

**NORTH DAKOTA
DEPARTMENT OF TRANSPORTATION**

**MATERIALS AND RESEARCH
DIVISION**

Experimental Study MR 99-01

Evaluation of Epoxy-Resin Pavement Marking

Construction Report & Final Report

November 1999

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Pavement Markings**

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Written by
Tom Bold

Disclaimer

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Evaluation of Epoxy Pavement Marking Paint

Objective

To compare the performance and cost-effectiveness of epoxy resin pavement marking material.

Scope

In order to achieve the objective, one test section was constructed in conjunction with Project IM-1-094(053)161, using material as described in Special Provision SP 70(97) dated July 17, 1998. The special provision utilizes several different types of pavement marking systems.

The types of marking materials applied in this test section are listed as follows:

1. Waterborne pavement marking paint- (median and outside edge lines, ramps, and gore areas).
2. Four inch white pavement marking tape (centerline).
3. Type II Long Term Pavement Marking, epoxy-resin - white and yellow (median and outside edge lines and 1 mile of centerline).

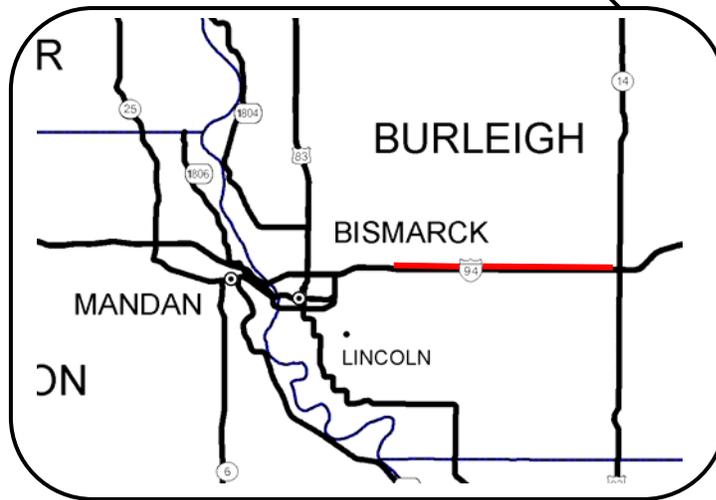
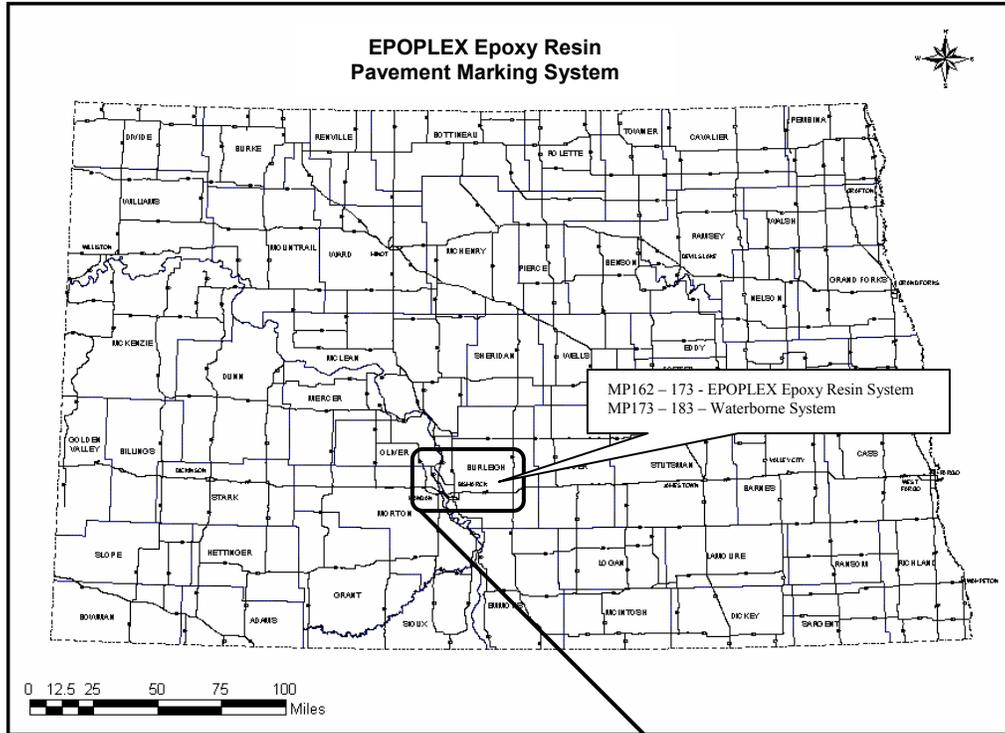
The waterborne system utilized VOGEL UC-1511, (white) & UC-3585, (yellow) paint, manufactured by Vogel Paint & Wax Co., Inc.; Orange City, Iowa and Canasphere M247-1 ND Dual 80% Premium Hwy Spheres, manufactured by Canasphere Industries Ltd.; Moose Jaw, Saskatchewan, Canada.

The LS60 epoxy resin pavement marking system is a two component system. The base resin/pigmentation (component A) is manufactured by EPOPLEX; Maple Shade, New Jersey. The activator/curing agent (component B) for the epoxy resin was CEX 12-993, manufactured by Henkel Corporation; Kankakee, Illinois. Canasphere M247-1 glass beads were also used with this marking system.

The pavement marking test section was constructed on a new asphalt overlay pavement surface. Pavement marking were applied to the west bound lanes of traffic. Marking materials were used to delineate the white outside edge line, the yellow median edge line, and the white lane skip lines of the west bound lane.

Location

The test section is located on the west bound lane of I-94 between reference point 162.360 and 182.874.



Construction

On June 9th - 16th, 1999, three types of pavement marking systems were installed on Project IM-1-094(053)161; Waterborne Paint, 3M Pavement Marking Tape, and Epoxy-Resin Paint. Traffic Safety Services Inc (TSS) applied all of the pavement marking systems.

The application of the marking systems was completed in stages. Table 1 provides information describing each system, location, and date of installation.

Table 1: Pavement Marking Systems - Material, Location, & Installation

Location (RP)	Material	Date Installed	Manufacturer & Product	*Glass Beads	Line Type	Color
163-182	Tape	5/21 to 5/29 1999	3M	No	Skip Lines	W
162-172	Epoxy-Resin	6/10/99	EPOPLEX-LS60	Yes	Edge Lines	Y/W
162-163	Epoxy-Resin	6/11/99	EPOPLEX-LS60	Yes	Skip Lines	W
162-172	Epoxy-Resin	6/11/99	EPOPLEX-LS60	Yes	Edge Lines	W
162-182	Paint	6/16/99	VOGEL UC-1511 & UC-3585 Waterborne Paint	Yes	Ramp & Gore	Y/W
172-182	Paint	6/14/99	VOGEL UC-1511 & UC-3585 Waterborne Paint	Yes	Edge Lines	Y/W

*Canasphere M247-1 ND Dual 80% Premium Highway Sphere

Installation of the VOGEL UC-1511 (white) and UC-3585 (yellow) waterborne paint and 3M Tape were completed following previously used procedures.

The application of long term pavement marking is specified in Special Provision SP 70(97), for project IM-1-094(053)161. Appendix A contains a copy of this Special Provision.

The EPOPLEX LS60 pavement marking system was selected for evaluation. It is classified as a Type II, slow cure, epoxy resin pavement marking system. EPOPLEX describes the LS60 product as “a two component 100% solids epoxy coating material designed as a slow setting highway marking coating offering durability, corrosion and abrasion resistance. LS60 is formulated to provide a simple volumetric mixing ratio of two volumes of Component A, (base resin/pigmentation), to one volume of Component B, (activator/curing Agent), and is free of TMPTA or multi-functional monomers.”

Installation of the EPOPLEX LS60 pavement marking system was performed on

June 10th & 11th, 1999. The installation was observed and photographed by Materials and Research Division personnel. Traffic control, as specified under the project Special Provisions, was required to provide protection for marking material while curing. Photo 1 shows the TSS striping equipment applying the LS60 system.



Photo 1: Application of EPOPLEX LS60 pavement marking system with traffic control.

The epoxy resin material was applied along with the Canasphere, (M247-1 ND Dual 80% Premium Hwy Spheres), glass beads. Traffic control was provided by an arrow board TSS “trail” vehicle, which also provided coning for protection of the marking material.

Photo 2 provides a closer view of the striping equipment. The application is being monitored by TSS personnel on the striping equipment and from the trailing vehicle by an EPOPLEX representative.



Photo 2: Application monitored by TSS and EPOPLEX personnel

Photo 3 shows the finished yellow median edge line and glass beads. Early in the striping, a condition known as “railroad tracking” occurred, this condition left longitudinal thin areas or “tracks” approximately 1/4" in width, located 1/4" from and parallel to the edge of the striping. Adjustments to the striping equipment eliminated this condition. Excess glass beads were present and were blown from the finished stripe by the light winds or passing vehicles.



Photo 3: Finished yellow median edge line with excess glass beads.

Photo 4 shows the “halo effect” which is a result of the Retroreflectivity of the sun from the glass beads.



Photo 4: “Halo Effect” of sun and glass beads.

Photo 5 shows the finished stripe being prepared for Retroreflectivity testing . Excess glass beads were removed from the finished stripe.



Photo 5: Preparation of median edge line for Retroreflectivity testing.

Photo 6 shows a ND DOT employee and the EPOPLEX representative respectively conducting 12m and 30m geometry Retroreflectivity tests. These tests were conducted on the LS60 system for the median edge line, outside edge line, and center line to establish a baseline for future evaluation of the marking system. The results of these test are included in Appendix B and C.



Photo 6: Conducting 12m and 30m geometry Retroreflectivity tests.

The yellow median edge line using the LS60 system was completed 6/10/99. A portion of the white outside edge line was completed before encountering equipment problems. Photo 7 and 8 show the white outside edge line prior to equipment problems. Notice the excellent coverage and well defined edge of the stripe.



Photo 7: Properly applied white outside edge line.



Photo 8: Well define white outside edge line.

The equipment problems created skips in the application of the outside edge line. Photo 9 shows the result of repairs to this section (6/11/99), which resulted in a poorly defined edge. The photo clearly shows the location where re-application of the system occurred after correction of the equipment problems. At this point, the line edges once again become clearly defined.



Photo 9: Application problems in final section of project.

Photo 10 shows the completion of the outside edge line and a section of the LS60 system applied as centerline striping. Notice the poorly defined edges on the centerline shown at the lower left of the photo. Photo 11 is a closer view of this poorly applied line. This may have been the result of the same equipment problems encountered on 6/10/99.



Photo 10. Completion of white outside edge line and poorly defined centerline.



Photo 11: Poorly applied centerline.

Initial Observations

Personnel from the NDDOT and EPOPLEX evaluated the LS60 pavement marking system on September 20, 1999 (30m geometry utilizing EPOPLEX equipment) and October 29, 1999 (12m geometry utilizing NDDOT equipment). This observation after several months of traffic was conducted to determine the short term changes occurring since construction, and to establish a new baseline prior to entering the winter season. The establishment of this new baseline is important as it provides the reference to quantify the durability of the LS60 system when subjected to winter environmental conditions and physical abuse from traffic and mechanical snow removal equipment.

