traffic Engineer of CDOH, Johan Bemelen,
The Chemical and Bituminous Engineer of CDOH, Robert LaForce,
The Safety Research Engineer of CDOH, Charles Smith, and
The Assistant Engineering Coordinator of Colorado Division of FHWA, Maurice Mitchell.

Charles Smith subsequently retired and was replaced by Richard Griffin on the panel.

The panel reviewed the projects about twice a year, both during the day and at night. Table A summarizes the longline projects reviewed by this panel, while below is a discussion of each marking project reviewed and the findings of the panel.

A. EPOXY PAINT I-25 NEAR MONUMENT

Two-part 100% solids epoxy was installed on June 28, 1984 as the skip stripe on I25 between milepost 156.5 and milepost 163.4 both northbound and southbound. See Photo 1. This installation marked Colorado's first major project with epoxy. The installed price of the material including beads and traffic control was $1.26 per square foot. The material was installed at 15 mils with 25 pounds per gallon of Type 1 beads. The material served this area until the summer of 1987 when epoxy was applied again. Traffic volume on this road is 24,000 vehicles per day and requires numerous applications of salt and sand and plowing to control ice and snow.

TABLE A
PAVEMENT MARKINGS REVIEWED BY PANEL

HIGHWAY	LOCATION	MILEPOSTS	MATERIAL	GLASS BEADS	DATE INSTALLED	PAVEMENT TYPE	TRAFFIC* (vel/day)	LIGHTED ?	COMMENTS
I25	Monument	156 - 163	epoxy	type 1	6/84	asphalt	24,600	no	heavily plowed and sanded rural highway
I70	Genesee to East Vail	254 - 180 westbound	epoxy	type 2 flotation	10/84	asphalt	37,000-12,000	no	heavily plowed and sanded mountain highway
I70	East Vail to Genesee	180 - 254 eastbound	polyester	type 2 flotation	9/84	asphalt	12,000-37,000	no	heavily plowed and sanded mountain highway
I25	Colorado Springs	142 - 149	epoxy	type 2	8/84	asphalt	67,000	yes	urban freeway
I25	South Colo. Springs	135 - 142	epoxy	type 2	8/86	asphalt	44,000	yes	urban freeway
I76	Bromley Lane	22	epoxy	type 2	9/86	concrete	8,200	no	rural highway
Bromley Lane	at I76	-	epoxy	type 2	9/86	asphalt	n/a	no	rural road
I25	Fossil Crk.	260 - 265	epoxy	type 2	9/86	new concrete	25,000	no	rural highway
I25	Fossil Crk.	250 - 260	extruded thermo	type 1	9/86	new concrete	25,000	no	rural highway
I70	Morrison Rd. to East Vail	259 - 180	epoxy	epoxy	5/88	asphalt	42,000-12,000	no	heavily plowed and sanded mountain highway
I25	Castle Rock to Lincoln Ave.	182 - 193	epoxy	epoxy	8/88	asphalt	30,000	no	rural highway
I70	East Vail west	180 west	epoxy	type 2	8/87	asphalt	12,000	no	heavily plowed and sanded mountain highway
I70	East Vail east	180 east	epoxy	epoxy	6/88	asphalt	12,000	no	heavily plowed and sanded mountain highway
I25	Erie Exit north	234	extruded thermo	type 1	1981	asphalt	35,000	no	rural highway
I25	Brighton Exit south	227	preformed and extruded	- type 1	 1988	asphalt asphalt	40,000	no	rural highway

* Total vehicular traffic per day, both directions.

The material was reviewed in March of 1985 and judged to be in excellent condition and could easily serve through another winter.

A review in July of 1985 found the epoxy paint to be in good condition.

The material was evaluated on March 26, 1987. See Photo 2. Thirty percent of the material was still intact with fair appearance and a retroreflectivity of 90 as measured by the CDOH beadreader. The adjacent alkyd paint was only 20 percent intact with a retroreflectivity of 50 as measured by the CDOH beadreader and represents the eighth alkyd paint re-striping since the installation of the epoxy paint in 1984.

B. 1984 EPOXY PAINT ON I70 GENESEE TO EAST VAIL INTERCHANGE

Two-part 100% solids epoxy paint was applied on October 11th and 12th of 1984 on eastbound I70 from milepost 180 (East Vail Interchange) to milepost 254 Genesee Interchange). A four-inch wide stripe was placed between the existing skip stripes. See Photo 3. Installed cost without beads or traffic control was 54 cents per square foot. Beads supplied by CDOH (Type 2 flotation grade) were generally applied at 20 pounds per gallon. Traffic volume on this mountain interstate ranges from 11,000 to 31,000 vehicles per day.

Stripes produced with a bead rate of 10 pounds per gallon were compared to stripes produced with a bead rate of 20 pounds per gallon. No significant difference in the retroreflectivity was noted. Immediately after the epoxy installation the following readings were taken with the CDOH Beadreader:

white epoxy stripe with 10 pounds per gallon of glass beads	120
white epoxy stripe with 20 pounds per gallon of glass beads	125
white existing alkyd paint stripe	100

Reviewed in March of 1985, the epoxy paint was rated good with good nighttime visibility--much better than the standard paint that was still intact. On Floyd Hill the standard paint was nearly gone while the epoxy was still quite visible.

The markings were reviewed again in July of 1985 and judged to be in good condition.

The material was reviewed on February 28, 1986, after two winters of service, and its condition was quite variable with an overall average of 30% intact.

C. 1984 POLYESTER PAINT ON I70 GENESEE TO EAST VAIL INTERCHANGE

Polyester paint was applied on September 6 & 7, 1984 as the skip stripe on westbound I70 from milepost 180 to milepost 254 between the remains of the old skip stripes. See Photo 4. This area has heavy winter traffic and requires aggressive snow and ice control operations to service the 11,000 to 31,000 vehicles per day which travel westbound on I70.

The paint was placed 13 to 15 mils thick with 12 pounds per gallon of Type 2 beads primarily on old asphalt pavement. Cost of the polyester paint was 20.101 cents per square foot. CDOH provided the personnel, the beads, the spraying equipment, and traffic control. The material, placed in 75 degree weather, had a no-track time of 5 minutes and full-cure time of 20 to 30 minutes. Retroreflectivity measurements taken at milepost 246.5 with the CDOH beadreader averaged 245 for the new polyester skip stripe and 140 for the new standard alkyd traffic paint. On a stretch of new asphalt pavement (milepost 243) retroreflectivity of the polyester averaged 205 and that of the standard traffic paint averaged 80.

The polyester was reviewed on October 11, 1984, and, at milepost 243 the retroreflectivity was 140 and the adjacent paint stripe was also 140.

The panel evaluated the material during the daylight on November 14, 1984, and on December 12, 1984 at night. The performance was quite variable; however, with either day or night observation the polyester stripes appear to be performing slightly worse than the standard paint.

The March of 1985 review found the marking to be quite variable. But the standard paint was always brighter and more visible than the adjacent polyester paint. This was true for both day and nighttime observations. The polyester material was reviewed again in July of 1985 and judged to be in poor condition with most areas essentially gone--even less intact than the standard traffic paint.

D. EPOXY PAINT ON I-25 THROUGH COLORADO SPRINGS

100% solids epoxy was installed in the summer of 1985 as the skip stripe on I25 from Harrison Road north through Colorado Springs between both northbound and southbound lanes.

The "installed" bid price was $2.75 per square-foot, which included 24 pounds per gallon of Type 2 beads and traffic control. This material served this area until September of 1988 when epoxy was applied again using the larger epoxy beads. Traffic volume on this road reaches 45,000 and requires numerous applications of salt and sand and plowing to control ice and snow.

The material was evaluated on March 26, 1987 and found to be 80 to 85 percent intact with good appearance and good retroreflectivity (120 as measured by the CDOH beadreader). See Photo 5.

Evaluation on January 25, 1988 found the epoxy skip stripes to be 80 to 85 percent intact with fair appearance and a retroreflectivity of only 65 on the beadreader. This lower retroreflectivity may be partially due to dirty pavement markings. See Photo 6.

On February 27, 1989 the panel reviewed the 1988 epoxy and judged it to be 95% intact while the 1985 epoxy was 50% intact except in some weaving areas where the 1985 epoxy was completely gone.

Additional retroreflectivity measurements were taken on April 17, 1989 at milepost 139. See Photo 7. Because a highway contractor had the left lane closed for median work, we inspected from the left lane and we were also able to inspect and test the center edgeline which was 1988 epoxy.

The following readings were taken:

Description	Beadreader	Mirolux
Standard Board	250	390
1988 skip stripe #1	95,100,90	142,139,145
1988 skip stripe #2	95,100,105	125,131,135
1985 skip stripe	110,95,105,105	196,198,210,187
1988 yellow edgeline	105,100,110,110	183,194,196

The new skip stripe which is less than 1 year old has marginal retroreflectivity (based on a minimum desirable value of 100 with the beadreader and 130 with the Mirolux). The old stripe, 2 3/4 years old, has similar retroreflectivity as measured by the beadreader but significantly better retroreflectivity as measured by the Mirolux which more closely simulates the headlight-driver-marking geometry.

Upon magnified inspection of each stripe, we found that the new skip stripe had moderate bead damage. The old skip stripe had significant bead loss but many of the beads were still in place and in good condition. The new yellow edgeline was in excellent condition with most of the beads remaining in place and in good condition.

E. 1986 EPOXY PAINT ON I-25 THROUGH SOUTH COLORADO SPRINGS

100% solids epoxy was installed in the summer of 1986 as the skip stripes and edgeline on I25 between Academy Blvd. and Harrison Road in Colorado Springs (northbound and southbound). The material was placed at 15 mils with 24 pounds per gallon of drop-on Type 2 glass beads at an installed cost of $1.01 per square foot.

The material was evaluated on March 26, 1987 and found to be 95 percent intact with very good appearance. See Photo 8. Retroreflectivity was marginal in some areas (90) and good in others (120) as measured by the CDOH beadreader.

The evaluation on January 25, 1988 found dirty skip stripes which were 95 to 100 percent intact with good appearance and a marginal retroreflectivity of 95 to 100. See Photo 9.

This area was again reviewed on February 27, 1989 after a second application of epoxy paint occurred in the summer of 1988 between the skip stripes installed in 1986. The 1986 striping used standard Type 2 beads, while the 1988 striping used the new Colorado epoxy bead specification.

The 1988 epoxy was judged to be 95% intact while the 1986 epoxy was 75% intact. The Mirolux was used to measure retroreflectivity giving the following values: (the Colorado beadreader was not operating at this time)

1988 Epoxy Skip -- 82,87,83
1986 Epoxy Skip -- 117
1988 Edgeline -- 142,146
1986 Edgeline -- 91

This testing was the first encounter of the Type 2 beads, installed in 1986, being brighter than the epoxy beads installed in 1988. Instrument error was suspected and because the CDOH Beadreader was malfunctioning we had no check on the Mirolux. Later measurement of the 1985 epoxy just north of here confirmed the higher retroreflectivity of the older stripes.

F. 1986 EPOXY PAINT ON I76 AND BROMLEY LANE

Two-part 100% solids epoxy was installed in the early fall of 1986 on new concrete pavement on I76 (Photo 10) and new asphalt pavement on Bromley Lane (Photo 11). The epoxy was used for all the marking at this intersection: edgelines, skip stripes, stop bars, and railroad crossing markings. Cost for this marking installed was $1.00 per square foot, which includes all traffic control and materials. Bromley Lane has low traffic volume and I76 has moderate traffic volume (8000 vehicles per day) with moderate snow and ice control operations.

The material was evaluated by the study panel on March 26, 1987 and found to be 100% intact with good appearance. Retroreflectivity was good with readings of 120 to 150 on the CDOH beadreader. Adjacent alkyd traffic paint stripes were almost completely gone. See Photo 12.

Because the material had discolored slightly, resulting in poor daytime contrast on the concrete, it was painted over with fast-dry alkyd traffic paint during the fall of 1987. The fast-dry paint reduced the nighttime visibility (retroreflectivity) and was obvious at night because the stripe was much brighter where the fast-dry striping missed part of the epoxy stripe. Over time, the fast-dry paint wore down re-exposing the beads in the epoxy paint and retroreflectivity improved.

An evaluation on January 25, 1988 determined that the epoxy paint on Bromley Lane was 90 percent intact and had good appearance. See Photo 13. The white edgeline had good retroreflectivity (120 on the CDOH beadreader), while the yellow skip stripe had poor retroreflectivity (85). The stop bar retroreflectivity ranged from 80 to 110. The fast-dry alkyd paint over the epoxy skip stripes on I76 looked whiter than the uncovered epoxy. But, the uncovered epoxy had much higher retroreflectivity. Exposed epoxy was 115 and the fast-dry paint was only 70. The epoxy was estimated to be 85% intact under the fast-dry paint.

On February 17, 1989 the panel discovered that this site had an additional application of fast-dry paint since our review in January 1988. On I76 northeast of Bromley Lane, the urban fast-dry paint didn't entirely cover the epoxy skip stripes. This allowed continued evaluation of the epoxy paint at this site. Although the fast-dry was whiter than the epoxy its retroreflectivity is lower. Because of the wear pattern at MP 22, an area of pure paint and pure epoxy was difficult to find for retroreflectivity measurement. These reading, therefore, may not be very accurate.

The stop bar at Bromley Lane and the northwest off ramp of I76 was never painted over and was also examined, along with a section of the frontage road which was never open to traffic. Except for the stop bar the epoxy still had adequate retroreflectivity.

The following retroreflectivity readings were obtained on February 17, 1989.

Description	Mirolux	Beadreader
epoxy paint stop bar good site	-- 129,123	85,90
epoxy paint stop bar worn site	-- 109,106	70,75
epoxy skip MP 22 SB I76 on new concrete	-- 120,130,124	110
epoxy skip MP 23 SB I76 on older concrete	-- 221,220	125,150
epoxy edgeline MP 22 I76 on new concrete	-- 100,100,110	100
epoxy edgeline MP 23 I76 on old concrete	-- 223,150	115,115
fast-dry skip MP 22 I76 on new concrete	-- 99,135,136	100
fast-dry skip MP 23 I76 on old concrete	-- 92	80
epoxy frontage road no traffic white	-- 194,209,185	125,150,150,160
epoxy frontage road no traffic yellow	-- 212,217,200	130,130,130

The epoxy paint may still be 85% intact, but the fast-dry paint on top makes it difficult to judge. The epoxy paint further northwest, which was not over-striped with alkyd paint, was observed by the panel and found to have poor daytime visibility. The yellowing of the epoxy paint with age and the off-white color of concrete pavement results in weak contrast which leads to poor visibility. The epoxy stripes, however, were still quite visible at night.

G. 1986 EPOXY PAINT ON I-25 NEAR FOSSIL CREEK

100% solids epoxy was placed on new concrete from milepost 260 to milepost 265 southbound on I25 in the September of 1986. See Photo 14. The material, placed at 15 mils, had 24 pounds of Type 2 drop-on glass beads per gallon.

The material was evaluated on March 26, 1987 and found to be 100% intact, with excellent appearance, and good retroreflectivity (120-150 on the CDOH beadreader). The adjacent hot-applied thermoplastic (milepost 254 to 265), also placed in September of 1986 on new concrete, was only 80% intact, with good appearance, and high retroreflectivity of 170 (as measured by CDOH beadreader).

Nighttime review on May 4, 1987 reinforced the findings of the retro-reflectometer. The epoxy skip stripes were visible 120 to 160 feet ahead of the vehicle with the headlights on low beam, while the thermoplastic stripes were visible for 160 to 200 feet ahead of the vehicle.

The evaluation on January 25, 1988 determined that the epoxy was 90 percent intact and had a good appearance and retroreflectivity of 95 to 110 as measured by the beadreader. See Photo 15. The thermoplastic skip stripes were 80 percent intact and had fair appearance (Photo 16), but the thermoplastic edgeline was only 50 percent intact. See Photo 17. Retro-reflectivity of the thermoplastic was slightly higher than the epoxy at 120.

In the fall of 1988 epoxy was applied in this area between the thermoplastic skip stripes and over the 1986 epoxy skip stripes. The evaluation on February 27, 1989 revealed that the thermoplastic skip stripes were from 0 to

50% intact with poor appearance. However, the pieces of thermoplastic that were still intact had good nighttime visibility. The thermoplastic edgeline was almost completely gone (10% intact). The portion of 1986 epoxy that was not over-striped with epoxy in 1988 had fair appearance and was 85% intact.

At this time, the following measurements were taken:

	Mirolux	Beadreader
1986 thermoplastic skip stripe	182,194	125,130
1988 epoxy skip stripe	118-124	80-85

The nighttime review on February 27, 1989, of this location indicated good visibility of the 1988 epoxy skip stripe and the 1986 thermoplastic skip stripe where it was still intact. The skip stripes were visible 240 to 280 feet ahead of the vehicle operating with its headlights on low beam. This is consistent with the retroreflectivity readings.

H. 1988 EPOXY PAINT ON I70 MORRISON ROAD TO EAST VAIL INTERCHANGE

This area was re-striped in May of 1988. The epoxy beads were used for most of the project at the rate of 24 pounds per gallon. A panel placed under the paint gun on May 4th, with the bead flow stopped, revealed an uneven distribution of epoxy material. The center 2 3/4 inches was 24 mils thick with a 6-mil thickness on each side about 3/8 inch wide and a 12 mil thickness on the outer edges of the line.

Retroreflectivity readings were taken at several locations along the project using the Mirolux 12 owned by In-Line. At the east end of the project, Mirolux values for the new epoxy, westbound, right skip stripe were 425 to 435. Mirolux readings of 160 and 180 were found on the adjacent yellow and white alkyd paint, respectively.

On May 5th, an experimental edgeline was placed on the outside shoulder of I70 westbound starting at the Genesee interchange and extending west. For this edgeline, a double bead drop system was devised so that 12 pounds per gallon of a very large bead (Potter's E16 glass beads) would be dropped on the edgeline followed by an application of AASHTO Type 2 beads at 12 pounds per gallon. See Photo 19. These dramatically different sized beads cannot be mixed, stored, and dropped together because they tend to segregate. There was no problem of the non-uniform line thickness and the line placement went smoothly with an excellent line being placed. It is believed that the continuous flow of epoxy helped prevent the non-uniformity across the stripe. Stopping and starting the paint flow for the skip stripes seemed to create this non-uniformity problem. Upon close inspection of the edgeline, the large beads were well embedded; however, the smaller Type 2 beads were submerged in the epoxy and only visible with a magnifying glass. The edgeline had a uniform thickness of 22 to 24 mils without beads. When the large beads were used up, edgeline beading continued with just Type 2 beads at the rate of 24 pounds per gallon from the El Rancho interchange to just east of the Dumont interchange.

The project was reviewed the afternoon and evening of May 5, 1988. Retroreflectivity measured by CDOH's new Mirolux 12 and CDOH's old beadreader were obtained as follows:

Location	Mirolux 12	Beadreader
MP251 WB white epoxy edgeline Type 2 beads	259	110
MP251 WB yellow alkyd paint edgeline	260	160
MP251 WB white epoxy skip epoxy beads	432	270
MP252 WB white epoxy edgeline double drop beads	311	150
MP252 WB yellow alkyd paint edgeline	291	160
MP252 WB white epoxy skip epoxy beads	368	165

The nighttime review revealed a dark spot in the middle of the stripe beaded with Type 2 beads. The extra thickness of the material in the middle of the line submerged the tiny Type 2 glass and reduced the line's nighttime visibility.

Retroreflectivity readings were again taken on this project on May 25, 1988 with the following results:

Location	Mirolux 12	Beadreader
MP252 EB white epoxy edgeline Type 2 beads	261	160
MP252 EB yellow alkyd paint edgeline	210	110
MP252 EB white epoxy skip epoxy beads	212	120
MP252 WB white epoxy edgeline double drop beads	246	125
MP252 WB yellow alkyd paint edgeline	282	150
MP252 WB white epoxy skip epoxy beads	270	145

The March 7, 1989 review (Photo 20) found the standard alkyd edgeline only 40% intact while the epoxy edgeline was 90% intact. Magnified examination revealed no beads left in the alkyd paint and extensive bead damage in the epoxy paint. Four different conditions existed in different locations in the epoxy paint:

1. The epoxy was scraped flat (probably by a snowplow blade) and the beads were sheared off.

2. The beads were missing, leaving little holes behind.

3. The beads were cracked and broken-up in place.

4. The beads were so deep in the epoxy they were protected from damage, but were too deep to provide a significant amount of retroreflectivity.

As a result of these phenomena, retroreflectivity of both the edgeline and skip stripes were low as evidenced in the following readings:

Location	Mirolux 12	Beadreader
MP252 EB white epoxy edgeline Type 2 beads	137	108
MP252 EB alkyd paint edgeline	81	88
MP252 EB white epoxy skip epoxy beads	86	88
MP252 WB white epoxy edgeline double drop beads	88	95
MP252 WB yellow alkyd paint edgeline	80	100
MP252 WB white epoxy skip, epoxy beads	90	100
MP251 WB white epoxy edgeline, Type 2 beads	102	98
MP251 WB white epoxy skip stripe, epoxy beads	90	100
MP238 WB white epoxy edgeline, Type 2 beads	103	97

During nighttime review on March 7, 1989, the panel noted that the old alkyd paint stripes were occasionally visible but disappeared completely wherever traffic regularly drove over the stripe. Further, the edgeline visibility was slightly better than the skip stripe near MP252 where the epoxy edgeline was applied with standard Type 2 beads. No brightness change was observed between the double drop edgeline and the Type-2-beaded edgeline.

The project was again reviewed on May 10, 1989 when the pavement marking was much cleaner due to a recent rainstorm. Magnified inspection of the stripes indicated that the large beads were badly damaged with only the broken-up bottom half of each bead remaining.

The following readings were obtained:

Location	Beadreader	Mirolux CDOH	Mirolux (Inline's)
MP252 EB white epoxy edgeline Type 2 beads	105	157	80
MP252 EB white epoxy skip, epoxy beads	112	176	92
MP252 WB white epoxy edgeline double drop beads	103	160	70

J. I25 CASTLE ROCK NORTH TO LINCOLN AVENUE

This area, reviewed by the panel on February 27, 1989, represents Colorado's first test of applying epoxy over old epoxy without removal. The first layer of epoxy was placed in 1986 and 1987 and the second layer was placed in the summer of 1988. The stripe appeared to be in good shape, better than 95% intact with no indication of bonding problems.

K. I70 AT EAST VAIL INTERCHANGE, MILEPOST 180

This site was examined to investigate the performance of Type 2 versus epoxy beads and to verify the findings in Colorado Springs on I25 and on I70 near the Buffalo Herd Overlook. This site was unique because it has end to end sections of epoxy with Type 2 beads and epoxy with epoxy beads. The skip stripe from this point west was 100% solids epoxy installed in the summer of 1987 with Type 2 glass beads, while the skip stripe from here east is 100% solids epoxy installed in late spring of 1988 with epoxy beads.

In the eastbound lanes, magnified inspection of these stripes revealed damage to the epoxy beads and the following retroreflectivity measurements were taken at this time:

Description	Beadreader	Mirolux (CDOH's)	Mirolux (Inline's)
Standard Board	250	376	322
1988 skip stripe Utah spec	125,130,115 120,120	171,176, 162,164	102,97, 101,91
1987 skip stripe Type 2	130,120, 135,130	162,162,173 178,182	94,102, 106,110

Both types of beads have similarly good retroreflectivity, although the Type 2 beads are one year older.

In the westbound lanes from milepost 180 west, the existing 1987 epoxy has been over-striped with epoxy with Utah spec. beads in the fall of 1988. There is no evidence of debonding between the new and old epoxy and it appears that new epoxy bonds well to old epoxy which is at least one year old.

The epoxy beads in this stripe, however, are also damaged with the tops broken off most of them. The following retroreflectivity values were obtained:

Beadreader	Mirolux (CDOH's)	Mirolux (Inline's)*
125,120, 110,110	176,180 200,165	92,129, 127,115

Retroreflectivity of this stripe is slightly higher than the other 1988 and 1987 stripes.

The good retroreflectivity of all the markings has a lot to do with their cleanliness. Even the broken-up beads provide retroreflectivity when they are very clean.

L. I25 SOUTHBOUND MILEPOST 234

This area north of the Erie exit reviewed by the panel on February 27, 1989, has extruded thermoplastic that was installed on a new asphalt overlay 8 years ago. The skip stripes still have good nighttime visibility of 200 feet with the headlights on low beam. There were occasional dark spots in the skip stripes which weren't apparent during the day. This may be caused by buried or damaged beads.

M. I25 SOUTHBOUND MILEPOST 227

This area just south of the Brighton exit reviewed by the panel on February 27, 1989, had preformed thermoplastic installed during the overlay. Extruded thermoplastic was used to repair the pavement marking in 1988. Because the pavement was slightly wet at this time, the preformed material was almost invisible here but the repair spots of extruded thermoplastic could be seen over 150 feet ahead of the vehicle.

N. PANEL CONCLUSIONS

The epoxy paint appears to be a good pavement marking system which can out last several applications of standard traffic paint, with adequate nighttime visibility when clean. The slight discoloration which occurs, however, can create a problem with daytime appearance on concrete roadways. The daytime appearance was enough of a problem to require over-striping with alkyd paint on I76.

Based on several observations by the panel on numerous projects, epoxy placed over epoxy, with one year or more of wear, bonds well.

The epoxy beads do not improve the dry retroreflectivity over that obtained from Type 2 beads. (In the case of I25 in Colorado Springs, the epoxy beads performed worse than the older Type 2 beads.) The epoxy beads do improve the nighttime visibility in the center of the stripes, eliminating the problem of the sunken beads.

Polyester paint appears to be unsuitable for the severe environment of our high traffic mountain interstate, failing to perform as well as our standard alkyd traffic paint.

Hot-applied thermoplastic, provided good nighttime visibility, but tends to break up and chip off when applied to concrete.

IV. TRANSVERSE PAVEMENT MARKING TEST SITE

A test site was established to test various pavement marking systems on I70 just east of Bennett, Colorado. This site, with a transition from asphalt pavement to concrete pavement, was chosen because pavement marking performance on both asphalt and concrete could be tested at one convenient location. Pavement markings were placed transverse to traffic to ensure equal traffic over each material. Average daily traffic here is 3310 passenger cars, 215 single unit trucks, and 775 combination trucks. Because this is a rural location, 75% of the traffic is expected to be travelling in the right lane where the transverse stripes were located.

The materials consisted of: standard traffic paint, fast-dry traffic paint, epoxy paint, hot-applied thermoplastic, and preformed plastic material from various vendors (both permanent and removable grades). Each material was applied to both the concrete pavement and the asphalt pavement. The test site was established to: 1) determine the relative performance of various marking systems as an aid in selecting the most cost-effective type of marking material, and 2) determine the relative performance of different brands of preformed plastic material for acceptance of these materials on projects and for maintenance procurement.

A. INSTALLATION

Material placement was accomplished in two sessions. The first application session was on June 23, 1987 when most of the preformed material was placed. During the second session on July 31, 1987, the Prismo preformed material was placed along with the paints (standard, fast-dry, and epoxy) and the hot-applied thermoplastic. All preformed materials and the hot-applied thermoplastic were provided by the manufacturers at no cost. Table B describes the materials that were placed.

When state forces installed the tape, manufacturer's recommended installation procedures were followed. And, when manufacturer's representatives were present, state forces helped with the installation by following the

TABLE B
MATERIALS AT TEST SITE
page 1 of 4

stripes	Acronym	Color	primer used?	Description
Asphalt section 1 (Pavemark) installed by state force on 6/23/87				
1-3	Pavemark	yellow	yes	preformed permanent grade
4-5	Pavemark	white	yes	preformed permanent grade
longit.	Pavemark	white	yes	preformed permanent grade
***Asphalt section 2 (Swarolite) installed by state forces on 6/23/87				
1-3	Swarolite	yellow	yes	preformed permanent grade
4-5	Swarolite	white	yes	preformed permanent grade
6-8	Swarolite	yellow	no	preformed removable grade
9-10	Swarolite	white	no	preformed removable grade
longit.	Swarolite	white	yes	preformed permanent grade
***Asphalt section 3 (Seibulite) installed by manufacturer rep. on 6/23/87.				
1-3	Seibulite	yellow	yes	preformed permanent grade
4-5	Seibulite	white	yes	preformed permanent grade
longit.	Seibulite	white	yes	preformed permanent grade
***Asphalt section 4 (Volare) installed by manufacturer rep. on 6/23/87.				
1-3	Volare	yellow	yes	preformed permanent grade
4-5	Volare	white	yes	preformed permanent grade
longit.	Volare	white	yes	preformed permanent grade
***Asphalt section 5 (Cataphote) installed by state forces on 6/23/87.				
1-3	Cataphote	yellow	no	preformed removable grade
4-8	Cataphote	white	no	preformed removable grade
9-12	Cataphote	yellow	no	preformed permanent grade
13-16	Cataphote	white	no	preformed permanent grade
17-18	Cataphote	yellow	yes	preformed permanent grade
19	Cataphote	white	yes	preformed permanent grade
longit.	Cataphote	white	yes	preformed permanent grade
***Asphalt section 6 (P.B. Laminations) installed by state force on 6/23/87.				
1-6	P.B lam.	white	no	preformed removable grade
***Asphalt section 7a (3M) installed by manufacturer rep. on 6/23/87.				
1-2	3M-std.	yellow	yes	preformed perm. grade Stamark 5731
3-5	3M-std.	white	yes	preformed perm. grade Stamark 5730
longit.	3M-std.	white	yes	preformed perm. grade Stamark 5730
***Asphalt section 7b (3M) installed by manufacturer rep. on 6/23/87.				
1-3	3M-350	yellow	yes	preformed perm. grade Stamark 350
4-5	3M-350	white	yes	preformed perm. grade Stamark 350
longit.	3M-350	white	yes	preformed perm. grade Stamark 350
***Asphalt section 7c (3M) installed by manufacturer rep. on 6/23/87.				
1-4	3M	yellow	no	preformed removable grade
5-8	3M	white	no	preformed removable grade

TABLE B
MATERIALS AT TEST SITE
page 2 of 4

stripes	Acronym	Color	primer used?	Description
***Asphalt section 8 (Prismo) installed by manufacture rep. on 7/31/87.				
1-2	Prismo*	yellow	yes	preformed permanent grade with liner
3	Prismo	white	yes	preformed permanent grade with liner
4	Prismo	yellow	no	preformed permanent grade with liner
lognit.	Prismo	white	?	preformed permanent grade with liner
6-9	Prismo	yellow	no	preformed removable grade
10-13	Prismo	white	no	preformed removable grade
14-15	Prismo	yellow	no	preformed permanent grade linerless
16-17	Prismo	white	no	preformed permanent grade linerless
18-19	Prismo	yellow	yes	preformed permanent grade linerless
20-21	Prismo	white	yes	preformed permanent grade linerless
***Asphalt section 9 (Paint) installed by state forces on 7/31/87.				
1-2	Alkyd-std.	white	no	CDOH spec. alkyd traffic paint
3-4	Alkyd-std.	yellow	no	CDOH spec. alkyd traffic paint
5	Fast-dry	white	no	CDOH spec. fast-dry alkyd traffic paint
6	Fast-dry	yellow	no	CDOH spec. fast-dry alkyd traffic paint
7	Epoxy	white	no	CDOH spec. 100%-solids epoxy
8	Epoxy	yellow	no	CDOH spec. 100%-solids epoxy
***Asphalt section 10 (Thermo) installed by manufacturer rep. on 7/31/89.				
***hot-applied thermoplastic, extruded at 125 mills thick.				
1-4	Thermo-w	yellow	yes	Pavemark with drop-on beads
5	Thermo-w/o	yellow	yes	Pavemark without drop-on beads
6-9	Thermo-w	yellow	res	Pavemark with drop-on beads
10	Thermo-w/o	yellow	yes	Pavemark without drop-on beads
11-14	Thermo-w	yellow	yes	Pavemark with drop-on beads
15	Thermo-w/o	yellow	yes	Pavemark without drop-on beads
16-19	Thermo-w	yellow	yes	Pavemark with drop-on beads
20	Thermo-w/o	yellow	yes	Pavemark without drop-on beads
21-24	Thermo-w	white	yes	Pavemark with drop-on beads
25	Thermo-w/o	white	yes	Pavemark without drop-on beads
26-29	Thermo-w	white	yes	Pavemark with drop-on beads
30	Thermo-w/o	white	yes	Pavemark without drop-on beads
31-34	Thermo-w	white	yes	Pavemark with drop-on beads
35	Thermo-w/o	white	yes	Pavemark without drop-on beads
36-39	Thermo-w	white	yes	Pavemark with drop-on beads
40	Thermo-w/o	white	yes	Pavemark without drop-on beads

* Prismo is now Linear Dynamics Inc.

TABLE B
MATERIALS AT TEST SITE

stripes	Acronym	Color	primer used?	Description
Concrete section 1 (Pavemark) installed by state force on 6/23/87				
1-3	Pavemark	yellow	yes	preformed permanent grade
4-5	Pavemark	white	yes	preformed permanent grade
longit.	Pavemark	white	yes	preformed permanent grade
***Concrete section 2 (Swarolite) installed by state forces on 6/23/87				
1-3	Swarolite	yellow	yes	preformed permanent grade
4-5	Swarolite	white	yes	preformed permanent grade
6-9	Swarolite	yellow	no	preformed removable grade
10-13	Swarolite	white	no	preformed removable grade
longit.	Swarolite	white	yes	preformed permanent grade
***Concrete section 3 (Volare) installed by manufacturer rep. on 6/23/87.				
1-3	Volare	yellow	yes	preformed permanent grade
4-5	Volare	white	yes	preformed permanent grade
longit.	Volare	white	yes	preformed permanent grade
***Concrete section 4 (Cataphote) installed by state forces on 6/23/87.				
1-2	Cataphote	yellow	yes	preformed permanent grade
3	Cataphote	white	yes	preformed permanent grade
4-7	Cataphote	yellow	no	preformed removable grade
8-11	Cataphote	white	no	preformed removable grade
longit.	Cataphote	yellow	yes	preformed permanent grade
***Concrete section 5 (P.B. Laminations) installed by state force on 6/23/87.				
1-6	P.B lam.	white	no	preformed removable grade
***Concrete section 6a (3M) installed by manufacturer rep. on 6/23/87.				
1-3	3M-std.	yellow	yes	preformed perm. grade Stamark 5731
4-5	3M-std.	white	yes	preformed perm. grade Stamark 5730
6-8	3M-std.	yellow	yes	preformed perm. grade Stamark 5731
9-10	3M-std.	white	yes	preformed perm. grade Stamark 5730
longit.	3M-std.	white	yes	preformed perm. grade Stamark 5730
11-13	3M-350	yellow	yes	preformed perm. grade Stamark 350
14-15	3M-350	white	yes	preformed perm. grade Stamark 350
longit.	3M-350	white	yes	preformed perm. grade Stamark 350
***Concrete section 6b (3M) installed by manufacturer rep. on 6/23/87.				
1-4	3M	yellow	no	preformed removable grade
5-8	3M	white	no	preformed removable grade
***Concrete section 7 (Seibulite) installed by manufacturer rep. on 6/23/87.				
1-3	Seibulite	yellow	yes	preformed permanent grade
4-5	Seibulite	white	yes	preformed permanent grade
longit.	Seibulite	white	yes	preformed permanent grade

TABLE B
MATERIALS AT TEST SITE
page 4 of 4

stripes	Acronym	Color	primer used?	Description
***Concrete section 8 (Prismo) installed by manufacture rep. on 7/31/87.				
1-2	Prismo*	white	yes	preformed permanent grade
3-4	Prismo	yellow	yes	preformed permanent grade
5-7	Prismo	yellow	yes	preformed permanent grade
8	Prismo	white	yes	preformed permanent grade
9	Prismo	white	no	preformed permanent grade
10-13	Prismo	yellow	no	preformed removable grade
14-17	Prismo	white	no	preformed removable grade
18-19	Prismo	yellow	yes	preformed permanent grade
20-21	Prismo	white	yes	preformed permanent grade
lognit.	Prismo	white	yes	preformed permanent grade
***Concrete section 9 (Paint) installed by state forces on 7/31/87.				
1-2	Alkyd-std.	white	no	CDOH spec. alkyd traffic paint
3	Alkyd-std.	yellow	no	CDOH spec. alkyd traffic paint
4	Fast-dry	white	no	CDOH spec. fast-dry alkyd traffic paint
5	Fast-dry	yellow	no	CDOH spec. fast-dry alkyd traffic paint
6	Epoxy	white	no	CDOH spec. 100%-solids epoxy
7	Epoxy	yellow	no	CDOH spec. 100%-solids epoxy
***Concrete section 10 (Thermo) installed by manufacturer rep. on 7/31/89.				
***hot-applied thermoplastic, extruded at 125 mills thick.				
1-3	Thermo-w	yellow	yes	Pavemark with drop-on beads
4	Thermo-w/o	yellow	yes	Pavemark without drop-on beads
5-8	Thermo-w	yellow	yes	Pavemark with drop-on beads
9	Thermo-w/o	yellow	yes	Pavemark without drop-on beads
10-13	Thermo-w	yellow	yes	Pavemark with drop-on beads
14	Thermo-w/o	yellow	yes	Pavemark without drop-on beads
15-18	Thermo-w	yellow	yes	Pavemark with drop-on beads
19	Thermo-w/o	yellow	yes	Pavemark without drop-on beads
20-23	Thermo-w	white	yes	Pavemark with drop-on beads
24	Thermo-w/o	white	yes	Pavemark without drop-on beads
25-28	Thermo-w	white	yes	Pavemark with drop-on beads
29	Thermo-w/o	white	yes	Pavemark without drop-on beads
30-33	Thermo-w	white	yes	Pavemark with drop-on beads
34	Thermo-w/o	white	yes	Pavemark without drop-on beads
35-38	Thermo-w	white	yes	Pavemark with drop-on beads
39	Thermo-w/o	white	yes	Pavemark without drop-on beads
longit.	Thermo-w	white	yes	Pavemark with drop-on beads
longit.	Thermo-w/o	white	yes	Pavemark without drop-on beads

* Prismo is now Linear Dynamics Inc.

representative's instructions. Extensive brooming was always used to clean the surface and, depending on manufacturer's recommendation, a primer was used for the permanent grade materials.

All the paint stripes were installed by pouring the paint ahead of a drawdown bar calibrated for a 15 mil wet film thickness. This procedure accounted for the sloppy appearance of the stripes, but the proper application thickness was assured. Fifteen-mil wet film thickness results in approximately 8-mil dry thickness for the alkyd paints and, since the epoxy is 100%-solids, 15-mil dry thickness for the epoxy.

Type 2 beads were dropped on with a hand-operated spreader. This procedure worked well except for the fast-dry paint which dried faster on the 140-degree pavement than we could apply the beads.

B. EVALUATION PROCEDURE

Evaluation of the materials involved photographing each section, estimating percent material intact, and measuring retroreflectivity on a regular basis. Removable materials were further evaluated by removing one-half stripe off each section during each visit. The ease of removal was recorded together with a note on any stain left behind on the pavement.

Evaluation sessions were held on a monthly basis until the first winter after installation. A three to five month schedule was followed after that. The primary reason for the monthly evaluations was to test the removability of the removable materials. Once the normal needed service life of removable material had passed, monthly evaluations were no longer necessary. The evaluation sessions were as follows:

July 31, 1987
August 27, 1987
September 25, 1987
November 4, 1987
December 21, 1987
March 29, 1988
April 10, 1988
August 23, 1988
October 21, 1988
March 8, 1989

Retroreflectivity measurements were initially made with the CDOH beadreader. In late March of 1988, a Mirolux 12 was procured and after that time both beadreader and Mirolux retroreflectivity readings were taken. The first set of readings with the Mirolux on April 10, 1988 were discarded because of reading errors caused by inexperience with this new machine and the rutted pavement encountered. Ambient light leaking into the Mirolux cavity between the pavement and the seal was probably the cause of the problem. The use of a black veil was established later to guard against light leakage.

C. ANALYSIS OF DATA

The data analysis was divided into two parts: analysis of materials intended for temporary use and analysis of materials intended for permanent use.

1. Removable Pavement Marking Materials

Removable preformed marking materials is a class of pavement markings which is intended to be used a few months for construction detour marking and then removed without leaving any significant mark on the pavement which may confuse the driver. Aside from the features of durability, appearance, and retroreflectivity, these removable materials must be easily removed and not leave permanent marks on the pavement. Paint, although it probably doesn't have the service life of the removable materials, is intended for permanent marking and is, therefore, not included in this section of the analysis.

Although some testing of the removable materials occurred on through 1988, the data analysis was stopped after March 29, 1988. The material is intended only for temporary use; therefore, its performance after nine months of service is seldom relevant.

During each evaluation session, one-half stripe of each brand of removable material was removed from the pavement by a panel member. A qualitative judgement of how strong a pull was required for removal was noted. Any tearing which occurred during the pull was also noted. Materials which do not remain in one piece during the removal require additional time and handwork.

Any stain which was left by the material was then noted. If stains were still evident from previous removal sessions, they were also noted.

a. Retroreflectivity results

Figure 2 through 5 are plots of the retroreflectivity of each removable material throughout the test period. The retroreflectivity is quite variable over the period of the test and tends to go down for all materials when exposed to long dry periods when dirt accumulates and then recovers after a rain. Values for yellow stripes tend to be lower than those for the white stripes. Yellow materials that maintain high retroreflectivity may not be indicative of quality but may indicate, in some cases, a fading of the yellow color to white. A faded yellow material would be more retroreflective than an unfaded yellow material. Because of this phenomenon, estimation of the performance of the materials should be based on the white retroreflectivity rather than the yellow.

(1) Performance on concrete

During the final test session, the results were reasonably close together with all the materials being within a value of 20 of each other using the beadreader. Only one material was below the value of 100 at this time. It should be noted, however, none of the materials stayed above 100 throughout the entire test period. However, Cataphote came closest to maintaining this level, with only one reading below 100. The 3M removable material had the worst record, having beadreader values below 100 on four separate occasions--one reading was down to 50. Accumulated dirt may be the primary cause.

(2) Performance on asphalt

The retroreflectivity of the markings on asphalt generally stayed above 100 for most of the test. For the last test, two of the materials were above 100 and two were below it. Cataphote remained above the 100 for the entire test period and PB Laminations dipped only slightly below the 100 mark.

b. Durability results

Durability was determined by measuring the percentage remaining in place upon each test session. The final percent intact and the photos are good indicators of the durability of these materials.

(1) Durability on concrete

All the materials remained 99 percent intact on March 29, 1988 (end of test for removable materials) except for the 3M removable grade which had significant losses resulting in being only 70% intact. See Photos 21 through 25. Because these removable grade markings are intended to be temporary, it's interesting to look back at the condition of the 3M material during earlier evaluation sessions. During the fall evaluation (11/21/87), the 3M material was about 95 percent intact, (Photo 26) indicating that most of the loss occurred over the winter. The 3M removable material, therefore, is suitable for a shorter period of time and may not be suitable for winter time use on concrete.

(2) Durability on asphalt

Upon a return trip one day after the installation (6/24/87), damage to three removable grade materials was noted. Two of the Swarolite stripes were torn and pulled up, one Cataphote stripe was torn in half, and all the P.B. Laminations material was pulled up--totally destroying this section. This failure was not the fault of the material, but of the placement errors. The ends of the material were picked up and trimmed with a pair of scissors and never re-rolled. New PB Laminations material was installed on 7/23/87.

All the materials on asphalt that remained after 7/23/87, remained 98% intact or better except for the Swarolite material which was 90% intact. Most loss of the Swarolite occurred between the installation on June 23, 1987 and the first evaluation session on July 21, 1987. Skid marks indicated that a truck skidded across the Swarolite material, ripping off about 9% of the material. Since almost no material was lost after this episode, Swarolite removable should be included in the ranks of the other materials as far as durability is concerned. Photos 26 through 30 show the condition of the material on 3/29/88.

c. Removability results

One important feature of the removable marking materials is the ease which it can be removed without leaving any scar or stain. To test this feature, 1/2 a stripe was removed during each evaluation session. The pull needed to remove the stripe, any tearing that occurred during the pull, and any staining that remained was noted each time.

(1) Removability on concrete

The results of the removability test for concrete are listed below.

Material	Date	Pull	tearing	staining
Swarolite	8/27/87	easy	none	none
	9/25/87	medium	none	slight
	11/5/87	easy	none	slight
	3/29/88	moderate	once	slight stain remains from previous 2 pulls
Cataphote	8/27/87	hard	none	slight
	9/25/87	hard	none	significant
	11/5/87	hard	none	slight
	3/29/88	hard	twice	
P.B. Laminations	8/27/87	moderate	none	slight
	9/25/87	moderate	none	slight
	11/5/87	hard	thru WPs	slight
	3/29/88	hard	thru WPs	
3M	8/27/87	hard	none	slight
	9/25/87	easy	none	slight
	11/5/87	moderate	thru RWP	slight
	3/29/88	hard	extensive	
Prismo	8/27/87	{permanent grade removed by mistake}		
	9/25/87	easy	none	slight
	11/5/87	easy	none	slight
	3/29/88	easy	edge tears	

The panel found that removal was much more difficult for most materials on 3/29/88 than during previous removal sessions, with none of the materials coming off in one piece. On 11/5/87 the 3M material tore only once and the PB Laminations material tore in each wheel path, while the rest of the materials did not tear at all. On the other side, the Swarolite material was able to be removed in only two pieces on 3/29/88.

In summary, all materials were adequately removable from concrete through 11/5/87 (4 plus months of service). Conversely, Swarolite and Cataphote were adequately removable on 3/29/88 while PB Laminations, 3M, and Prismo were not.

(2) Removability on asphalt

The removability of the materials on asphalt are listed below.

Material	Date	Pull	tearing	staining
Swarolite	8/27/87	easy	none	none
	9/25/87	very hard	in WP	slight to severe
	11/5/87	very hard	extreme	moderate
	3/29/88	moderate	none	slight stain remains from last pull
Cataphote	8/27/87	moderate	none	none
	9/25/87	hard	none	moderate
	11/5/87	hard	none	slight
	3/29/88	hard	none	
P.B laminations	8/27/87	hard	none	none
	9/25/87	hard	none	moderate
	11/5/87	hard	once	moderate
	3/29/88	moderate	edges+1/2	
3M	8/27/87	hard	none	slight
	9/25/87	hard	in LWP	slight
	11/5/87	hard	none	slight
	3/29/88	hard	once	
Prismo				
	9/25/87	moderate	in WP	slight
	3/29/88	moderate	edge	

Upon the last removal test on 3/29/88 both Cataphote and Swarolite were able to be removed in one piece, while PB Laminations, Prismo, and 3M were able to be removed with only slight tearing. As opposed to the other materials which became more difficult to remove with age, the Swarolite material seemed to lose bond and become easier to remove than it was at early stages.

In conclusion, 3M was adequately removable from asphalt for the entire test period, while PB Laminations and Prismo were a problem to remove on 3/29/88 because of edge tears. Strangely, the Swarolite material was adequately removable at the end of the test but not in the middle of the test.

d. Summary of performance of removable marking materials

Ideally, removable pavement marking should remain in place, with good appearance and retroreflectivity until construction is complete, at which time they can easily be removed without leaving any mark.

On asphalt, the PB Laminations and Prismo experienced edge tears, which presented a significant problem for the removers, while other materials tore only once or not at all during the removal. All the materials demonstrated good durability on asphalt through 3/29/88, and retroreflectivity of all the materials stayed close to or above a beadreader value of 100 during the entire test period.

On concrete, removal was more of a problem with all materials tearing during removal. Swarolite only tore once, but the other materials tore at least twice, with Prismo experiencing edge tears and 3M experiencing numerous tears during the process. All the materials remained almost completely intact through 3/29/88 except the 3M material which was only 70% intact on this date. Although all the materials finished the test with beadreader values close to or above 100, all of the materials dropped significantly below a beadreader value of 100 at least one time during the test period. On one occasion the 3M material had a beadreader value of 50. Variable performance as noted above is part of the reason that contractors are required to maintain temporary markings in construction areas.

Based on durability, all materials tested should be acceptable for use for periods up to 120 days. All but the 3M removable material on concrete remained over 90% intact through the winter (8 to 9 months). Therefore, as long as intended use does not exceed 120 days all of the materials are acceptable.

The dramatic loss of material the first day after installation and the almost insignificant loss after that date indicates how critical the first few days after installation are to the marking performance. A requirement that the material must remain in-place for a short term (1 or 2 weeks) before it is accepted protects the state. This is why the contractor is required to install and maintain the temporary marking for the duration of the applicability for one fixed cost.

2. Permanent Pavement Marking Materials

The performance of all the materials which are not designed to be removed will be discussed in this subsection. This category includes all permanent grade preformed plastic materials, hot-applied thermoplastic, and epoxy and alkyd based paints.

The primary criteria for the performance of these materials will be: retroreflectivity during the testing, and appearance and percentage of material intact at the end of the test.

a. Retroreflectivity results

Retroreflectivity of all the materials varied widely over the test period. It is, therefore, inappropriate to judge each material based only on retroreflectivity at the end of the test period. Retroreflectivity data was plotted and each material's values throughout the test period were used in the analysis. Furthermore, since high yellow retroreflectivity values may be indicative of the yellow fading, the primary performance analysis was based on values measured from the white markings.

The analysis was complicated by the changeover from the CDOH Beadreader to a Mirolux 12 for measuring retroreflectivity. Measurements through August, 1988 were taken with the beadreader, while measurements on and after this date were taken with the Mirolux 12. Although some materials behave quite different with the two instruments; in general, a reading of 100 on the beadreader corresponds to a reading of 130 on the Mirolux 12.

(1) Retroreflectivity on concrete

Figures 6 through 12 are plots of the retroreflectivity on all the permanent materials installed on concrete. Because of the number of preformed materials, Figures 6 through 9 had to be presented on two pages each. Figures 6, 8, 10, 11, and 12 are based on beadreader values taken from 6/23/87 to 8/27/88 for preformed white, preformed yellow, thermoplastic, white paints, and yellow paints, respectively. Similarly, Figures 7 and 9 are based on Mirolux values taken on and after 8/27/88 for white preformed and yellow preformed materials respectively. The paint and thermoplastic were not in adequate condition to warrant retroreflectivity measurements after the Mirolux was available. The graphs for the yellow material are included here but most of the discussion will be related to the white materials.

Examination of these graphs reveals broad variations of retroreflectivity over time. For example, all materials experienced a dip on 7/31/87 after a long dry spell without rain. Strong recovery occurred by 8/27/87 with the advent of some cleansing afternoon rainstorms. Another dip occurred on 11/4/87 with a recovery on 12/21/87. The Prismo tended to be the highest until August of 1988 when it dropped to slightly below the average of all the materials (75). Prismo remained above 100 the longest (until June of 1988). The higher readings, however, may be due to significant material loss (60 to 70 percent intact at the end of the test). The duller stripes could have been the ones that were lost. When comparing beadreader values on Figure 11 with Mirolux values on Figure 7, the poor correlation between the two instruments becomes apparent. For example, the 3M standard material, which had the lowest beadreader value in August of 1988, has the highest Mirolux value on that same date.

Figure 10 shows the retroreflectivity for various configurations of hot-applied thermoplastic. Both yellow and white material were applied with and without drop-on glass beads. (Thermoplastic contains intermixed beads, but some beads are usually applied upon extrusion to improve the materials initial retroreflectivity.) The values for the white material with drop-on beads started high and stayed high (above 120) until the material became badly damaged and measurements were discontinued after March of 1988. The material without drop-on beads started low and began to increase with age. The wearing of the material began to expose the intermixed beads.

Figure 11 shows the retroreflectivity of white paints applied to concrete. Here again, measurements were discontinued after March of 1988, because of the poor condition of the paints. The epoxy material remained highly retroreflective (120+), while the standard alkyd paint was almost adequate at just below 100. The very low values of the fast-dry paint is related to our inability to drop the beads on the paint before it dried. Fast-dry paint applied under normal spraying operations would result in much higher initial brightness.

(2) Retroreflectivity on Asphalt

Figure 13 through 21 are plots of the retroreflectivity on all the permanent materials installed on asphalt. As with the concrete, due to the number of preformed materials, Figures 13 through 16 had to be presented on two pages each. Figures 13, 15, 17, 19, and 20 are based on Beadreader values taken from 6/23/87 to 3/8/89 for preformed white, preformed yellow, thermoplastic, white paints, and yellow paints, respectively. Similarly, Figures 14, 16, 18, and 21 are based on Mirolux values taken on and after 8/27/88 for white preformed, yellow preformed, thermoplastic, and paint, respectively.

Similar to the concrete sections, there was broad variation in the retro-reflectivity over time for each material. The biggest drop in retro-reflectivity occurred before the July 31, 1987 measurements when Pavemark and Volare dropped to about 50 and Cataphote dropped to about 70. Similar drops occurred for these materials when installed on concrete. By the end of the test, the retroreflectivity for all the preformed materials was relatively close together with all the readings falling between 80 and 100. 3M-350 ended at the 100 mark and Cataphote ended at the 80 mark. Based on interpolation after about mid-June of 1988, none of the materials would exceed the 100 value.

Although the yellow materials will not be used to judge retroreflectivity performance, their retroreflectivity data does give some indications of consistency of performance of materials. See Figure 15. For example, retroreflectivity of the yellow Pavemark, Volare, and Seibulite dropped way down on 7/31/89, just like their white counterparts. Similarly, the yellow 3M-350 is the strongest performer, just like its white counterpart.

Figure 17 shows a gradual merging of the retroreflectivity of thermoplastic without drop-on beads and thermoplastic with drop-on beads. By the end of the test, the "without drop-on beads" and the "with drop-on beads" have the same retroreflectivity for each color. The test results indicate the importance of drop-on beads for initial retroreflectivity. The hot-applied thermoplastic with drop-on beads (a CDOH practice) ended the test at 110 but had one measurement that dropped to 92. The Mirolux readings on Figure 18, which is more indicative of what the nighttime driver sees, shows the thermoplastic with drop-on beads staying above 130 throughout the test.

Figure 19, a plot of retroreflectivity of paints, indicates the epoxy paint had good retroreflectivity above 100 until about mid-June; while the alkyd paint lost its reflectivity after the first winter of service. The fast-dry material never did have good retroreflectivity--due to inadequate beading upon application. Figure 20 for the yellow paints shows similar results. Mirolux

measurements of the paints were limited to one reading each and indicates that the epoxy with the highest reading was still slightly under 130, measuring in at 125. Since this reading was not until August of 1988, it could be surmised that the epoxy dropped below the 130 Mirolux value about June when its beadreader reading dropped below the 100 standard.

b. Durability results

Durability was determined by measuring the percentage remaining in place upon each test session. The final percent intact and the photos are good indicators of the durability of these materials.

(1) Durability on concrete

Photos 31 through 40 indicate the condition of the pavement marking at the end of the test on 3/8/89. Although the yellow materials appear as a dull gray in these black and white photos, they have good appearance with the naked eye. The percentage intact of each of the materials was estimated and is shown below.

Pavemark	94	3M-std.	95	Thermoplastic	15
Swarolite	70	3M-350	100	Epoxy	60
Seibulite	75	Prismo primerless	70	Std. Alkyd	30
Volare	95	Prismo w primer	60	Fast-dry	20
Cataphote	99				

It's encouraging to note, that four materials (three vendors) performed well on concrete by remaining 94% or better in-place. The 3M-350 looked the best remaining essentially 100% intact. The Swarolite damage did not occur immediately; in fact, it went into the first winter almost completely intact. Starting in the winter of 87/88, the test section began losing material. The Seibulite test section lost a short section of tape near the shoulder by December of 1987 and the rest of the loss occurred through the spring and summer of 1988. The Prismo test section remained mostly intact until December of 1987 when the loss began to occur.

The thermoplastic was almost completely lost, even though it was properly applied. Other poor experiences with thermoplastic on concrete indicate that it is probably not suitable for use on concrete pavements.

The paint test section gradually wore down with the process continuing faster in the winter time. The photographs, however, tend to make the materials look better than they really are. The photographs do not show the fine detail the naked eye can see and fail to show up the exposed pavement in the middle of the stripes.

(2) Durability on asphalt

Photos 41 through 51 are photos that indicate the condition of the pavement marking at the end of the test on 3/8/89. The percentage intact of each of the materials was estimated and is shown below.

Pavemark	100	3M-std.	100	Thermoplastic	99
Swarolite	70	3M-350	100	Epoxy paint	90
Seibulite	100	Prismo primerless	95	Std. Alkyd	80
Volare	97	Prismo with primer	90	Fast-dry	60
Cataphote w/o	97				
Cataphote	100				

Preformed material performance on asphalt is better than on concrete, with six materials staying at least 97% intact. Four of those materials were still 100% intact. Also, Cataphote, when installed with primer remained 100% intact. Two feet of Volare stripe material were lost during the first month of the test. After that time, no more Volare material was lost. The first 10% loss of the Swarolite test section occurred within the first month of installation when a truck skidded across it. However, losses continued to occur, reaching 30% by the end of the test. A significant portion of the prismo losses occurred near the right edge of the lane where the snow plow blades could have had an extra bite due to the severe rutting of the asphalt pavement.

The hot-applied thermoplastic remained essentially intact with just minor chipping throughout. Performance was much better than the concrete test section.

The epoxy paint is still mostly intact except for some chipping. For the standard alkyd and fast-dry alkyd the photograph makes the materials look more intact than they really are. The thinning of the material and exposure of the asphalt does not show up in the photo.

c. Summary of Performance of Permanent Marking Materials

(1) Materials on concrete

Preformed materials performed significantly better than other marking materials on concrete--paints wore away much quicker and hot-applied thermoplastic became brittle, debonded, and was lost from the concrete pavement. Between the brands of preformed materials there was quite a range of performance. Considering retroreflectivity based on the Mirolux, Pavemark, Cataphote, 3M std., 3M-350, and Prismo stayed above 130. All these products remained at least 94% intact except Prismo. However, the Prismo products tested here have since been discontinued. Volare material also showed good durability with 95% being intact at the end of the test but with lower retroreflectivity.

Based on durability, the following materials were better than 94% intact at the end of the test and are acceptable when applied to concrete: Pavemark, Volare, Cataphote, 3M-std., and 3M-350.

(2) Materials on Asphalt

All materials performed better on asphalt than on concrete. The most dramatic improvement was with extruded thermoplastic, which was almost a total loss on concrete, but remained 99% intact on asphalt. The alkyd paints performed better on asphalt but still experienced significant wear through the test period.

Most of the brands of preformed material and hot-applied thermoplastic were all better than 97% intact at the end of the test. Two of the materials, 3M-350 and hot-applied thermoplastic had Mirolux readings that stayed above 130. Based on the averages of readings at two different times, Seibulite, Pavemark, and 3M standard came close to the value of 130. Based on both durability and retroreflectivity on asphalt pavements, hot applied thermoplastic worked as well as the best preformed material.

Based on durability, the following materials were better than 94% intact at the end of the test and are acceptable when applied to asphalt: Pavemark, Seibulite, Volare, Cataphote, 3M-std., 3M-350, and Prismo primerless.

V. FUTURE DIRECTION FOR PAVEMENT MARKING RESEARCH

Pavement marking materials continue to be developed and there never seems to be enough time and money for marking installation and maintenance which will provide good delineation, year around, day and night. As money for maintaining roads dwindles, it becomes more and more important to select the optimum material for pavement marking.

A. ACCEPTANCE TESTING OF IN-PLACE MARKING

Because pavement markings have, historically, been installed by state maintenance crews, acceptance testing procedures have not been developed. However, with the more durable, longer lasting and more expensive pavement marking materials being installed by contractors, it is important to have a comprehensive acceptance testing procedure to insure that Colorado is buying a long lasting, properly performing product. Acceptance tests must address: proper formulation and mixing, uniform and adequate thickness, and proper glass bead embedment with the proper size, quality, and quantity of glass beads.

Acceptance testing for proper bead embedment has to be addressed, to some degree, in pavement marking contracts. Because the epoxy paint is very hard and experiences little wear from traffic, bead embedment is important for good initial and long term nighttime visibility (retroreflectivity). If the beads are too deeply embedded, the epoxy will not wear enough to expose the beads for good retroreflectivity.

B. PAVEMENT MARKING MAINTENANCE CONTRACTS

Contracts which require a contractor to both place pavement markings and maintain them on a specific stretch of highway could eliminate some of the problems of acceptance testing. Such contracts could also give the striping contractors the freedom to select materials and application methods which optimize life-cycle cost of the markings based on the local traffic and weather conditions.