A representative from EPOPLEX provided the 30m Retroreflectivity test data for the LS60 system from MP163 to MP172. NDDOT personnel, utilizing 12m geometry equipment, conducted Retroreflectivity tests on the edge and center line striping from MP163 to MP175. The striping at MP173 to MP175 is the standard ND Specification waterborne paint system. This paint system will be used as a control section for the evaluation of the LS60 epoxy system. The average Retroreflectivity results for the 30m tests are presented in Table 1 and Charts 1-2-3. The average Retroreflectivity results for the 12m tests are presented in Table 2 and Charts 4-5-6. The complete data sets for the construction and pre-winter observations are included in Appendix B (30m geometry) and Appendix C (12m geometry).

A reduction in Retroreflectivity has occurred in the LS60 white test section since construction. Closer inspection shows that many of the glass beads have been lost as indicated by empty craters in the paint surface. As predicted by the EPOPLEX representative, there has been an improvement in the Retroreflectivity of the LS60 yellow test section.

EPOPLEX LS60 Pavement Marking System
 EPOPLEX Retroreflectivity Test Results - 30m Geometry (Average)
 IM-1-094(053)161 WB

MILE	06/11/99		09/20/99		
	White	Yellow	White	Yellow	Center Line
172	465	278	438	318	
171	432	272	447	318	
170	387	261	414	303	
169	424	279	447	315	
168	331	304	266	308	
167	390	272	352	336	
166	321	322	407	365	
165	328	342	319	386	
164	329	291	311	332	
163	354	287	421	342	410

Table 1: Average Retroreflectivity - 30m Geometry

EPOPLEX LS60 Pavement Marking System
 NDDOT Retroreflectivity Test Results - 12m Geometry (Average)
 IM-1-094(053)161 WB

MILE	06/11/99			09/20/99				
	White	Yellow	Center Line *	White	Yellow	Center Line *		
						Stripe 1	Stripe 2	
175				407	177			VOGEL UC-1511 & UC-3585
174				408	166			Waterborne Paint Edge Stripes
173		365		396	110			
172		402		364	347			
171		395						
170		376		367	315			
169								LS-60 Epoxy Paint Edge Stripes
168				401	328			
167	459							Average
166	436		858	406	353	863	881	872
165	428							
164				315	355	673	818	746
163				384	316	387	395	391

Note: * Center Line LS-60 Epoxy @ MP 163
 Center Line Tape @ MP 164 & 166

Table 2: Average Retroreflectivity - 12m Geometry

30m Geometry Test Results

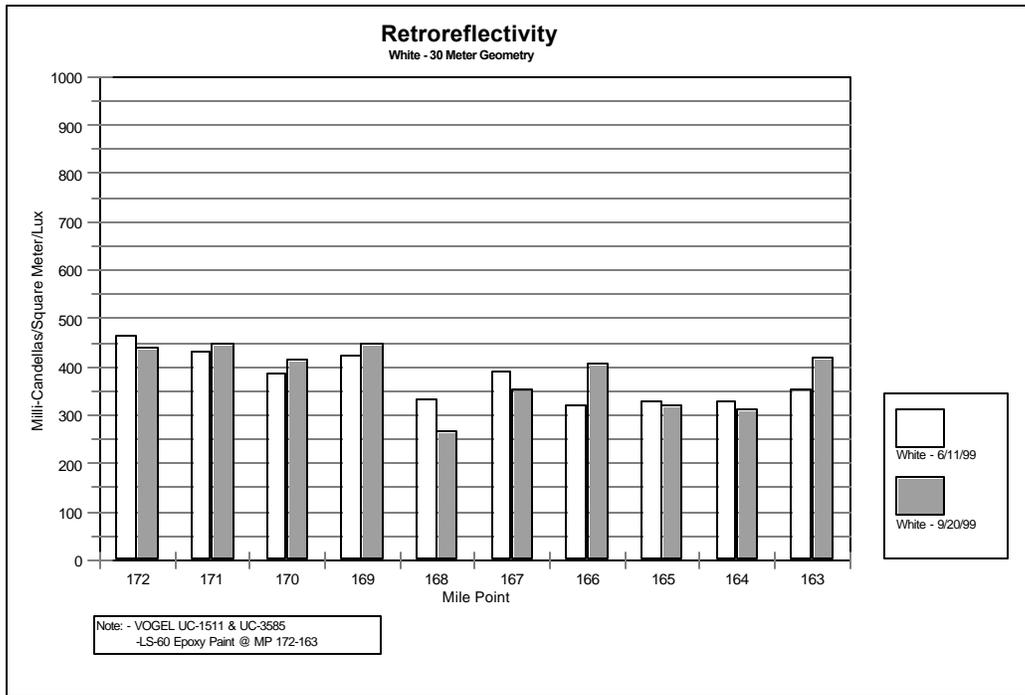


Chart 1: White - Retroreflectivity Test Results (30m geometry)

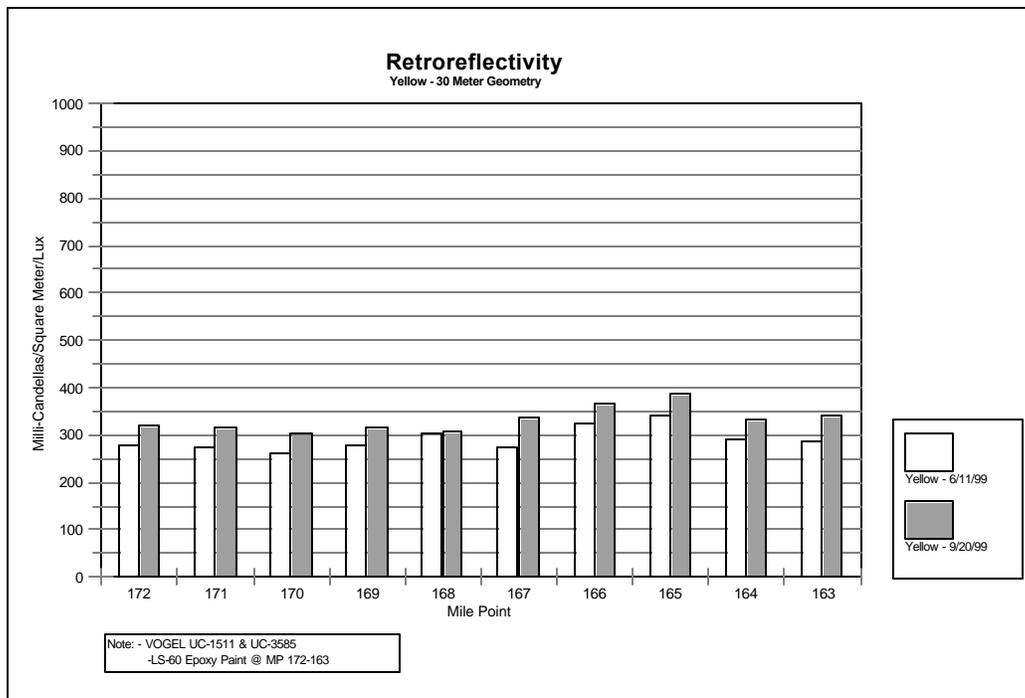


Chart 2: Yellow - Retroreflectivity Test Results (30m geometry)

30m Geometry Test Results(cont.)

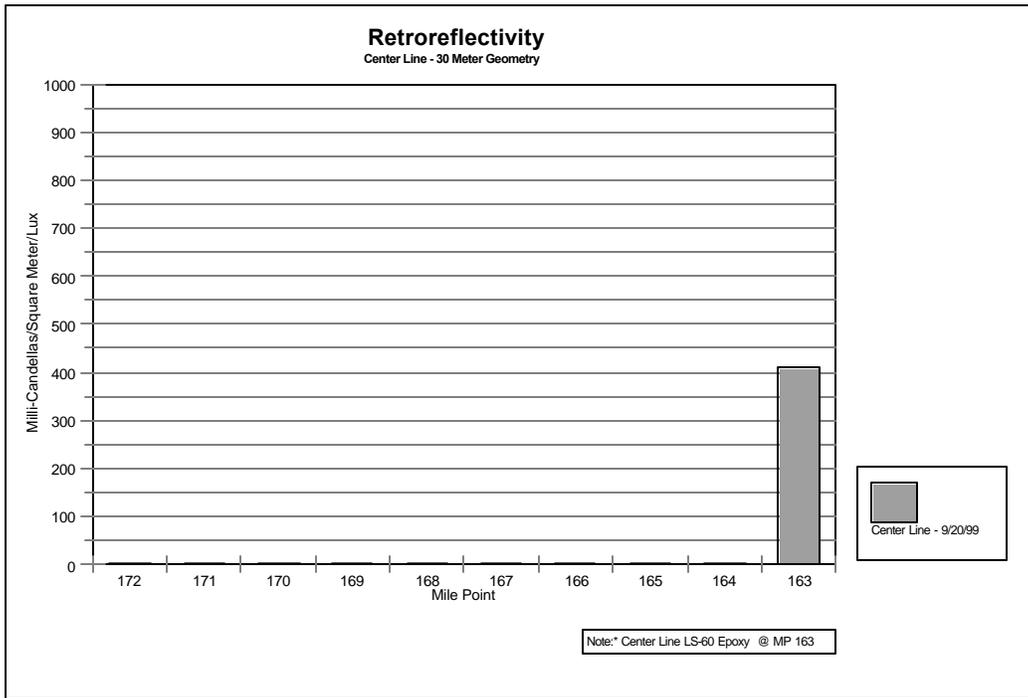


Chart 3: Center Line - Retroreflectivity Test Results (30m geometry)

12m Geometry Test Results

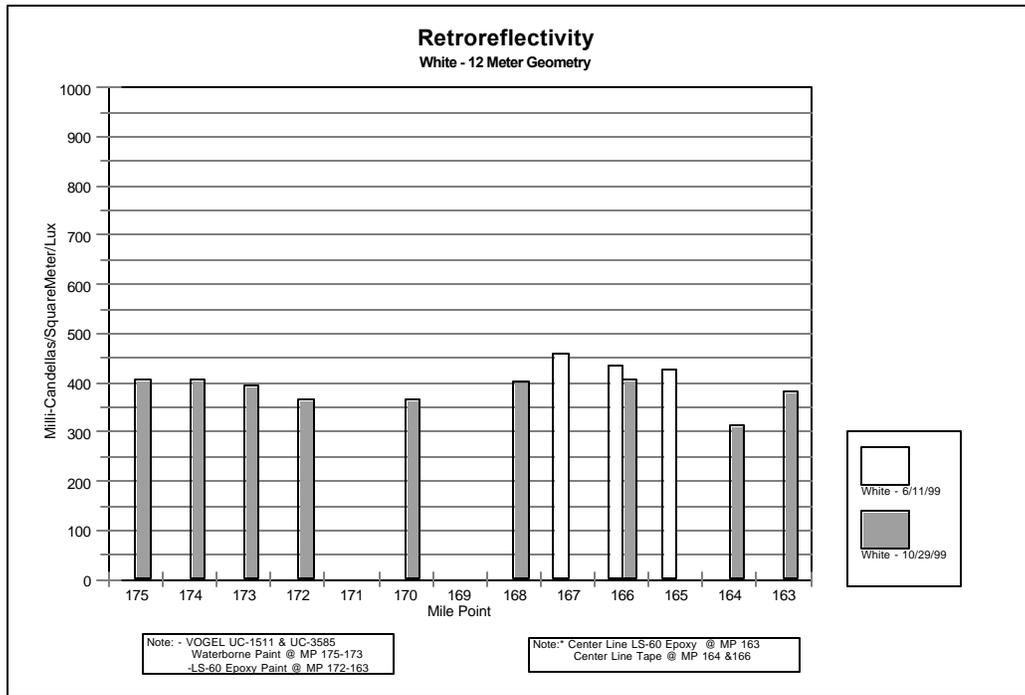


Chart 4: White - Retroreflectivity Test Results (12m geometry)

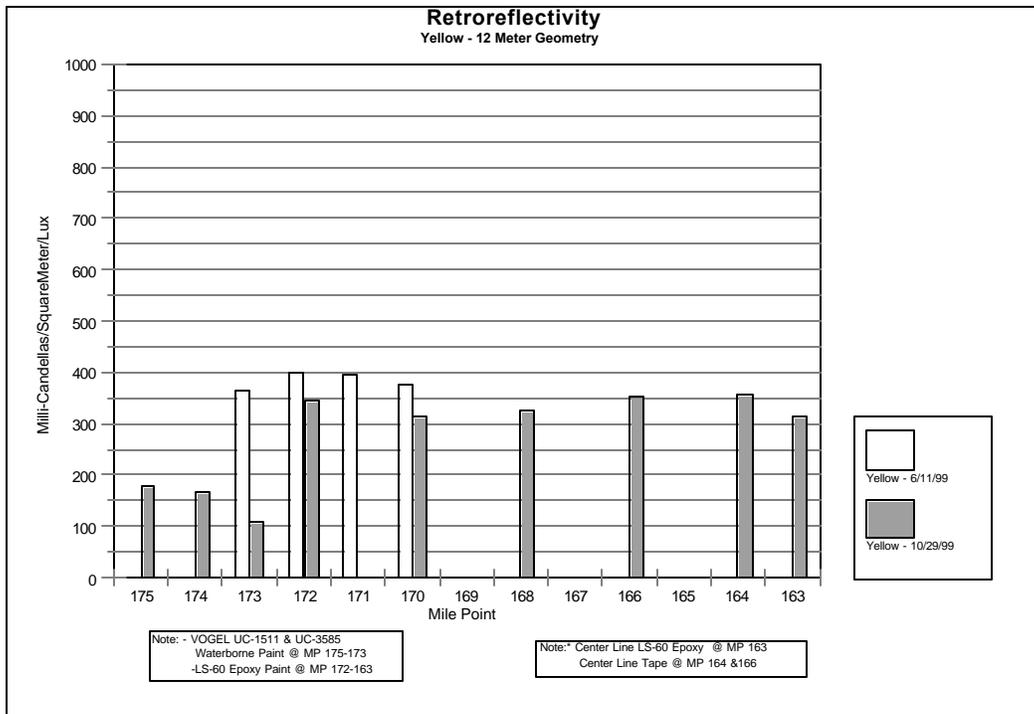


Chart 5: Yellow - Retroreflectivity Test Results (12m geometry)

12m Geometry Test Results(cont.)

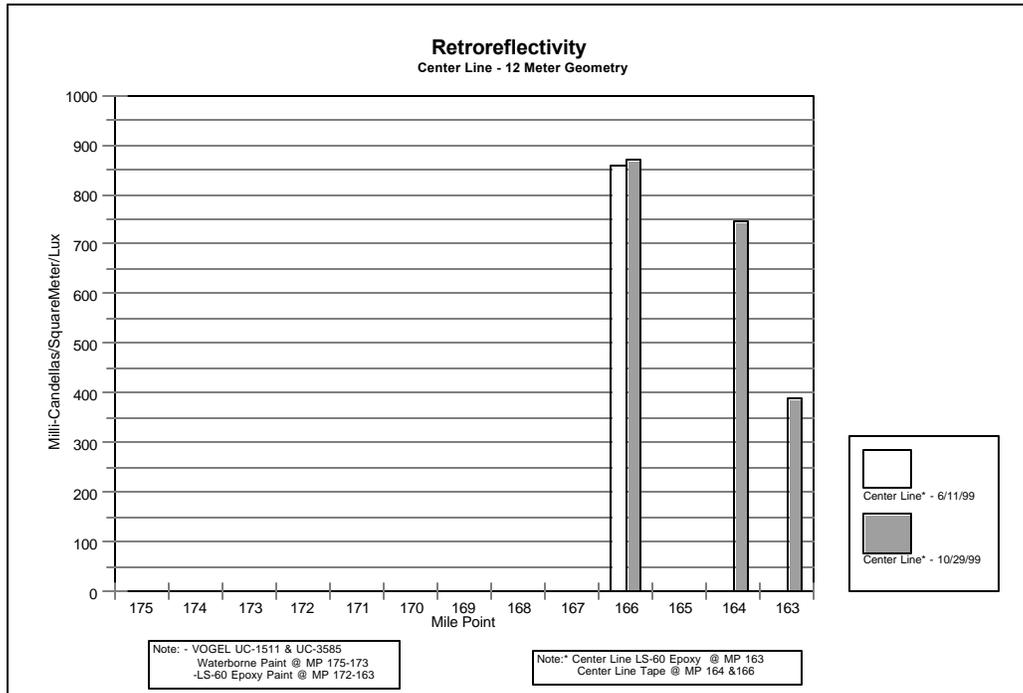


Chart 6: Center Line - Retroreflectivity Test Results (12m geometry)

Material Testing

Laboratory testing of the EPOPLEX LS60 epoxy resin pavement marking material was conducted by Advanced Materials Center, Inc. The material was evaluated against the specifications contained in Special Provision SP 70(97) issued July 17, 1998. The results of these tests were received after the LS60 system had been applied. The test results indicate the material failed, (in several categories), to meet the specifications, as outlined in SP 70(97). Table 2 provides the results of the tests and the specifications they were tested against.

Table 2: EPOPLEX LS60 Test Results

	Daylight Reflectance (Y)		Abrasion Resistance (loss in mg)		Shore D Hardness		Avg Tensile Break Load (psi)		Avg Compress. Break Load (psi)	
	Test	Spec	Test	Spec	Test	Spec	Test	Spec	Test	Spec
Color	29.82	50 min	97.7	82 max	84	75-90	2420	6000 min	9730	12,000 min
White	95.28	83 min	26.5	82 max	85	75-90	3540	6000 min	9960	12,000 min

The chromaticity limits of $x=0.536$, and $y=0.404$ for the yellow material, do not fall in the boundary of those specified by the special provision.

Summary

General Statements

As of this report, all of the paint systems are performing well, however a reduction in Retroreflectivity of the LS60 white test stripes has occurred in the time since construction. This may be attributed to the loss of glass beads as noted during the observation. There has been an improvement in the Retroreflectivity of the LS60 yellow test stripes, as predicted by the EPOPLEX representative.

Based on 12m geometry Retroreflectivity tests, the UC-1511 (white) waterborne system is outperforming the LS60 (white) epoxy system, however the LS60 (yellow) epoxy system is outperforming the UC-3585 (yellow) waterborne system.

12m Retroreflectivity tests on the centerline tape striping and LS60 epoxy striping indicate that the Retroreflectivity of the centerline tape is as much as two times greater than that of the LS60 system. Neither of these marking systems was constructed as ground-in sections; therefore both will be subjected to similar environmental and physical abuse.

Recommendations

Since the EPOPLEX LS60 material failed to meet the specifications outlined in SP 70(97), it is recommended that further observation of this project be discontinued. The detailed information included in this report may be utilized for comparative purposes when evaluating future projects.

Appendix A

NORTH DAKOTA DEPARTMENT OF TRANSPORTATION

SPECIAL PROVISION

LONG TERM PAVEMENT MARKING

IM-1-094(053)161

July 17, 1998

DESCRIPTION.

The work shall consist of furnishing and installing reflectorized white and yellow two-component, 100 percent solids epoxy pavement markings. Applications are lines, legends, symbols, crosswalks and stop lines placed on properly prepared asphaltic and portland cement concrete pavement surfaces in accordance with the Plans, Specifications, and as directed by the Engineer. Upon curing, the materials produce pavement markings of specified thickness, width and retroreflectivity that resist wear from high traffic volumes for several years. During darkness and weather permitting, yellow markings shall be readily distinguishable from white markings.

MATERIAL CLASSIFICATION.

This specification provides for the classification of epoxy resin pavement marking systems by type.

1. Type I

A fast cure material suitable for line applications and, under ideal conditions, may not require coning.

2. Type II

A slow cure material suitable for all applications of pavement markings under controlled traffic conditions, i.e., coning is required and flagging may be as directed by the Engineer.

EPOXY AND BEAD REQUIREMENTS.

A. Epoxy Resin Material

1. General. The material shall be composed of epoxy resins and pigments only. No solvents are to be given off to the environment upon application to a pavement surface. Type II material shall be completely free of TMFPTA (Tri-Methyl Propane Tri-Acrylate) and other multi-functional monomers.

2. Color. The color of the white epoxy shall be a pure flat white, free of tints. The color of the yellow epoxy shall closely match Color Number 33538 of Federal Standard 595 and shall conform to the following CIE Chromaticity limits using illuminant "C":

x|0.470|0.485|0.520|0.480
y|0.440|0.460|0.450|0.420

Daylight Directional Reflectance (Y), white, minimum: 83
Daylight Directional Reflectance (Y), yellow, minimum: 50

Testing will be according to:

Daylight Directional Reflectance: ASTM D 2805
Color: ASTM D 2805

3. Adhesion Capabilities. When the adhesion of the material to Portland cement concrete (the concrete shall have a minimum of 300 psi tensile strength) is tested according to American Concrete Institute Committee 403 testing procedure, the failure of the system must take place in the concrete. The concrete shall be 90° F when the material is applied, after which the material shall be allowed to cure for 72 hours at 73±2° F.

4. Abrasion Resistance. When the abrasion resistance of the material is tested according to ASTM C 501 with a CS-17 wheel under a load of 1000 grams for 1000 cycles, the wear index shall be no greater than 82. (The wear index is the weight in milligrams that is abraded from the sample under the test conditions).

5. Hardness. The Type D durometer hardness of the material shall be not less than 75 nor more than 90 when tested according to ASTM D2240 after the material has cured for 72 hours at 73±2° F.

6. Tensile Strength. The tensile strength of the material, when tested according to ASTM D 638, shall not be less than 6,000 psi after 72 hours cure time at 73±2° F.

7. Compressive Strength. The compressive strength of the material, when tested according to ASTM D 695, shall not be less than 12,000 psi after 72 hours cure time at 73±2° F.

8. Shelf Life. The individual components shall not require mixing prior to use when stored for a period of 12 months.

9. Yellowness Index.

ASTM D1925 Max. Before QUV 10
Max. After QUV 20

B. Glass Beads.

General. Glass Beads shall meet the requirements of ASSHTO M247, Type I, and :

- a. Moisture resistance - the beads shall be silicone treated to meet the requirements of Section 4.4.2 of M247, and
- b. Roundness - the beads shall have a roundness of at least 80%.