C. OPTIMUM GLASS BEAD SIZE

More research is needed in the selection of beads for epoxy paint. Appropriate tradeoffs between bead embedment, bead damage, and wet nighttime visibility must be established. The problem is somewhat specific to Colorado where hard silica-based aggregates and snow plowing down to bare pavement are employed to maximize safety during snowy and icy conditions. The large beads which maintain proper embedment and aid in wet nighttime visibility, may serve well on Colorado plains, but may be too susceptible to damage on our mountain roadways.

Another experimental test section on I70 west of Denver has already been striped to further investigate this problem.

D. METHYL METHACRYLATE PAVEMENT MARKING

A methyl methacrylate based pavement marking material has been developed and has performed well on concrete pavements in the State of Washington. Since methyl methacrylate is a very durable material that bonds well to concrete, it should be tested as soon as it's available.

E. PAVEMENT MARKING FOR CONCRETE

Although epoxy paint performs well on concrete, problems with its off-white appearance and the occasionally poor daytime visibility still occur. We must continue to search for a more suitable material or study other techniques such as a black epoxy background for the white stripes on concrete. Along this line we must determine if white epoxy paint will stick to a new black epoxy stripe.

F. PREFORMED PLASTIC ACCEPTANCE

The preformed plastic pavement marking industry is continually developing new products. Since the start of the preformed-plastic testing, new products were introduced by Windsor, 3M, LDI, and Volare which could not be incorporated into the testing program. If CDOH bases its list of acceptable materials solely on the performance in the transverse test section, delays of several years would result between the time a new product is made available and the time it would be acceptable to CDOH. The cost of repeating these acceptance tests every two years would also be significant.

CDOH currently uses a combination of the results from this test and detailed specifications to accept preformed plastic. But research is needed in this area which will allow acceptance of new material in a more timely fashion while still insuring acceptable performance on the road.

SASHTO has a regional test center for safety materials which includes a program for testing pavement marking materials. Utilization of this center, or participation in a similar program under WASHTO for western states, may be an effective way to evaluate and specify pavement marking materials.

VI. CONCLUSIONS

The epoxy paint appears to be a good pavement marking system which can outlast several applications of standard traffic paint, with adequate nighttime visibility when clean. The slight discoloration which occurs, however, can create a problem with daytime appearance on concrete roadways.

Based on several observations by the panel on numerous projects, epoxy placed over epoxy, with one year or more of wear, bonds well.

The epoxy beads do not improve the dry retroreflectivity over that obtained from Type 2 beads. (In the case of I25 in Colorado Springs the epoxy beads performed worse than the older Type 2 beads.) The large beads do improve the nighttime visibility in the middle of stripes when not placed at a uniform thickness. These beads do not submerge in the deep center part of the paint stripe.

Polyester paint appears to be unsuitable for the severe environment of our high traffic mountain interstate, failing to perform as well as our standard alkyd traffic paint.

Extruded thermoplastic provides good nighttime visibility throughout its life. Extruded thermoplastic installed on asphalt was found to remain in place for years, while extruded thermoplastic installed on concrete tends to chip off in a matter of months.

Preformed plastic materials tend to lose their initial high retroreflectivity after a few months of service, and fall below that of extruded thermoplastic. When installed properly on concrete or asphalt, the material is highly durable and remains in place for years. It would serve well on roadways with continuous lighting.

Retroreflectivity varies significantly over time for all pavement marking materials and is particularly sensitive to the cleanliness of the marking materials. Because of this variation, some standard cleaning process may be required when testing retroreflectivity for pavement marking maintenance contracts.

The preformed materials and extruded thermoplastic on asphalt performed much better than any of the paints in the transverse test. Of the paints, the alkyd fast-dry paint wore out quickly, while the standard alkyd paint lasted a little longer and the epoxy paint lasted much longer.

VII. IMPLEMENTATION

The use of extruded thermoplastic on asphalt should be increased, especially on new or close-to-new asphalt. Some caution, however, should be used in areas where snow plowing and rutting are extensive. In theses areas the thermoplastic would be the highest point on the road and tends to get damaged from snow plowing.

Many states have obtained excellent results using alkyd paint as a primer for thermoplastic. Colorado is currently investigating this practice.

Good performance was obtained with preformed plastic and epoxy paint on concrete and both are recommended. The preformed plastic test was on an old smooth concrete surface. Since no testing was done on new concrete, no recommendations are offered for this mode. However, pretreatment of the new concrete which creates a surface similar to old smooth concrete would probably result in similar good performance. Grinding the tining off and removal of curing compound and latents should be the minimum pretreatment.

Of the permanent preformed plastic material installed on concrete, Pavemark, Volare, Cataphote, 3M-5730, and 3M-350 remained over 94% intact during the test and are recommended. Similarly on asphalt, Pavemark, Seibulite, Volare, Cataphote, 3M-5730, 3M-350, and Prismo primerless remained over 94% intact during the test period and are recommended.

All the removable plastic materials tested remained over 94% intact for at least 120 days and are recommended.

Because proper installation is critical to the performance of all preformed plastic, it is recommended that an acceptance period of at least 30 days be incorporated into marking contracts.

All the removable materials tested should be acceptable when used for periods of less than 120 days. After 120 days most of the removable materials became difficult to remove and the 3M material began to come off on its own. Because of these problems removable grades of preformed plastics are not recommended for periods longer than 120 days.

Continued use of epoxy paint is recommended, but the use of epoxy beads (as defined in section II. C.) should be further investigated--especially in aggressive sanding and snow-plow areas where bead damage could be more of a problem.

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FIGURES

FIGURE 1

RETROREFLECTIVITY MEASUREMENTS MIROLUX VERSUS CDOH BEADREADER

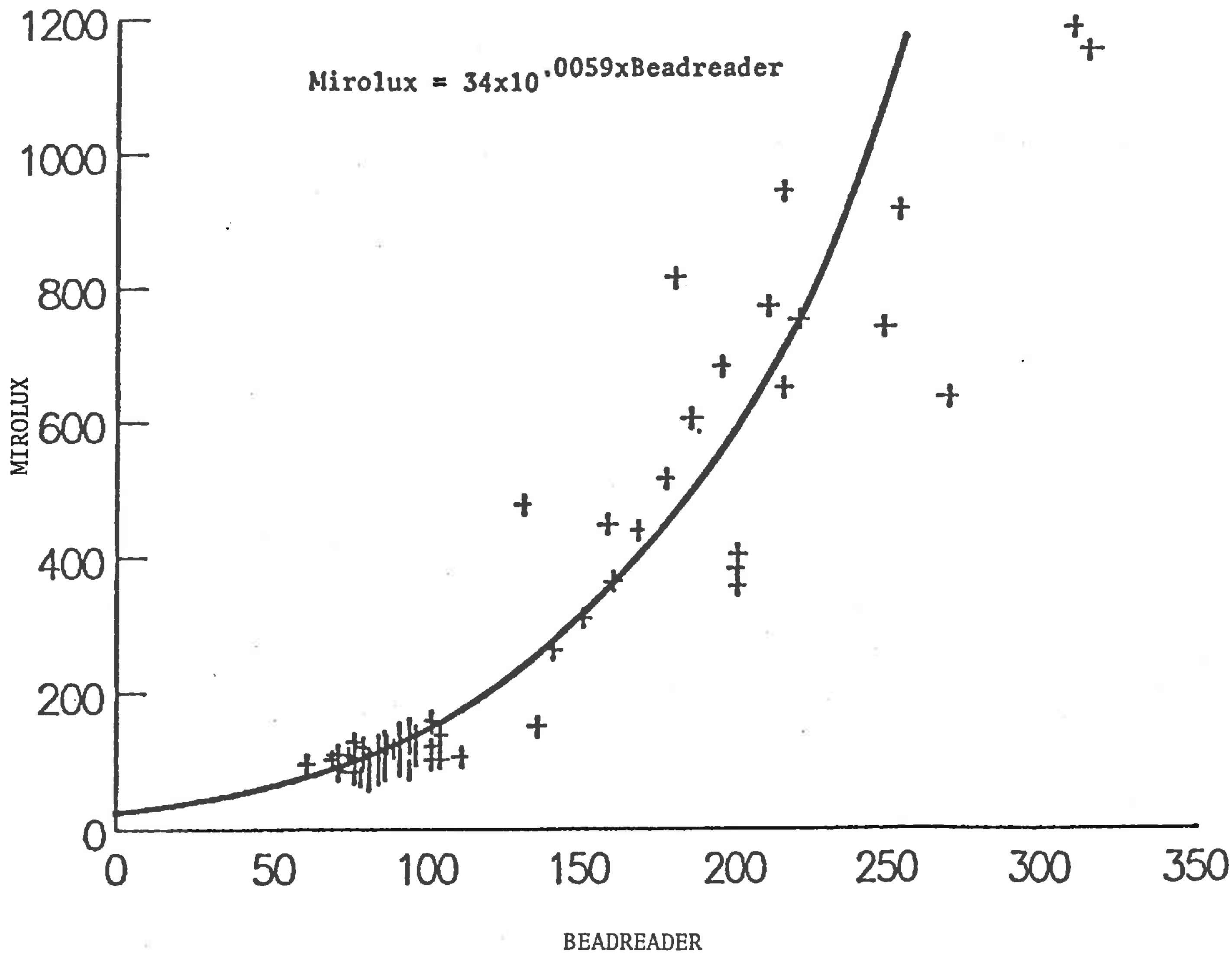


FIGURE 2

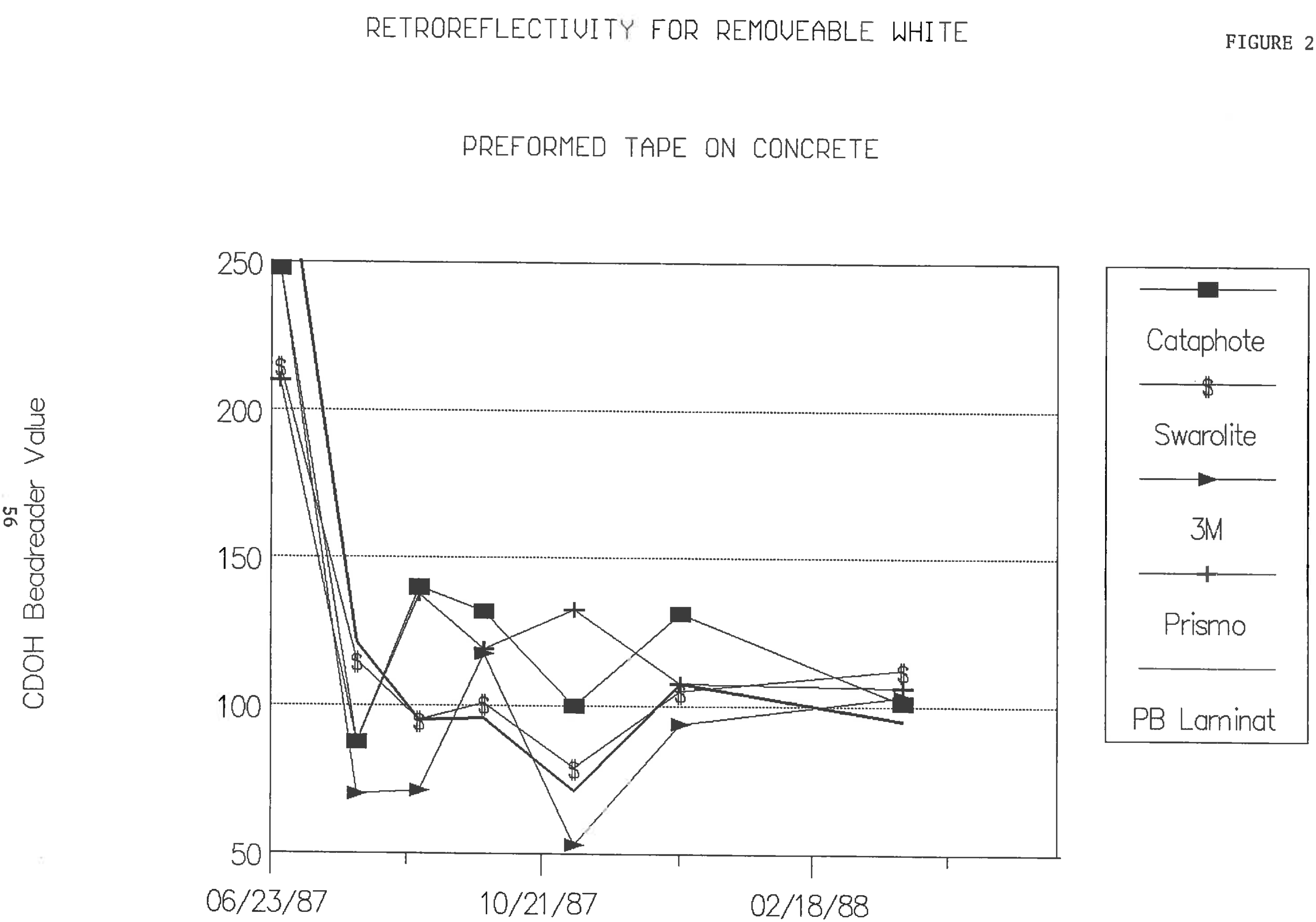

RETROREFLECTIVITY FOR REMOVEABLE WHITE
PREFORMED TAPE ON CONCRETE
CDOH Beadreader Value
250
200
150
100
50
06/23/87
10/21/87
02/18/88
Cataphote
Swarolite
3M
Prismo
PB Laminat

FIGURE 3

RETROREFLECTIVITY FOR REMOVEABLE YELLOW

PREFORMED TAPE ON CONCRETE

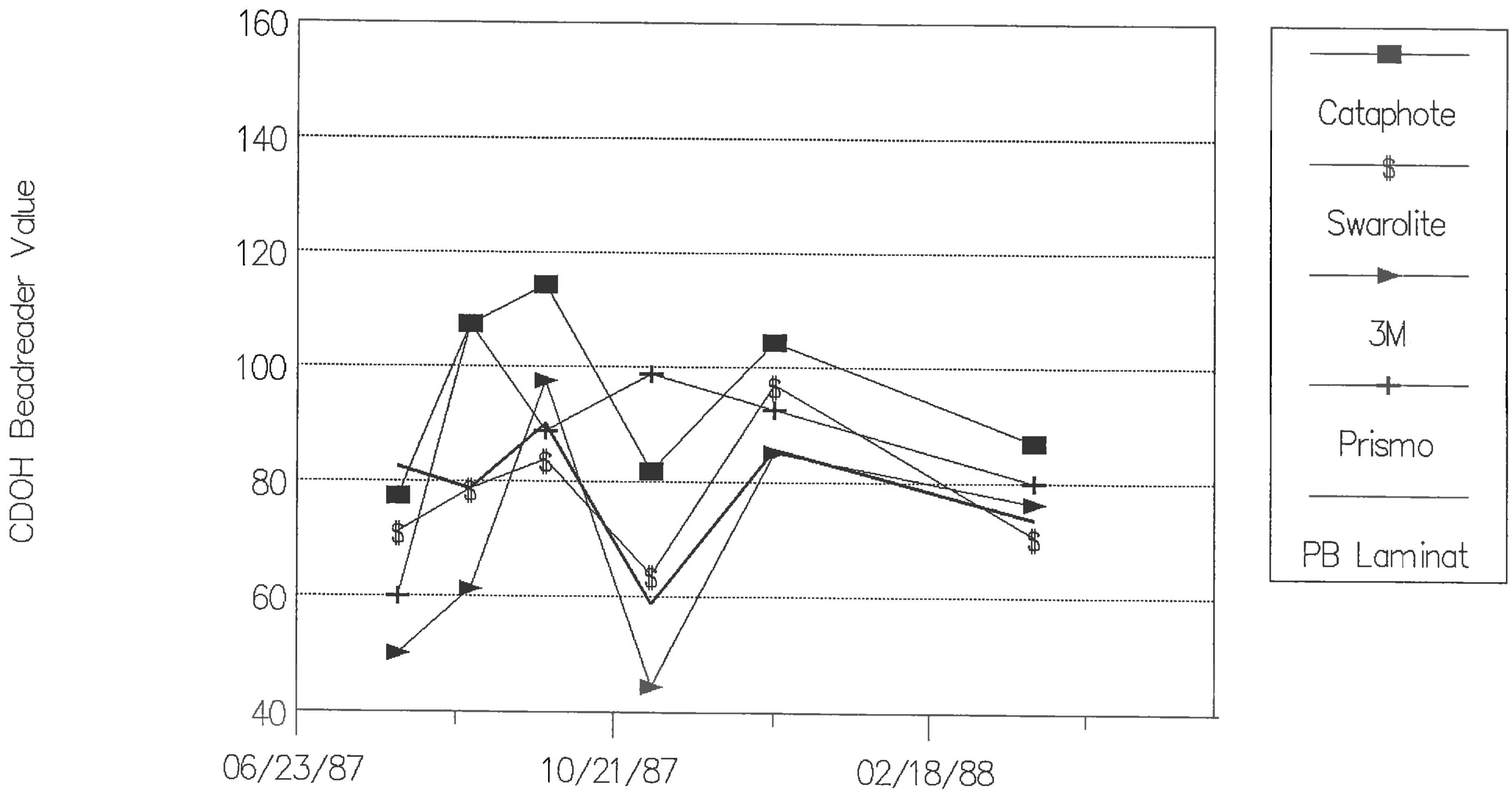


FIGURE 4

RETROREFLECTIVITY FOR REMOVEABLE WHITE

PREFORMED TAPE ON ASPHALT

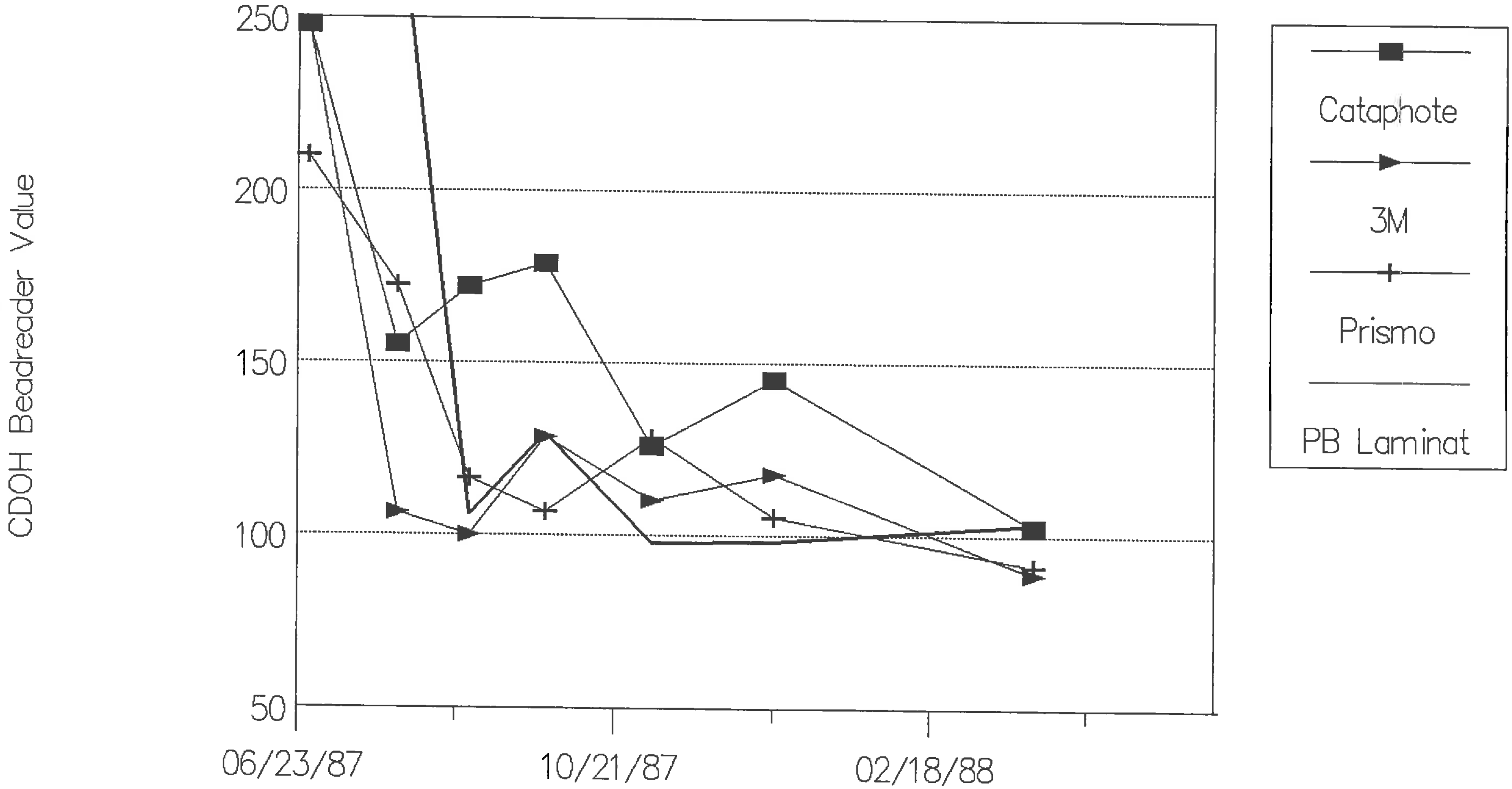


FIGURE 5

RETROREFLECTIVITY FOR REMOVEABLE YELLOW

PREFORMED TAPE ON ASPHALT

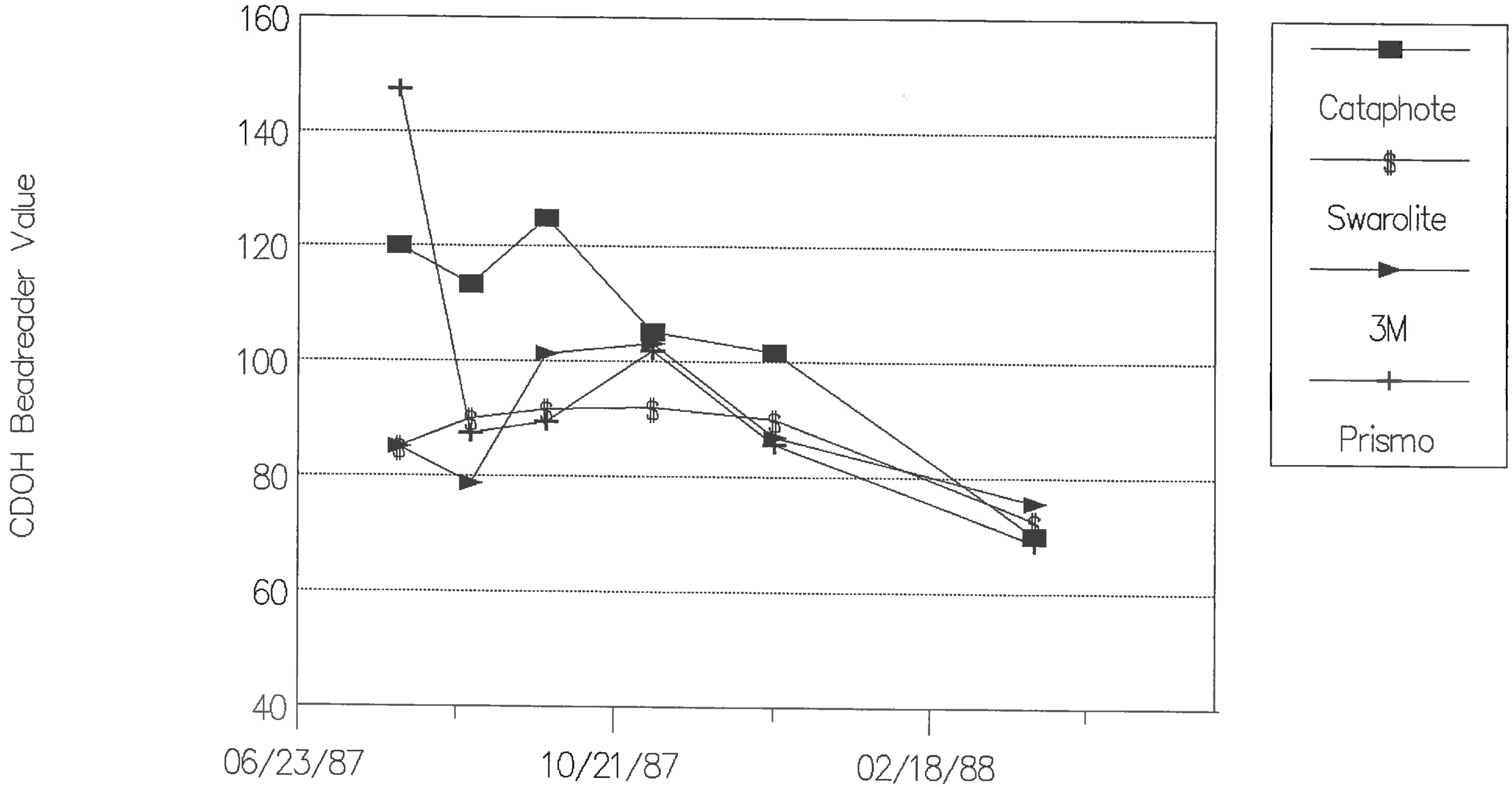


FIGURE 6A

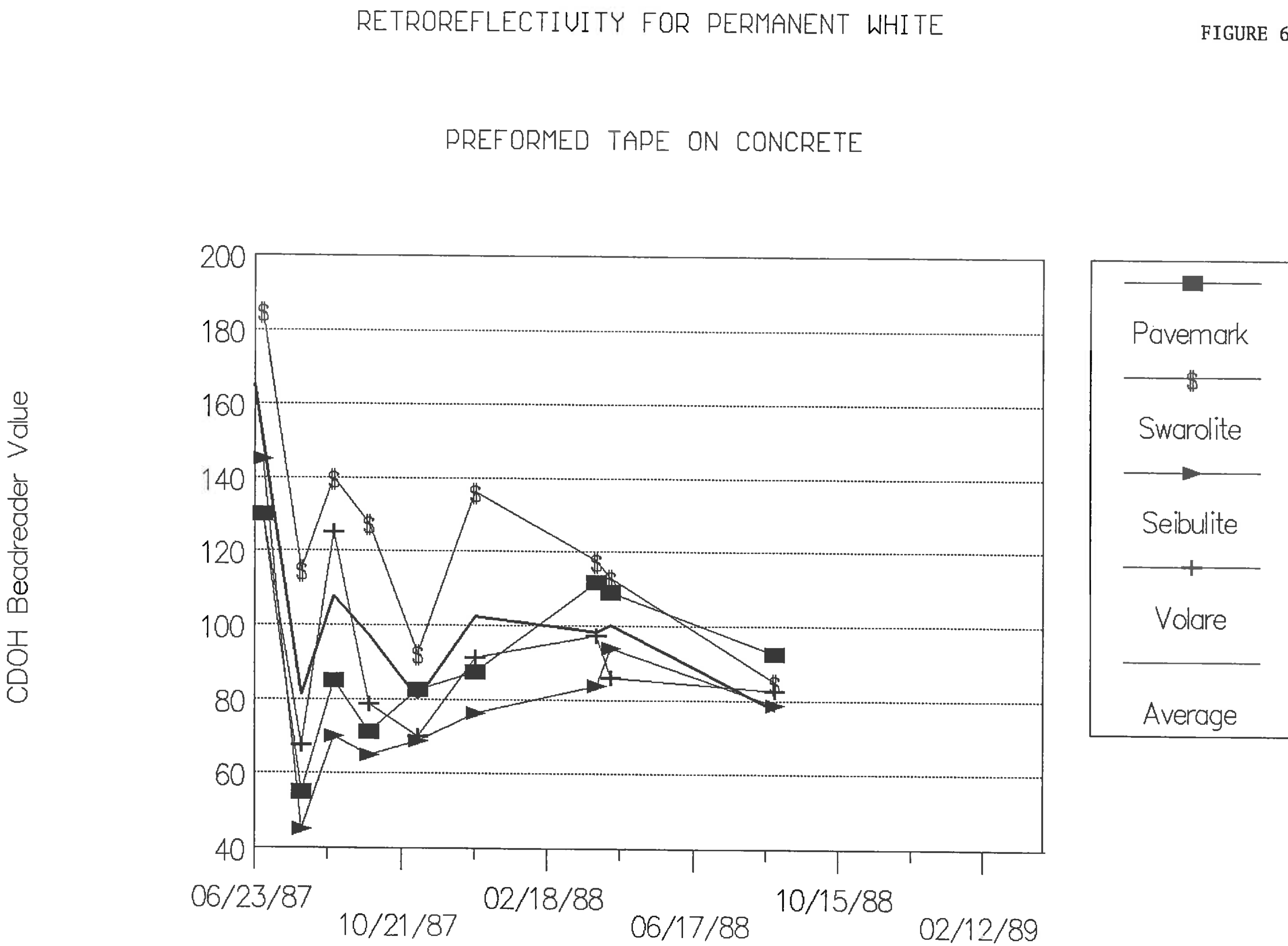

RETROREFLECTIVITY FOR PERMANENT WHITE
PREFORMED TAPE ON CONCRETE
CDOH Beadreader Value
200
180
160
140
120
100
80
60
40
06/23/87
10/21/87
02/18/88
06/17/88
10/15/88
02/12/89
Pavemark
Swarolite
Seibulite
Volare
Average