For 20 mil. applications, glass beads shall be applied at a rate of at least 20 lb/gal.

Time to No-Track. Type I material shall be in "no-tracking" condition in 15 minutes or less and within 45 minutes for Type II material. The "no-tracking" condition shall be determined on an application of specified thickness to the pavement and covered with glass beads at the rate of at least 20 lb/gal. The lines for this test shall be applied with striping equipment operated so as to have the material at manufacturer's recommended application temperature. This maximum "no-tracking" time shall not be exceeded when the pavement temperature varies from 50 to 120° F and under all humidity conditions, providing the pavement is dry. The no-tracking time shall be determined by passing over the line with a passenger car or pickup truck at a

speed of 25 to 35 mph in a simulated passing maneuver. A line showing no visual deposition of the material to the pavement surface when viewed from a distance of 50 ft. shall be considered as showing "no-tracking" and conforming to this requirement for time to "no-track."

APPLICATION EQUIPMENT AND PROCEDURES.

A. Equipment.

General. Equipment furnished shall include an applicator truck of adequate size and power, designed to apply an epoxy resin material and glass reflectorizing beads in a continuous or intermittent line pattern. The equipment shall be capable of placing stripes on the left and right sides. The left carriage shall be capable of two lines simultaneously with either line in a solid or intermittent pattern in yellow or white. With change in color usage, an amount of material equal to fifteen 10 ft. stripes shall be wasted to eliminate the change of the incorrect color, being applied.

The applicator truck (striper) and other vehicles in the striping train shall have permanently mounted Type C flashing arrow boards. They shall be visible to oncoming or following traffic, depending on the type of line being placed. Arrow board requirements are detailed in the MUTCD (Manual of Uniform Traffic Control Devices). Also, truck equipment shall be capable of accumulating the footage applied per gun, individually each day. Only material application shall activate the footage accumulators. The readout shall be digital and not adjustable.

The equipment shall be capable of applying glass beads in a pressurized system at a rate of at least 20 lb/gal.

All guns on the spray carriages shall be in full view of the operator(s) during operation.

Each crew shall include at least one technical expert knowledgeable in equipment operation, application techniques, control of traffic, and safety regulations.

B. Procedures.

General. Pavement markings shall be placed in accordance with the details shown in the Plans and the control points established by the Engineer.

The road surface shall be cleaned at the direction of the Engineer just prior to an application. Pavement cleaning shall consist of at least brushing with a rotary broom (non-metallic), or as recommended by the material manufacturer and acceptable to the Engineer. New portland cement concrete surfaces shall be sandblasted clean to remove any surface treatments and/or laitance. On low speed [Speed Limit 65 km/h (40 mph) or less] urban portland cement concrete roadways, sandblast cleaning shall be used for all epoxy pavement markings.

If the roadway surface is dry, the epoxy material application shall immediately follow the pavement cleaning and be preceded by an air blast. However, markings shall not be applied when the wind or other conditions cause a film of dust to be deposited on the pavement surface before the material can be applied.

The Engineer will place necessary spotting at appropriate points as overall horizontal control for striping and to indicate necessary starting and cutoff points. Broken line intervals will not be

marked. Longitudinal joints, pavement edges, and existing markings shall serve as control points when so directed.

The minimum line width shall be its nominal width with 1/4 in. greater than the nominal width allowed provided the variation is gradual and does not detract from the general appearance. Broken line segments, normally 6.56 ft. every 32.81 ft., may vary up to 3 in. from the specified lengths provided the over and under variations are reasonably compensatory. Alignment deviations from the control guide shall not exceed, except when approved by the Engineer. Material shall not be applied over a longitudinal joint. Establishment of application tolerances shall not relieve the Contractor of his responsibility to comply as closely as practicable with the planned dimensions.

C. Spraying Operation.

General. Placement of epoxy materials shall be permitted only on a clean, dry pavement surface and air and pavement temperatures at least 50° F unless the manufacturer, in writing, approves a lower temperature.

Two parts of epoxy component A (pigment) and one part component B (hardener) shall be heated separately at $110 \pm 1^\circ$ F and thoroughly mixed. All material heated over 140° F shall be discarded. The sprayed epoxy shall be applied at $110 \pm 1^\circ$ F or as recommended by the manufacturer.

Glass beads shall be applied immediately after the placement of the epoxy. The dispenser system must deliver at least 20 lb/gal of beads per liter of epoxy material.

The Contractor shall cooperate with inspection personnel in reviewing operation of the equipment, safety precautions, measurement of materials (components and beads), computations to determine epoxy thickness, and notifications as to work schedule.

Type II epoxy material shall be used for epoxy pavement markings except when specified as otherwise.

Traffic control for the pavement marking operations shall be in substantial conformance with the MUTCD. A shadow vehicle with a truck-mounted attenuator shall be used on high speed [SPEED LIMIT (40 mph) and greater], high volume (ADT 1500 and greater) highways.

SAMPLING RATE & PROCEDURES.

One pint samples of each manufacturer's lot or batch furnished for the contract shall be submitted at least 15 days prior to use. All samples must be submitted to the NDDOT Materials and Research Laboratory. Samples shall be identified as follows:

1. Manufacturer's Name
2. Manufacturer's Product Number
3. Lot/Batch Number
4. Color
5. Intended state project numbers
6. Date Manufactured

CERTIFICATIONS

Containers for epoxy components shall be marked with the manufacturer's name, product identification number, lot or batch number, date of manufacture, color, net weight of contents. Containers for glass

beads shall be marked with the name of manufacturer, the wording "Glass Beads," lot or batch number, coating type, date manufactured, and the net weight.

CONTAINER MARKINGS.

Containers for epoxy components shall be marked with the manufacturer's name, product identification number, lot or batch number, date of manufacture, color, net weight of contents. Containers for glass beads shall be marked with the name of manufacturer, the wording "Glass Beads," lot or batch number, coating type, date manufactured, and the net weight.

ACCEPTANCE OF PAVEMENT MARKING.

In order to be a long-life pavement marking, epoxy markings placed in North Dakota must retain a satisfactory level of retroreflectivity in addition to demonstrating good adhesion, resisting chipping, and exhibiting proper daytime and nighttime colors. These attributes have been observed and evaluated for several years and are the basis for acceptance/rejection procedures and values used herein.

A. Retroreflectivity.

1. Acceptable Minimum Retroreflectivity Values.

MINIMUM AVERAGE RETROREFLECTIVITY VALUES
FOR EPOXY MARKING
(mcd/m²/lux)

<u>Period</u>	<u>White</u>	<u>Yellow</u>
Initial*	275	180
After-One-Winter*	150	120

* Described under Miscellaneous Controls, numbers 4 and 5.

2. Retroreflectometers. Measurements shall be taken with either a portable or mobile retroreflectometer conforming to 30-meter geometry which is defined as: the entrance angle (the angle between the illumination axis and the retroreflector axis) shall fall between 88.50° and 88.76° and the observation angle (the angle between the illumination axis and the observation axis) shall fall between 1.0° and 1.05°; and, the co-viewing angle (the complement of the entrance angle) shall fall between 2.29° and 2.50°. All retroreflectivity readings and data analysis will be provided by NDDOT at no cost to the Contractor. NDDOT reserves the right to:

- make daytime and/or nighttime visual inspections with or without the presence of the Contractor's representative, mainly to locate obvious or suspect areas of deficiency, and
- determine retroreflectivity of symbols, legends and lines wider than 200 mm (8 in) using the portable retroreflectometer only.

3. Test Segments. The following methodology will be used to evaluate retroreflectivity performance of in-service longitudinal line pavement markings:

LENGTH AND NUMBER OF TEST SEGMENTS^a PER ROADWAY^b PER LINE TYPE^c

Length of Roadway	Number of Test Segments	Length of Test Segments
Less than 1 mile	1	0.2 mile
Greater than or equal to 1 mile	1 per mile	0.2 mile

- ^a **TEST SEGMENTS:** Areas of a roadway chosen for measuring retroreflectivity of the line types.
- ^b **ROADWAY:** As used here, means that portion of a street or highway ordinarily used for vehicular traffic. In the event a street or highway includes two or more separate roadways, the term roadway shall refer to each roadway separately.
- ^c **LINE TYPE:** Longitudinal lines of the same color and function. For example, white and yellow edge lines are each a line type.

4. Measurement in Test Segments.

A. Portable Retroreflectorometer

1. Take a minimum of 10 readings in each test segment per line type.
2. On broken lines (skip striping), measure every other stripe, taking no more than two readings per stripe with readings 20 in. from the ends of the marking.
3. For solid lines, divide test segment into ten areas of 100 ft.; space readings a minimum of 33 ft. and a maximum of 100 ft. apart.
4. For 10 percent of each message type, take 5 readings on each message line; for 10 percent of each symbol type, take 5 readings on each symbol.
5. Upon completion of the evaluation, regardless of the results, additional test segments may be ordered by the Engineer.

B. Mobile Retroreflectorometer

1. Calibration of the instruments shall be in accordance with the manufacturer's instructions.
2. Retroreflectivity shall be measured at a minimum rate of 20 percent of each roadway length by line type.
3. Should another mobile unit be available, the maximum acceptable deviation for measurements made by the two different instruments of the same manufacturer and for the same roadway length shall be $\pm 10\%$.
4. Repeatability for the given mobile unit shall be $\pm 6\%$.
5. Upon completion of the evaluation, regardless of the results, additional test segments may be ordered by the Engineer.

C. Miscellaneous Controls

1. Take measurements on a clean, dry roadway.
2. Collect data in direction of traffic flow.
3. Measurement units are: mcd/m²/lux.
4. Wait at least two weeks from date of placement of the markings before taking initial readings.
5. Take after-one-winter readings in May or June to assure that spring rains have cleaned the beads.
6. Randomly select test segments unless night reviews or other knowledge supersedes a random selection process.

7. Measure each line type separately.
8. The Engineer may request additional readings or test segments.
9. In the event LASERLUX is not available, the Engineer may require the use of the portable retroreflectometer or establish an alternative evaluation plan.

5. Contents of Retroreflectivity Report. The report shall consist of:

- State Project number
- Trunk Highway number
- Test date
- Geographical location of the test site(s), including distance from the nearest permanent site identification, such as a reference point.
- Identification of the pavement marking material tested: type, color, age, and transverse location on the road
- Identification of the retroreflectometer
- Remarks concerning the overall condition of the line, messages and symbols such as carryover of asphalt, snow plow damage, uneven distribution of beads, etc.
- Average of the readings for each test segment with one standard deviation calculated.
- Average of the readings for each message and symbol type.