FIGURE 6B

RETROREFLECTIVITY FOR PERMANENT WHITE

PREFORMED TAPE ON CONCRETE

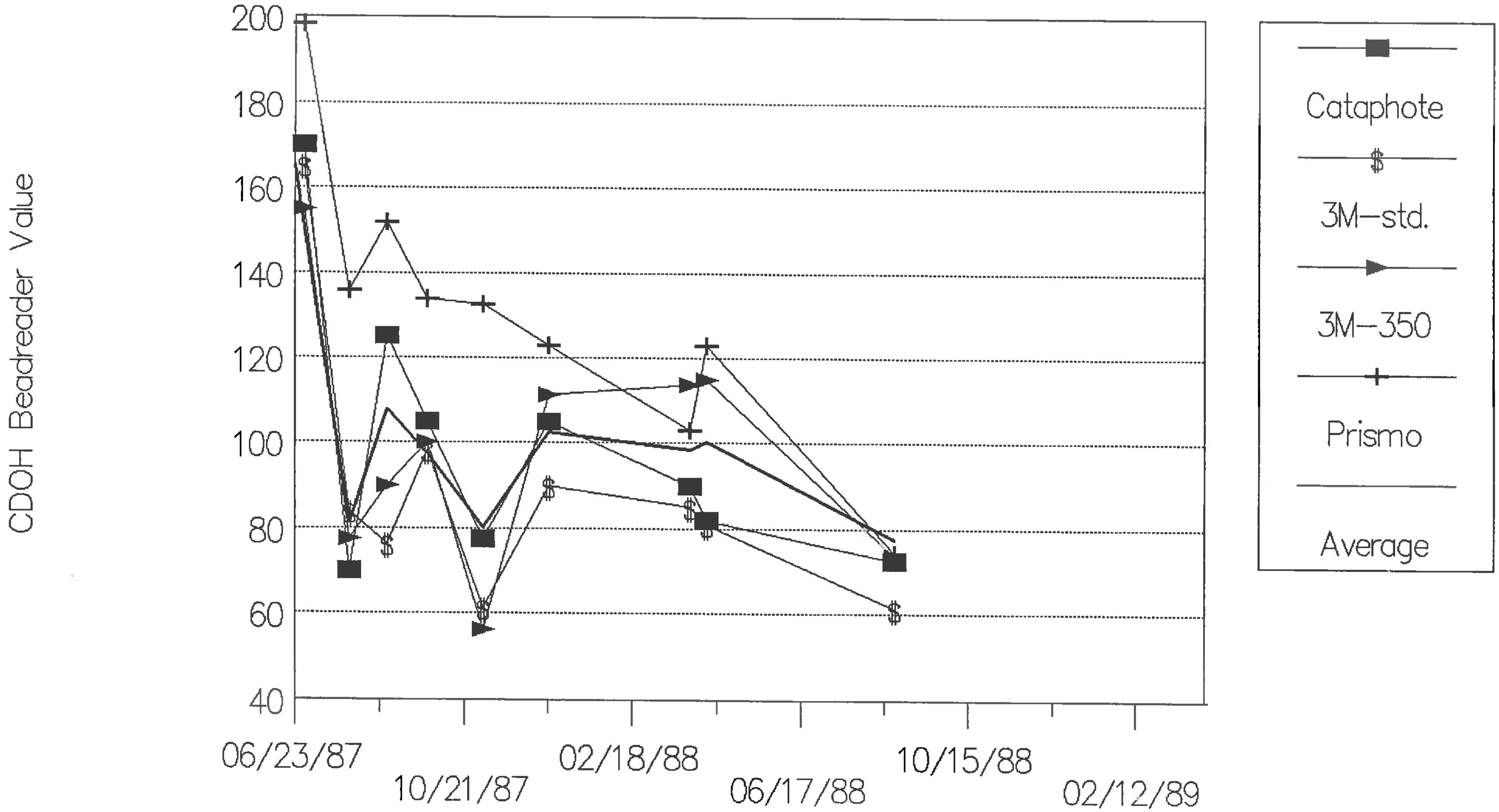


FIGURE 7A

RETROREFLECTIVITY (MIROLUX) FOR WHITE

PERMANENT PREFORMED TAPE ON CONCRETE

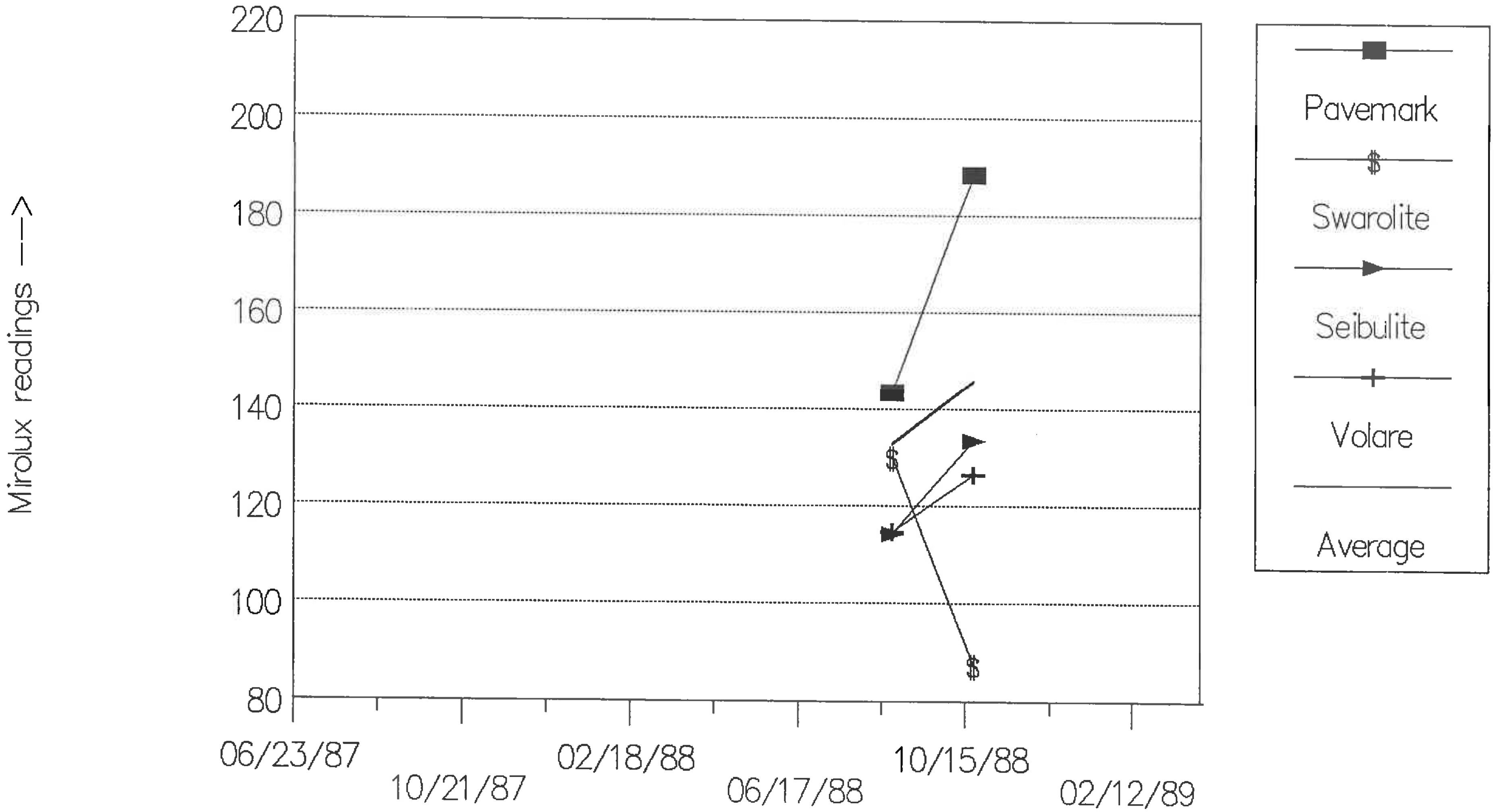


FIGURE 7B

RETROREFLECTIVITY (MIROLUX) FOR WHITE

PERMANENT PREFORMED TAPE ON CONCRETE

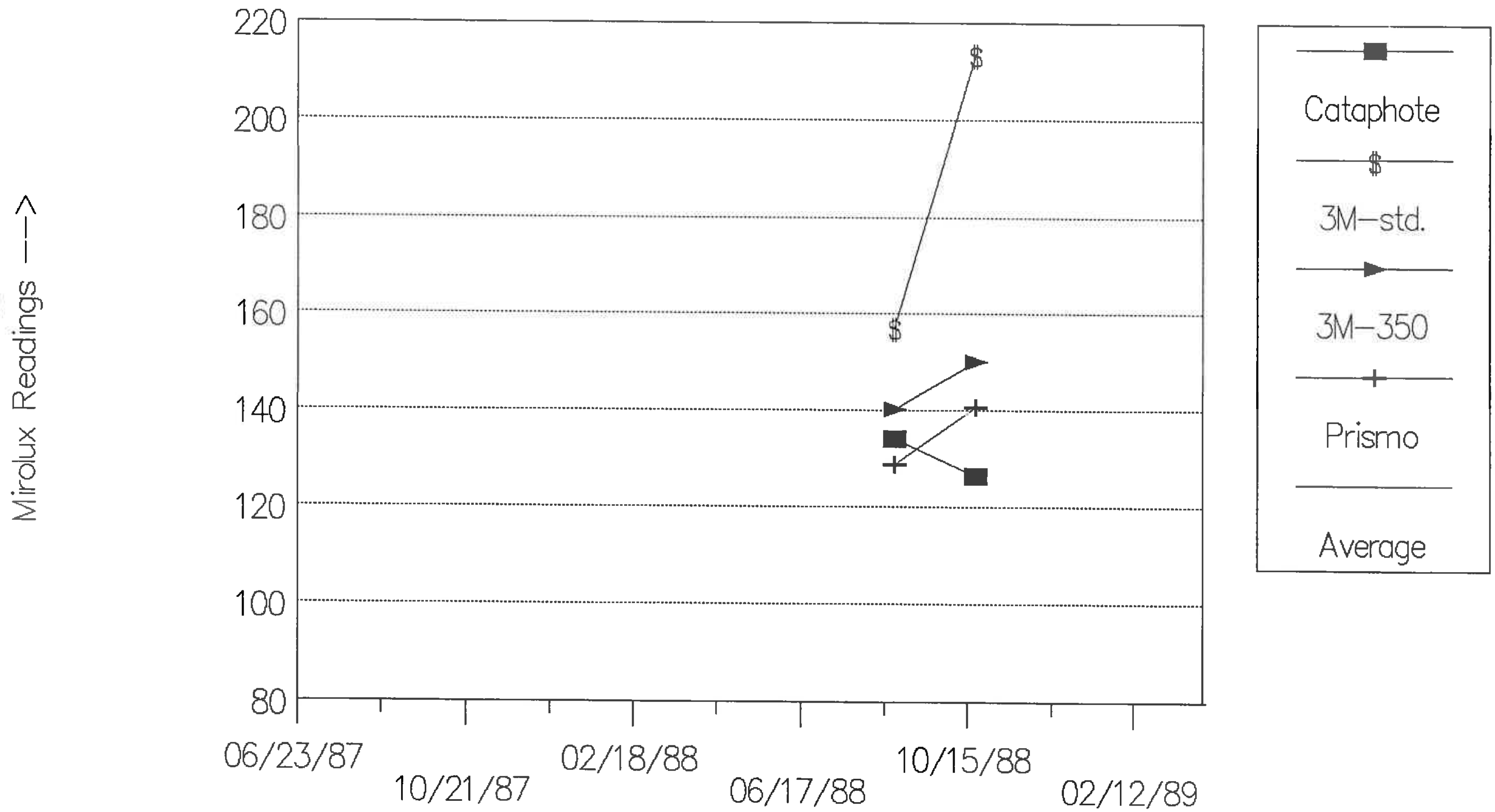


FIGURE 8A

RETROREFLECTIVITY FOR PERMANENT YELLOW

PREFORMED TAPE ON CONCRETE

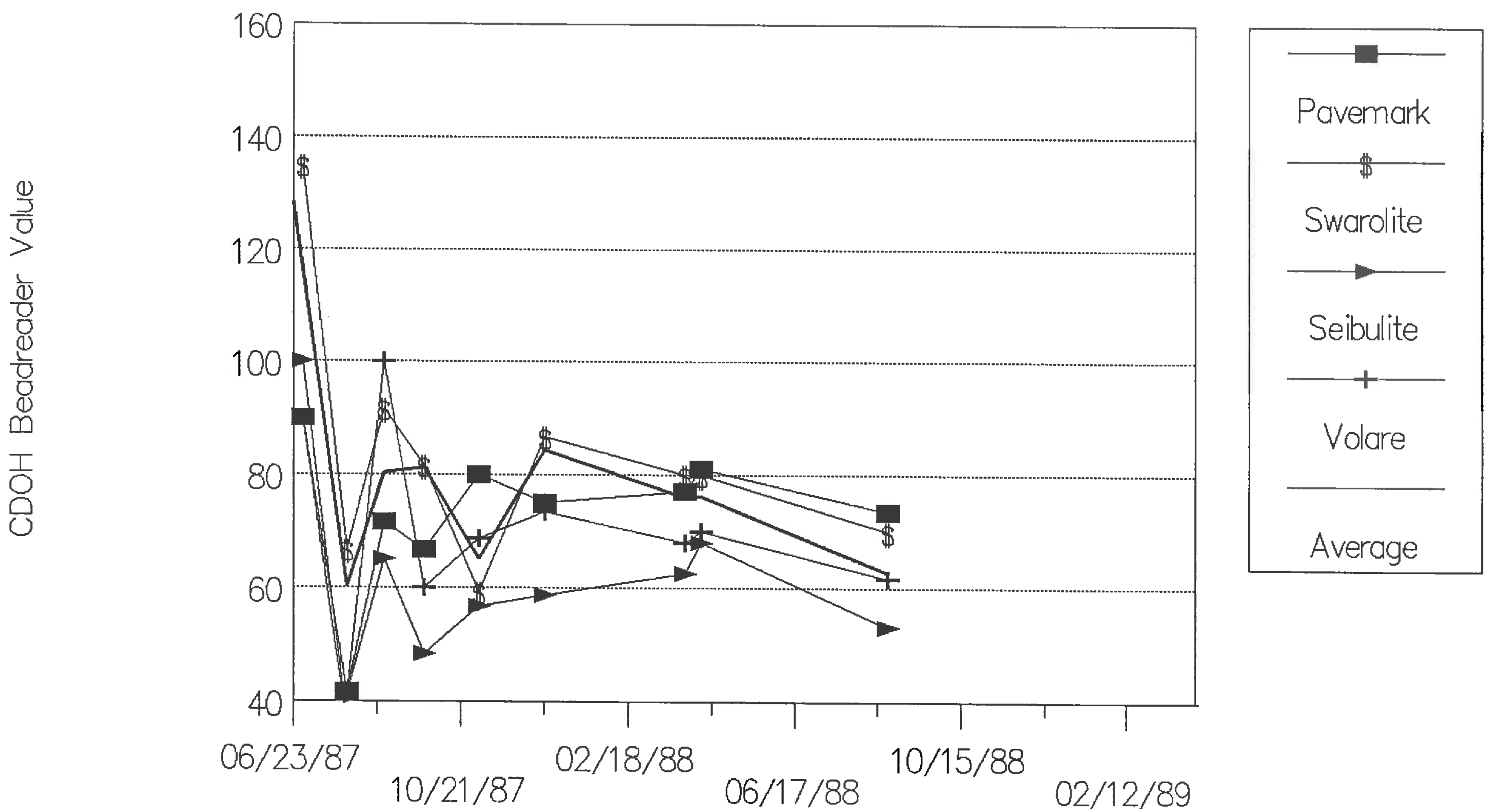


FIGURE 8B

RETROREFLECTIVITY FOR PERMANENT YELLOW

PREFORMED TAPE ON CONCRETE

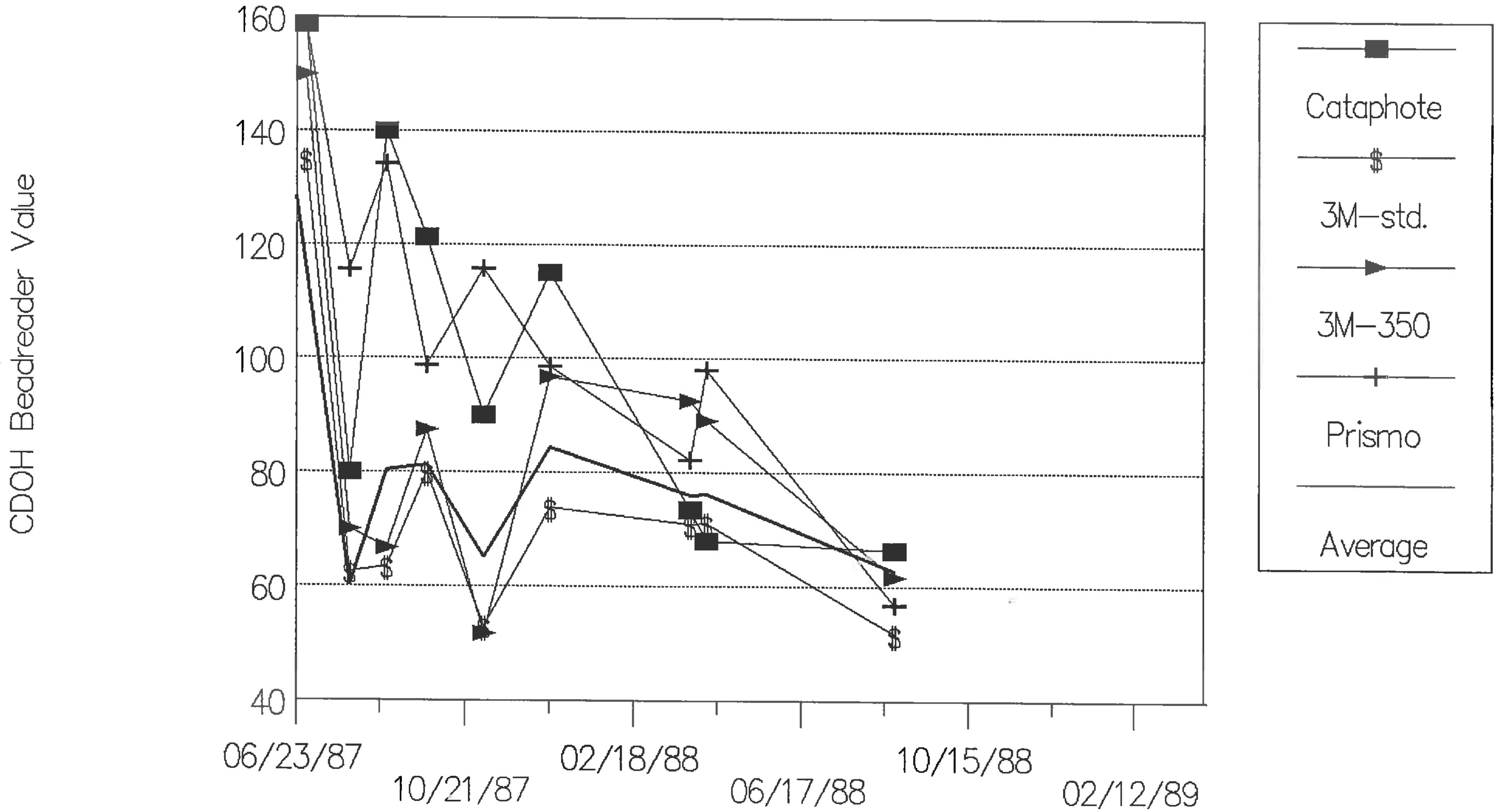


FIGURE 9A

RETROREFLECTIVITY (MIROLUX) FOR YELLOW

PERMANENT PREFORMED TAPE ON CONCRETE

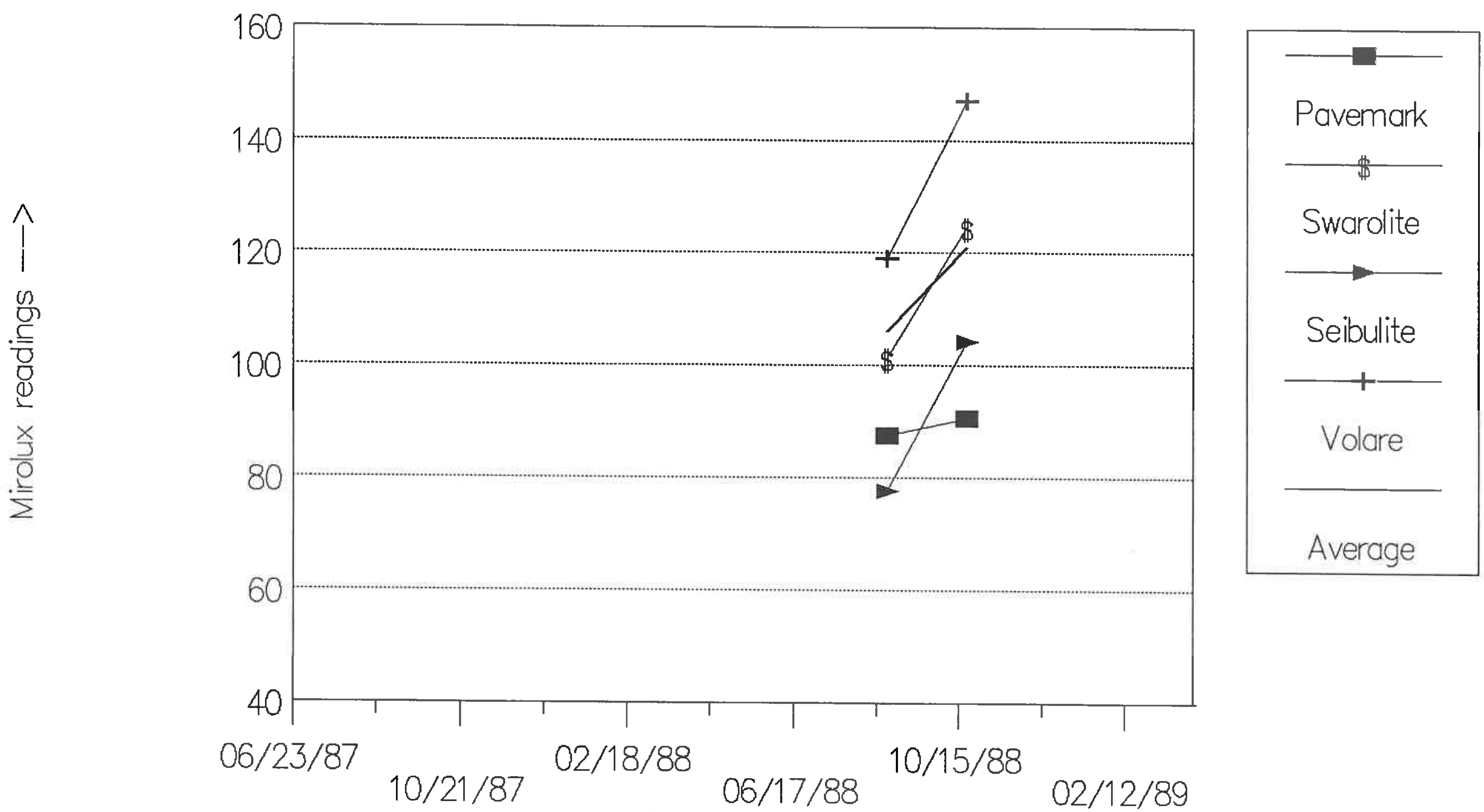


FIGURE 9B

RETROREFLECTIVITY (MIROLUX) FOR YELLOW

PERMANENT PREFORMED TAPE ON CONCRETE

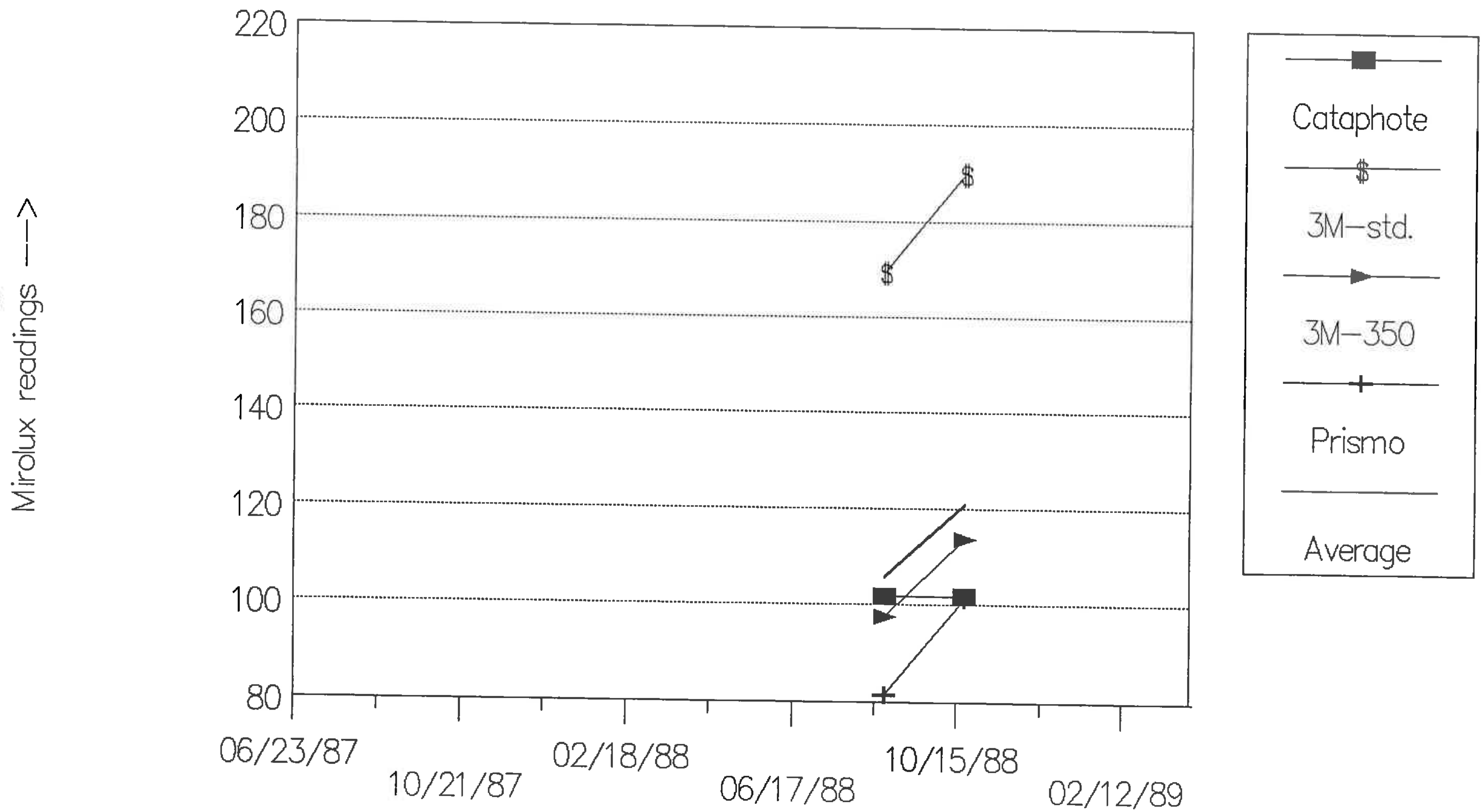


FIGURE 10

RETROREFLECTIVITY FOR EXTRUDED

THERMOPLASTIC ON CONCRETE

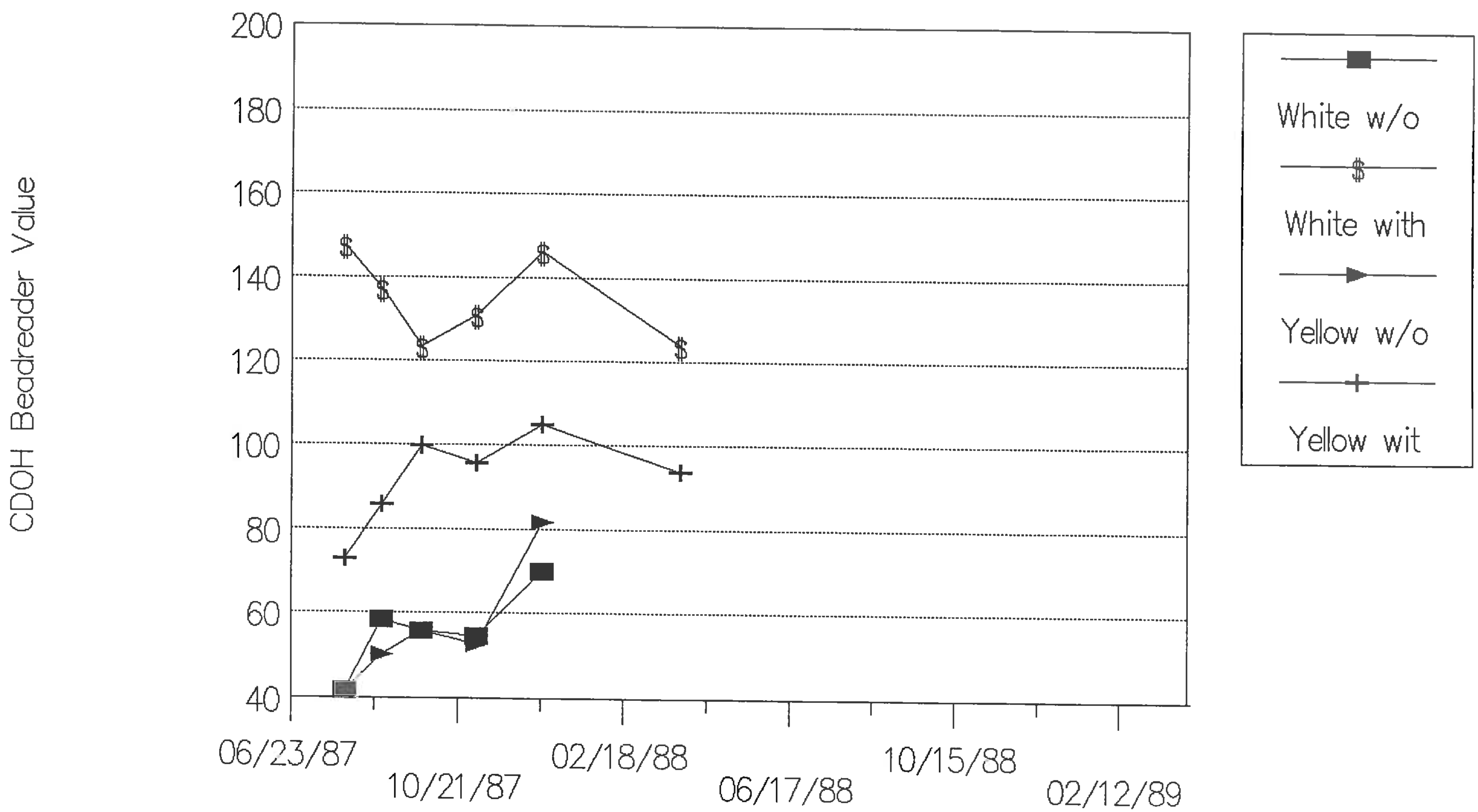
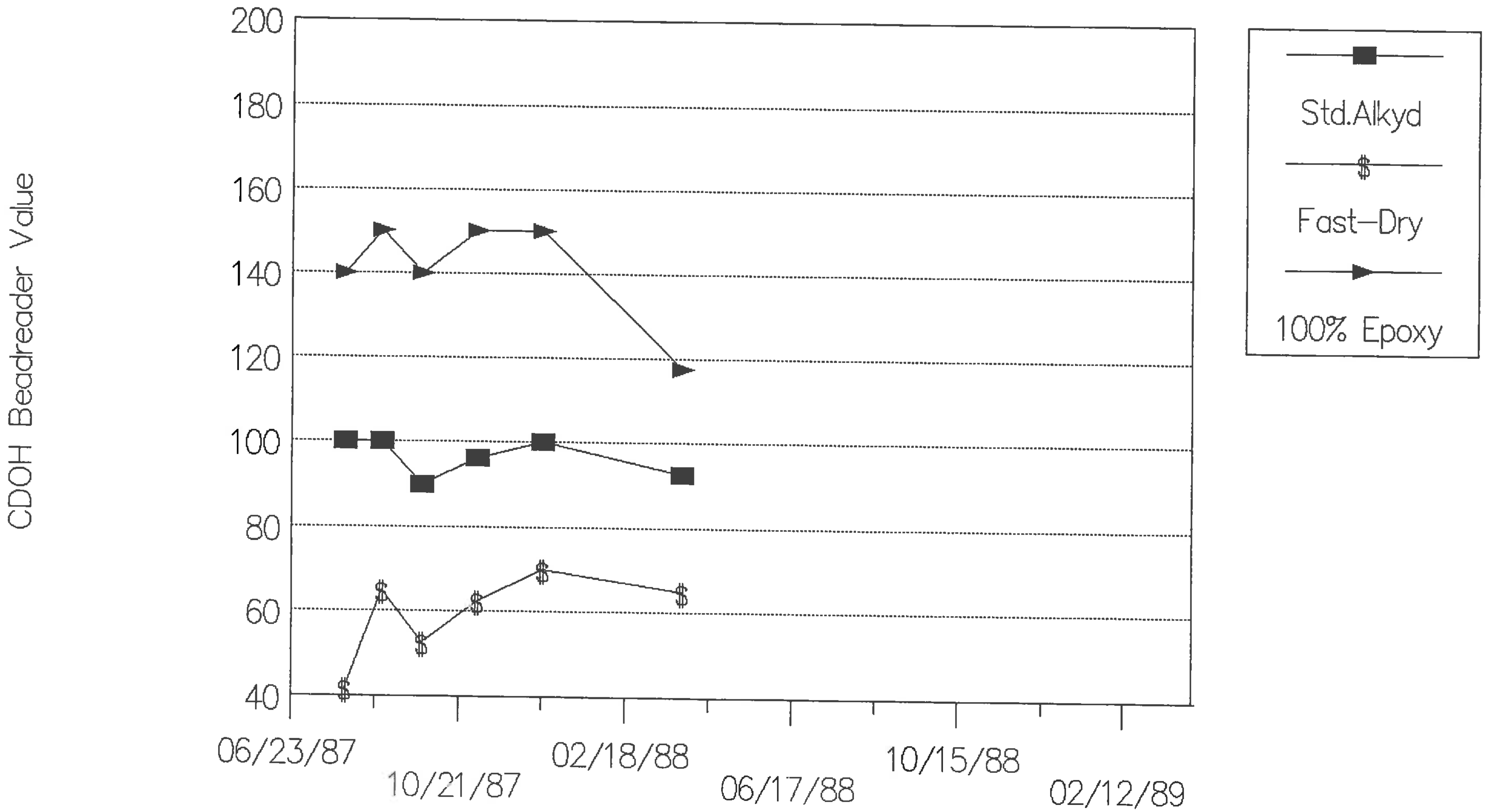