B. Correction of Defects/Penalties.

1. All pavement markings not conforming to the requirements of the Contract shall be removed and replaced or otherwise repaired to the satisfaction of the Engineer. Removal of unacceptable work shall be accomplished with suitable blasting or grinding equipment unless other means are authorized by the Engineer.
2. Where yield computations show a deficiency in material usage of not more than 20 percent, NDDOT may require satisfactory repair or may accept the work at a reduced unit price which is in direct proportion to the percent of the deficiency. Where the deficiency in material usage exceeds 20 percent, NDDOT may require removal and replacement to the satisfaction of the Engineer unless other means are approved by the Engineer.
3. If the Engineer requires removal and replacement, the contractor shall remove (by an approved process) at least 90% of the deficient line, with no excessive scarring of the existing pavement. The removal width shall be one inch wider all around the nominal width of the pavement marking to be removed.
4. Where initial retroreflectivity falls below the minimum acceptable levels but not more than 20%, the Engineer may require satisfactory repair or may accept the work at a reduced unit price which is in direct proportion to the percent of the deficiency. Where the deficiency in retroreflectivity exceeds 20%, i.e., less than 220 mcd/m²/lux for white and 145 mcd/m²/lux for yellow, the Engineer may require the removal and replacement to the satisfaction of the Engineer unless other means are approved by the Engineer. Where minimum levels after one winter fall below the specified levels (150 mcd/m²/lux - 120 mcd/m²/lux), NDDOT will notify the project contractor and manufacturer(s) of the failure. If the initial readings were above NDDOT's specified initial minimum levels (275 mcd/m²/lux - 180 mcd/m²/lux), the Engineer, contractor, and manufacturer(s) of the material(s) shall review the project together. Based on the review and of all known aspects, the Engineer will make a determination as to why the job failed and notify the Contractor, pavement marking contractor, and/or manufacturer(s) in writing.
5. If this process has to be repeated on several projects with either the same contractor and/or manufacturer(s), NDDOT will take corrective action. This corrective action will be a two step process:

- Step 1: Pavement marking contractor/manufacturer(s) will be considered not approved for NDDOT projects, except to bring workmanship/product back into compliance.
- Step 2: If the first step cannot be attained, pavement marking contractor/manufacturer(s) will not be allowed to participate in NDDOT projects and/or be removed from Approved Product List.

METHOD OF MEASUREMENT.

Long Term Pavement Marking Line. This item will be measured by the Linear Foot of the various widths of installed line, complete, in place, and accepted. Only marked portions of broken lines will be measured. Long Term Pavement Marking - Messages will be measured by the square footage shown on the Plans, in place, and accepted by the Engineer.

BASIS OF PAYMENT.

Payment will be made under:

Pay Item	Pay Unit
Type __ Long Term Pavement Marking - __ Inch line	Linear Foot
Type __ Long Term Pavement Marking - Message	Square Foot

This payment will be full compensation for all labor, equipment, and materials necessary to complete the work.

Appendix B

EPOPLEX LS60 Pavement Marking System
EPOPLEX Retroreflectivity Test Results - 30m Geometry (Average)
IM-1-094(053)161 WB

	06/11/99		09/20/99		
MILE	White	Yellow	White	Yellow	Center Line
172	465	278	438	318	
171	432	272	447	318	
170	387	261	414	303	
169	424	279	447	315	
168	331	304	266	308	
167	390	272	352	336	
166	321	322	407	365	
165	328	342	319	386	
164	329	291	311	332	
163	354	287	421	342	410

EPOPLEX DATA -- Retroreflectivity Test Results
(30m Geometry)
IM-1-094(053)161 WB

MILE 172 File #022

White Edge Line

	06/11/99		
1	426		
2	418	11	449
3	386	12	449
4	502	13	412
5	511	14	464
6	463	15	505
7	479	16	497
8	489	17	456
9	505	18	460
10	480	19	476
		AVG	465

LS-60 Epoxy Paint

	09/20/99				
1	429				
2	437				
3	429				
4	438				
5	438				
6	435				
7	440				
8	442				
9	442				
10	448				
	AVG	438			

MILE 172 File #023

Yellow Edge Line

	06/11/99		
1	275		
2	287	11	282
3	258	12	285
4	286	13	276
5	291	14	258
6	274	15	284
7	287	16	290
8	280	17	272
9	271	18	272
10	269	19	289
		AVG	278

LS-60 Epoxy Paint

	09/20/99				
1	329				
2	325				
3	328				
4	321				
5	315				
6	312				
7	310				
8	318				
9	311				
10	315				
	AVG	318			

MILE 171 File #024

White Edge Line

	06/11/99
1	426
2	433
3	429
4	413
5	436
6	427
7	438
8	441
9	431
10	433
AVG	431

LS-60 Epoxy Paint

	09/20/99				
1	429				
2	449				
3	458				
4	460				
5	456				
6	454				
7	449				
8	444				
9	433				
10	439				
AVG	447				

MILE 171 File #025

Yellow Edge Line

	06/11/99
1	274
2	266
3	264
4	275
5	263
6	275
7	273
8	270
9	279
10	282
AVG	272

LS-60 Epoxy Paint

	09/20/99				
1	316				
2	324				
3	320				
4	332				
5	322				
6	316				
7	291				
8	305				
9	326				
10	324				
AVG	318				

MILE 170 File #026

White Edge Line

	06/11/99
1	377
2	413
3	395
4	384
5	377
6	388
7	376
8	392
9	372
10	397
AVG	387

LS-60 Epoxy Paint

	09/20/99				
1	425				
2	420				
3	422				
4	405				
5	412				
6	425				
7	426				
8	422				
9	373				
10	414				
AVG	414				

MILE 170 File #027

Yellow Edge Line

	06/11/99
1	266
2	248
3	263
4	268
5	273
6	255
7	249
8	268
9	246
10	271
AVG	261

LS-60 Epoxy Paint

	09/20/99				
1	321				
2	313				
3	280				
4	302				
5	309				
6	303				
7	290				
8	304				
9	306				
AVG	303				

MILE 169 File #028

White Edge Line

	06/11/99
1	434
2	431
3	431
4	430
5	419
6	428
7	414
8	416
9	434
10	405
AVG	424

LS-60 Epoxy Paint

	09/20/99				
1	441				
2	461				
3	456				
4	467				
5	453				
6	428				
7	434				
8	442				
9	441				
AVG	447				

MILE 169 File #029

Yellow Edge Line

	06/11/99
1	280
2	272
3	263
4	288
5	281
6	274
7	266
8	289
9	289
10	292
AVG	279

LS-60 Epoxy Paint

	09/20/99				
1	313				
2	322				
3	315				
4	329				
5	328				
6	277				
7	327				
8	305				
9	316				
AVG	315				

MILE 168 File #030

White Edge Line

	06/11/99
1	343
2	317
3	328
4	338
5	328
6	317
7	312
8	325
9	318
10	346
11	327
12	352
13	350
14	335
AVG	331

LS-60 Epoxy Paint

	09/20/99				
1	241				
2	246				
3	254				
4	285				
5	252				
6	301				
7	270				
8	275				
9	274				
AVG	266				

MILE 168 File #031

Yellow Edge Line

	06/11/99
1	301
2	314
3	308
4	299
5	291
6	313
7	306
8	302
9	293
10	308
AVG	304

LS-60 Epoxy Paint

	09/20/99				
1	306				
2	305				
3	306				
4	300				
5	321				
6	306				
7	316				
8	312				
9	303				
AVG	308				

MILE 167 File #032

White Edge Line

	06/11/99
1	391
2	368
3	402
4	417
5	359
6	383
7	411
8	386
9	392
10	394
AVG	390

LS-60 Epoxy Paint

	09/20/99				
1	339				
2	366				
3	347				
4	347				
5	342				
6	357				
7	348				
8	367				
9	358				
AVG	352				

MILE 167 File #033

Yellow Edge Line

	06/11/99
1	283
2	254
3	279
4	277
5	263
6	281
7	276
8	262
9	284
10	261
AVG	272

LS-60 Epoxy Paint

	09/20/99				
1	309				
2	340				
3	344				
4	331				
5	341				
6	336				
7	341				
8	340				
9	342				
AVG	336				

MILE 166 File #034

White Edge Line

	06/11/99
1	320
2	308
3	332
4	346
5	329
6	321
7	306
8	342
9	309
10	311
11	305
AVG	321

LS-60 Epoxy Paint

	09/20/99				
1	405				
2	408				
3	411				
4	401				
5	392				
6	397				
7	419				
8	417				
9	414				
AVG	407				

MILE 166 File #035

Yellow Edge Line

	06/11/99
1	318
2	324
3	337
4	329
5	316
6	337
7	311
8	290
9	306
10	347
AVG	322

LS-60 Epoxy Paint

	09/20/99				
1	369				
2	383				
3	357				
4	331				
5	371				
6	367				
7	376				
8	367				
9	357				
10	374				
AVG	365				

MILE 165 File #036

White Edge Line

	06/11/99
1	330
2	320
3	336
4	319
5	345
6	320
7	325
8	322
9	329
10	334
AVG	328

LS-60 Epoxy Paint

	09/20/99				
1	314				
2	327				
3	321				
4	313				
5	303				
6	321				
7	335				
8	303				
9	331				
10	317				
AVG	319				

MILE 165 File #037

Yellow Edge Line

	06/11/99
1	336
2	343
3	326
4	344
5	345
6	341
7	343
8	327
9	347
10	353
11	358
AVG	342

LS-60 Epoxy Paint

	09/20/99				
1	397				
2	387				
3	387				
4	391				
5	379				
6	389				
7	395				
8	365				
9	380				
AVG	386				

B-10

MILE 164 File #038
White Edge Line

	06/11/99
1	344
2	320
3	341
4	325
5	338
6	314
7	315
8	297
9	339
10	336
11	348
12	331
AVG	329

LS-60 Epoxy Paint

	09/20/99			
1	306			
2	318			
3	308			
4	295			
5	318			
6	310			
7	304			
8	306			
9	330			
AVG	311			

MILE 164 File #039
Yellow Edge Line

	06/11/99
1	287
2	309
3	298
4	292
5	270
6	304
7	281
8	286
9	286
10	306
11	277
AVG	291

LS-60 Epoxy Paint

	09/20/99			
1	324			
2	335			
3	333			
4	341			
5	338			
6	346			
7	304			
8	335			
9	329			
AVG	332			

B-11

MILE 163 File #040

White Edge Line

	06/11/99
1	356
2	351
3	335
4	351
5	364
6	354
7	368
8	349
9	354
10	362
AVG	354

LS-60 Epoxy Paint

	09/20/99			
1	427			
2	409			
3	408			
4	412			
5	432			
6	448			
7	395			
8	411			
9	444			
AVG	421			

MILE 163 File #041

Yellow Edge Line

	06/11/99
1	275
2	298
3	284
4	306
5	273
6	297
7	303
8	261
9	270
10	292
11	300
AVG	287

LS-60 Epoxy Paint

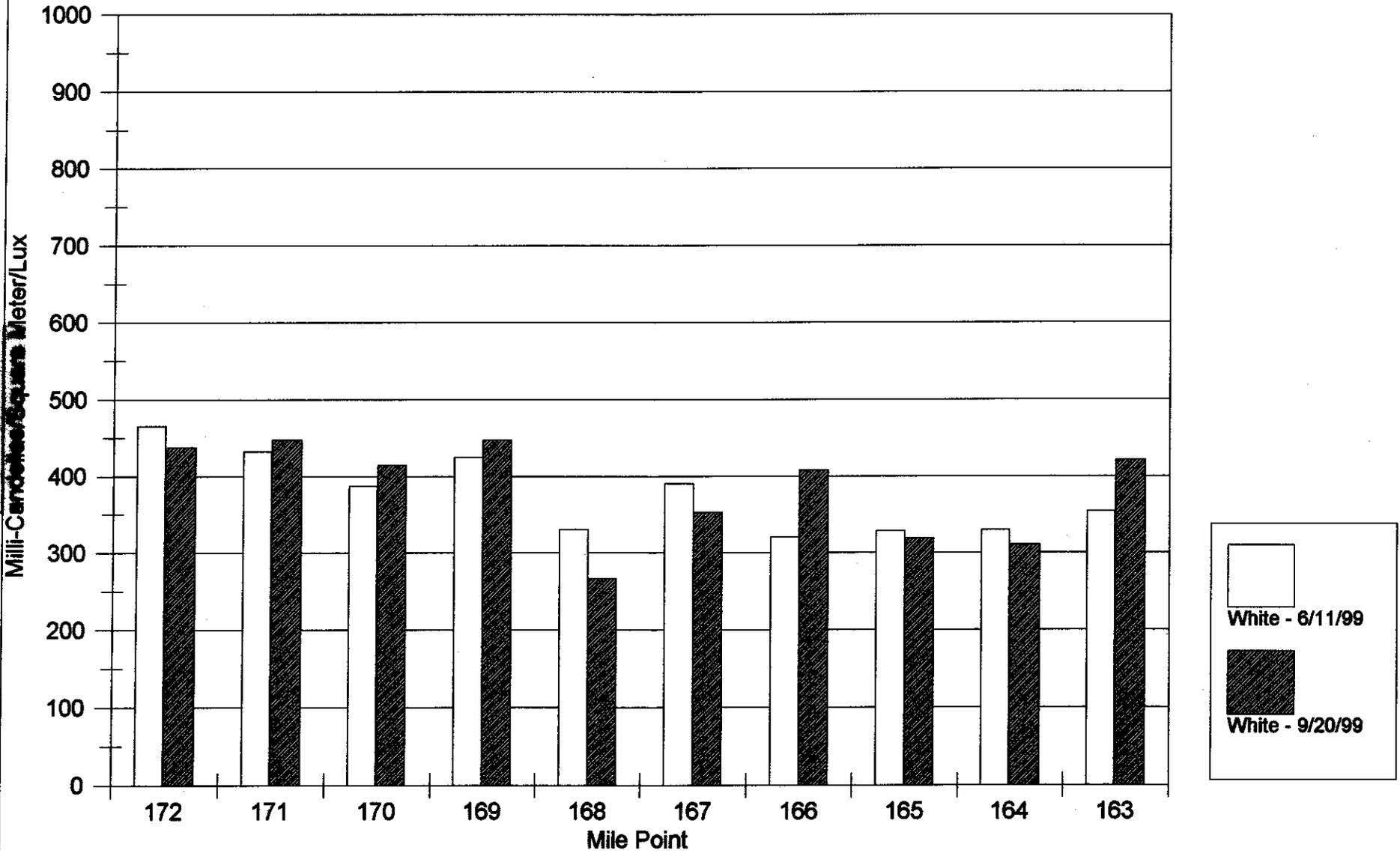
	09/20/99			
1	344			
2	354			
3	328			
4	349			
5	337			
6	341			
7	340			
8	334			
9	350			
AVG	342			

Center Line

	09/20/99
1	398
2	412
3	384
4	414
5	432
6	413
7	425
8	414
9	394
AVG	410

Retroreflectivity

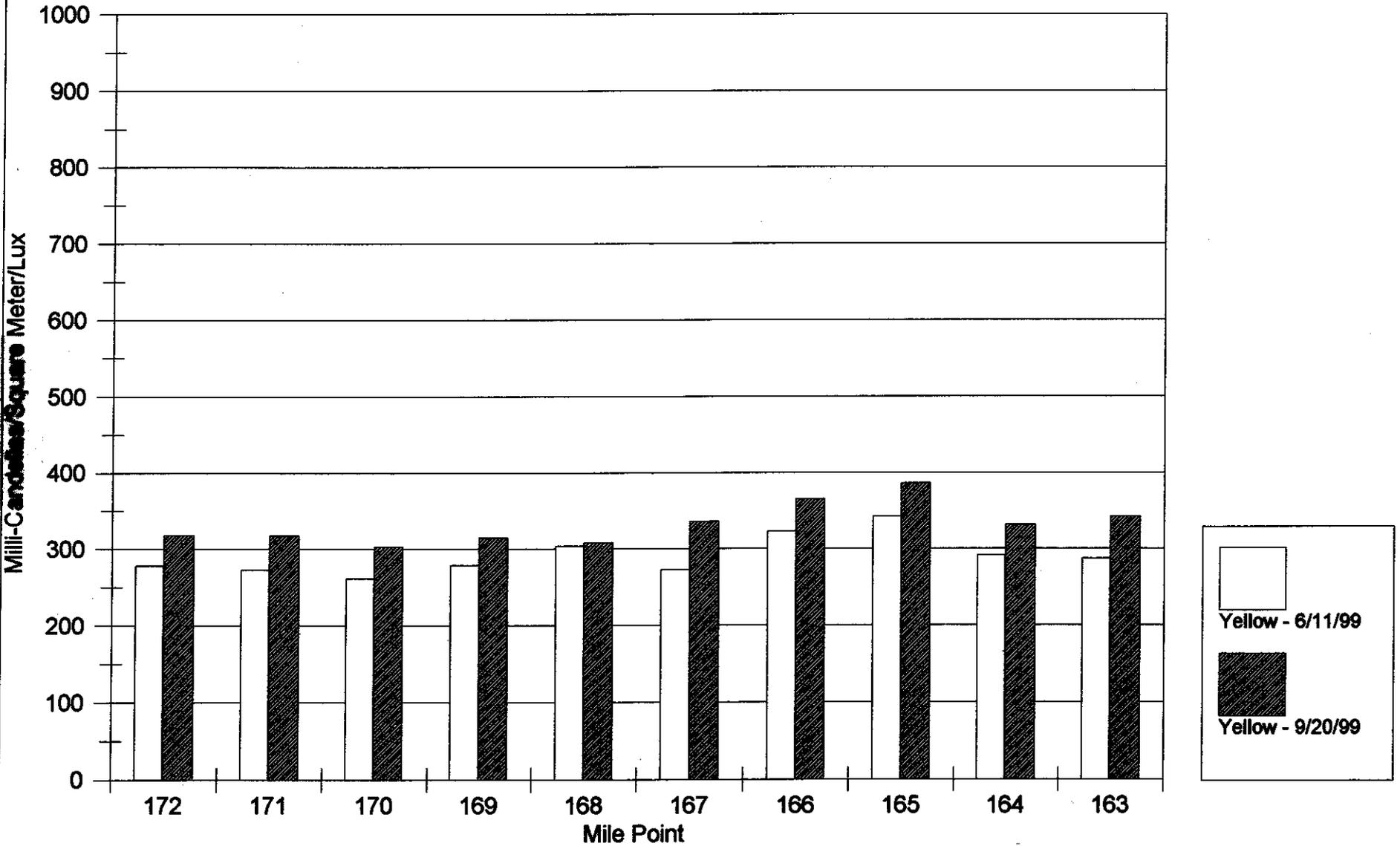
White - 30 Meter Geometry



Note: - VOGEL UC-1511 & UC-3585
-LS-60 Epoxy Paint @ MP 172-163

Retroreflectivity

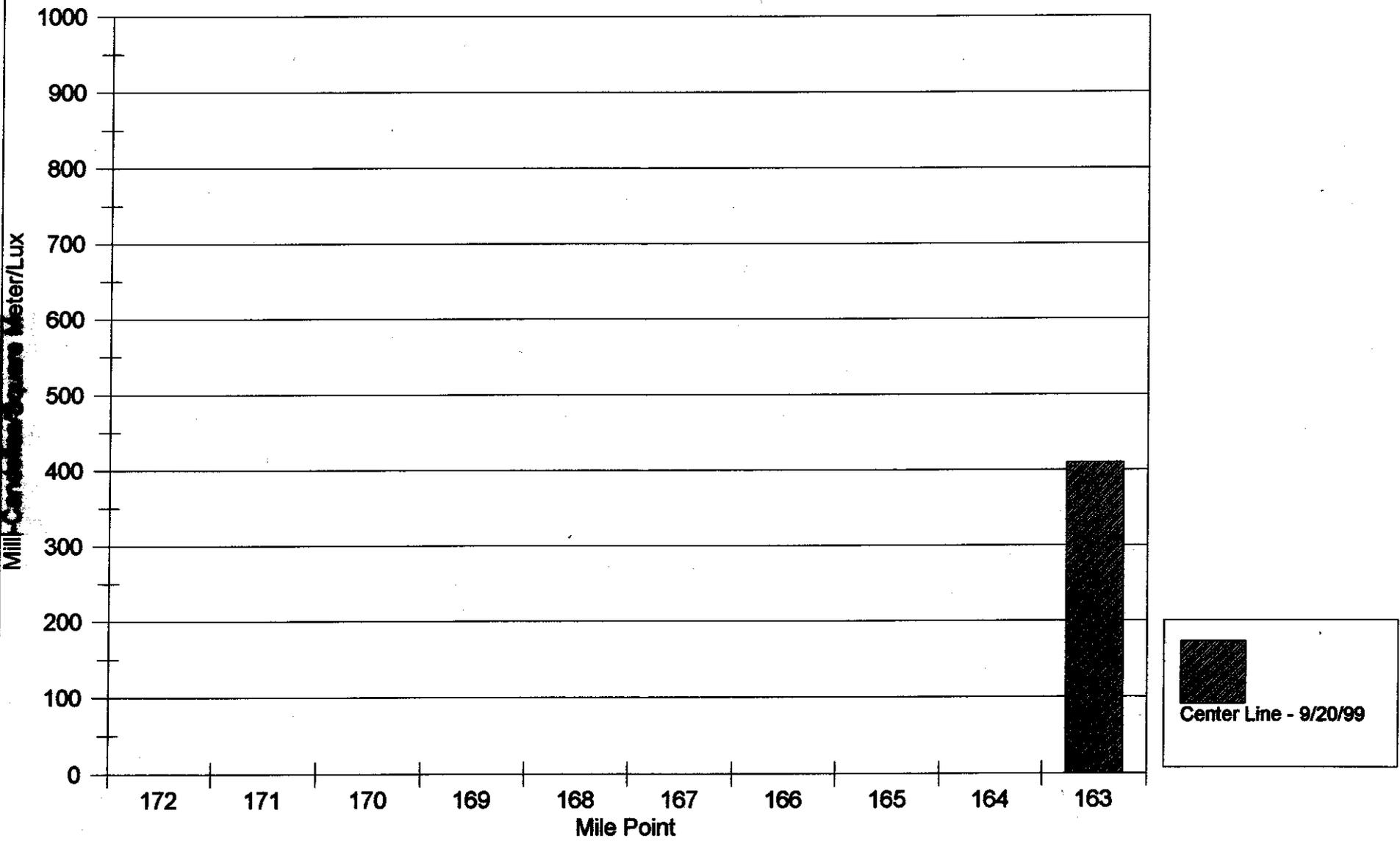
Yellow - 30 Meter Geometry



Note: - VOGEL UC-1511 & UC-3585
-LS-60 Epoxy Paint @ MP 172-163

Retroreflectivity

Center Line - 30 Meter Geometry



Note:* Center Line LS-60 Epoxy @ MP 163

Appendix C

EPOPLEX LS60 Pavement Marking System
ND DOT Retroreflectivity Test Results - 12m Geometry (Average)
IM-1-094(053)161 WB