FIGURE 11

RETROREFLECTIVITY FOR WHITE PAINTS

ON CONCRETE



RETROREFLECTIVITY FOR YELLOW PAINTS

ON CONCRETE

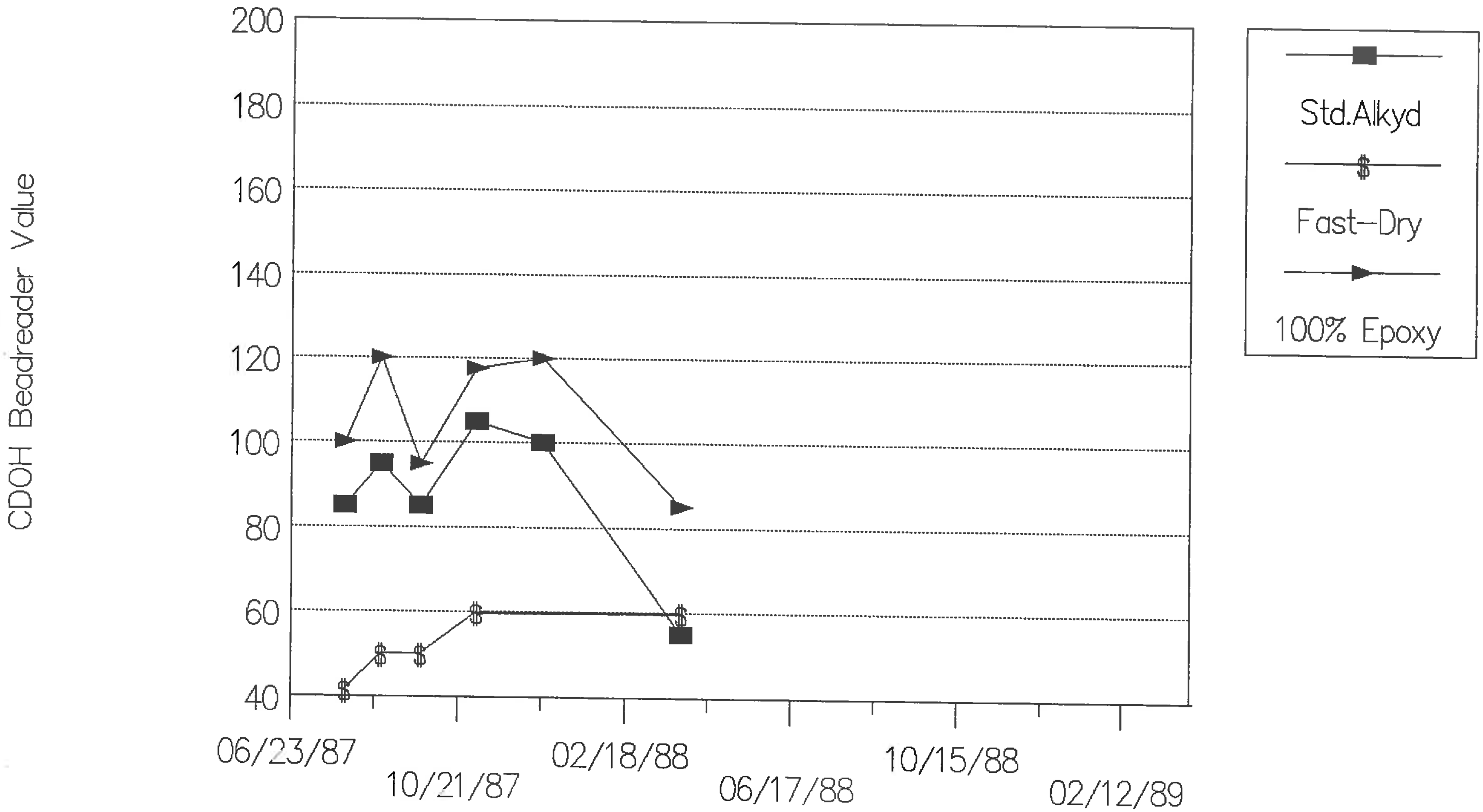


FIGURE 13A

RETROREFLECTIVITY FOR PERMANENT WHITE

PREFORMED TAPE ON ASPHALT

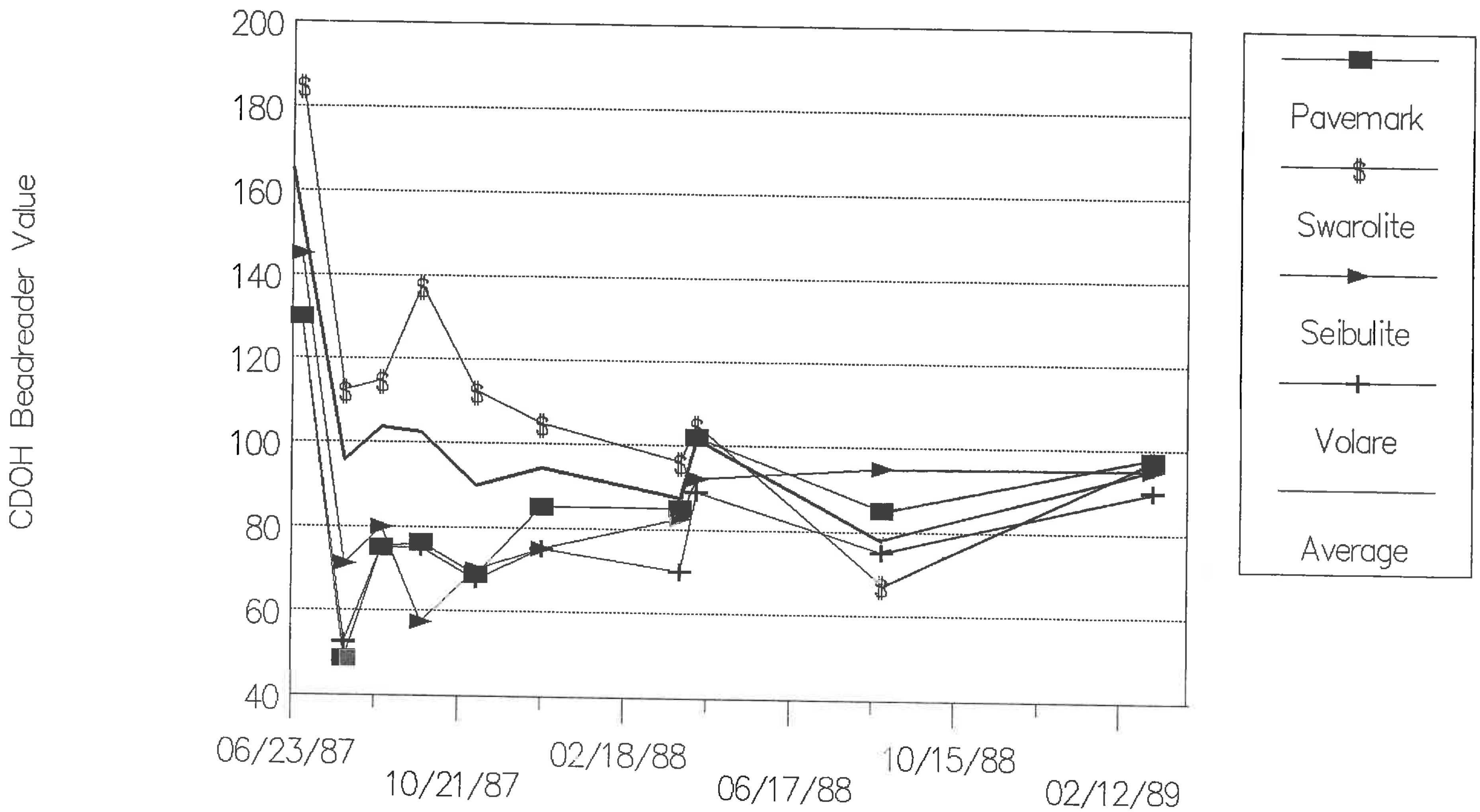
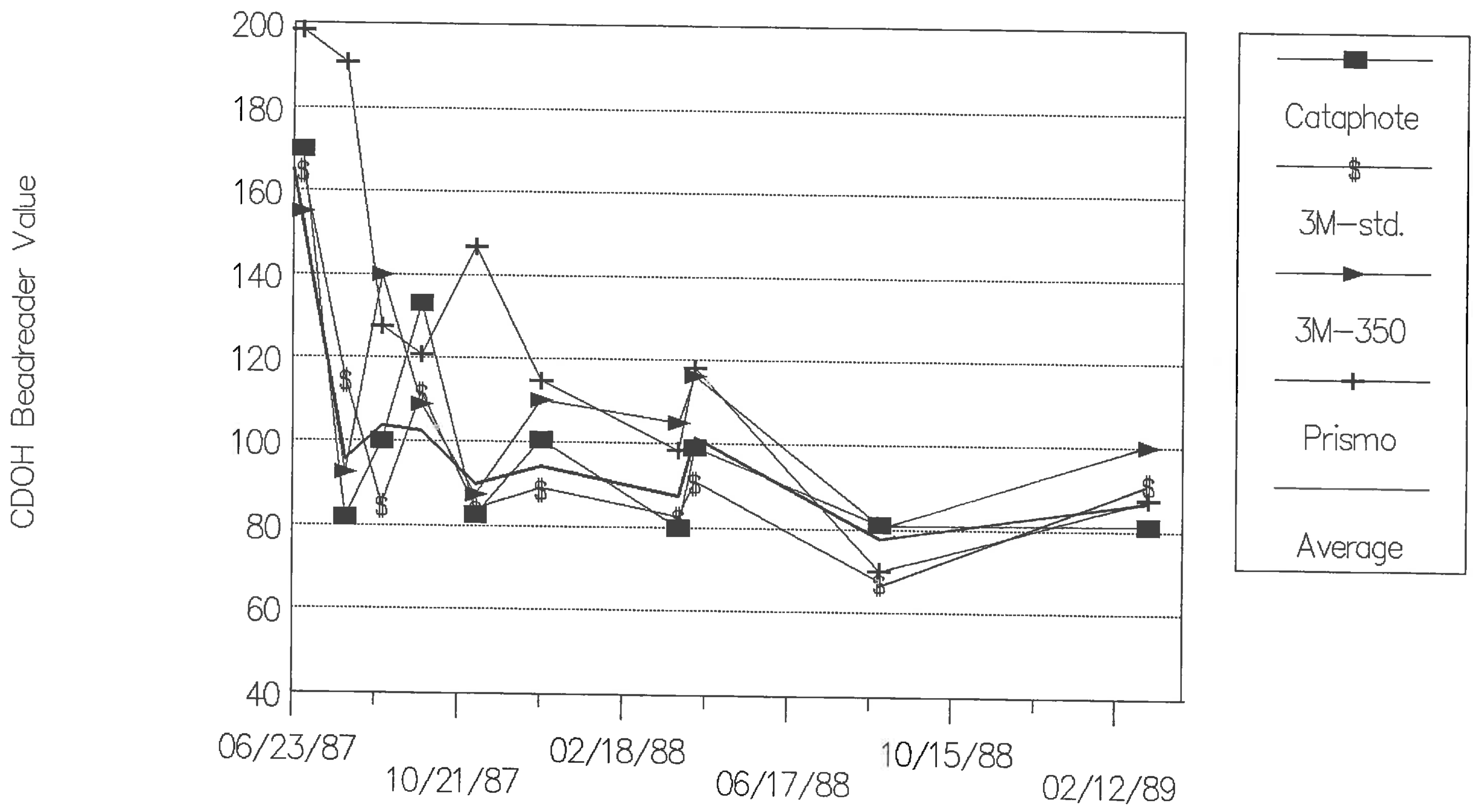


FIGURE 13B

RETROREFLECTIVITY FOR PERMANENT WHITE

PREFORMED TAPE ON ASPHALT



RETROREFLECTIVITY (MIROLUX) FOR WHITE

PERMANENT PREFORMED TAPE ON ASPHALT

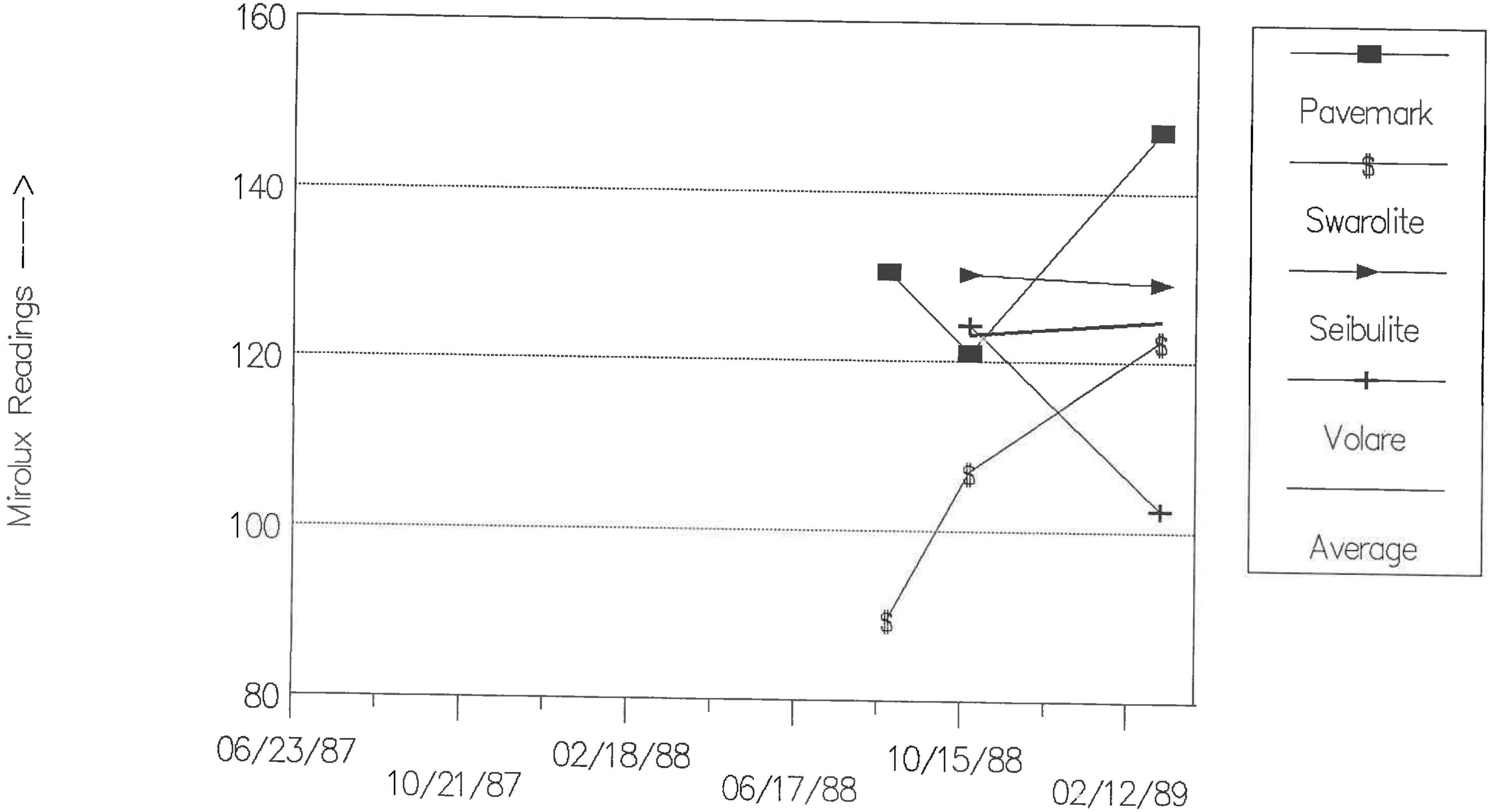
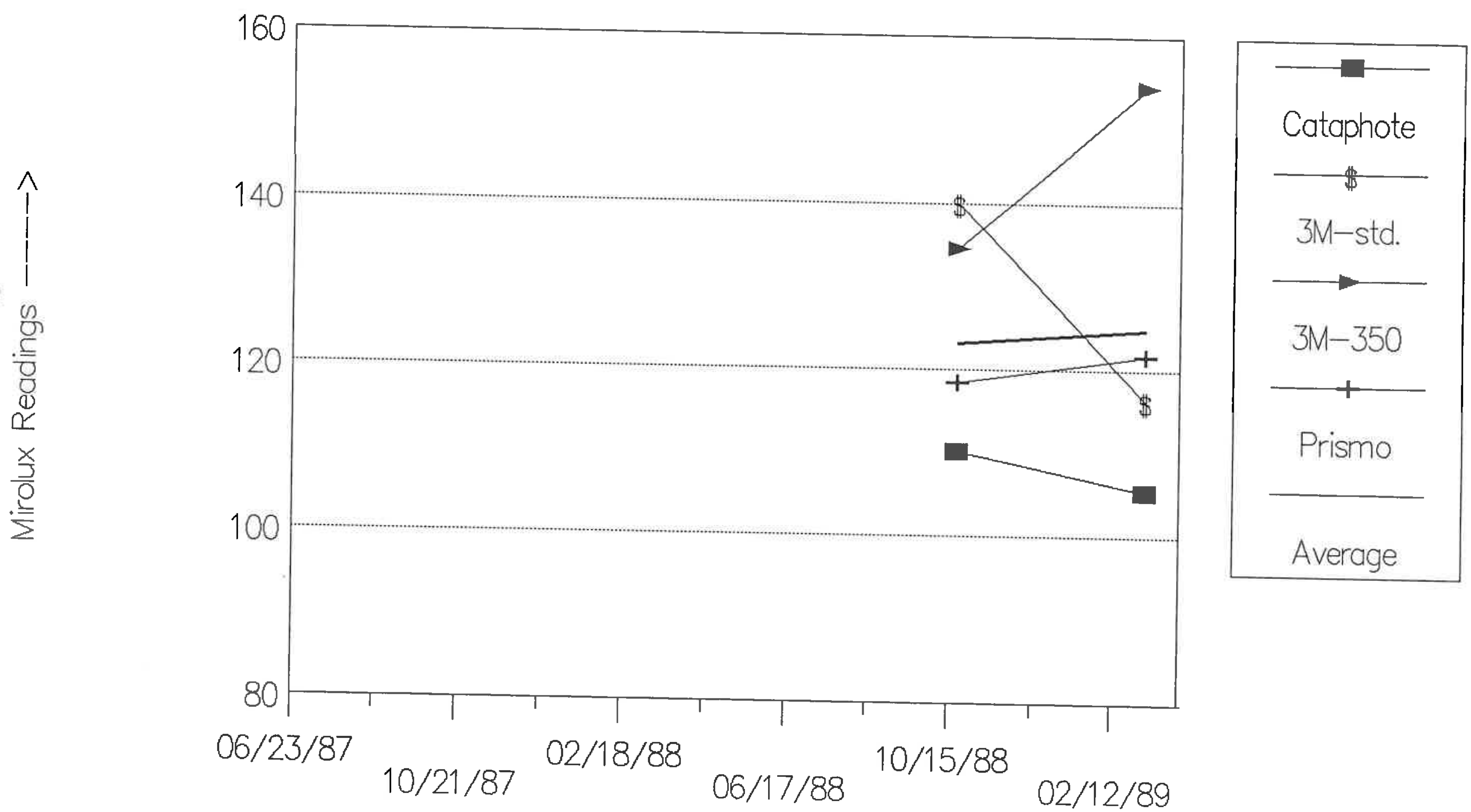