MILE	06/11/99			09/20/99				Average
	White	Yellow	Center Line *	White	Yellow	Center Line *		
						Stripe 1	Stripe 2	
175				407	177			
174				408	166			
173		365		396	110			
172		402		364	347			
171		395						
170		376		367	315			
169								
168				401	328			
167	459							
166	436		858	406	353	863	881	872
165	428							
164				315	355	673	818	746
163				384	316	387	395	391

VOGEL UC-1511 & UC-3585
Waterborne Paint Edge Stripes

LS-60 Epoxy Paint Edge Stripes

Note: * Center Line LS-60 Epoxy @ MP 163
Center Line Tape @ MP 164 & 166

MATERIALS and RESEARCH DATA - Retroreflectivity Test Results
(Mirolux Unit #106 - 12m Geometry)
IM-1-094(053)161 WB

MILE 175

White Edge Line

	06/11/99
1	No Data
2	" "
3	" "
4	" "
5	" "
AVG	0

VOGEL UC-1511 Waterborne Paint

	10/29/99			
1	408			
2	389			
3	407			
4	396			
5	434			
AVG	407			

MILE 175

Yellow Edge Line

	06/11/99
1	No Data
2	" "
3	" "
4	" "
5	" "
AVG	0

VOGEL UC-3585 Waterborne Paint

	10/29/99			
1	180			
2	173			
3	192			
4	171			
5	169			
AVG	177			

MILE 174
White Edge Line

	06/11/99
1	No Data
2	" "
3	" "
4	" "
5	" "
AVG	0

VOGEL UC-1511 Waterborne Paint

	10/29/99				
1	399				
2	415				
3	408				
4	410				
5	410				
AVG	408				

MILE 174
Yellow Edge Line

	06/11/99
1	No Data
2	" "
3	" "
4	" "
5	" "
AVG	0

VOGEL UC-3585 Waterborne Paint

	10/29/99				
1	152				
2	166				
3	171				
4	165				
5	176				
AVG	166				

**MILE 173
White Edge Line**

	06/11/99
1	No Data
2	" "
3	" "
4	" "
12	" "
AVG	0

VOGEL UC-1511 Waterborne Paint

	10/29/99				
1	404				
2	417				
3	378				
4	403				
5	378				
AVG	396				

**MILE 173
Yellow Edge Line**

	06/11/99
1	395
2	395
3	395
4	341
5	334
6	363
7	335
8	393
9	335
10	380
11	378
12	340
AVG	365

VOGEL UC-3585 Waterborne Paint

	10/29/99				
1	114				
2	102				
3	117				
4	110				
5	105				
AVG	110				

MILE 172**White Edge Line**

	06/11/99
1	No Data
2	" "
3	" "
4	" "
5	" "
AVG	0

LS-60 Epoxy Paint

	10/29/99			
1	375			
2	370			
3	370			
4	359			
5	348			
AVG	364			

MILE 172**Yellow Edge Line**

	06/11/99
1	387
2	399
3	404
4	404
5	411
6	402
7	397
8	410
9	379
10	424
11	408
12	396
13	399
AVG	402

LS-60 Epoxy Paint

	10/29/99			
1	340			
2	345			
3	360			
4	333			
5	355			
AVG	347			

MILE 171
White Edge Line

	06/11/99
1	No Data
2	" "
3	" "
4	" "
5	" "
AVG	0

LS-60 Epoxy Paint

	10/29/99				
1	No Data				
2	" "				
3	" "				
4	" "				
5	" "				
AVG	0				

MILE 171
Yellow Edge Line

	06/11/99
1	398
2	398
3	383
4	382
5	422
6	404
7	406
8	381
9	391
10	380
AVG	395

LS-60 Epoxy Paint

	10/29/99				
1	No Data				
2	" "				
3	" "				
4	" "				
5	" "				
AVG	0				

MILE 170**White Edge Line**

	06/11/99
1	No Data
2	" "
3	" "
4	" "
5	" "
AVG	0

LS-60 Epoxy Paint

	10/29/99				
1	365				
2	364				
3	377				
4	367				
5	362				
AVG	367				

MILE 170**Yellow Edge Line**

	06/11/99
1	385
2	399
3	384
4	360
5	381
6	362
7	364
8	371
9	374
AVG	376

LS-60 Epoxy Paint

	10/29/99				
1	310				
2	323				
3	316				
4	327				
5	300				
AVG	315				

MILE 169
White Edge Line

	06/11/99
1	No Data
2	" "
3	" "
4	" "
5	" "
AVG	0

LS-60 Epoxy Paint

	10/29/99			
1	No Data			
2	" "			
3	" "			
4	" "			
5	" "			
AVG	0			

MILE 169
Yellow Edge Line

	06/11/99
1	No Data
2	" "
3	" "
4	" "
5	" "
AVG	0

LS-60 Epoxy Paint

	10/29/99			
1	No Data			
2	" "			
3	" "			
4	" "			
5	" "			
AVG	0			

MILE 168**White Edge Line**

	06/11/99
1	No Data
2	" "
3	" "
4	" "
5	" "
AVG	0

LS-60 Epoxy Paint

	10/29/99				
1	394				
2	403				
3	397				
4	396				
5	416				
AVG	401				

MILE 168**Yellow Edge Line**

	06/11/99
1	No Data
2	" "
3	" "
4	" "
5	" "
AVG	0

LS-60 Epoxy Paint

	10/29/99				
1	332				
2	333				
3	338				
4	318				
5	318				
AVG	328				

**MILE 167
White Edge Line**

	06/11/99
1	451
2	469
3	464
4	450
5	462
6	471
7	457
8	459
9	444
10	465
AVG	459

LS-60 Epoxy Paint

	10/29/99				
1	No Data				
2	" "				
3	" "				
4	" "				
5	" "				
AVG	0				

**MILE 167
Yellow Edge Line**

	06/11/99
1	No Data
2	" "
3	" "
4	" "
5	" "
AVG	0

LS-60 Epoxy Paint

	10/29/99				
1	No Data				
2	" "				
3	" "				
4	" "				
5	" "				
AVG	0				

MILE 166

White Edge Line

	06/11/99
1	444
2	438
3	442
4	440
5	433
6	428
7	451
8	449
9	416
10	414
AVG	436

LS-60 Epoxy Paint

	10/29/99				
1	414				
2	395				
3	386				
4	415				
5	422				
AVG	406				

MILE 166

Yellow Edge Line

	06/11/99
1	No Data
2	" "
3	" "
4	" "
5	" "
AVG	0

LS-60 Epoxy Paint

	10/29/99				
1	348				
2	352				
3	363				
4	340				
5	360				
AVG	353				

Center Line Tape (not ground into pavement)

	06/11/99
1	869
2	868
3	872
4	877
5	836
6	825
AVG	858

	10/29/99					
	Stripe 1	Stripe 2	Stripe 1	Stripe 2	Stripe 1	Stripe 2
1	869	870				
2	892	878				
3	827	896				
AVG	863	881				

MILE 165**White Edge Line**

	06/11/99
1	437
2	435
3	427
4	426
5	438
6	415
7	421
8	426
9	423
10	429
AVG	428

LS-60 Epoxy Paint

	10/29/99				
1	No Data				
2	" "				
3	" "				
4	" "				
5	" "				
AVG	0				

MILE 165**Yellow Edge Line**

	06/11/99
1	No Data
2	" "
3	" "
4	" "
5	" "
AVG	0

LS-60 Epoxy Paint

	10/29/99				
1	No Data				
2	" "				
3	" "				
4	" "				
5	" "				
AVG	0				

MILE 164

White Edge Line

	06/11/99
1	No Data
2	" "
3	" "
4	" "
5	" "
6	" "
7	" "
8	" "
9	" "
10	" "
11	" "
12	" "
AVG	0

LS-60 Epoxy Paint

	10/29/99			
1	286			
2	334			
3	317			
4	325			
5	314			
AVG	315			

MILE 164

Yellow Edge Line

	06/11/99
1	No Data
2	" "
3	" "
4	" "
5	" "
AVG	0

LS-60 Epoxy Paint

	10/29/99			
1	357			
2	352			
3	357			
4	358			
5	353			
AVG	355			

Center Line Tape (not ground into pavement)

	10/29/99					
	Stripe 1	Stripe 2	Stripe 1	Stripe 2	Stripe 1	Stripe 2
1	839	870				
2	376	848				
3	805	737				
AVG	673	818				

MILE 163

White Edge Line

	06/11/99
1	No Data
2	" "
3	" "
4	" "
5	" "
AVG	0

LS-60 Epoxy Paint

	10/29/99				
1	378				
2	399				
3	395				
4	392				
5	355				
AVG	384				

MILE 163

Yellow Edge Line

	06/11/99
1	No Data
2	" "
3	" "
4	" "
5	" "
AVG	0

LS-60 Epoxy Paint

	10/29/99				
1	323				
2	317				
3	323				
4	311				
5	307				
AVG	316				

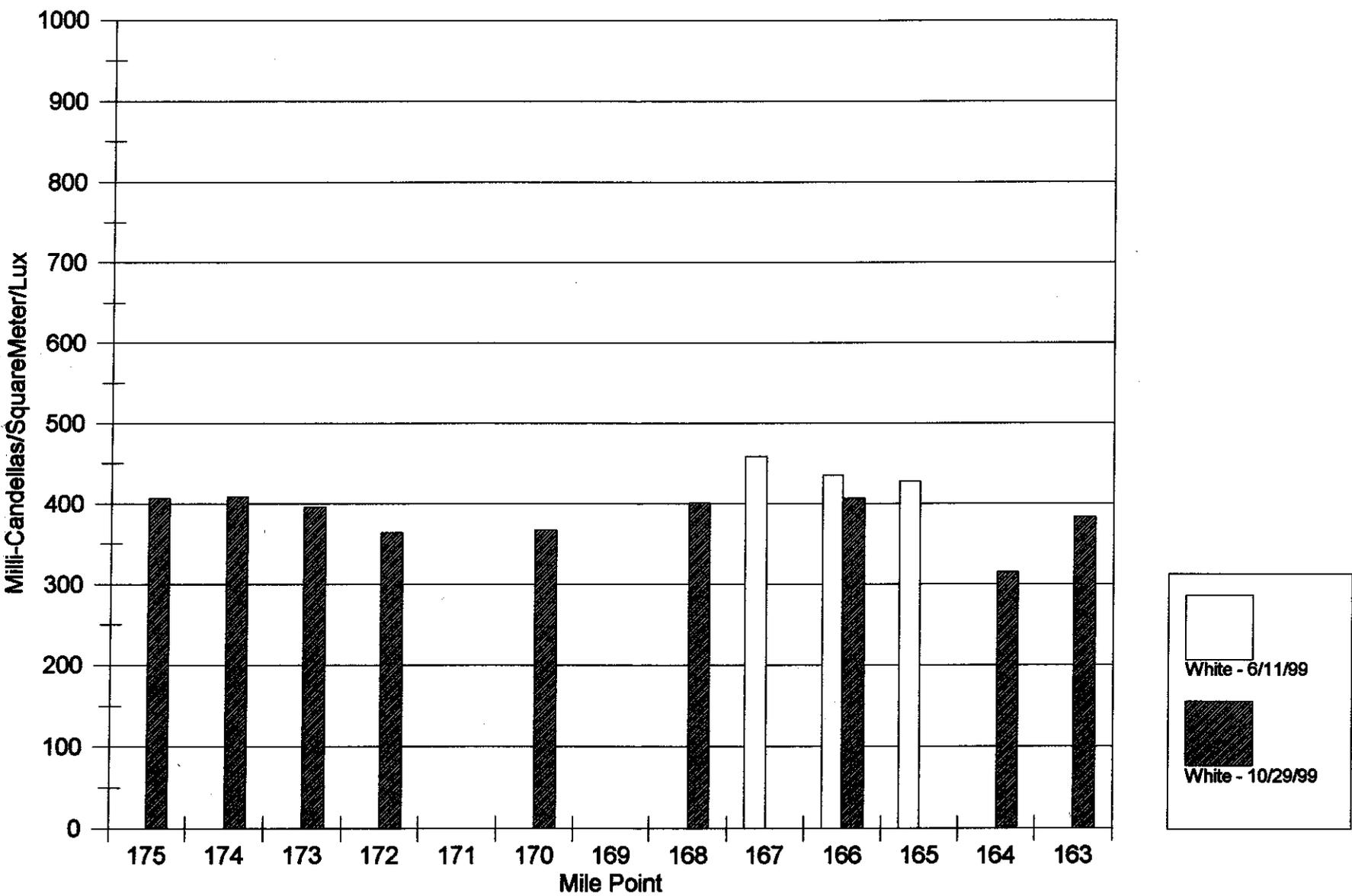
Center Line LS-60 Epoxy (not ground into pavement)

	10/29/99					
	Stripe 1	Stripe 2	Stripe 1	Stripe 2	Stripe 1	Stripe 2
1	389	388				
2	376	393				
3	397	404				
AVG	387	395				

Note: * Stripe 1 located 2 stripes back from MP 163
 **Stripe 2 located 1 stripe ahead of ground in skip line

Retroreflectivity

White - 12 Meter Geometry

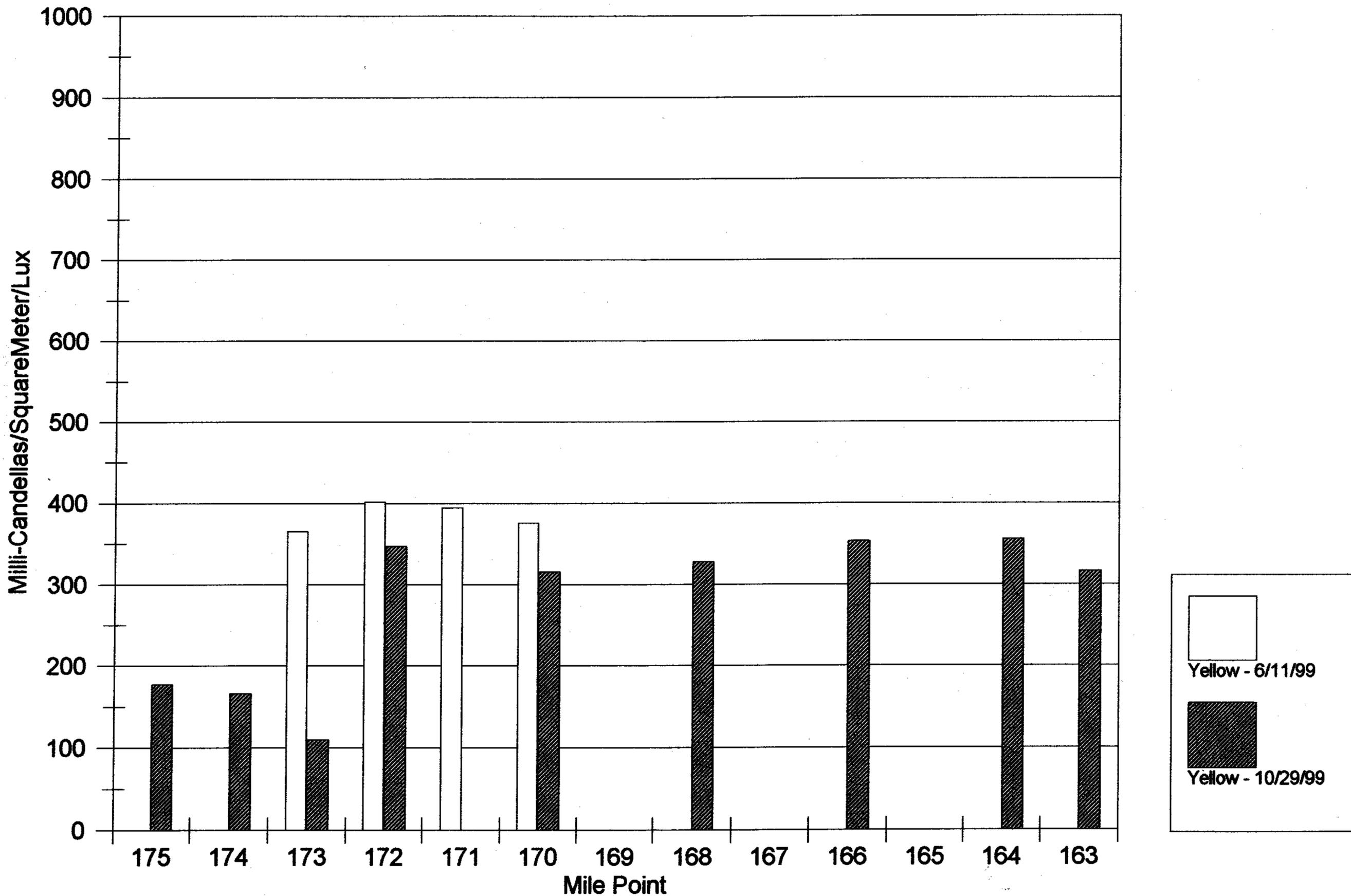


Note: - VOGEL UC-1511 & UC-3585
 Waterborne Paint @ MP 175-173
 -LS-60 Epoxy Paint @ MP 172-163

Note: * Center Line LS-60 Epoxy @ MP 163
 Center Line Tape @ MP 164 & 166

Retroreflectivity

Yellow - 12 Meter Geometry



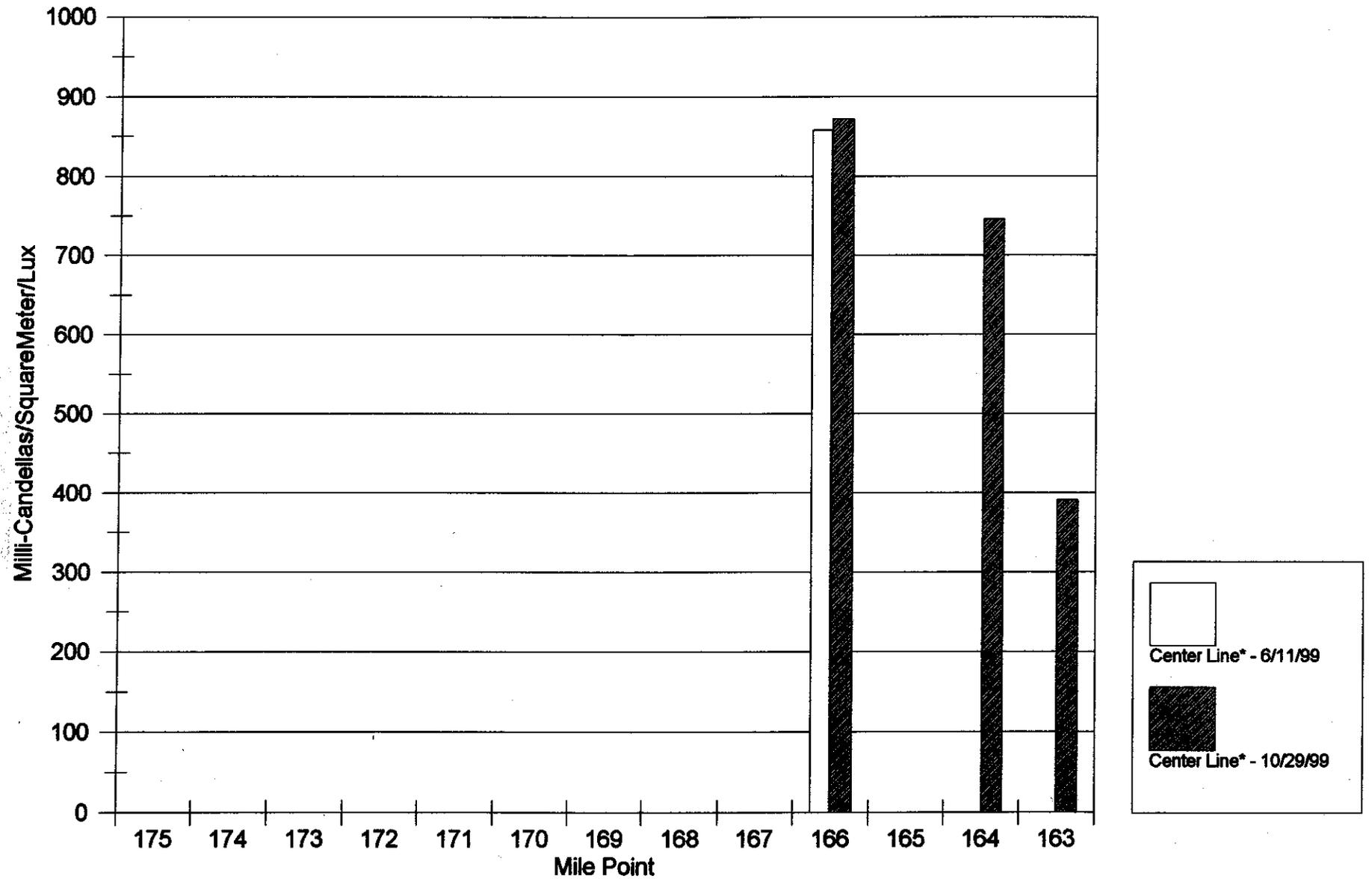
Note: - VOGEL UC-1511 & UC-3585
Waterborne Paint @ MP 175-173
-LS-60 Epoxy Paint @ MP 172-163

Note:* Center Line LS-60 Epoxy @ MP 163
Center Line Tape @ MP 164 & 166

C-17

Retroreflectivity

Center Line - 12 Meter Geometry



Note: - VOGEL UC-1511 & UC-3585
Waterborne Paint @ MP 175-173
-LS-60 Epoxy Paint @ MP 172-163

Note:* Center Line LS-60 Epoxy @ MP 163
Center Line Tape @ MP 164 & 166