FIGURE 14B

RETROREFLECTIVITY (MIROLUX) FOR WHITE

PERMANENT PREFORMED TAPE ON ASPHALT



RETROREFLECTIVITY FOR PERMANENT YELLOW

FIGURE 15A

PREFORMED TAPE ON ASPHALT

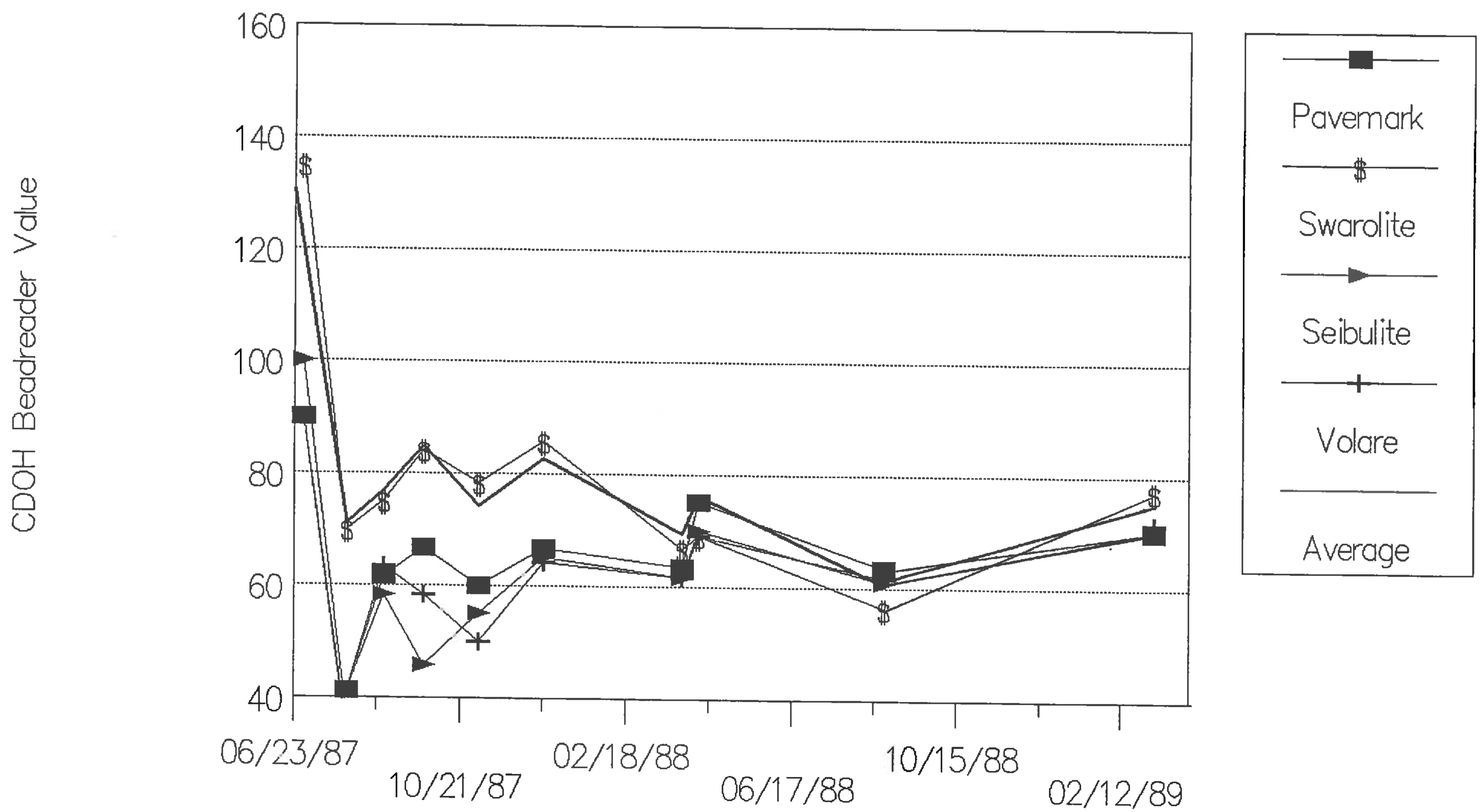


FIGURE 15B

RETROREFLECTIVITY FOR PERMANENT YELLOW

PREFORMED TAPE ON ASPHALT

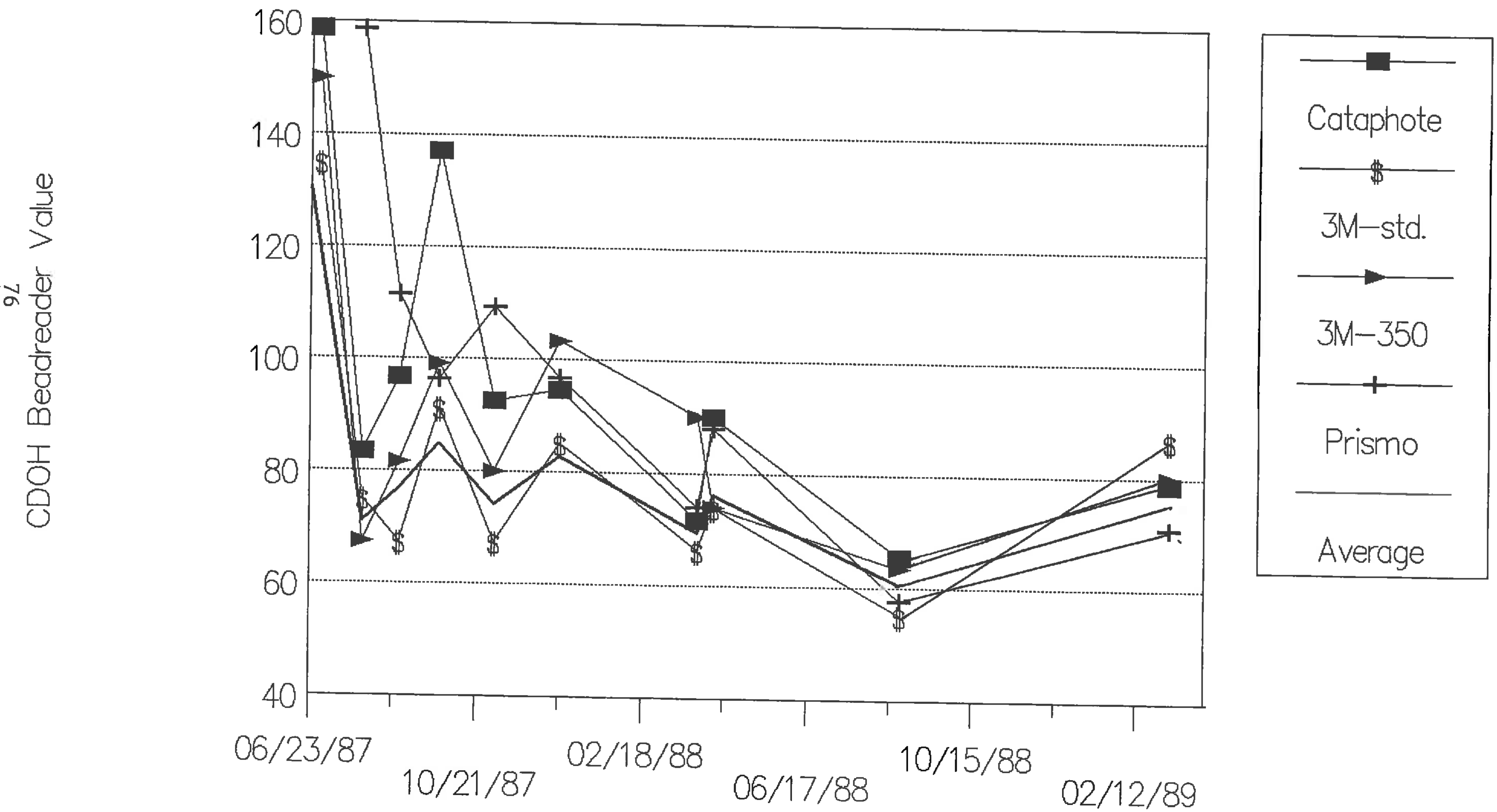


FIGURE 16A

RETROREFLECTIVITY (MIROLUX) FOR YELLOW

PERMANENT PREFORMED TAPE ON ASPHALT

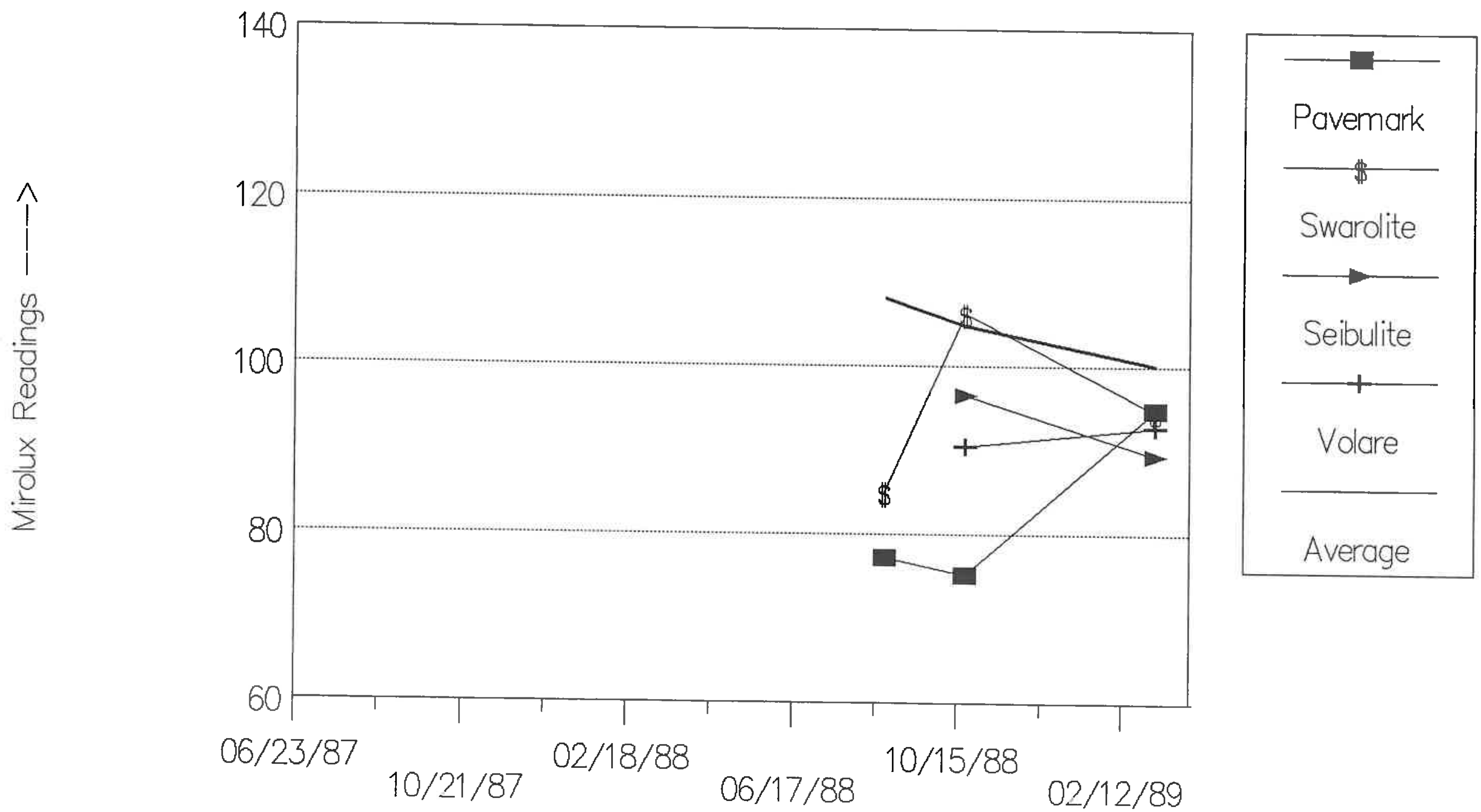


FIGURE 16B

RETROREFLECTIVITY (MIROLUX) FOR YELLOW

PERMANENT PREFORMED TAPE ON ASPHALT

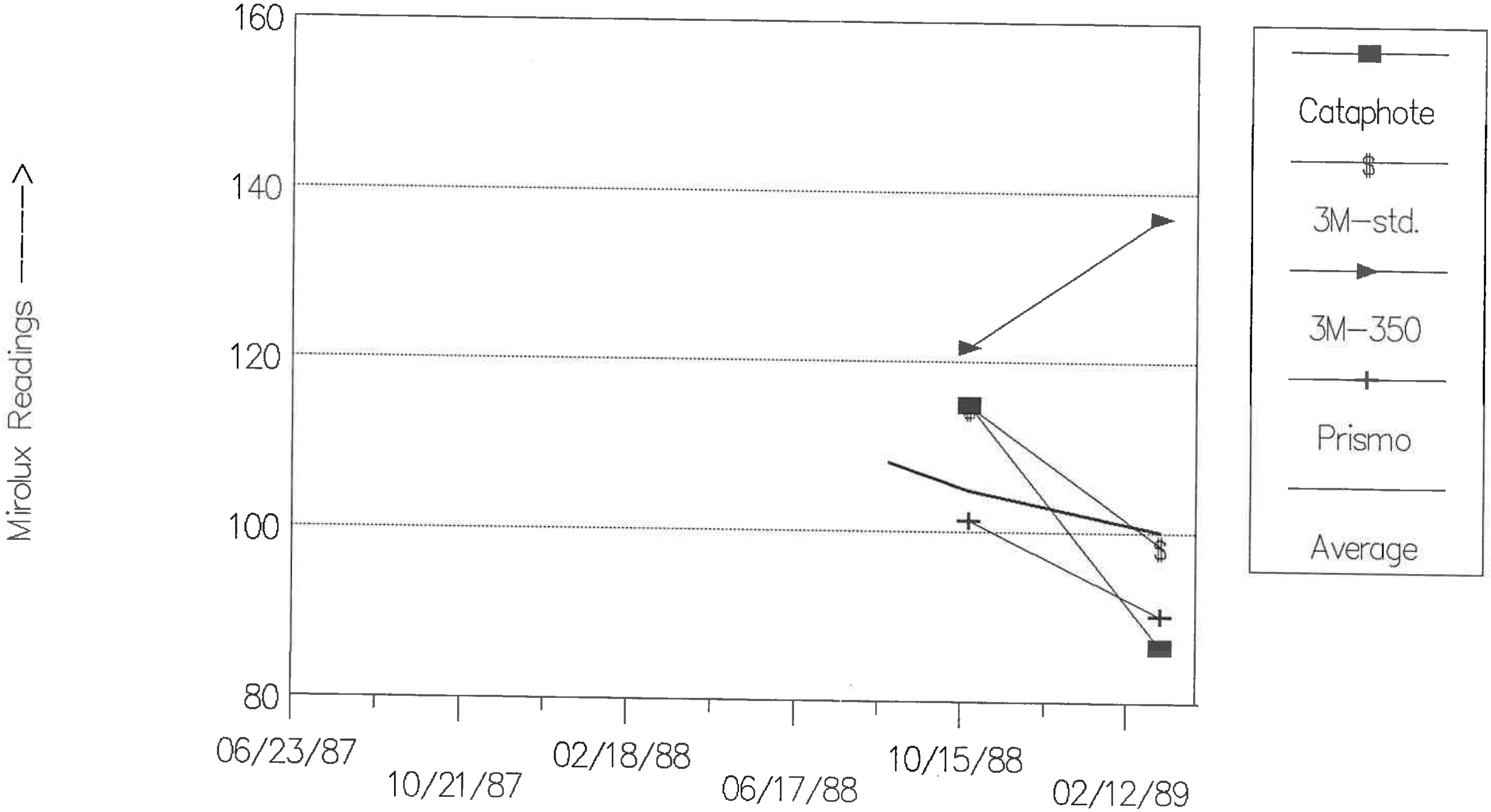
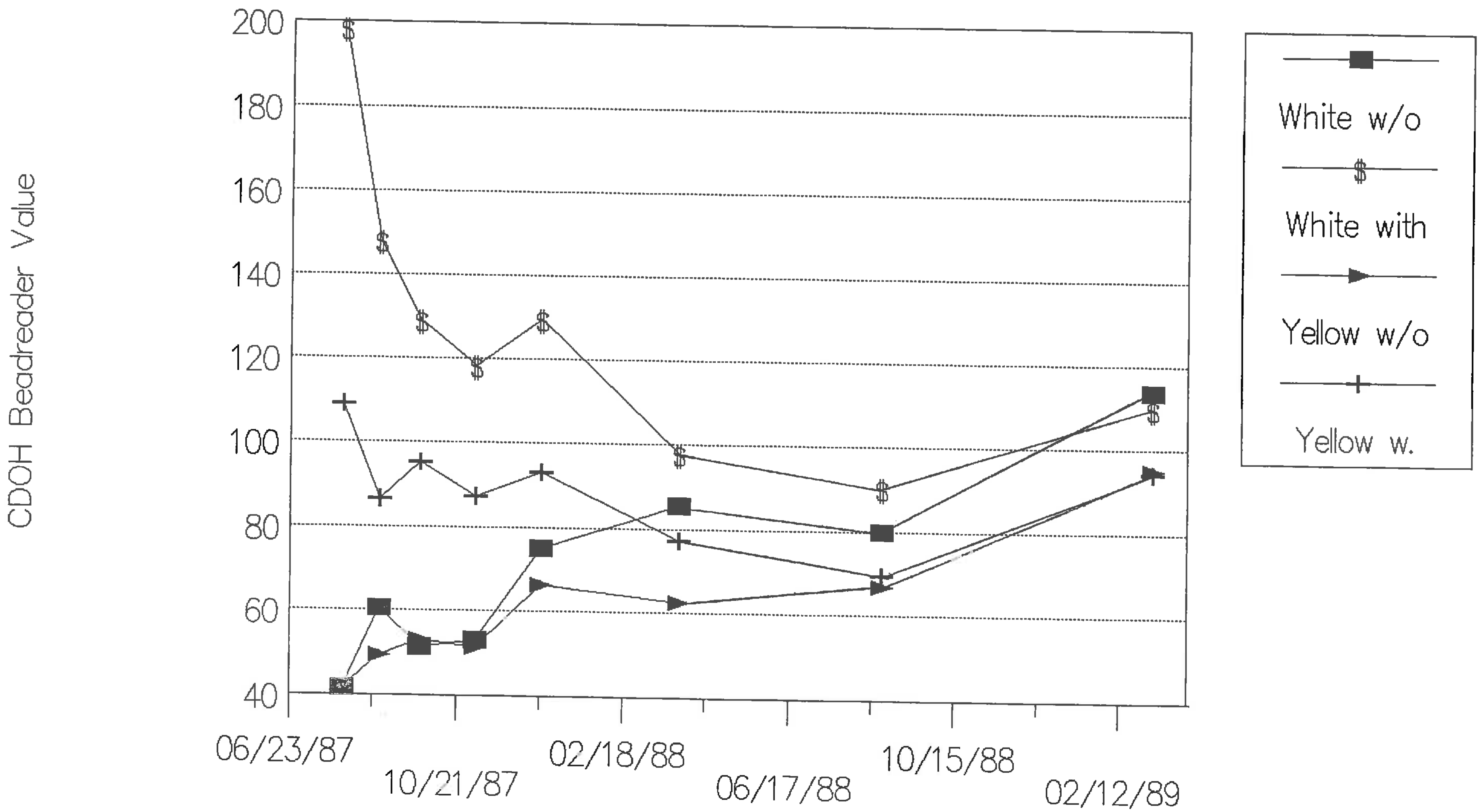


FIGURE 17

RETROREFLECTIVITY FOR EXTRUDED

THERMOPLASTIC ON ASPHALT



RETROREFLECTIVITY (MIROLUX) FOR

EXTRUDED THERMOPLASTIC ON ASPHALT

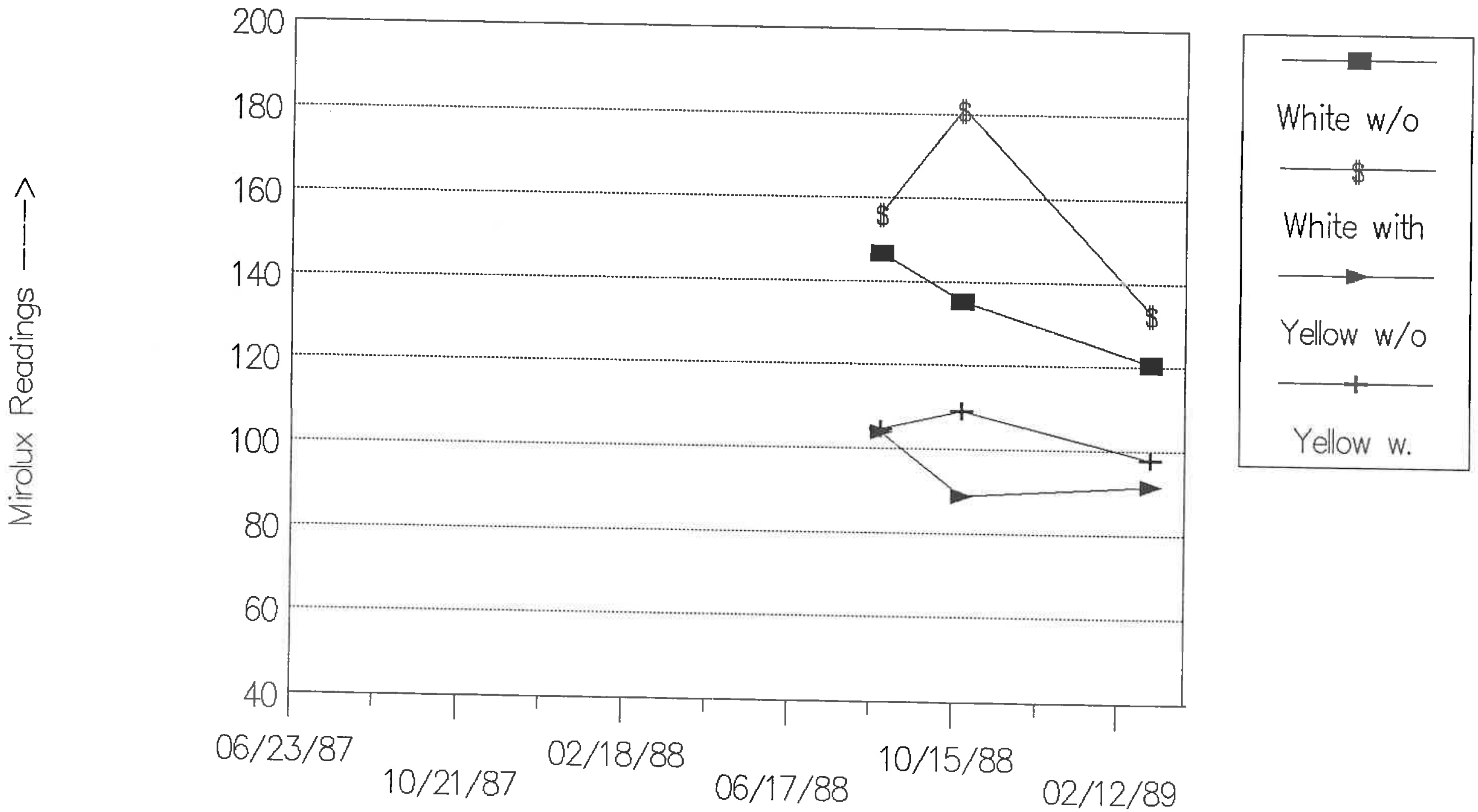


FIGURE 19

RETROREFLECTIVITY FOR WHITE PAINTS

ON ASPHALT

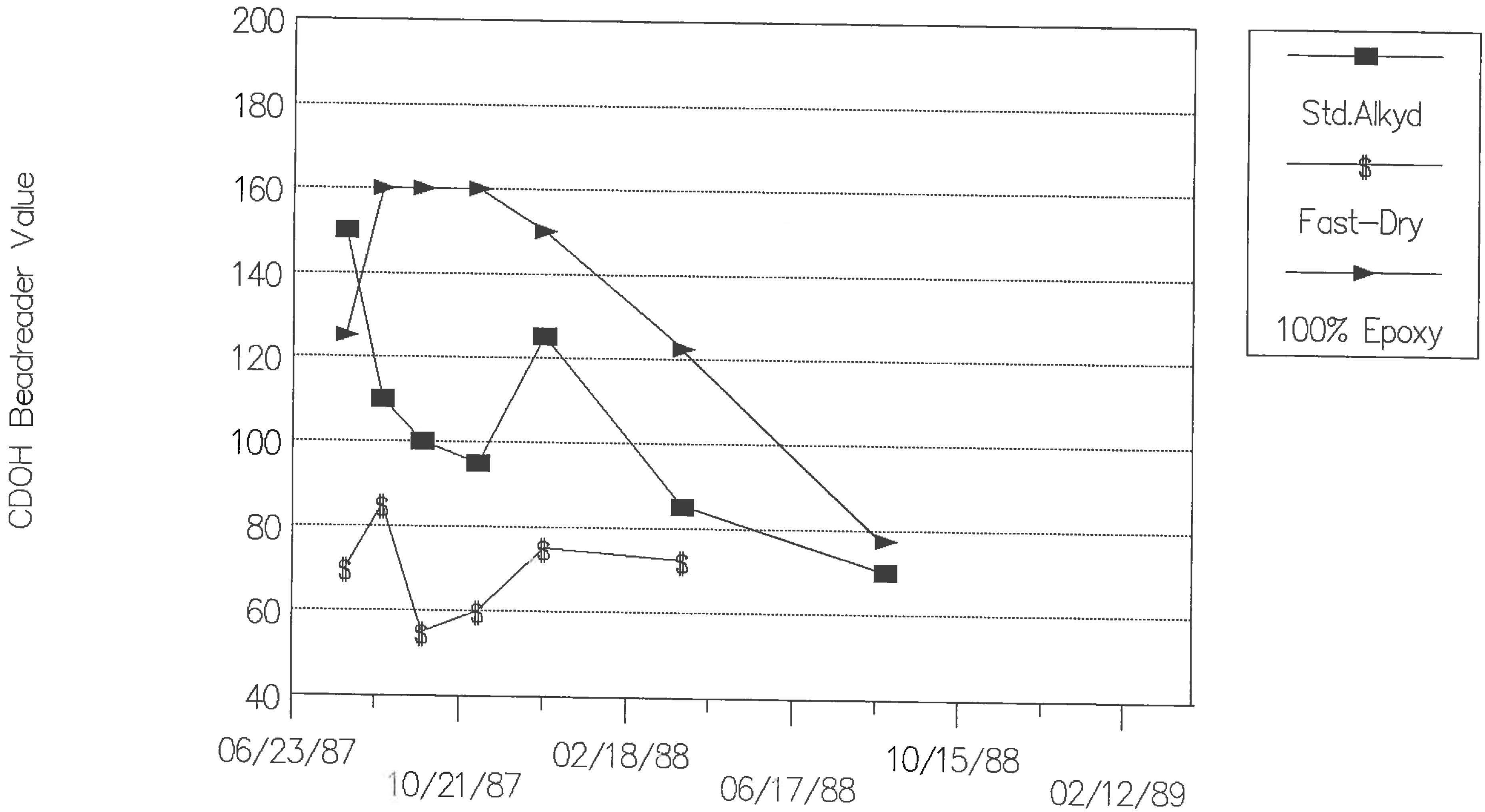


FIGURE 20

RETROREFLECTIVITY FOR YELLOW PAINTS

ON ASPHALT

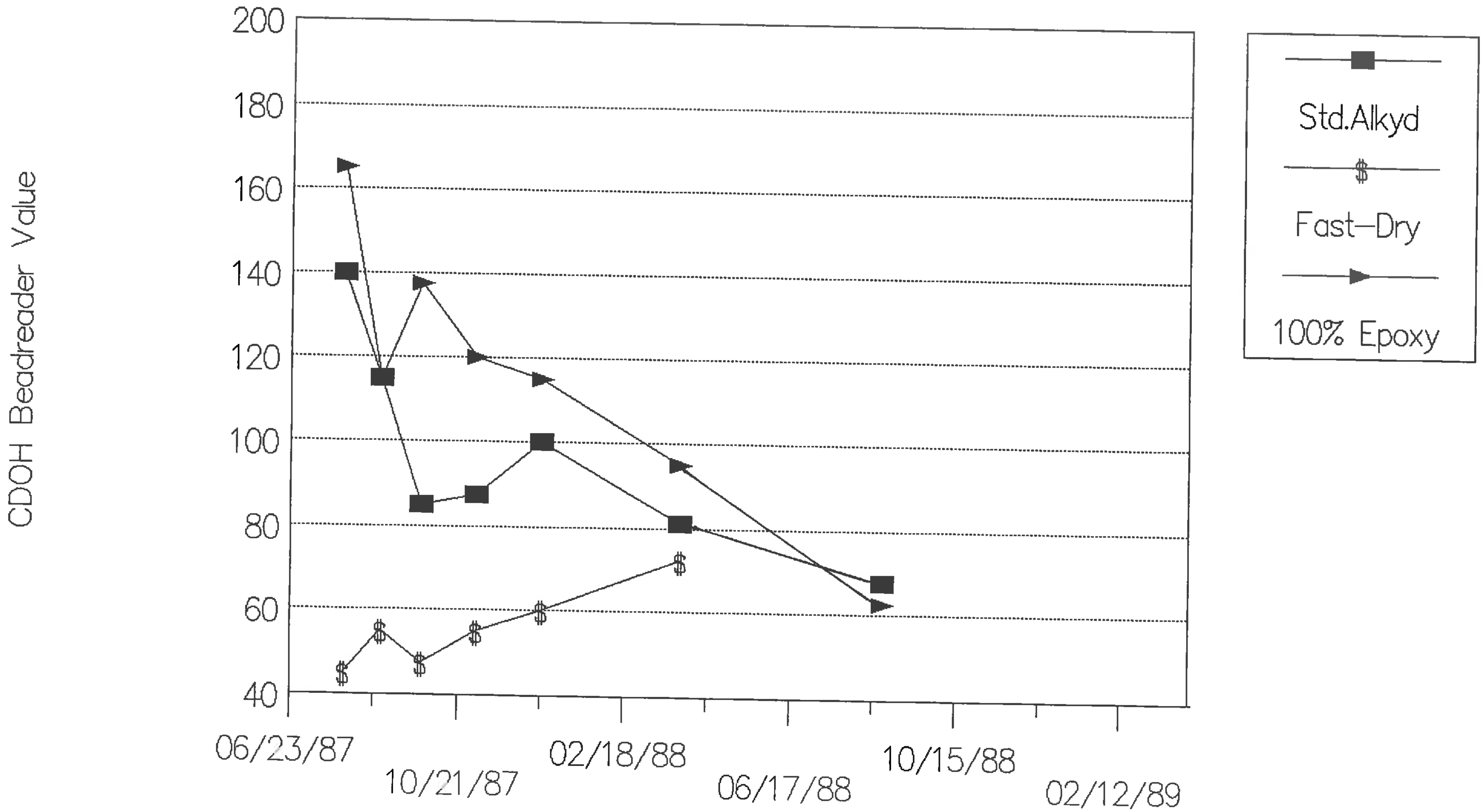
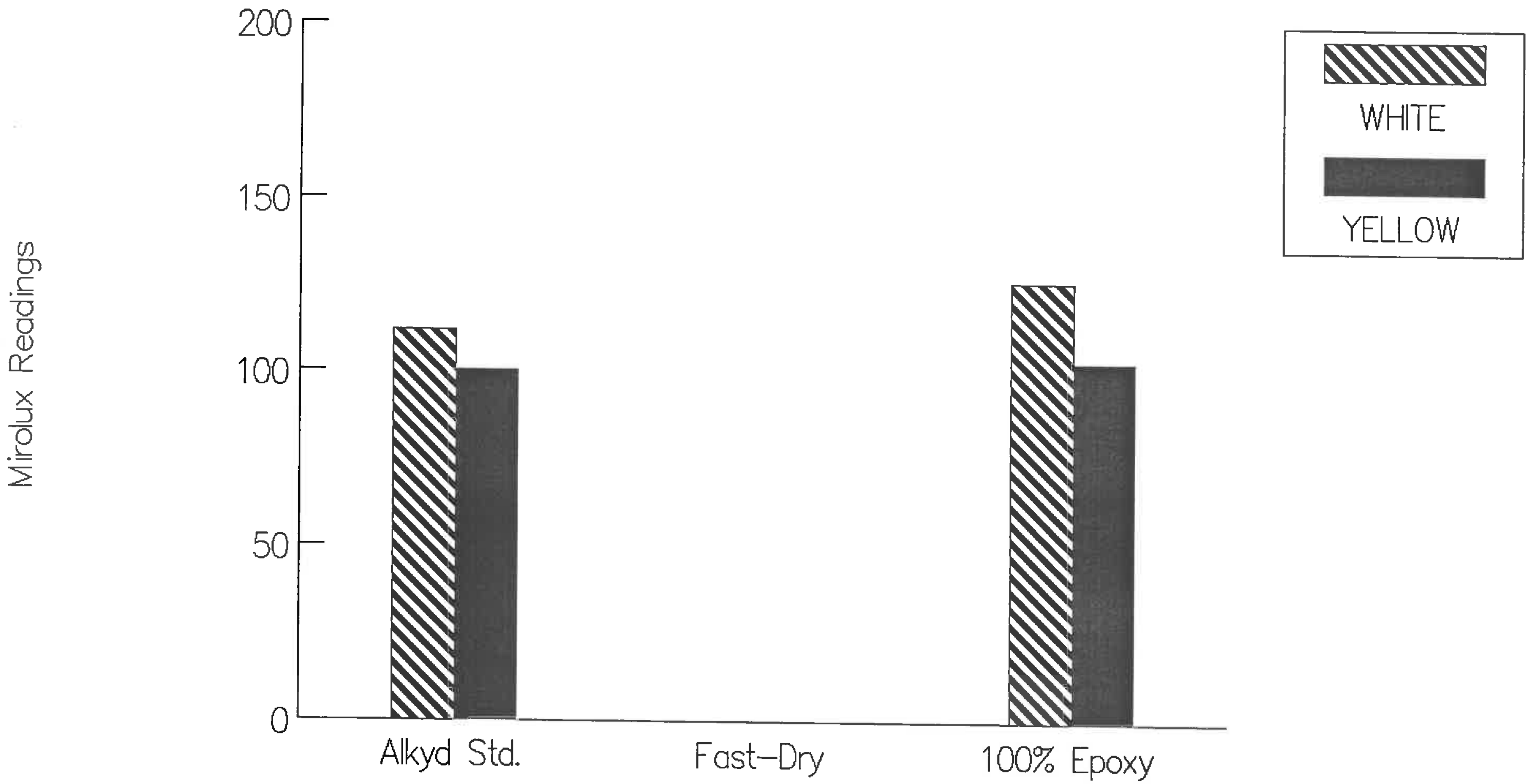


FIGURE 21

RETROREFLECTIVITY (MIROLUX) FOR PAINTS

ON ASPHALT ON 8/23/88



PHOTOS

Photo 1. 6/28/84
I25 southbound, milepost 159, north of Monument, 1984 epoxy paint.

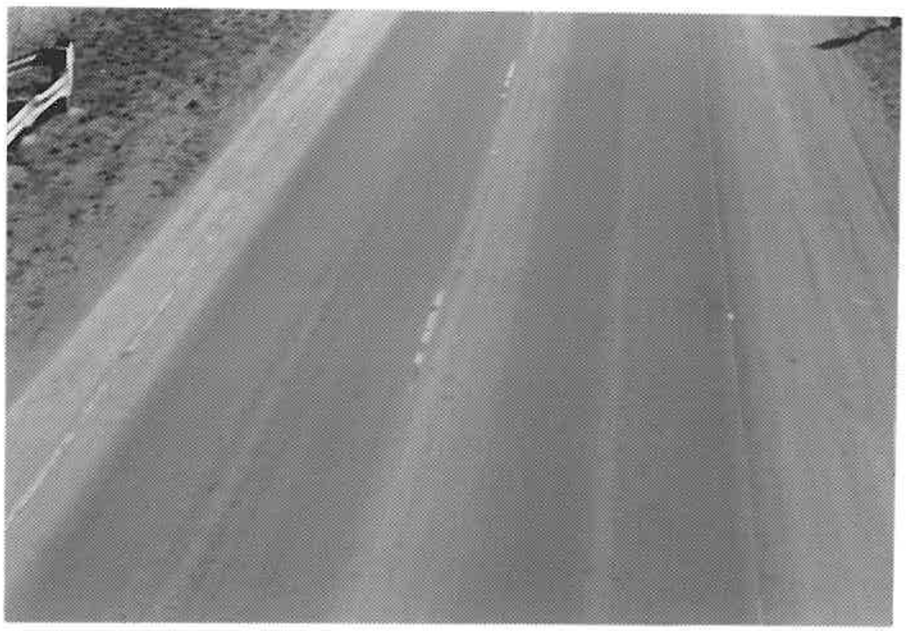


Photo 2. 3/16/87
I25 southbound, milepost 163.4, north of Monument, 1984 epoxy paint.

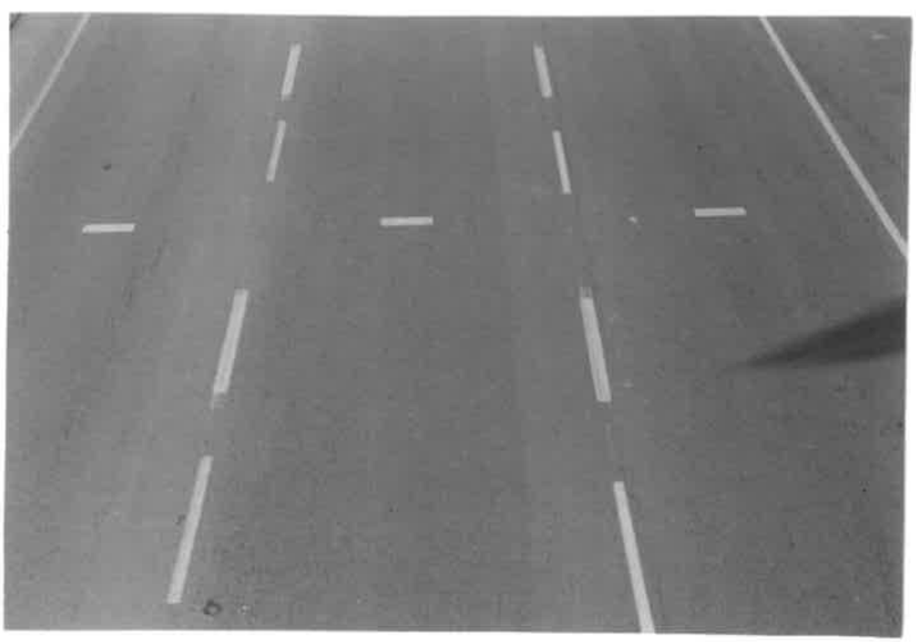


Photo 3. 12/84
I70 eastbound, milepost 248, near El Rancho Interchange, 1984 epoxy paint.

Photo 4. 12/84
I70 westbound, milepost 248, near El Rancho Interchange, 1984 polyester paint installed.

Photo 5. 3/16/87
I25 southbound, milepost 146, just north of Garden of The Gods Road, 1985 epoxy paint.

Photo 6. 1/25/88
I25 southbound, milepost 145, 1985 epoxy paint.

Photo 7. 4/17/89
I25 southbound, milepost 139, 1985 and 1988 epoxy paint.

Photo 8. 3/16/87
I25 southbound, milepost 138, Harrison Road Interchange, 1986 epoxy paint.

Photo 9. 1/25/88
I25 southbound, milepost 138, Harrison Road Interchange, 1986 epoxy paint.

Photo 10. 4/13/87
I76 southbound, just
south of Bromley Lane,
1986 epoxy paint.

Photo 11. 4/13/87
Bromley Lane westbound,
just east of I76, 1986
epoxy paint.

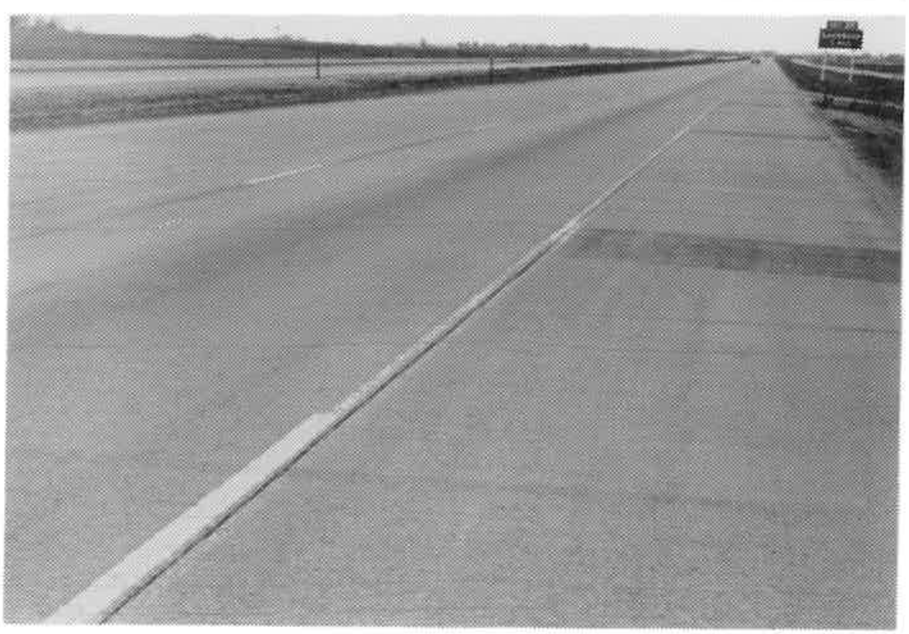


Photo 12. 4/13/87
I76 northbound, just
north of Bromley Lane,
1986 epoxy paint in
lower left, and alkyd
paint in upper right.

Photo 13. 1/25/88
I76 southbound, just north of Bromley Lane, 1987 fast-dry alkyd paint on bottom, 1986 epoxy paint on top of photo.

Photo 14. 2/27/89
I76 southbound, just north of Bromley Lane, 1986 epoxy paint overstriped with fast-dry alkyd paint.

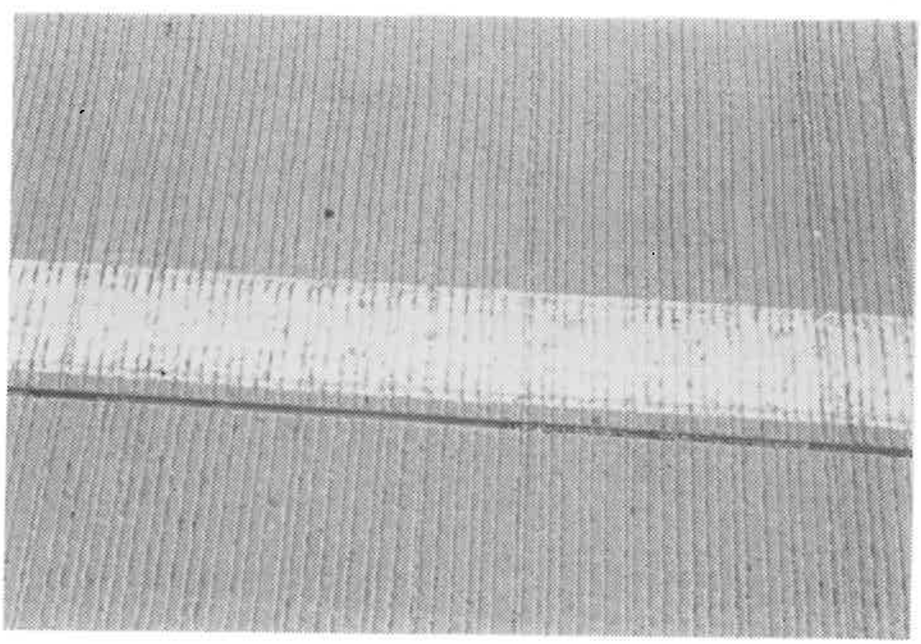


Photo 15. 1/25/88
I25 southbound, milepost 269 near Fossil Creek, 1986 epoxy paint skip stripe.

Photo 16. 1/25/88
I25 southbound, milepost 260 near Fossil Creek, 1986 extruded thermoplastic skip stripe.

Photo 17. 1/25/88
I25 southbound, milepost 260 near Fossil Creek, 1986 extruded thermoplastic edgeline.

Photo 18. 2/27/89
I25 southbound, milepost 260 near Fossil Creek, 1986 extruded thermoplastic skip stripe on lower right and 1988 epoxy paint skip stripe in upper left.

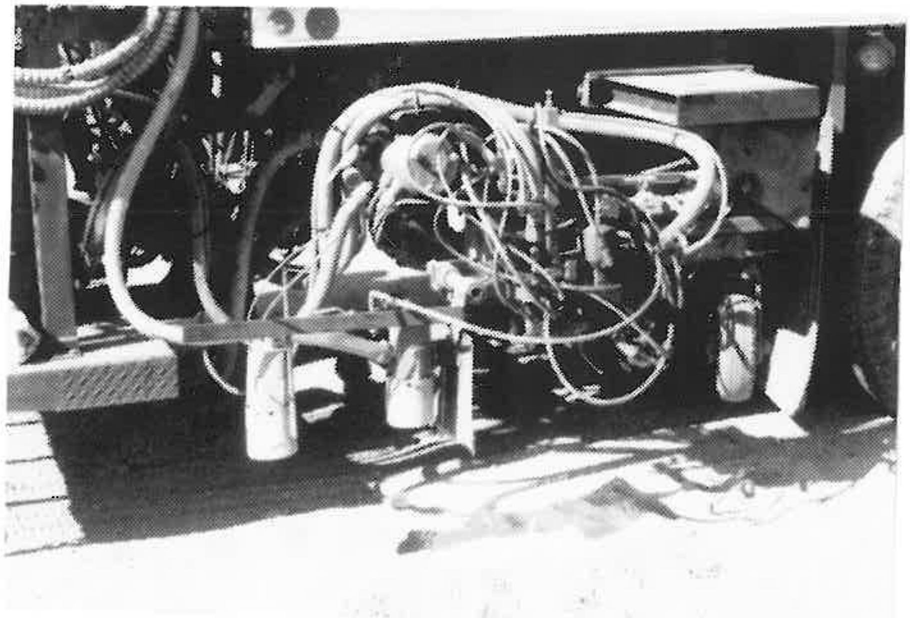


Photo 19. 5/5/88
Double drop bead system mounted on paint truck.

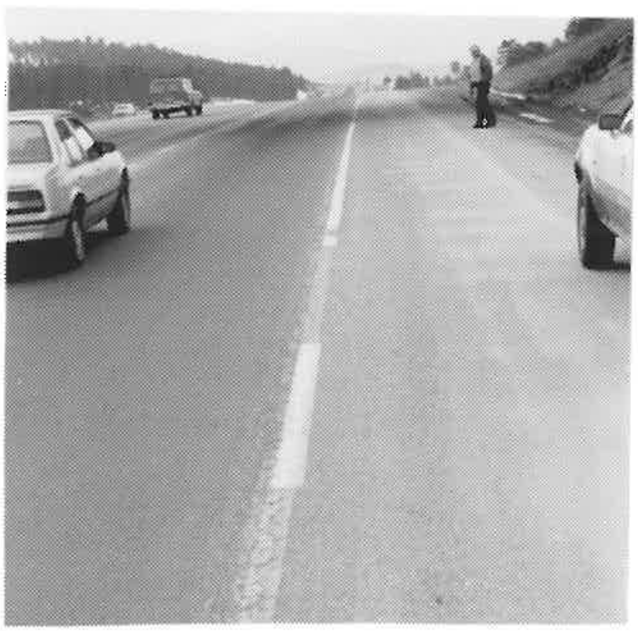


Photo 20. 3/6/89
I70 westbound, Buffalo Heard Overlook, 1988 epoxy and alkyd paints.

Photo 21. 3/29/88
Cataphote removable grade preformed plastic on concrete.

Photo 22. 3/29/88
Swarolite removable grade preformed plastic on concrete.

Photo 23. 3/29/88
3M removable grade preformed plastic on concrete.

Photo 24. 3/29/88
Prismo removable grade preformed plastic on concrete.

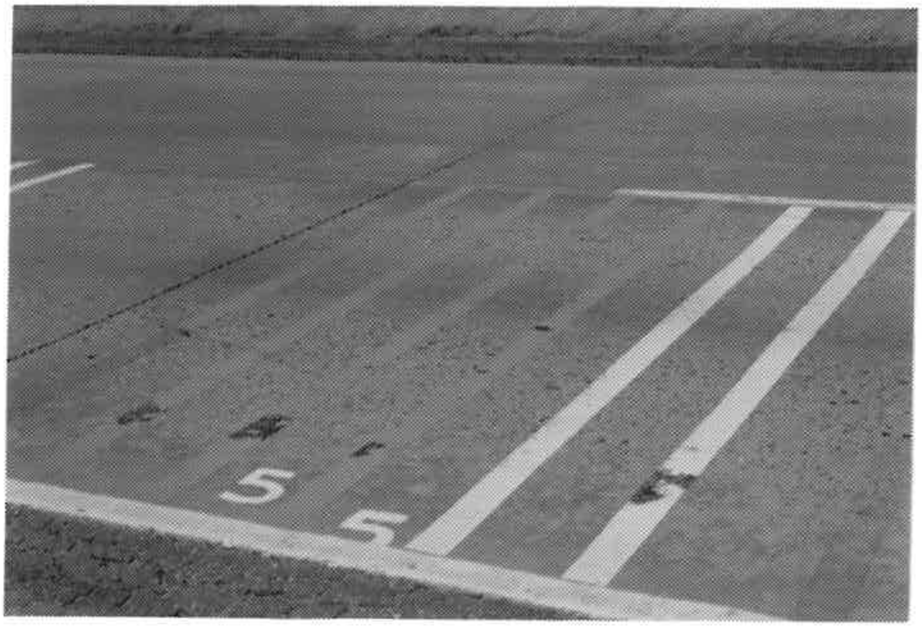


Photo 25. 3/29/88
PB Laminations removable grade preformed plastic on concrete.

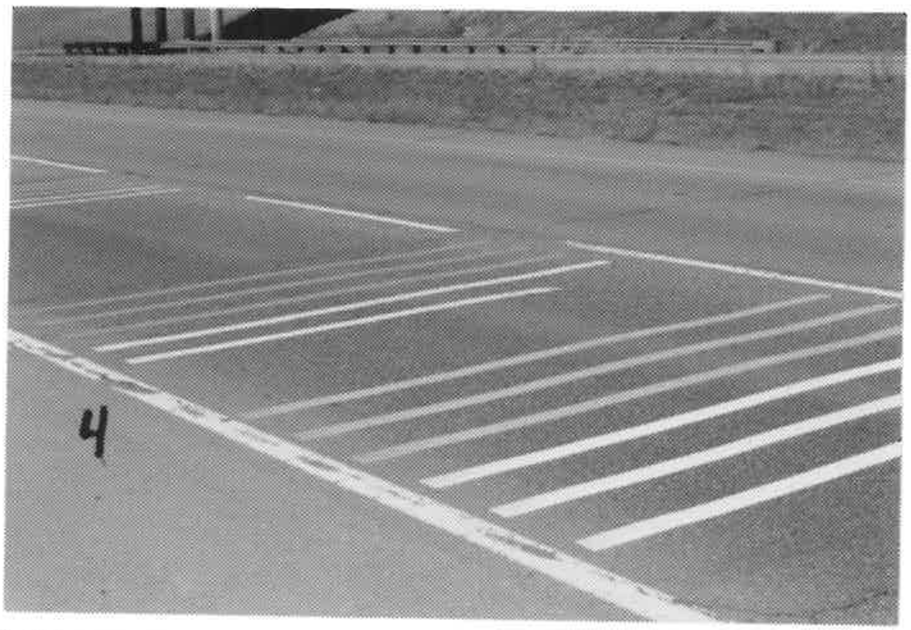


Photo 26. 3/29/88
Cataphote removable grade preformed plastic on asphalt. (Six stripes in foreground)

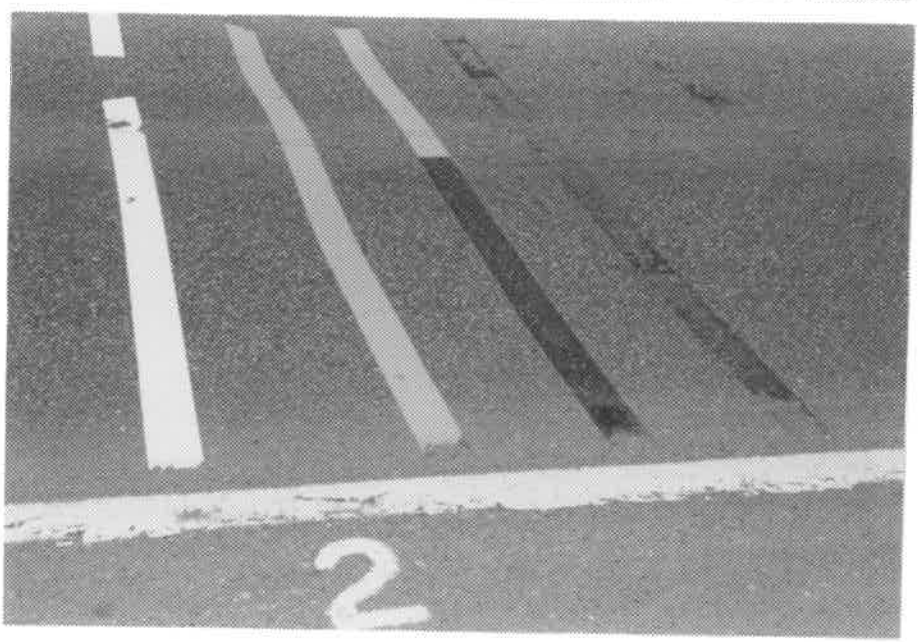


Photo 27. 3/29/88
Swarolite removable grade preformed plastic on asphalt.

Photo 28. 3/29/88
3M removable grade preformed plastic on asphalt. (Center four stripes)

Photo 29. 3/29/88
Prismo removable grade preformed plastic on asphalt.

Photo 30. 3/29/88
PB Laminations removable grade preformed plastic on asphalt.

Photo 31. 3/8/89
Pavemark permanent grade preformed plastic on concrete.

Photo 32. 3/8/89
Swarolite permanent grade preformed plastic on concrete.

Photo 33. 3/8/89
Seibulite permanent grade preformed plastic on concrete.

Photo 34. 3/8/89
Volare permanent grade preformed plastic on concrete.

Photo 35. 3/8/89
Cataphote permanent grade preformed plastic on concrete.

Photo 36. 3/8/89
3M-Std. permanent grade preformed plastic on concrete on left and 3M-350 permanent grade preformed plastic on concrete.

Photo 37. 3/8/89
Prismo permanent grade preformed plastic on concrete.

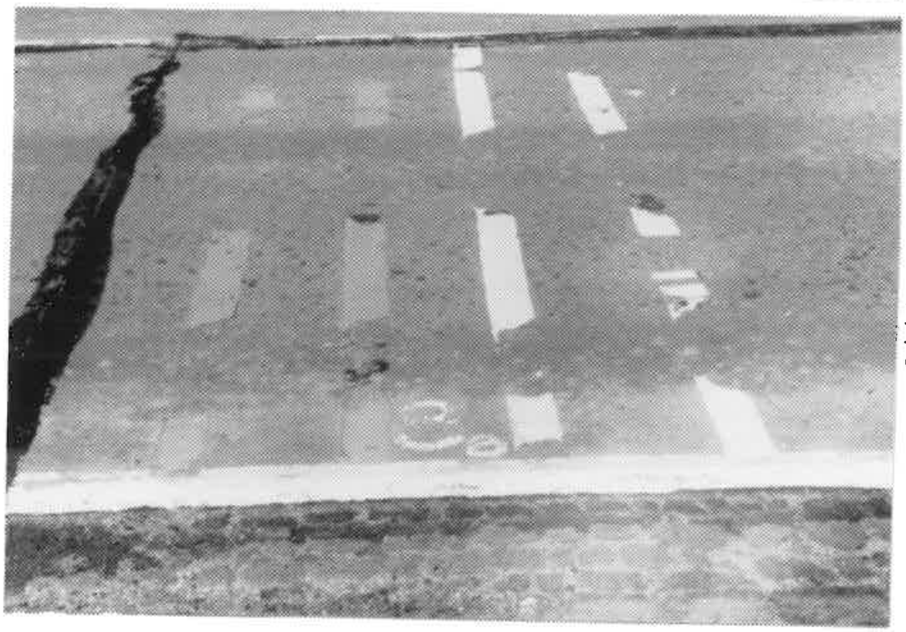


Photo 38. 3/8/89
Prismo permanent grade preformed plastic on concrete.

Photo 39. 3/8/89
Extruded thermoplastic on concrete.

Photo 40. 3/8/89
Paints on concrete.

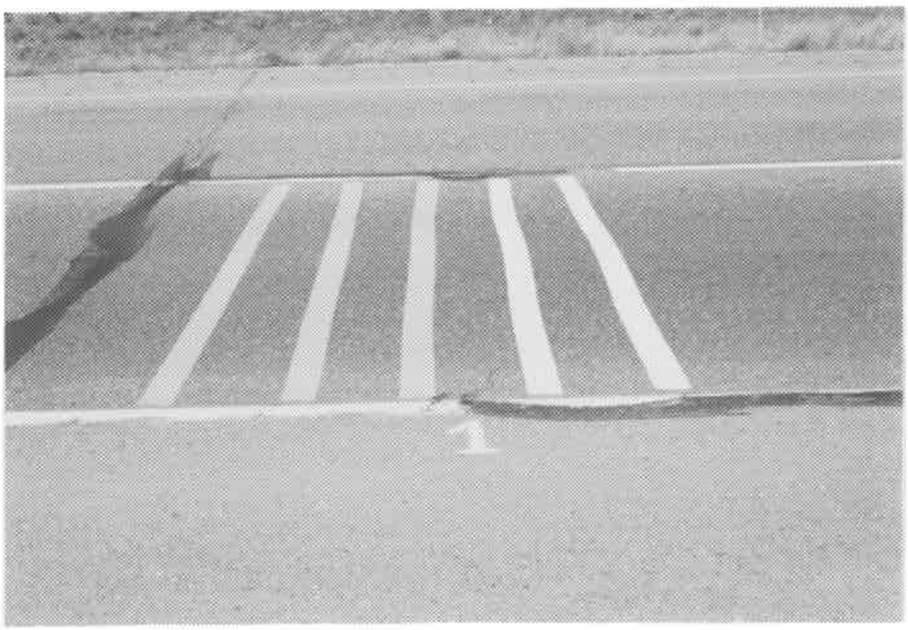


Photo 41. 3/8/89
Pavemark permanent grade preformed plastic on asphalt.

Photo 42. 3/8/89
Swarolite permanent grade preformed plastic on asphalt.

Photo 43. 3/8/89
Seibulite permanent grade preformed plastic on asphalt. (Far left four stripes)

Photo 44. 3/8/89
Volare permanent grade preformed plastic on asphalt.

Photo 45. 3/8/89
Cataphote permanent grade preformed plastic on asphalt.

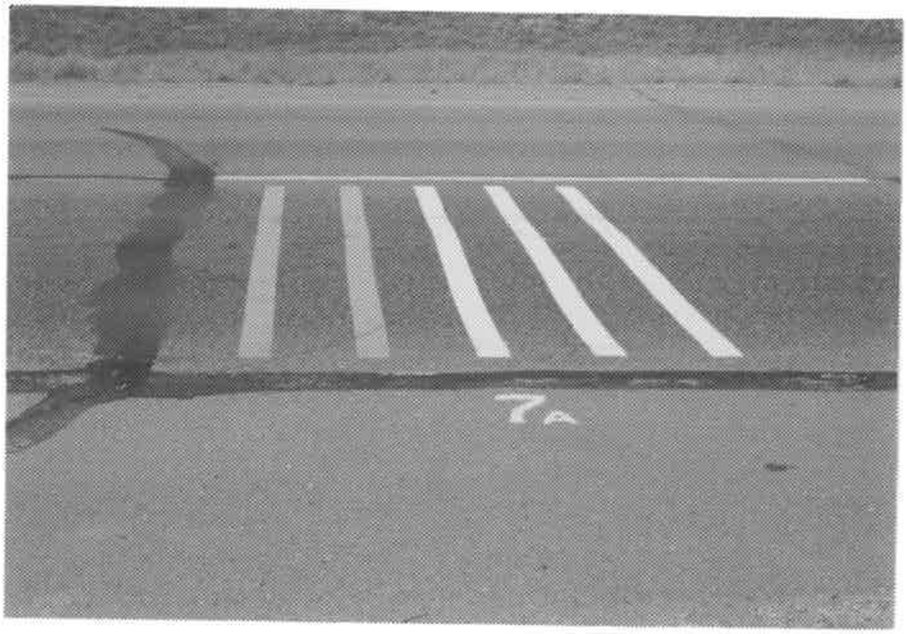


Photo 46. 3/8/89
3M-Std. permanent grade preformed plastic on asphalt.

Photo 47. 3/8/89
3M0350 permanent grade preformed plastic on asphalt.

Photo 48. 3/8/89
Prismo permanent grade preformed plastic on asphalt.

Photo 49. 3/8/89
Prismo permanent grade preformed plastic on asphalt.

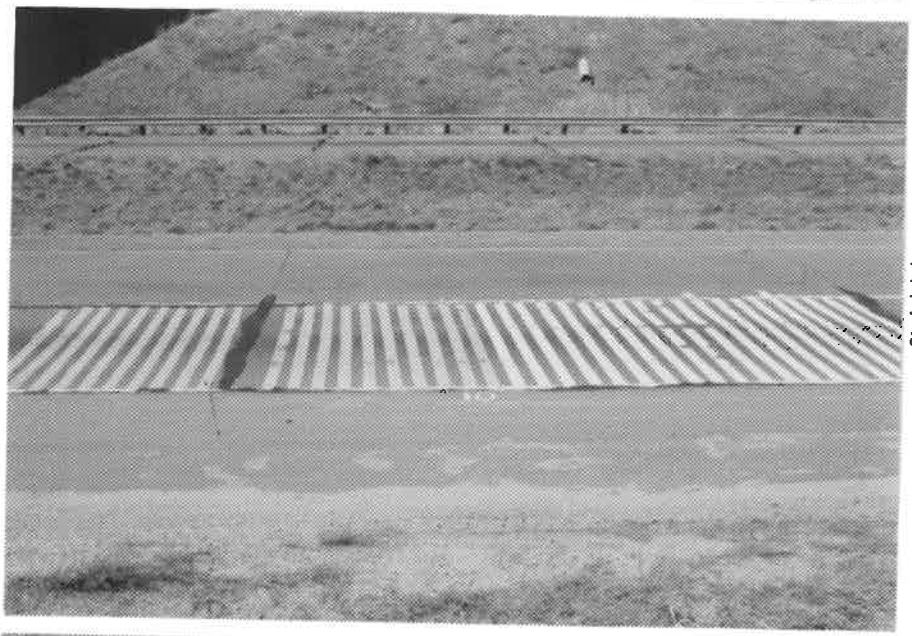


Photo 50. 3/8/89
Extruded thermoplastic on asphalt.

Photo 51. 3/8/89
Paints on asphalt.

APPENDIX A

COLORADO DEPARTMENT OF HIGHWAYS

EPOXY PAINT SPECIFICATION

REVISION OF SECTIONS 627 AND 713
EPOXY PAVEMENT MARKING

Sections 627 and 713 of the Standard Specifications are hereby revised for this project as follows:

Subsection 627.02 shall include the following:

Epoxy pavement marking materials (100% solids) shall conform to the requirements of subsection 713.15 included in this provision.

Subsection 627.06 shall include the following:

(a) EPOXY PAVEMENT MARKING. The epoxy pavement marking compound shall be applied with equipment that will precisely meter the two components in the ratio given in 713.15(a). The equipment shall automatically shut off or warn the operator if one component is not being mixed. The equipment shall produce the required amount of heat at the mixing head and gun tip to provide and maintain the temperatures specified.

Before mixing, the individual components A and B shall each be heated to a temperature of 80°F (26.7°C) to 140°F (60°C). After mixing, the application temperature for the combined material at the gun tip shall be 80°F (26.7°C) to 140°F (60°C). The 140°F upper limit is the maximum temperature under any circumstances.

Pavement and air temperature shall be 50°F minimum at the time of epoxy pavement marking application.

The surface areas of new portland cement concrete pavement and decks that are to receive markings shall be sandblasted prior to placement of the epoxy pavement marking. The amount of sandblasting shall be sufficient to remove all dirt, laitance, and curing compound residue.

The surface areas of new asphalt pavement, existing asphalt pavement, and existing concrete pavement that are to receive markings shall be cleaned with a high pressure air blast to remove loose material prior to placement of the epoxy pavement marking. Should any pavement become dirty, from tracked mud etc. as determined by the Engineer, it shall be cleaned prior to the placement of the epoxy pavement marking.

If recommended by the epoxy manufacturer, a high pressure water blast integrated into the gun carriage shall be used to clean the pavement surface prior to epoxy pavement marking application. The water blast shall be followed by a high pressure air blast to remove all residual water, leaving only a damp surface.

Epoxy pavement marking shall be applied to the road surface according to the epoxy manufacturer's recommended methods at 15 mils minimum thickness.Glass beads shall be applied into the epoxy pavement marking by means of a pressurized bead applicator at a rate of 0.25 pounds per square foot (25 pounds per gallon).

Epoxy pavement marking and beads shall be applied within the following limits:

	Application Rate or Coverage Per Gallon of Epoxy Pavement Marking	
	MINIMUM	MAXIMUM
15 Mil Marking:	100 sq. ft.	110 sq. ft.
Beads:	25 lbs.	-

Subsection 627.10(a) shall include the following:

Epoxy Pavement Marking (100% solids) will be measured by the gallon.

REVISION OF SECTIONS 627 AND 713
EPOXY PAVEMENT MARKING

Subsection 627.11 shall include the following:

PAY ITEM	PAY UNIT
Epoxy Pavement marking	Gallon

Sandblasting as required by subsection 627.06 for new concrete pavement will be measured and paid for in accordance with Section 202.

Glass beads and cleaning with high pressure water blast or air blast shall be included in the cost of the epoxy pavement marking.

Subsection 713.08 shall include the following:

Glass beads for epoxy pavement marking shall conform to AASHTO M 247, Type I, except that they shall be silane coated (AC-04), 75 percent minimum true spheres per sieve size, and conform to the following gradation:

Sieve Size (ASTM E-11)	% Passing
14	100
16	95-100
20	10-50
40	0-5

Subsection 713.15 shall be added as follows:

713.15 EPOXY PAVEMENT MARKING MATERIAL (100% SOLIDS).

(a) FORMULATION. Epoxy pavement marking material shall be a two component 100% solid material formulated to provide simple volumetric mixing ratio of two volumes of component A and one volume of component B unless otherwise recommended by the material manufacturer.

(b) COMPOSITION. The component A of both white and yellow shall be within the following limits:

	WHITE:	YELLOW:
Pigments	Min. % by weight 18% Titanium Dioxide (ASTM D-476 Type II)	Min. % by weight 23% Chrome Yellow (ASTM D-211 Type III)
Epoxy Resin	75-82%	70-77%

(c) EPOXIDE NUMBER. The epoxy number of the epoxy resin shall be 0.38 + 0.05 as determined by ASTM D-1652 for white and yellow component A on pigment free basis.

(d) AMINE NUMBER. The amine number of the curing agent (component B) shall be 410 + 50 per ASTM D-2071.

(e) TOXICITY. Upon heating to application temperature, the material shall not produce fumes which are toxic or injurious to persons or property.

(f) COLOR AND WEATHER RESISTANCE. The mixed epoxy compound, both white and yellow, when applied to 3 inch by 6 inch aluminum panels at 15 ± ½ mils in thickness with no glass beads and exposed in the Q.U.V. Environmental Testing Chamber as described in ASTM G-53, shall conform to the following minimum requirements. (The test shall be conducted for 75 hours at 50°C, 4 hours humidity and 4 hours U.V., in alternating cycles. The prepared panels shall be cured at 77°F for 72 hours prior to exposure.) The color of the white epoxy system shall not be darker than Federal Standard No. 595A - 17778. The color of the yellow epoxy system shall be in reasonably close conformity to Federal Standard No. 595A - 13538. The gloss values of both samples shall not be less than 70° after the test.

(g) DRYING TIME. The epoxy pavement marking material shall have a setting time to a no-tracking condition of not more than 10 minutes at a temperature of 73°F and above.

(h) CURING. The epoxy material shall be capable of fully curing under the constant surface temperature condition of 25°F and above.

(i) ADHESION TO CONCRETE. The catalyzed epoxy pavement marking material, when tested according to ACI Method 503, shall have such a high degree of adhesion to the specified (4,000 psi minimum) concrete surface that there shall be a 100% concrete failure in the performance of this test.

(j) HARDNESS. The epoxy pavement marking materials, when tested according to ASTM D-2240, shall have a Shore D Hardness between 75 and 100. Samples shall be allowed to cure at room temperature (75°F ± 2°F) for a minimum of 12 hours and a maximum of 48 hours prior to performing the indicated test.

(k) ABRASION RESISTANCE. The abrasion resistance shall be evaluated on Taber Abrader with a 1000 gram load and CS-17 wheels. The duration of the test shall be 1000 cycles. The wear index shall be calculated based on ASTM test method C-501 and the wear index for the catalyzed material shall not be more than 70. The tests shall be run on cured samples of material which have been applied at film thickness of 15 ± ½ mils to code S-16 stainless steel plates. The samples shall be allowed to cure at 75°F ± 2°F for a minimum of 48 hours prior to performing the indicated tests.

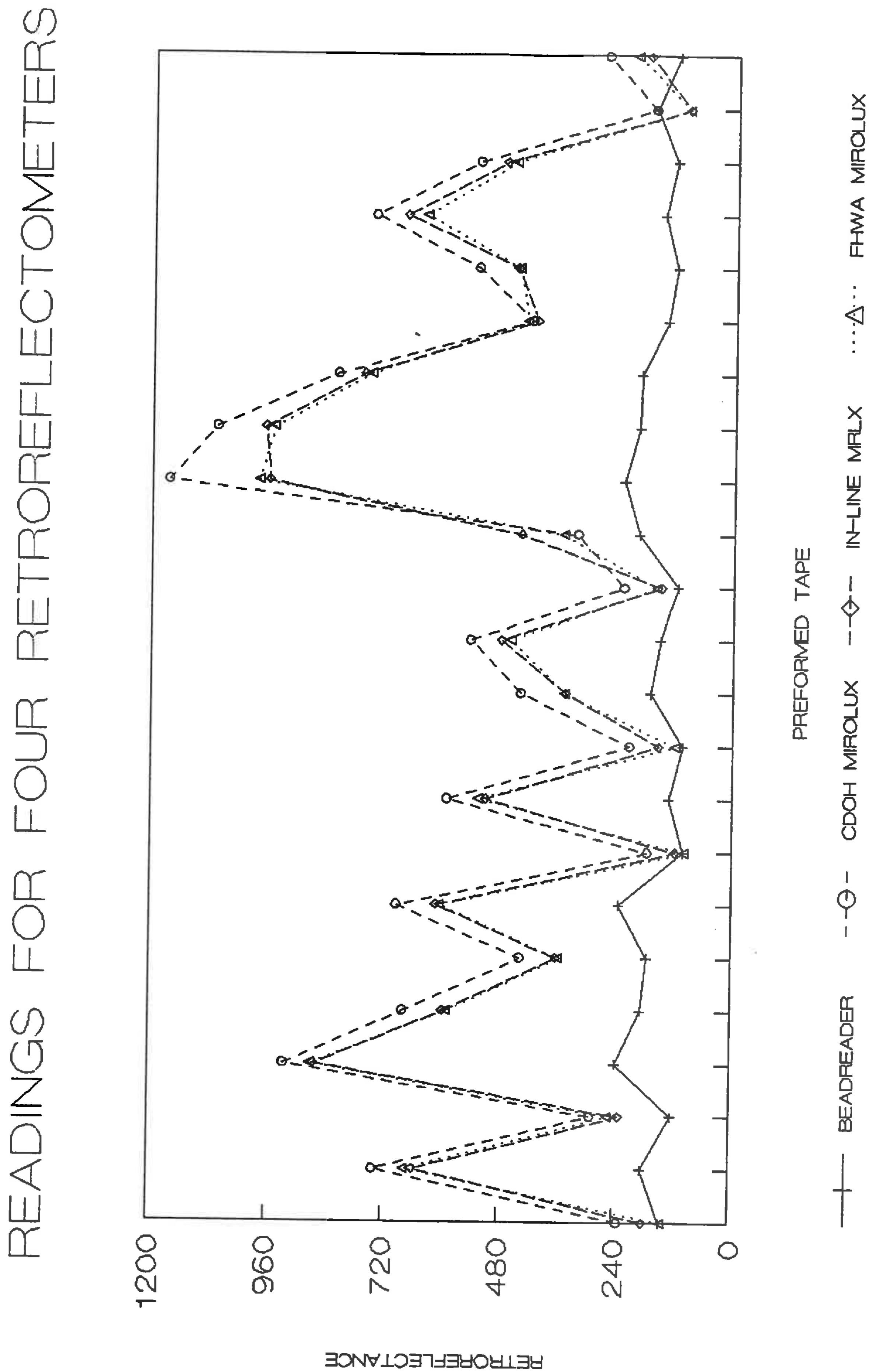
(l) TENSILE STRENGTH. When tested according to ASTM D-638, the epoxy pavement marking materials shall have a tensile strength of not less than 6,000 pounds per square inch. The Type IV Specimens shall be cast in a suitable mold and pulled at a rate of ¼ inch per minute by a suitable dynamic testing machine. The samples shall be allowed to cure at room temperature (75°F ± 2°F) for a minimum of 12 hours and a maximum of 48 hours prior to performing the indicated tests.

(m) COMPRESSIVE STRENGTH. When tested according to ASTM D-695, the catalyzed epoxy pavement marking materials shall have a compressive strength of not less than 12,000 pounds per square inch. The cast sample shall be conditioned at room temperature (75°F ± 2°F) for a minimum of 12 hours and a maximum of 48 hours prior to performing the tests. The rate of compression of these samples shall be no more than ¼ inch per minute.

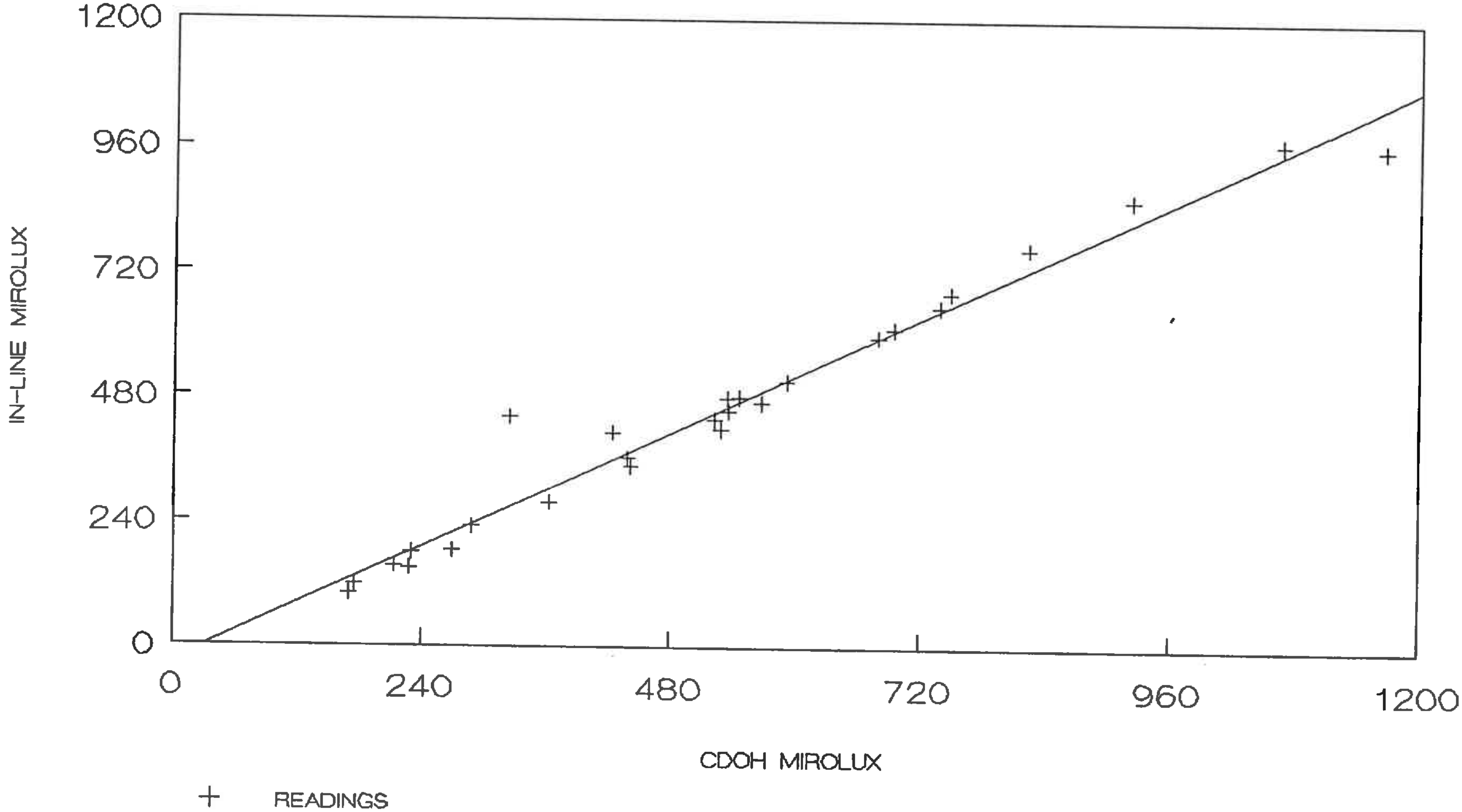
APPENDIX B

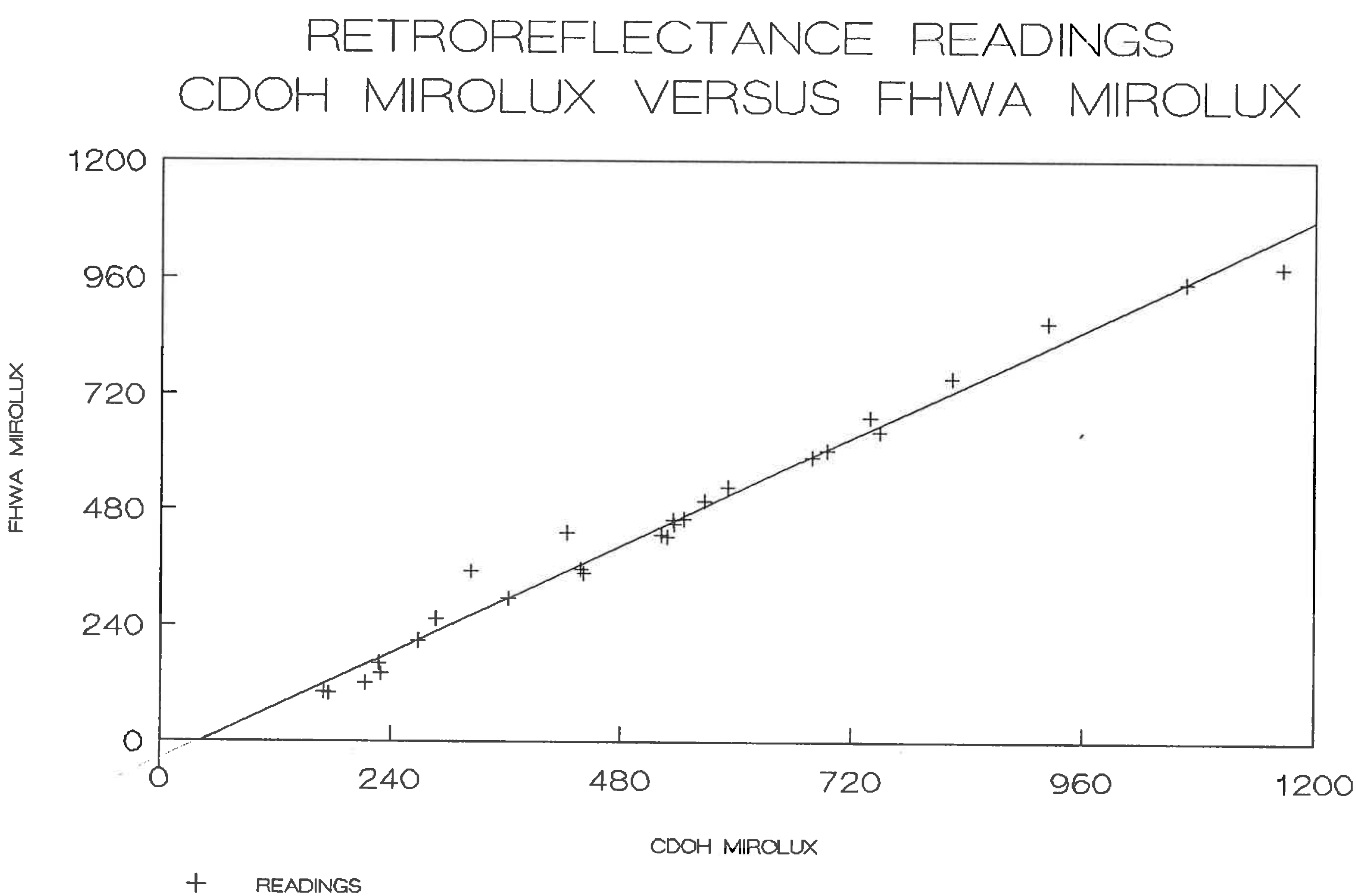
RETROREFLECTOMETER

CORRELATION

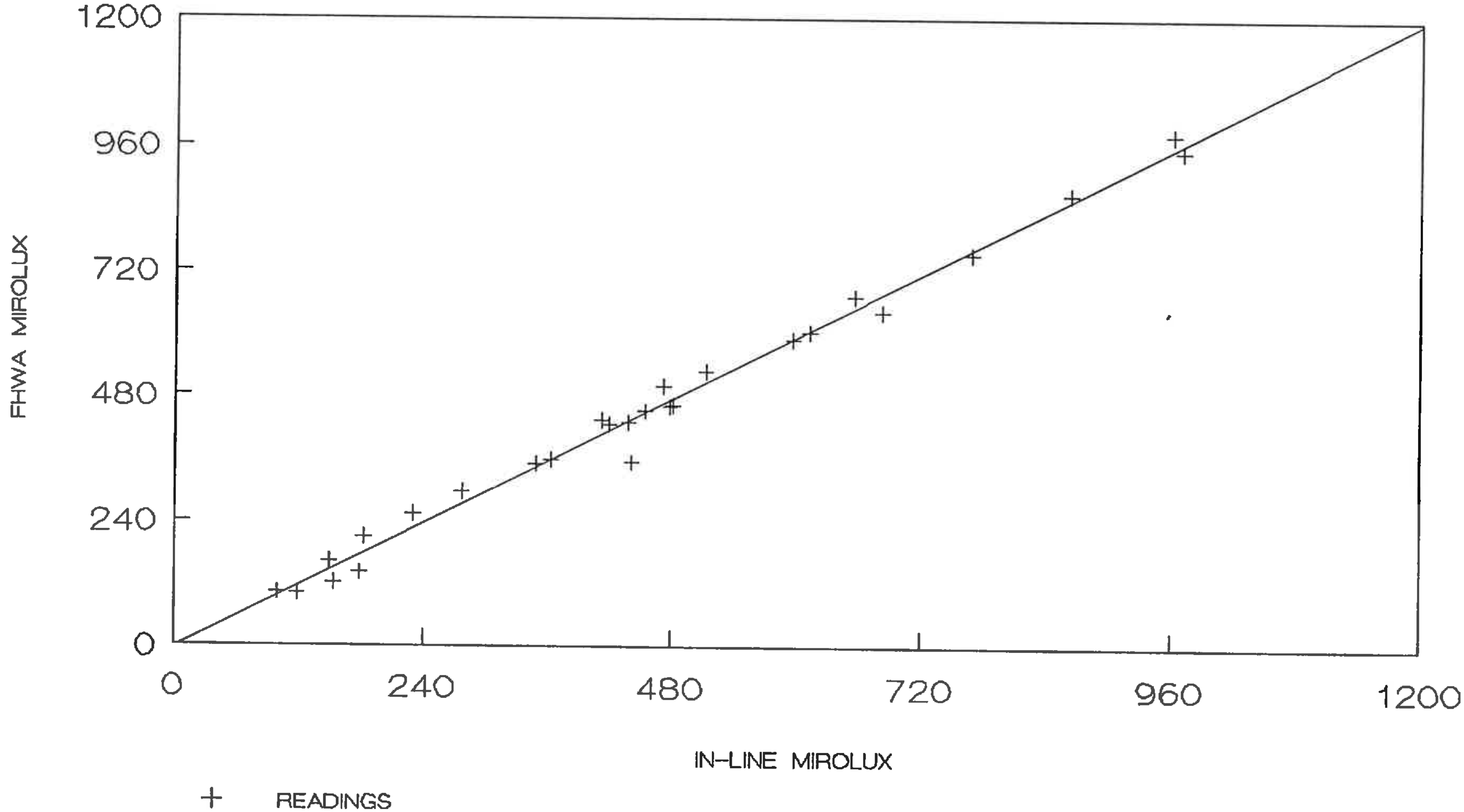

READINGS FOR FOUR RETROREFLECTOMETERS
1200
960
720
480
240
0
RETROREFLECTANCE
PREFORMED TAPE
BEADREADER
CDOH MIROLUX
IN-LINE MRLX
FHWA MIROLUX

RETROREFLECTANCE READINGS
CDOH MIROLUX VERSUS IN-LINE MIROLUX

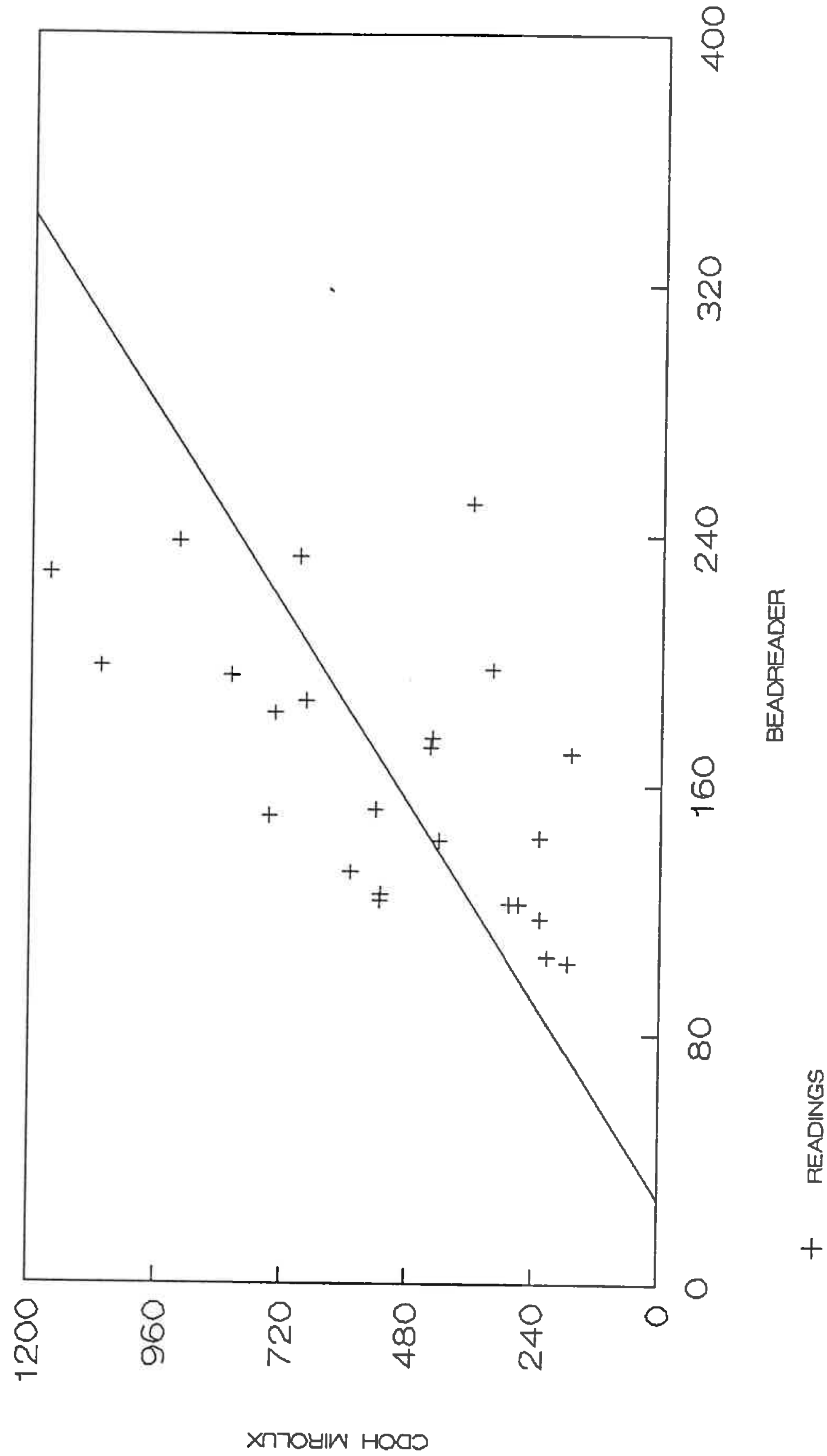


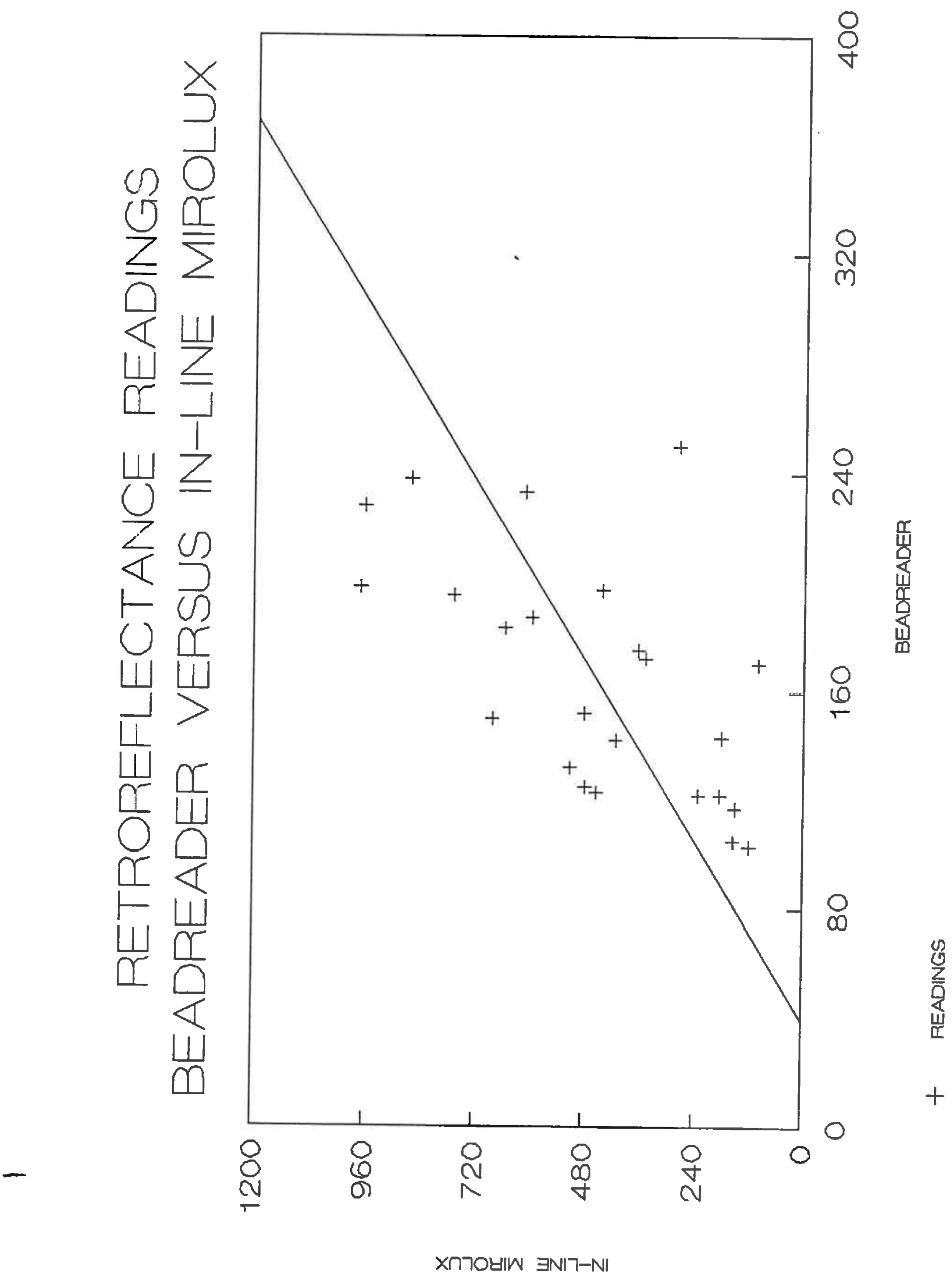

RETROREFLECTANCE READINGS
CDOH MIROLUX VERSUS FHWA MIROLUX
FHWA MIROLUX
1200
960
720
480
240
0
240
480
720
960
1200
CDOH MIROLUX
+ READINGS

RETROREFLECTANCE READINGS
IN-LINE MIROLUX VERSUS FHWA MIROLUX

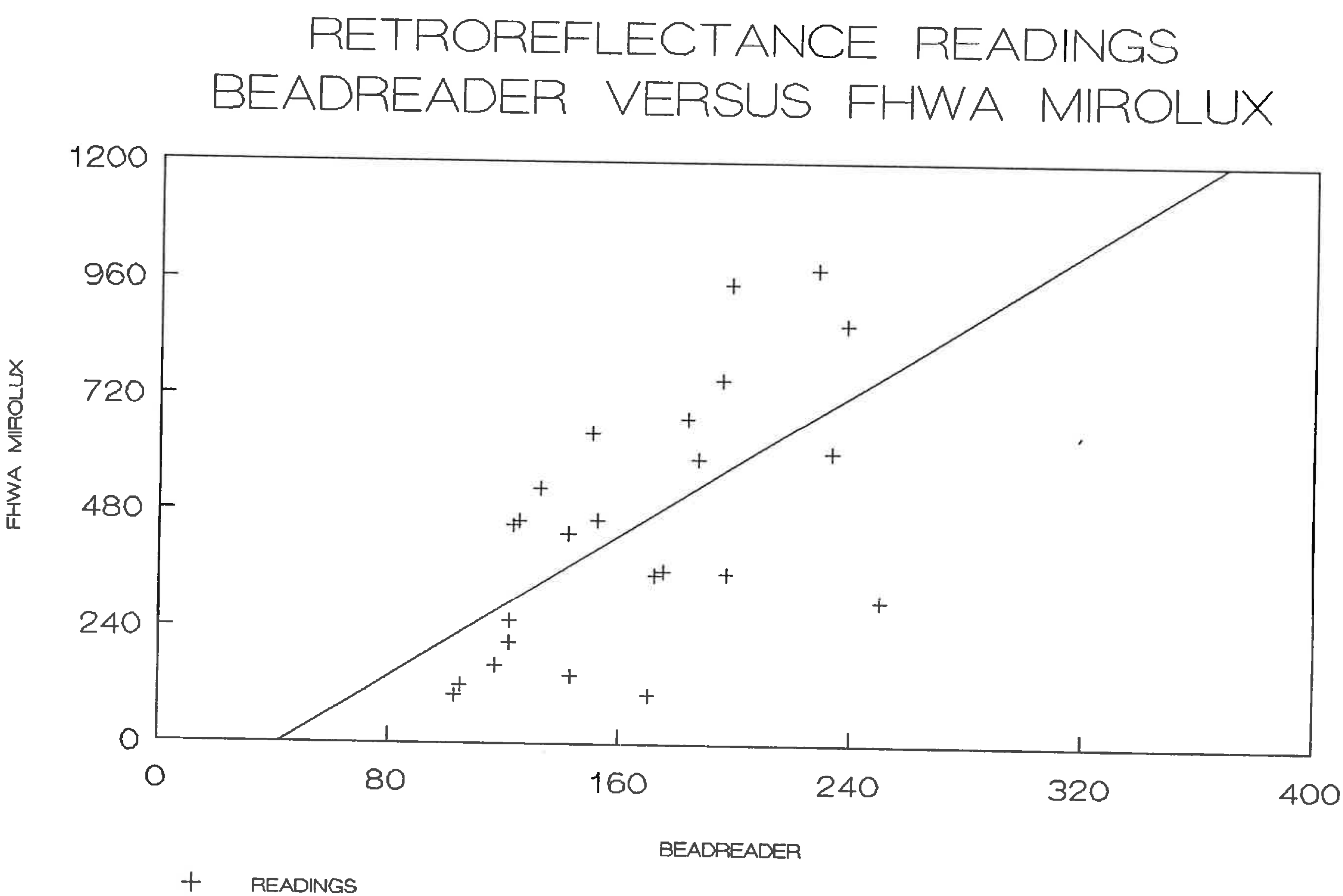


RETROREFLECTANCE READINGS
BEADREADER VERSUS CDOH MIROLUX





RETROREFLECTANCE READINGS
BEADREADER VERSUS IN-LINE MIROLUX
IN-LINE MIROLUX
BEADREADER
0
240
480
720
960
1200
0
80
160
240
320
400
+ READINGS


RETROREFLECTANCE READINGS
BEADREADER VERSUS FHWA MIROLUX
FHWA MIROLUX
1200
960
720
480
240
0
0
80
160
240
320
400
BEADREADER
+ READINGS